PEBBLE PROJECT
ENVIRONMENTAL BASELINE DOCUMENT
2004 through 2008

CHAPTER 7.
SURFACE WATER HYDROLOGY
Bristol Bay Drainages

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ACRONYMS AND ABBREVIATIONS

AASHTO	American Association of State and Highway Transportation Officials
ABR	Alaska Biological Research, Inc. – Environmental Research and Services
ADF&G	Alaska Department of Fish and Game
ADNR	Alaska Department of Natural Resources
ADOT&PF	Alaska Department of Transportation and Public Facilities
APC	Alaska Peninsula Corporation Services, LLC
BEESC	Bristol Environmental & Engineering Services Corporation
cfs	cubic feet per second
CH2M	CH2M Hill, Inc.
CQ	continuous discharge
EBD	environmental baseline document
EPA	Environmental Protection Agency
FHWA	Federal Highway Administration
GIS	geographic information system
GS	gaging station
HDR	HDR Alaska Inc.
IQ	instantaneous discharge
KC	Kaskanak Creek
KPL	Knight Piésold Ltd.
KR	Koktuli River Main Stem
LIDAR	Light Detection and Ranging
mi^2	square mile(s)
NK	North Fork Koktuli River
NOAA	National Oceanic and Atmospheric Administration
NRCS	Natural Resource Conservation Service
OHMP	Office of Habitat Management and Permitting
SK	South Fork Koktuli River
SWE	snow water equivalent
URO	unit runoff
USFWS	U.S. Fish and Wildlife Service
USGS	U.S. Geological Survey
UT	Upper Talarik Creek
WRIR	water-resources investigations report

7. SURFACE HYDROLOGY

Chapter 7 consists of three sections: Region, Mine Study Area, and Transportation Corridor Study Area.

The first section of Chapter 7 (Section 7.1) describes the regional hydrologic characteristics of the Bristol Bay drainages of southwestern Alaska, in which the mine study area and most of the transportation corridor study area are situated. The regional hydrology section uses published government information to describe key hydrologic characteristics in the region, including the spatial variability in hydrologic characteristics within the region.

The second section of Chapter 7 (Section 7.2) presents the hydrologic and snow data collected through an extensive streamflow gaging and snow surveying program within the mine study area. This section presents and discusses mean annual streamflow and snowpack values at numerous measurement sites; annual patterns of snowpack accumulation, snowpack ablation (loss through melt, sublimation, or wind transport) and streamflow runoff; analysis of extreme peak and low flow conditions; and physical processes related to snow distribution, runoff generation, surface and subsurface hydrologic interactions, and the influence of inter-basin transfer of groundwater on stream runoff.

The third section of Chapter 7 (Section 7.3) describes the stream channels that intersect the linear study area of the transportation corridor, and provides estimated streamflow statistics for those stream channels based mainly on regional methods with some site-specific input.

The surface hydrology studies in the mine study area constitute the largest portion of Chapter 7. An overview of these studies is presented in Section 7.2, but the main reports for these studies are found in five appendices (Appendices 7.2A through 7.2E). In contrast, the main report for hydrology studies in the transportation corridor study area is found in Section 7.3. The two appendices to Section 7.3 (Appendices 7.3A and 7.3B) contain supplementary information but do not constitute self-standing reports like the appendices of Section 7.2.

7.1 Region

7.1.1 Introduction

This section provides an overview of regional hydrology in the Bristol Bay drainages of southwestern Alaska, with an emphasis on providing hydrological context for the mine study area and transportation corridor study area. This section summarizes the publically available regional hydrologic records and assesses their applicability for the quantification of long-term hydrologic statistics in this region.

7.1.2 Study Objectives

The objectives of the regional hydrology section are as follows:

- To summarize publically available regional streamflow and snowpack records.

- To provide an overview of spatial and temporal patterns in regional hydrology.
- To assess the applicability of regional data for estimating long-term hydrologic statistics in the mine study area.

7.1.3 Study Area

The Bristol Bay drainages encompass approximately 41,900 square miles (mi^2) in southwestern Alaska. The Bristol Bay watershed boundary is defined by the Alaska Range to the east, the Aleutian Range on the Alaska Peninsula to the southeast, the Kuskokwim Mountains to the west, and by a range of hills to the north that separate it from the Kuskokwim River watershed, as shown on Figure 7.1-1. The largest rivers draining into Bristol Bay are the Nushagak and Kvichak rivers, which have drainage areas of 12,700 mi^2 and 8,000 mi^2, respectively. The watersheds of these two rivers collectively comprise 49 percent of the Bristol Bay drainages. The mine study area straddles the boundary of the Nushagak River and Kvichak River watersheds, as shown on Figure 7.1-1.

The mountain ranges bordering the Bristol Bay drainages have been intensely glaciated during the Pleistocene Epoch. The Alaska and Aleutian ranges are still actively glaciated, while the Kuskokwim Mountains are not, due to their lower elevation. The lowland area between the Alaska Range and Kuskokwim Mountains is covered by thick deposits of glacially eroded sediment, much of it deposited by glacial meltwater. These surficial materials contain aquifers that tend to moderate peak flows and provide sustained baseflows. Several glacially scoured valleys within the mountain ranges, and extending out into the lowland area, contain large lakes, which also buffer streamflows. The largest lake in the Bristol Bay watershed is Iliamna Lake, which lies within the Kvichak River basin and covers 1,015 mi^2.

In the main part of the Bristol Bay drainages that is comprised of the Nushagak River and Kvichak River watersheds, the climate is transitional between maritime and continental. The narrow strip of Bristol Bay watershed along the northwestern side of the Alaska Peninsula is more maritime. Regional precipitation is greatest from late summer through early winter and is primarily generated by maritime storm systems. The most common circulation pattern consists of atmospheric lows moving in from the North Pacific Ocean along the Aleutian Island chain into the central and eastern Bering Sea (Albanese, 2008). These storms produce a strong southeasterly air flow near ground surface as winds spiral in a counter-clockwise direction toward the center of the low pressure cell. The storms are loaded with maritime moisture, with the heaviest precipitation occurring along the southeastern flanks of the Alaska and Aleutian ranges, outside of the Bristol Bay drainages. Considerable precipitation also occurs within the watershed, especially on higher terrain with southerly to easterly exposure. Less frequently, atmospheric lows situated at Kodiak Island and the Shelikof Strait area result in northeasterly air flows. Moisture is much lower with this flow pattern, but it still may produce precipitation in the main part of the watershed. By mid-winter, the lows tend to move into the central to eastern Gulf of Alaska, resulting in northerly to northwesterly surface-level air flows of colder, drier, continental air.

Regional streamflow is dominated by spring snowmelt and autumn rainfall runoff, with the relative proportions of flow in these two seasons depending mainly on basin elevation and corresponding temperatures, which control the timing of snowfall onset in the autumn. Streamflows are generally lower in the summer, except in basins with high mountainous headwaters in the Alaska and Aleutian ranges, where summer snow and glacier melt sustain high flows through the summer. The lowest flows of the year occur in late winter throughout the region.

7.1.4 Previous Studies

The U.S. Geological Survey (USGS) is the main public agency that collects and provides streamflow data throughout the United States. Streamflow records and statistics are available online at: http://waterdata.usgs.gov/usa/nwis/sw.

In 1996, the USGS conducted an evaluation of the Alaskan streamflow gaging network, including an analysis of the southwestern Alaska region, most of which is comprised of the Bristol Bay drainages (Brabets, 1996). The purpose of their analysis was to evaluate the representativeness of the then-existing gaging network and to make recommendations for network modifications, as required.

The USGS has delineated seven streamflow analysis regions for Alaska. Regional regression equations have been developed for each region to relate streamflow statistics to climatic and physiographic basin characteristics. The Bristol Bay and Cook Inlet watersheds are collectively referred to as Region 4 in the USGS system, as shown on Figure 7.1-2. Region 4 has a transitional climate between the more maritime Region 3, which is located along the exposed southern coast of Alaska and the eastern coast of the Alaska Peninsula (Aleutian Range), and the more continental Region 6, which covers the interior of Alaska. The mine and transportation corridor study areas lie near the boundary between Regions 3 and 4.

The Natural Resources Conservation Service (NRCS) is the main public agency that collects snowpack data throughout the Unites States. Snow course data are available online at: http://www.wcc.nrcs.usda.gov/snowcourse/sc-data.html

7.1.5 Scope of Work

The regional overview of surface hydrology was prepared by Knight Piésold Ltd. The scope of work for the overview consisted of the following tasks:

- Summarize publically available regional streamflow and snowpack records collected by the USGS and the NRCS.
- Provide an overview of spatial and temporal patterns in regional hydrology.
- Assess the applicability of regional data for estimating long-term hydrologic statistics in the mine study area.

7.1.6 Methods

The USGS website (USGS, 2010) was used to compile an updated summary table of active and discontinued gaging station information in the Bristol Bay watershed, including drainage area, period of record, completeness of record, mean annual discharge, and mean annual runoff per unit area. These results were used to describe regional streamflow patterns, and to develop an updated assessment of the regional network's representativeness.

Curran et al. (2003) was used to compile regional peak flow statistics for all regional gaging stations with records containing 10 or more systematic peak flow values. The methodology of Curran et al. (2003) combines frequency analyses of individual station records with a regional regression analysis of peak flow statistics and basin characteristics. The standard error in the resulting regression equations is used to assign an equivalent period of record that would need to be collected at a site to obtain an estimate with the same error. For each station, the actual period of peak flow record and the equivalent period of record associated with the regression equations are used to weight the peak flow estimates derived from the two sources. For example, at gages with long periods of record and located within a region with weak regression equations (i.e., high standard error), the flood frequency statistics obtained from the gage record will be weighted more heavily than the statistics obtained from the regional regression analysis. Conversely, at gages with short periods of record and located within a region with strong regional regression equations (i.e., low standard error), the statistics obtained from the regional regression equations will be weighted more heavily.

The NRCS website (NRCS, 2010) was used to compile an updated summary table of active snow course information in the Bristol Bay drainages. These results were used to describe regional patterns of snowpack accumulation.

7.1.7 Results and Discussion

7.1.7.1 Regional Streamflow Gaging Stations

The USGS has historically collected streamflow records at 22 gaging stations within the Bristol Bay drainages. These stations are listed in Table 7.1-1 and their locations are shown on Figure 7.1-1. As of 2008, only eight of these gaging stations were active. The eight active gaging stations consist of the following:

- Three gaging stations that were installed by the USGS in 2004 on watercourses within the mine study area (Upper Talarik Creek: 15300250, (South Fork) Koktuli River: 15302200, and North Fork Koktuli River: 15302250). In this study, these stations are referred to as UT100B, SK100B, and NK100A, respectively. The “Koktuli River” according to the USGS is called “South Fork Koktuli River” in Pebble studies.
- Three gaging stations that were installed after 2004 on watercourses in lowland terrain near the mine study area (Bear Creek: 15300100, Roadhouse Creek: 15300200, and Kaskanak Creek: 15300520).
- Two gaging stations with greater than 10 years of record located in the Alaska Range (Iliamna River, 15300300) and Kuskokwim Mountains (Nuyakuk River, 15302000).

The Bristol Bay region gaging station with the longest record (47 years) is located on the Nuyakuk River (15302000). The Nuyakuk River drains a chain of large lakes. This gage started operation in 1953 and is still active, but its record contains a gap between 2004 and 2007. The long record at this station provides the best dataset for characterizing long-term annual runoff statistics in the region, but it is not suitable for characterizing regional peak flow or low flow statistics due to the influence of the lakes. The missing record from 2004 to 2007 limits the usefulness of this station for characterizing the periods of record at the other active gaging stations in the region with respect to long-term conditions.

The next longest streamflow records in the region (16 to 20 years) were recorded at the discontinued gages on the Nushagak River (15302500), the Kvichak River (15300500), and the Newhalen River (15300000) between the 1950s and the 1990s. The basins upstream of these three gages are the largest gaged basins in the region, and contain large lakes and/or extensive lowland areas. The records from these stations are useful for characterizing annual runoff statistics but not for estimating regional peak flow or low flow statistics for much smaller ungaged basins.

The USGS evaluation of the streamflow gaging network in the southwestern region of Alaska was based on the network status in 1994 (Brabets, 1996). At that time, there were only two active gaging stations in southwestern Alaska. In the Bristol Bay drainages, which comprise most of the region, there was only one active gaging station (Nuyakuk River, 15302000) and 14 discontinued stations in 1994. The evaluation report concluded that the existing streamflow dataset for the region was insufficient to support regional regression analyses for the estimation of average, peak, and low flow statistics in ungaged basins. This assessment was based on the spatial density of stations, the length of records, and basin characteristics including large lakes. The evaluation report recommended the continued operation of the Nuyakuk River gaging station, the reactivation of five discontinued gaging stations, and the installation of another 16 new stations in the Bristol Bay drainages. The recommended stations would be installed on watercourses with basins of various sizes, mostly in the range of 100 mi^2 to 1,000 mi^2.

Since the USGS network evaluation report was published, 10 new USGS gaging stations have been installed in the Bristol Bay drainages, including the eight active stations listed at the start of this section, and two stations that operated near Chignik for 1 year before being discontinued. Of these new stations, only the Iliamna River gage has greater than 10 years of record, while the rest of the gages have records of 4 years or less.

The main point of this regional gaging station review is that the availability of active, long-term hydrologic records in the region is sparse, but that the USGS has concentrated its recent efforts in establishing new gages in this region in and around the Pebble Project mine study area and transportation corridor, on streams representing a wide range of drainage areas and basin characteristics. Therefore, the availability of hydrologic data with which to evaluate the spatial distribution of mean annual runoff conditions throughout the portion of the Bristol Bay region in which the mine and transportation corridor study areas are situated has increased markedly in the past few years.

7.1.7.2 Regional Streamflow Patterns

The mean annual discharge and mean annual unit runoff for each of the USGS gaging stations is presented in Table 7.1-1. The following spatial patterns are evident:

- The Iliamna River (15300300) in the Alaska Range and East Creek (15303100) and the Elva Lake Outlet (15302840) in the Kuskokwim Mountains have the highest unit runoff rates in the region at around 7 cubic feet per second (cfs) per mi^2 (or 95 inches of annual basin runoff depth).
- Eskimo Creek (15297900) and Roadhouse Creek (15300200) are lowland watercourses lacking mountainous headwaters and have the lowest unit runoff rates in the region at around 1 cfs/mi^2 (or 14 inches of annual basin runoff depth).

- The Nushagak River (15302500), Kvichak River (15300500), and Newhalen River (15300000) have large basins containing mountainous headwaters and extensive lowland areas, and have intermediate unit runoff rates of around 2.5 cfs/mi^2 (or 34 inches of annual basin runoff depth).
- The three gages within the mine study area [Upper Talarik Creek: 15300250, (South Fork) Koktuli River: 15302200, and North Fork Koktuli River: 15302250] have moderately hilly basins and intermediate unit runoff rates of around 2.6 cfs/mi^2 (or 35 inches of annual basin runoff depth).

The annual pattern of streamflows also varies between mountainous and lowland basins. Annual hydrographs showing the magnitude of mean monthly flows relative to the mean annual flow at selected gaging stations are presented on Figure 7.1-3 and the patterns are summarized below:

- The Iliamna River (15300300), with its mountainous basin, records the highest monthly flows in June due to mountain snowmelt. Flows are sustained at moderate levels through the summer and autumn, but decline to low levels in the winter.
- Roadhouse Creek (15300200), with its lowland basin, records a modest snowmelt freshet in the spring, but a much smaller fraction of the annual runoff occurs during this period as compared to the Iliamna River. Flows decline in the summer following the depletion of snowmelt runoff, and increase during the autumn rainfall season. Autumn rainfall contributes a much larger fraction of the annual runoff in Roadhouse Creek than in the Iliamna River due to differences in basin elevation and snow/rain distribution. Flows in Roadhouse Creek decline to low levels through the winter.
- Flows in the Newhalen River (15300000) are affected by several large lakes upstream of the gaging station. The snowmelt freshet is delayed relative to the Iliamna River, with the highest average monthly flows occurring in July and August due to lake storage effects. Flows gradually decline through the autumn and reach minimum levels in late winter.
- The annual hydrographs for the three USGS gages within the mine study area (Upper Talarik Creek: 15300250, (South Fork) Koktuli River: 15302200, and North Fork Koktuli River: 15302250) have characteristics intermediate between those of the Iliamna River and Roadhouse Creek. Spring flows represent a larger fraction of the annual flow in the mine study area than in Roadhouse Creek due to the higher terrain and greater snow accumulation in the mine study area as compared to the lowland basin of Roadhouse Creek. Spring flows occur earlier and represent a smaller fraction of the annual flow in the mine study area as compared to the Iliamna River, which has a more mountainous basin. Summer flows in the mine study area are relatively low and are more similar to Roadhouse Creek than the Iliamna River. Autumn flows as a fraction of the annual total flow in the mine study area are intermediate between Roadhouse Creek, where autumn flows dominate the annual hydrograph, and the Iliamna River, where autumn flows are considerably lower than spring flows.
- The lowest monthly flows at the mine study area gages occur in the winter, which is consistent with the patterns of the other regional gages. However, winter flows in Upper Talarik Creek (15300250) are distinctly higher, relative to mean annual discharge, than they are at the other mine study area gages or at the other regional gages shown on Figure 7.1-3. This is due to unusually large aquifer storage and cross-basin transfers of groundwater in the Upper Talarik Creek basin, as will be described in Section 7.2.

7.1.7.3 Regional Peak Flows

The regional peak flow statistics estimated by Curran et al. (2003) are presented in Table 7.1-2. Eleven gaging stations had at least 10 years of systematic peak flow records in the Bristol Bay drainages at the time that Curran et al. (2003) performed their analysis. The length of peak flow record at some gaging stations, such as Roadhouse Creek (15300200), is longer than the period of complete streamflow record due to the inclusion of seasonal records during high-flow seasons and/or instantaneous peak flow values estimated through the use of crest gages. The Iliamna River gaging station (15300300) was installed in 1996 and did not have 10 years of record at the time that Curran et al. (2003) performed their analysis.

The estimated peak flow values for the 2-year and 200-year floods are presented for each of the applicable gaging stations in Table 7.1-2. The stations are ordered by increasing drainage area. The unit-discharge values for the flood estimates generally decrease with increasing basin area, as expected, but considerable other variability is also evident. Unit-discharges for 200-year floods range from roughly 10 to 30 cfs/mi^2 for large basins (greater than 1,000 mi^2) and from 30 to over 100 cfs/mi^2 for small basins (less than 100 mi^2).

The flood discharge estimates presented in Table 7.1-2 are weighted values obtained using flood frequency analysis of the individual gage records and a set of regional regression equations. The regression equations for Region 4 had large standard errors, meaning that peak flows were not well-correlated to basin characteristics across the diverse and sparsely gaged region. Therefore, the weighting procedure of Curran et al. (2003) placed more emphasis on the local gage records at each station, and little emphasis on the regional regression estimates. For example, the average weighting for the 2-year peak flow estimates presented by Curran et al. (2003) is 95 percent for the local gage analysis and 5 percent for the regional analysis. For the 200-year peak flows, the average weighting is 74 percent for the local gage analysis and 26 percent for the regional analysis.

The Iliamna River gaging station (15300300) now has 12 years of record, but return period peak flow estimates for this system were not included in Table 7.1-2 because of a lack of data at the time of the Curran et al. study. This gage has recorded floods with much larger unit discharge values than any other gage in the Bristol Bay drainages, due to the exposure of its high mountainous headwaters to southeasterly atmospheric flow from the Gulf of Alaska. The unit discharge of the *mean annual* peak flow recorded during the 12-year gage record is 127 cfs/mi^2; this is greater than the *200-year* peak flow estimated by Curran et al. (2003) for any other gaging station in the Bristol Bay drainages [113 cfs/mi^2 at Wood River tributary (15303011)].

7.1.7.4 Regional Snowpack Patterns

The six NRCS snow courses located within the main part of the Bristol Bay drainages (i.e., the Nushagak River and Kvichak River watersheds) are listed in Table 7.1-3, along with the periods of record and mean spring snowpack values for each site. The lengths of record indicate the number of years in which snow surveys were recorded in either March or April (i.e., around the time of annual maximum snowpack accumulation). The snow water equivalent (SWE) of the snowpack is the equivalent water depth of the snow if it were to instantly melt.

The six snow courses are all located along the eastern side of the Bristol Bay drainages, as shown on Figure 7.1-1, on the lee side of the Alaska and Aleutian ranges with respect to southeasterly atmospheric flows, at elevations of 150 feet to 2,000 feet. Thus, these snow courses are representative of lowland and foothill areas adjacent to the mountain ranges, but are not representative of the mountainous headwater areas of the larger rivers in the region.

The snow courses are listed in order of descending elevation in Table 7.1-3. Mean April SWE values generally decrease from around 7 to 10 inches at the higher snow courses to 2 to 4 inches at the lower snow courses. The March and April SWE values are similar at most stations, with slightly greater April values at the higher stations and slightly greater March values at the lower stations.

7.1.8 Summary

The USGS has historically collected streamflow records at 24 gaging stations within the Bristol Bay drainages. As of 2008, only eight of these gaging stations were active, including three gages established within the mine study area in 2004. There are no active, long-term gaging stations that have overlapping periods of record with the mine study area gages. Therefore, the regional gaging network is not suitable as the primary basis for estimating long-term streamflow statistics for the mine study area. Instead, long-term precipitation and snowpack records combined with precipitation/snowpack/runoff modeling calibrated with site-specific flow data should form the basis for estimating long-term streamflow statistics.

7.1.9 References

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7.2 Mine Study Area

7.2.1 Introduction

This section presents the findings of tasks completed for the surface hydrology study in the mine study area between April 2004 and December 2008. Relevant data from hydrology studies conducted by Cominco in the early 1990s are also presented. In the surface hydrology field program, streamflow, snowpack, and small pool water data were collected at a series of streamflow gaging stations, snow survey sites, and small pool study sites in the mine study area to support five related studies: (1) hydrologic analysis of year-round stream discharge patterns, (2) analysis of low flow conditions, (3) analysis of flood conditions, (4) analysis of snow accumulation and melt, and (5) small pool hydrodynamics.

Related studies that are referenced in this document are climate and meteorology (Chapter 2), geology and mineralization (Chapter 3), physiography (Chapter 4), groundwater hydrology (Chapter 8), water quality (Chapter 9), and fish and aquatic invertebrates (Chapter 15).

7.2.1.1 Surface Hydrology Chapter Organization

The 2004 to 2008 surface hydrology baseline program consists of five studies that are described in appendices to this chapter: hydrologic analysis (Appendix 7.2A), low flows (Appendix 7.2B), peak flows (Appendix 7.2C), snow (Appendix 7.2D), and small pools (Appendix 7.2E). Detailed methods and results can be found in each appendix. Appendix 7.2A describes the development of stream discharge records (hydrographs) from electronically recorded water level (stage) data at each continuous discharge (CQ) gaging station in the network. Annual discharge patterns at each gaging station are presented, and comparisons between stations are used to infer surface and subsurface hydrologic processes within the study area. Appendices 7.2B and 7.2C characterize the magnitude and spatial variability in extreme streamflows (low flows and peak flows, respectively). Appendix 7.2D characterizes the accumulation, redistribution, and ablation of annual snowpack, which plays a key role in the generation of stream runoff. Appendix 7.2E characterizes the hydrodynamics of small perched-precipitation and flow-through pools.

7.2.2 Study Objectives

Objectives of the hydrologic analysis baseline study included data collection for the following:

- Characterization of year-round streamflow throughout the mine study area.
- Calibration of a site-wide watershed model that links precipitation, groundwater dynamics, and surface water runoff.
- Support for characterization of aquatic resources, fish resources, and wetlands habitat.

Specific objectives of the five studies conducted as part of the overall surface hydrology program are provided below.

7.2.2.1 Hydrologic Analysis

The objectives for the hydrologic analysis were to install and maintain a network of baseline continuous discharge (CQ) gaging stations covering the major drainage basins in the proposed mine site area, to create rating curves for each station that can be used to develop hydrographs from continuous stage data, and to derive a preliminary understanding of seasonal and spatial variability in surface runoff across the study area.

7.2.2.2 Low Flow Analysis

The objectives of the low flow study were to identify periods during the winter and summer when streamflow is composed predominantly of groundwater upwelling (also called baseflow), to establish stations and measurement protocols to capture instantaneous discharge (IQ) measurements during low flow periods, and to relate observed baseflow patterns to groundwater flow, especially in gaining and losing reaches and areas where interbasin transfer of groundwater occurs.

7.2.2.3 Peak Flow Analysis

The objective of the peak flow study was to develop magnitude-frequency relations for flood discharges with return intervals from 2 to 500 years for each baseline gaging station using regional regression equations developed by the USGS. The analysis also included an evaluation of the accuracy of the regional peak flow estimates by comparison to recorded flood flows in the study area, and the development of a modified method to adjust the regional estimates on the basis of the local gage records.

7.2.2.4 Snow Distribution Survey

The objectives of the snow survey were to characterize snow distribution and ablation in the major drainage basins of the study area for baseline water-balance studies. Late-season snow distribution and ablation were mapped using field surveys, climate data, terrain characteristics, and satellite imagery. A snow model was also developed based on terrain characteristics and climate data. Snowpack ablation rates were calculated from field survey data and compared to model outputs.

7.2.2.5 Small Pools Study

The objectives of the small pools study were to differentiate between perched-precipitation pools and flow-through pools and to characterize the hydrodynamics of each pool type.

7.2.3 Study Area and Hydrologic Setting

7.2.3.1 General Hydrologic, Geologic, and Climatic Setting

The mine study area straddles the boundary of the Nushagak River and Kvichak River watersheds, both of which drain into Bristol Bay, as shown on Figure 7.2-1. More specifically, the general deposit location straddles the watershed boundary of the South Fork Koktuli River (SK) and Upper Talarik Creek (UT), and lies close to the headwaters of the North Fork Koktuli River (NK). The mine study area comprises the drainages of these three watercourses, as well as the headwaters of Kaskanak Creek (KC), which is located adjacent to the lower part of the SK basin. The location of the study area drainages relative to the Nushagak River and Kvichak River watersheds is shown on Figure 7.2-1. The four study area drainages and the general deposit location are shown on Figure 7.2-2.

The NK and SK join to form the Koktuli River mainstem approximately 17 miles west of the general deposit location. The Koktuli River flows into the Mulchatna River, which flows into the Nushagak River. UT flows into Iliamna Lake, which is drained by the Kvichak River. KC is located approximately 16 miles southwest of the general deposit location and has been included in the study area to investigate potential interbasin transfer of groundwater from the SK. KC drains to the Kvichak River below Iliamna

Lake. The NK, SK, UT, and KC watersheds encompass a combined area of 373 square miles (mi^2) above the lowermost gaging station on each watercourse. The Newhalen River lies to the east of the mine study area and drains out of Lake Clark and into Iliamna Lake. The Newhalen River is much larger than the watercourses in the mine study area, with a drainage area of almost 3,500 mi^2 at the mouth.

The study area topography is relatively gentle, consisting of elevations ranging from around 3,000 feet on Groundhog Mountain northeast of the deposit location to 46 feet at Iliamna Lake. Mean basin elevations range from approximately 1,000 feet in the UT to almost 1,300 feet in the NK. The KC basin is lower, with a mean elevation of 605 feet in the study area. The gentle topography is partially a result of intensive weathering on upland surfaces and the deposition of thick sediment units in bedrock valleys (Hamilton, 2007). Glacial and fluvial sediment of varying thickness cover most of the project area at elevations below about 1,400 feet and play an important role in surface water runoff and groundwater storage and exchange. In several areas, subsurface flows follow former pre-glacial surface drainage pathways that have since been buried by subsequent sediment deposits, resulting in cross-basin transfers relative to the current surface topography. No permafrost has been found in the mine study area.

The closest location where long-term meteorological records are kept is at the Iliamna Airport at 160 feet above sea level and approximately 17 miles southeast of the study area. The short-term meteorological station with the most complete record within the study area is Pebble 1 at 1,560 feet above sea level (Chapter 2 of this Environmental Baseline Document [EBD]). Data from this station may better represent upland conditions than valley bottom conditions. Summer temperatures in the mine study area are maritime, moderated by the large waterbodies of Iliamna Lake, Bristol Bay, and Cook Inlet. Winter temperatures are more continental because of the presence of ice on Iliamna Lake and sea ice in Bristol Bay during the coldest months of the year.

The long-term mean annual precipitation at the Iliamna Airport is 26.4 inches. The average annual precipitation at the Iliamna Airport during the four complete water years of the study period (October 2004 through September 2008) was close to average: 25.3 inches. The mean annual runoff at the USGS gaging stations on the lower reaches of the three main stream channels in the mine study area (NK, SK, and UT) during the study period was 35 to 38 inches, indicating that precipitation in the mine study area is considerably greater than at Iliamna.

7.2.3.2 Extent of Study Area

A network of 29 continuous streamflow (CQ) gaging stations provides the foundation of the baseline program for surface hydrology. The gaging stations are distributed along the main stream channels and tributary channels of the four study area watersheds, and on the lower reach of the nearby Newhalen River, as shown on Figure 7.2-2. Instantaneous discharge (IQ) measurements were also collected at a number of sites to support the water-quality monitoring program. These sites are presented in Figure 7.2-2. The instantaneous discharge data collected at these sites are archived with the CQ station data for use in future analyses, but are not presented in this report.

Low flows were measured at all CQ gaging stations and IQ sites, and at additional sites specifically to characterize low flow patterns and groundwater interactions. The low flow measurement locations varied by year based on data needs and accessibility during ice-covered periods. The supplementary low flow measurement sites are not shown on Figure 7.2-2, but are presented in Appendix 7.2B.

Peak flows were estimated at the 13 CQ gaging stations installed in 2004 and 2005, using regional regression equations published by the USGS combined with an analysis of recorded flood peaks. Peak flows were not estimated for the stations installed in 2007 and 2008 due to their short periods of record. The 13 stations for which peak flow estimates were developed are not indicated on Figure 7.2-2, but are presented in Appendix 7.2C.

Snow surveys were initially concentrated in the general deposit area. In 2007, the extent of the snow survey program was expanded to cover all of the four watershed areas included in the stream gaging program, excluding the lower Newhalen River.

Locations of the seven small pools in the mine study area that were instrumented at detailed study sites, and the 123 small pools located throughout the study area, are presented in Appendix 7.2E.

7.2.4 Previous and Related Studies

7.2.4.1 Cominco Gaging Stations

The mine site was originally studied by Cominco in the early 1990s. Continuous hydrologic data were collected at two stations in the UT watershed and two stations in the SK watershed for various periods between 1991 and 1994. Data from these stations, which are somewhat limited in accuracy and completeness, are discussed in Appendix 7.2A. Cominco also collected meteorological data at one station near the deposit location from August 1991 to September 1993 (Chapter 2). The Cominco meteorological data are of limited use in hydrologic studies because the data recovery for precipitation and evaporation was very low.

7.2.4.2 USGS Gaging Stations

The USGS has installed and operated three stream gaging stations within the study area. These gages, which are discussed in more detail in Appendix 7.2A, were installed in 2004 specifically for the Pebble Project. The three USGS gaging stations are considered part of the CQ gaging network in the study area.

An inactive USGS gage site is located on the lower Newhalen River. A Pebble Project gaging station has been re-established at this site.

No known detailed hydrologic analysis studies have been previously conducted in the study area.

7.2.4.3 Snow Distribution

Six Natural Resource Conservation Service (NRCS) snow courses exist within 100 miles of the snow courses in the mine study area. Data collection from these six NRCS snow courses was inconsistent, but the information obtained is useful for comparing 2004 to 2008 data to long-term averages in the region.

7.2.4.4 Geology, Geomorphology, and Hydrogeology

Relevant aspects of surficial geology, physiography, and hydrogeology from Hamilton (2007) and from Chapters 3, 4, and 8 were used for the surface hydrology study. The thickness and spatial distribution of glaciofluvial and moraine deposits plays a large role in runoff generation processes and interactions between surface and subsurface flow. Basin morphology characteristics such as slope, aspect, and elevation influence precipitation, snow dynamics, and runoff patterns and are considered within each of these components. The subsurface flow patterns described in the hydrogeology studies relate to patterns of surface flow losses and gains in the monitored streams.

7.2.5 Scope of Work

The scope of work for surface hydrology studies in the mine study area consisted of the following tasks:

- Collect continuous streamflow records at key sites required for calibration of a site-wide water balance model and to support fish habitat impact assessment.
- Collect late-winter baseflow measurements and open-water observations to support an understanding of hydrologic patterns during extreme low-flow conditions.
- Compile peak flow measurements and estimate flood magnitude-frequency relations at the streamflow gaging stations.
- Measure snow accumulation and ablation throughout the mine study area and develop a model to predict accumulation and ablation based on terrain characteristics and climate data.
- Collect physical and chemical hydrology data from seven small pools and conduct a rapid assessment of chemical hydrology of 123 additional small pools, then develop a conceptual model describing the hydrological connectivity between the small pools and the broader hydrological landscape.

The work to date has been carried out by a number of firms contracted to the Pebble Partnership, as well as the USGS. The USGS has operated three streamflow gaging stations in the mine study area since August 2004. Pebble Project contactors have installed and operated another 26 gaging stations. The firms involved in the streamflow data collection and analysis consist of Knight Piésold Ltd. (KPL); HDR Alaska, Inc. (HDR); Alaska Peninsula Corporation Services, LLP (APCS); and CH2M Hill, Inc. (CH2M). Alaska Biological Research, Inc. – Environmental Research and Services (ABR) performed the snow surveys and analysis. Mark Rains, from the University of South Florida, led the small pools study. Data preparation and reporting has been a collaborative effort of KPL, HDR, ABR, APCS, and Mark Rains.

7.2.6 Methods

7.2.6.1 Streamflow Gaging Program

The USGS has operated three streamflow gaging stations in the mine study area since August 2004. Pebble Project contractors have installed and operated another 26 gaging stations. The stations have varying periods of record, which are summarized in Table 7.2-1. A combined total of 76 complete water years of streamflow data has been recorded at the 29 gaging stations, including 4 complete water years (extending from October 2004 to September 2008) at each of 11 of the stations.

CH2M Hill installed 11 of the streamflow gages in July 2004 and collected data until October 2004. Data collection, data management, and quality assurance responsibilities for these 11 stations were transferred to HDR in October 2004. Since then, HDR has established two new gaging stations in 2005 and seven new stations in 2007. APC became involved in the streamflow data collection program starting in 2007.

They installed three new gaging stations in 2007 and three more in 2008. As of 2008, HDR and APC have each been responsible for collecting and managing the data at the stations that they established, and HDR has continued to manage the stations inherited from CH2M. KPL has provided technical assistance and data review, developed the stage-discharge rating curves, led the data analysis, and participated in some field data collection. Data preparation and reporting has been a collaborative effort between KPL, HDR, and APC.

The continuous streamflow gaging stations were sited in locations that were expected to best characterize surface streams in the study area. Special attention was paid to locations upstream and downstream of the general deposit location, areas of groundwater loss or upwelling, locations near historical (Cominco) gaging stations, and waterbodies in the vicinity of the general deposit location. Additional low flow measurement stations were selected during field events based on data needs, accessibility, and safety.

At each CQ station operated by Pebble Project contractors, stage (water level) was recorded every 15 minutes at each station during ice-free months. The gage equipment was removed during the winter months because ice build-up invalidates stage-discharge relationships. Therefore, no continuous data were recorded at these stations during ice-covered periods. Manual measurements of instantaneous discharge (IQ) were collected monthly throughout the year, including winter. Rating curves relating discharge to stage were developed to best fit the measured IQ values. The equations from these curves were used to calculate discharge from continuous stage data collected by the dataloggers during ice-free months.

Winter hydrographs for USGS stations SK100B, UT100B, and NK100A were estimated by the USGS using IQ measurements in conjunction with meteorological data and a general understanding of hydrograph recession patterns during winter low-flow conditions. The winter hydrographs for SK100B and NK100A are similar in form and in the magnitude of unit runoff (URO), whereas the winter hydrographs for UT100B are less variable and have higher unit runoff due to greater groundwater contributions. Winter hydrographs for the stations operated by Pebble Project contractors were estimated by scaling USGS station hydrographs based on regression analyses of instantaneous discharge measurements at Pebble Project stations versus corresponding daily discharge at USGS stations.

Low-flow IQ measurements have been collected at 55 sites along gaged channels during low-flow events, usually in late winter, although not all sites were sampled in any given year (maximum of 41 sites in March 2008). Gaining and losing characteristics of surface flow were estimated by comparing absolute discharge and unit runoff rates between stations of known drainage area. An aerial survey of channels was performed late each winter starting in 2006 to delineate upwelling reaches, where warmer groundwater discharge prevented ice formation. Intermittent dry reaches within the SK were surveyed aerially in the summer and by ice augering in winter.

Direct instantaneous measurements of peak flows are rarely possible because high-flow events are difficult to predict, short in duration, and often unsafe or impractical to measure. Therefore, peak flow values are obtained by extrapolating stage-discharge rating curves to the maximum recorded stage and reading off the corresponding discharge. Because the period of record is too short to adequately characterize the size of low-frequency floods, a series of USGS regression equations developed for ungaged basins in Alaska (Curran et al., 2003) was used to estimate the 2- through 500-year return interval discharges for all stations installed in 2004 or 2005. These estimates are based on regional regression equations for southwest Alaska that relate drainage area, precipitation, and surface water storage (lake area) to peak discharges in gaged basins. The mean annual peak flows from the local stations were compared to the USGS regression estimates and were used to adjust the USGS regression estimates.

7.2.6.2 Snow Survey Program

Snow survey locations were chosen to represent predominant slope, aspect, and elevation zones within the major drainages and were distributed across the main watershed and smaller sub-catchment areas to correspond with gaging station locations. The 2004 to 2006 snow surveys were concentrated in the headwaters of the three major drainage basins within the study area: NK, SK, and UT. The 2007 and 2008 snow surveys covered the entire drainage basins.

In 2004 to 2006, snow depth and snow water equivalent (SWE) were measured at 103 to 130 of 175 unique plots each year along two snow courses and numerous longitudinal transects extending from ridge tops to valley bottoms throughout the mine study area. The two long-term snow courses, one at 2,000 feet elevation on Groundhog Mountain and one at 1,200 feet elevation in the UT headwaters, were established in the mine study area in 2004 to provide data suitable for comparison with existing NRCS snow course sites and to provide precise inter- and intra-annual comparison of SWE. The transects were established to provide distributed baseline SWE and calibrate the distribution model. In 2007, the number of plots increased to 233, and an additional 1,011 supplementary and drift profile measurements of snow depth were taken. Snow accumulation and redistribution were also modeled by using topographic and wind data to determine areas of drift.

Starting in 2008, snow depth was measured in early April using aerial LIDAR (light detection and ranging). A snow density model based on the manual snow survey results was used to convert LIDAR snow depths into SWE values. Also starting on 2008, snow temperature profiles were sampled at several primary plots. Additional discretionary data, such as weather conditions, snow surface profiles, snow conditions in snow pits, and the location of the edge of the snow pack and snow free areas were often collected as well.

Ablation rates were estimated by resurveying the snow course plots and plots along selected transects at approximately 2- to 3-week intervals following the initial mid-April snow survey. In addition, aerial photographs and satellite imagery were used to estimate large-scale patterns of snow accumulation and ablation in the mine study area.

7.2.6.3 Small Pools Study

All small pools were classified a priori as either perched-precipitation pools or flow-through pools based on specific conductance and the presence/absence of unvegetated margins by middle-late summer.

In June and August 2006, precipitation, surface water, and groundwater samples were collected at the seven small pools located at the three detailed study sites. In August 2007, precipitation, surface water, and groundwater samples were collected at the seven small pools located at the three detailed study sites, and surface water samples were collected at the 123 additional small pools located throughout the study area. Precipitation samples were collected from late-spring snowfields and summer rainfall collectors. In total, 179 water samples were collected, not including duplicate and triplicate water samples used for quality assurance and quality control.

Physical hydrology data were collected at the seven small pools located at the three detailed study sites. Precipitation was measured continuously at each of the three detailed study sites, while net radiation, temperature, relative humidity, and wind speed were measured hourly at one location within approximately 1 to 10 kilometers of each of the three detailed study sites.

Daily reference evapotranspiration, ETo, was computed using the American Society of Chemical Engineers Standardized Reference Evapotranspiration Equation (Allen et al., 2005).

Stages (i.e., surface-water levels) were measured hourly, and hydraulic heads (i.e., groundwater levels) were measured either hourly or monthly. Net groundwater recharge through the small pools to the broader hydrological landscape was computed with a water-budget approach.

7.2.7 Results and Discussion

7.2.7.1 Hydrologic Analysis

The annual pattern of streamflows in the mine study area is characterized by high flows in spring due to snowmelt, lower flows in early to mid-summer, another high-flow period in late summer and autumn due to frequent frontal rainstorms, and the lowest flows in winter when most precipitation falls as snow. Figure 7.2-3 shows these seasonal patterns within a representative hydrograph from USGS gaging station SK100B on the South Fork Koktuli River for the 2004-05 water year.

The period of record has included a wide range of hydrologic conditions, The complete study-period hydrograph for Station SK100B is presented on Figure 7.2-4 to illustrate the range and pattern of stream flows at one gaging station. Large snowmelt freshets occurred in 2006 and 2008, and a small snowmelt freshet occurred in 2007, at SK100B and throughout the study area. At most stations, the average volume of runoff in the summer-autumn rainstorm season exceeded the spring runoff volume during the period of record, with 30 to 35 percent of the annual runoff occurring from April through June and 40 to 60 percent occurring from August through November. In any given year, the duration of snowmelt was shorter than the duration of the rainstorm season, so average monthly flows at most stations were highest in May, followed by September and October. The lowest monthly flows, and the most prolonged periods of low flows, always occurred in the late winter (February through April) at all stations and in all years of the study period. Annual maximum daily and instantaneous flows occurred in both the spring and autumn seasons at all stations.

At the USGS gaging stations located on the lower reaches of the SK, NK, and UT, the mean annual unit runoff was similar at around 2.6 to 2.8 cubic feet per second (cfs) per mi^2. This equates to 35 to 38 inches of runoff depth. Elsewhere, annual unit runoff varied from gage to gage because of catchment topography and precipitation, cross-drainage transfers of groundwater, surface and subsurface flow exchanges along stream channels, and seasonal redistribution of snow by wind. In the KC watershed, with lower terrain than the other three main watersheds, the mean annual unit runoff was only 1.4 cfs/mi^2, or 19 inches of runoff depth. In the upland tributaries gaged at NK119A and SK119A, the mean annual unit runoff values were 3.2 cfs/mi^2 and 3.4 cfs/mi^2, respectively, or 43 to 46 inches of runoff depth. These differences are attributable mainly to catchment elevation and the orographic influence on precipitation.

Groundwater plays a prominent role in the flow patterns of all the creeks and rivers that were studied, but its role was especially notable at SK100C, which goes dry seasonally because of upstream losses of surface flow to groundwater, and at UT119A, which gains substantial flow from the SK to the extent that its hydrograph is dominated by baseflow. High annual unit runoff values were recorded at UT119A because much of the streamflow at that gaging station is not generated within the topographic watershed boundaries, but rather enters via subsurface pathways that cross the topographic divide. Conversely, low annual unit runoff values were recorded at SK100C because of upstream losses of groundwater to the UT watershed, and the bypassing of additional groundwater beneath the gage prior to upwelling into the channel further downstream.

The average rate of groundwater transfer from SK to UT via UT119A is approximately 22 cfs, which represents a loss of approximately 8 percent of the mean annual runoff from the SK watershed, as gaged near the watershed outlet at SK100A. At the USGS gaging station SK100B, the loss amounts to 10 percent of the mean annual runoff. The groundwater transfer into the UT watershed accounts for 10 percent of the average annual runoff at Station UT100B.

7.2.7.2 Low Flow Analysis

Low flow periods occur between rainstorms in the summer and during the winter freeze, both times when surface flow in streams is composed entirely of groundwater discharge. During the period of record, baseflow (that portion of streamflow not directly attributable to precipitation or snowmelt) has been higher during the summer because of recent snowmelt recharge of aquifers and intermittent storms. Baseflow has been the lowest in late winter, after several months without surface runoff. Spatial and temporal patterns in baseflow conditions are useful for estimating groundwater discharge and inferring groundwater gains and losses along channels and between basins. Low flow conditions are also influenced by fluctuations in surface storage features such as lakes, ponds, and wetlands. However, changes in surface storage are minimized during the late winter freeze.

In addition to flow measurements, open-water surveys were used to determine areas of groundwater upwelling. Groundwater is several degrees warmer than surface water in the winter, and strong upwelling areas do not freeze over and are visible from the air.

During low flow conditions, the lowermost stations on the NK have URO of 0.5 to 0.7 cfs/mi^2, those on the SK have URO of 0.6 to 0.8 cfs/ mi^2, and those on the UT have URO of around 1.1 cfs/ mi^2. Average low flow URO values for sub-basins ranged from 0 at SK100C to 5.5 cfs/ mi^2 at UT119A. These patterns are consistent with the annual runoff patterns described above, which result from a groundwater transfer across the topographic divide from the middle SK (above SK100C) to the middle UT (via UT119A).

Gaining and losing reaches along rivers occur within all three basins, though they are most pronounced in the mainstem of the SK. Each major river valley was partially filled by glacial drift and outwash with varying permeability. SK, NK, and UT all appear to lose some surface water to the subsurface where these deposits are especially permeable and the valley is broad. Each channel also regains flow where the bedrock valley narrows downstream, forcing groundwater up from the subsurface. Large-scale patterns of gaining and losing reaches are consistent with results from the hydrogeology baseline study presented in Chapter 8, which indicates that local variations in near-surface geology and topography drive groundwater recharge and discharge. Smaller-scale upwelling and percolation along all three main channels are apparent from both open-water surveys and unit discharge profiles; however, gaging stations are not spaced closely enough to confidently identify some of the shorter gaining and losing reaches.

The NK appears to lose discharge to groundwater where it passes through permeable valley fill of outwash sands and gravels near NK100C, and regains discharge where the valley narrows and bedrock is nearer to the surface near NK100LF3 (Figure 7.2-5). Open water was continuous from NK100LF3 to NK100LF5 in February 2006, and several small reaches of open water were visible above and below this reach. The extent of open water was less in the 2007 and 2008 surveys.

Below Frying Pan Lake, SK rapidly loses flow into thick, permeable glacial deposits that fill a broad bedrock valley. It appears that about two-thirds of this groundwater follows a buried valley to the west of the surface channel and resurfaces in the SK near SK100B2. Approximately one-third of the flow moves southeast beneath the glacial deposits that compose the surface water divide between the SK and UT. The February 2006 survey shows open water in the gaining reach of UT119A and a dry channel from around SK100D to SK100LF4, a reach that is adjacent to the UT divide (Figure 7.2-5). SK is also dry from just upstream of SK100C to around SK100LF6. Given the topography, it is unlikely that flow from this reach is leaving the basin. A more likely scenario is that surface water percolates into basin fill beneath the channel and upwells in the springs near SK100B2, where open water was observed during the February 2006 open-water survey.

Areas of open water have been observed in the reach feeding UT100E, indicating groundwater upwelling (Figure 7.2-5). This upwelling likely results mostly from groundwater storage within outwash sand and gravel deposits in the upper UT watershed. Another gaining reach is apparent around UT100LF6, above the confluence with the tributary that contains UT119A, due to groundwater discharge from outwash deposits along the east side of the middle UT watershed. The open water conditions observed in UT119A are due to the interbasin transfer from the SK, as described above.

7.2.7.3 Peak Flow Analysis

Peak discharges recorded at CQ stations occurred either during spring snowmelt or autumn rainstorms. Peak flow URO displayed a similar pattern to mean annual URO. Maximum recorded peak flow URO varied from 71 cfs/mi^2 at SK119A, and greater than 50 cfs/mi^2 in the other upland tributaries gaged at SK124A and NK119A, to 15 to 25 cfs/mi^2 at the lower gages on the mainstem channels. The lowest peak flow UROs were recorded at the gages with large groundwater influences, SK100C and UT119A, either due to loss of flow (SK100C) or buffering of peak flows due to groundwater storage. Although SK124A recorded higher peak flow URO than the main channel gages, its peak flows were relatively low compared to SK119A on the neighboring tributary. The two tributaries are comparable in steepness and elevation, but glacial sedimentary deposits are more extensive in tributary 1.240 (SK124A) than in tributary 1.190 (SK119A), and these may result in significant surface runoff losses and/or storage during storms. Beaver dams were also more numerous above SK124A than above SK119A, and these dams probably also attenuate peak flows.

The USGS regional regression equations were used to estimate peak flows for return periods from 2 to 500 years at each of the CQ gaging stations with 3 or more years of record. According to the USGS equations, the recorded mean annual peak flows for gaging stations on main stream channels have predicted return periods of 5 to 20 years, except at SK100C where a portion of the flow is lost to the subsurface. The maximum recorded peak flows at these gages, based on record lengths of 4 years (or less), have predicted return periods of 10 to 200 years. The recorded mean annual peak flows for gaging stations on steep upland tributaries (SK119A, SK124A, and NK119A) have return periods of greater than

50 years. The maximum recorded peak flows at these gages, based on record lengths of 4 years (or less), have predicted return periods of greater than 100 years.

These results indicate that the regional regression equations likely underestimate peak flows in the mine study area in general, and in upland tributaries within the mine study area in particular. Thus, an alternative approach to peak flow estimation is warranted. A combined local-regional approach was developed to improve the peak flow estimates. This approach uses 2-year and 5-year peak flow estimates developed from flood-frequency analyses of the local gage records, then scales these to longer return periods using the ratios between *n*-year and 2-year peak flows inherent in the regional equations. The 200-year peak flow results obtained using this approach are presented in Table 7.2-1.

7.2.7.4 Snow Surveys and Modeling

Snow accumulation and melt drive streamflow patterns for more than half of the year, as illustrated on Figure 7.2-3. As snow accumulates and surface water freezes, streamflow drops to baseflow levels. Baseflow typically drops gradually until April as groundwater levels decrease in the absence of surface input. The spring snowmelt event typically extends from mid- to late April through June.

Snow does not accumulate evenly across the study area, and it is redistributed frequently during high wind events. Annual surveys indicated that mid-April snow depth varied from 0 at wind-scoured sites to 207.7 inches in deep drifts on the leeward side of ridges. The mean mid-April SWE measured at the two snow courses was 10.3 inches at Snow Course 1 and 10.4 inches at Snow Course 2. At both snow courses, the lowest mid-April values were recorded in 2007 (5.3 inches and 6.3 inches, respectively), while the highest mid-April values were recorded in 2008 (16.7 inches and 15.6 inches, respectively). The small snowpack in 2007 corresponds to one of the lowest snow years on record in the surrounding region, although the regional records are only one to two decades in length. The large snowpack in 2008 corresponds to an above-average, but not an extreme, snow year in the region. The large peak flows recorded in the mine study area in the spring of 2006, as represented at Station SK100B on Figure 7.2-4, resulted from the late, rapid melt of a moderate snowpack, indicating that spring melt conditions are at least as important as snow volume in controlling peak discharges. The small spring freshet in 2007 resulted from the anomalously low snowpack combined with a slow melt.

Ablation, or snowmelt, was measured between mid-April and mid-June along the two permanent snow courses. In 2004 and 2005, over 50 percent of the snow (water equivalent depth) melted between mid-April and mid-May at both snow courses. In 2006 and 2008, the years with the highest spring peak flows, over 50 percent of the snowpack (water equivalent depth) remained un-melted in mid-May. In 2007, the year with the lowest snowpack and the slow melt rate, around 50 percent of the snow (water equivalent depth) remained in mid-May.

A snow distribution model was used to estimate mean SWE for each gaging-station drainage basin each year (from 2006 to 2008), based on topography, wind speed and direction, and extrapolated field measurements. The model results are presented in Table 7.2-2, and the modeled spatial distribution of SWE in each year is shown on Figure 7.2-6. In any given year, the basins with the highest modeled SWE values were those located in the upper portions of the SK, NK, or UT watersheds. The basins represented by the gaging stations on the lower reaches of the SK, NK, and UT had lower SWE values due to the inclusion of lower elevation terrain in their basins. Station KC100A, which has the lowest elevation basin, also had the lowest modeled SWE each year.

An ablation model was used to estimate melt rates for each drainage basin each year, based on field survey data, satellite imagery, and meteorological data. In general, the timing of snowmelt predicted by the ablation model matches the stream hydrographs reasonably well.

7.2.7.5 Small Pools

Results indicate there are two types of small pools in the study area: perched-precipitation pools and flow-through pools. Though they look similar, and were formed by similar processes, these two types differ with respect to their water sources and hydrodynamics.

Specific conductance and solute concentrations were generally lowest in precipitation and perched-precipitation pool surface water and groundwater, and highest in the flow-through pool surface water and groundwater. Mean ± standard deviation (SD) specific conductance were 16 ± 5, 7 ± 3, 18 ± 7, 28 ± 8, and 67 ± 44 microsiemens per centimeter for precipitation, surface water in the perched-precipitation pools, groundwater underneath the perched-precipitation pools, surface water in the flow-through pools, and groundwater underneath and adjacent to the flow-through pools, respectively. Generally, mean ± SD solute concentrations were lower in the perched-precipitation pools than in the flow-through pools. This was true for the conservative solutes sodium (0.68 ± 0.18 v. 1.61 ± 0.50 ppm), magnesium (0.13 ± 0.03 v. 1.02 ± 0.37 ppm), calcium (0.41 ± 0.14 v. 4.19 ± 1.32 ppm), and silica (0.14 ± 0.06 v. 1.20 ± 1.18 ppm) but was not true for the conservative solute chloride (0.73 ± 0.16 v. 0.64 ± 0.16 ppm).

Silica and chloride concentrations measured in the perched-precipitation pools and flow-through pools show that flow-through pools are preferentially enriched with silica. Therefore, the measured and modeled results indicate groundwater discharges to the flow-through pools but not to the perched-precipitation pools to any significant degree.

Patterns observed in the small pools at the detailed study sites also were observed in the 123 additional small pools located throughout the study site. The basic mass-balance mixing relationship observed in the surface water in the small pools at the detailed study sites also was observed in the surface water in the 123 additional small pools located throughout the study site.

Perched-precipitation pools and flow-through pools had different hydrographic characteristics. The former were at full pool immediately following breakup in late May/early June. Precipitation was relatively infrequent and of low intensity in June and July. During this time, the perched-precipitation pool stages declined 1.45 centimeters per day, and the perched-precipitation pools were nearly empty and had large, unvegetated margins by late July. Precipitation increased in frequency and intensity in August and September. During this time, the perched-precipitation pool stages increased slightly then remained relatively low but stable through September. Conversely, three of the four flow-through pools were at full pool throughout the summer, showing little to no effect from breakup in late May/early June, the relatively low frequency and intensity precipitation in June and July, or the relatively high frequency and intensity precipitation in August and September.

Groundwater hydraulic gradients, where found, were vertical downward adjacent to or under perched-precipitation pools, indicating groundwater recharge occurred through them. Groundwater adjacent or under flow-through pools indicated groundwater flowed through them with groundwater discharge occurring at the up-gradient ends of the flow-through pools and groundwater recharge occurring at the down-gradient ends of the flow-through pools. Where groundwater was present, groundwater remained unfrozen through the winter in only three locations, all of which were adjacent to or underneath flow-through pools.

Groundwater recharge occurred through both perched-precipitation pools and flow-through pools. However, patterns and amounts differed, with groundwater recharge being concentrated in the early summer and larger overall in the perched-precipitation pools, and relatively uniform throughout the summer and smaller overall in the flow-through pools.

Perched-precipitation pools have inflows by meltwater and direct precipitation, outflows by evapotranspiration and groundwater recharge, and are seasonally inundated because infiltration through the low-permeability surficial deposits is slow. These pools are typically located where groundwater discharge is unlikely to occur (e.g., shallow pools in nearly level ground moraine) and typically have wide, unvegetated margins by middle-late summer. Surface water has geochemical characteristics of precipitation, while groundwater has geochemical characteristics of precipitation that has undergone slight modification due to short-term water-rock interaction.

Flow-through pools have inflows by meltwater, direct precipitation, and groundwater discharge; outflows by evapotranspiration and groundwater recharge; and are perennially inundated because of the groundwater throughflow. These pools are typically located where groundwater discharge is likely to occur (e.g., deep pools on gently to strongly sloping lateral moraines) and typically have stable, vegetated margins throughout summer. Surface water has geochemical characteristics of mixed precipitation and groundwater, while groundwater has geochemical characteristics of precipitation that has undergone slight modification due to short-term water-rock interaction.

7.2.8 Summary

The 2004 to 2008 baseline studies of surface hydrology focused on establishing a network of baseline streamflow gaging stations and deriving a preliminary understanding of streamflow and snow distribution for the NK, SK, UT, and KC drainage basins, which drain the area surrounding the general deposit location. Key factors controlling the magnitude, timing, and distribution of surface runoff are basin topography, snow accumulation, snowmelt, and groundwater exchange with permeable glacial deposits. The lowest streamflows were recorded in late winter (March or April), after several months of freezing temperatures. The highest average runoff occurred during the peak snowmelt period in May. The spring snowmelt and autumn rainstorm seasons each accounted for approximately 30 to 40 percent of annual runoff on average at each gaging station.

Snow was distributed unevenly across the study area during all years of study, with the highest values measured in the middle of the study area. Snow distribution and ablation models have been used to estimate snow accumulation and melt in the study drainage basins.

Late winter low flow measurements and open-water surveys delineated gaining and losing reaches associated with permeable glacial fill in each of the three major drainage basins—NK, SK, and UT. High baseflows and open water were found in areas of persistent groundwater upwelling along the main channels of NK, SK, and UT. These findings may be due to the geometry of the underlying bedrock valley or changes in the permeability of the aquifer. Extremely high baseflows were recorded in UT tributary 1.190 at gaging station UT119A. The adjacent reach of the SK mainstem channel is dry during low-flow periods. Subsurface flow follows a permeable pathway beneath the SK-UT topographic divide.

Peak flows were recorded either during spring snowmelt or autumn rainstorms. Peak flow URO was highest in steep, upland tributaries with bedrock near the surface, and lowest in flatter reaches with substantial loss to groundwater through glacial sedimentary deposits. Regional regression estimates of flood frequency appear to underestimate floods in the mine study area, particularly in the steep tributaries. Continued streamflow gaging and the collection of more instantaneous high-flow measurements for the stage-discharge rating curves will improve the estimation of peak flows in the study area.

There are two types of small pools identified in the study area: perched-precipitation pools and flow-through pools. Perched-precipitation pools have inflows by meltwater and direct precipitation, outflows by evapotranspiration and groundwater recharge, and are seasonally inundated because infiltration through the low-permeability surficial deposits is slow. Flow-through pools have inflows by meltwater, direct precipitation, and groundwater discharge, outflows by evapotranspiration and groundwater recharge, and are perennially inundated because of the groundwater throughflow. Both types of small pools serve as groundwater recharge focal points. This is particularly true for perched-precipitation pools, where net groundwater recharge rates during June through September are about three times higher than in flow-through pools and about four times higher than in the surrounding landscape.

7.2.9 References

Curran, J.H., D.F. Meyer, and G.D. Tasker. 2003. Estimating the Magnitude and Frequency of Peak Streamflows for Ungauged Sites on Streams in Alaska and Conterminous Basins. U.S. Geological Survey Water-Resources Investigations Report 03-4188.

Hamilton, T.D. 2007. Surficial Geologic Map of the Pebble Limited Partnership’s Pebble Project.

7.3 Transportation Corridor Study Area

7.3.1 Introduction

This section presents the findings of the baseline surface-water hydrology studies for the transportation corridor study area within the Bristol Bay drainage. These studies consisted of a field component to characterize stream channels crossing the linear study area and to collect spot measurements of instantaneous discharge, a basin analysis component to characterize the drainage basins of the study streams, and a regional analysis component to estimate high and low flow statistics for each stream based on published guidelines and regression analyses.

7.3.2 Study Objectives

The objectives of the surface-water hydrology studies within the transportation corridor study area are as follows:

- Characterize annual streamflows in the anadromous fish-bearing stream channels that cross the transportation corridor study area.
- Estimate maximum and minimum flow statistics, and other index flows required for aquatic habitat studies, in these channels.

7.3.3 Study Area

The transportation corridor study area extends from the Newhalen River in the west to the drainage divide between Bristol Bay and Cook Inlet in the east, along the north shore of Iliamna Lake. These features are shown on Figure 7.3-1. The Newhalen River is included in the mine study area, not the transportation corridor study area. From west to east, the principal (named) streams that cross the linear transportation corridor study area are Roadhouse Creek, Chekok Creek, Canyon Creek, Knutson Creek, Pile River, Long Lake Creek, Iliamna River, and Chinkelyes Creek. All of these watercourses flow directly or indirectly into Iliamna Lake. The transportation corridor study area currently has 18 “Title 16” streams (including the streams named above) as designated by Alaska Statute (AS) 16.05.871 and managed by the Alaska Department of Fish and Game (ADFG), Habitat Division) in the Bristol Bay drainages study area. Title 16 streams are so designated because they support anadromous fish, and any modifications to the stream channel must comply with this section of the Alaska Statutes.

The study area is located within Streamflow Analysis Region 4, as defined by the U.S. Geological Survey (USGS) and shown on Figure 7.1-2. Region 4 has a transitional climate between the more maritime Region 3, which is located along the exposed southern coast of Alaska and the eastern coast of the Alaska Peninsula (Aleutian Range), and the more continental Region 6, which covers the interior of Alaska. The study area lies near the boundary between Regions 3 and 4.

The eastern part of the study area has mountainous physiography and a maritime climate, while the western part has lower-relief physiography and a more continental climate. The western front of the mountains is located near Canyon Creek, approximately midway along the linear study area. In the eastern part of the study area, rapid snowmelt and rainstorm runoff is facilitated by the steep terrain, thin deposits of surficial materials on mountain slopes, and the paucity of lakes and wetlands. In the western part of the study area, peak flow attenuation and baseflow augmentation are facilitated by the gentler terrain, more abundant deposits of surficial materials, and more abundant surface water bodies.

The only meteorological station within the study area is located at Iliamna Airport, where the mean annual precipitation is 26 inches. The precipitation map of Alaska (Jones and Fahl, 1994) indicates that mean annual precipitation in the western half of the study area (west of Canyon Creek) is between 20 to 30 inches. Mean annual precipitation increases rapidly in an eastward direction from the western front of the mountains near Canyon Creek toward the drainage divide between Bristol Bay and Cook Inlet. Mean annual precipitation on the state map is shown to range from 30 inches near the mouth of Canyon Creek to over 80 inches in the headwaters of the Iliamna River.

Besides the regional precipitation gradient illustrated on the state map, the varied topography within the study area is assumed to produce more localized orographic precipitation gradients (i.e. variability in precipitation due to air mass uplift over high elevation terrain), with substantially greater precipitation falling over higher elevation terrain and neighboring lowland areas as compared to broad lowland areas. These local variations in precipitation are beyond the resolution of the state precipitation map.

The USGS operates two continuous streamflow gaging stations within the study area on Roadhouse Creek in the west and on the Iliamna River in the east. The locations of these gaging stations are shown on Figure 7.3-1, and the mean annual discharge and unit runoff rates at each station are presented in Table 7.3-1. The mean annual unit runoff rates at the two gages are 1.4 cubic feet per second (cfs) per square mile (mi^2) and 7.1 cfs/mi^2, respectively. These values equate to mean annual runoff depths of 19 inches in the Roadhouse Creek basin and 96 inches in the Iliamna River basin. These runoff values are indicative of the strong spatial precipitation gradient traversed by the study area. The Roadhouse Creek runoff value is consistent with an average basin precipitation of around 25 to 30 inches per year, as suggested by the state precipitation map. The Iliamna River runoff value indicates that average basin precipitation is in excess of 100 inches per year, with even greater precipitation rates presumably occurring in the highest parts of the basin. This exceeds the precipitation estimate shown on the state map (Jones and Fahl, 1994). There are no USGS gages located elsewhere along the study area that would help to clarify the spatial pattern of the regional precipitation gradient in the transitional area between Canyon Creek and the Iliamna River.

The USGS gage records on Roadhouse Creek and the Iliamna River also illustrate the differences in runoff generation characteristics between the western and eastern parts of the study area. Normalized annual hydrographs of mean monthly flows at each station are presented on Figure 7.3-2. This figure shows that Roadhouse Creek experiences the lowest flows of the year in the winter, followed by a modest spring snowmelt freshet, a moderately low-flow period in the summer, and the highest monthly flows of the year during the autumn rainstorm season. The Iliamna River has a somewhat similar pattern of annual flows, except that the highest monthly flows of the year occur during the spring snowmelt freshet due to the large snowpack that accumulates in the mountainous basin, and monthly flows in the autumn are more modest due to the accumulation of snow in the mountains during that season. The summer low-flow period is also less pronounced in the Iliamna River than in Roadhouse Creek due to ongoing flow contributions from high-elevation snowmelt and glacier melt through the summer.

7.3.4 Previous Studies

The USGS operates two continuous streamflow gaging stations within the study area, on Roadhouse Creek and the Iliamna River. The Roadhouse Creek gaging station has only been in operation since 2005, but 10 years of peak flow data are available from a crest gage that was maintained between 1973 and 1983 (with 1 year of missing data). The Iliamna River gaging station has been in continuous operation since 1996. The USGS has also maintained a peak flow crest gage on a tributary to Chinkelyes Creek since 1997. The locations of these gaging stations and crest gages are shown on Figure 7.3-1, and the periods of record are summarized in Table 7.3-1.

The USGS conducted studies throughout Alaska to determine regional regression equations for estimating various local hydrologic flows based on limited regional data. These were published as Water Resources Investigations Reports (WRIRs) 03-4114 and 03-4188. WRIR 03-4114 (Wiley and Curran, 2003) provides estimates of annual high-flow statistics, and monthly and seasonal low-flow statistics for ungaged sites. WRIR 4188 (Curran et al., 2003) provides estimates of peak flow magnitude and frequency for ungaged sites. Regression equations have been developed to predict various return frequency flows for ungaged streams in each region based on precipitation, climate, and terrain factors.

The minimum length of continuous or peak flow (crest gage) record required for inclusion in the USGS regional analyses was 10 years. At the time of publication, the Roadhouse Creek gaging station was the only USGS gage in the study area that met this criterion.

7.3.5 Scope of Work

The field studies were completed by Bristol Environmental & Engineering Services Corporation (BEESC) between July 2004 and October 2005. BEESC also led the basin analysis and regional analysis tasks, and prepared a draft report. KPL produced the final report.

Basin characteristics and streamflow measurements were compiled at 15 sites on 14 streams in the study area (two sites on Roadhouse Creek). The four Title 41 streams that were not gaged are small, unnamed streams with difficult access conditions and are assumed to have similar hydrologic characteristics to the gaged streams. Two of the study sites are located at USGS gaging stations (Roadhouse Creek and Iliamna River). The Iliamna River gage was in operation prior to the start of the Pebble field study, whereas the Roadhouse Creek gage was re-established by the USGS after the start of the Pebble field study.

The baseline study was designed and implemented by Mr. William F. Barber, Hydrologist, BEESC, and was conducted according to the approach described in the consolidated study program for Pebble Project (Appendix E of this environmental baseline document), the annual field sampling plans (Appendix F), and the annual quality assurance project plans (Appendix G). The study was designed to account for the wide range in climatic conditions and stream types encountered in the study area. A *2004 Progress Report* was drafted to account for the preliminary findings in 2004 and to provide the necessary tools to support the environmental process (NDM, 2005).

Activities completed in 2004 focused on compiling physical drainage-basin characteristics, installing crest gages, and collecting monthly streamflow measurements at 14 sites. The 2005 study scope reduced the number of sites (with the inclusion of one new site on Chinkelyes Creek) but looked at representative stream types for evaluating hydrologic data. A map depicting the gage station locations for the 2004 and 2005 data collection effort is shown as Figure 7.3-1. In 2006, the USGS regional regression models were used to estimate characteristic streamflows, which were compared to the field results.

All baseline data were collected using guidelines established by Alaska Department of Transportation and Public Facilities (ADOT&PF), the Federal Highway Administration (FHWA), the USGS, and the American Association of State and Highway Transportation Officials (AASHTO). The magnitude and frequency of streamflows were computed in accordance with USGS Bulletin 17B (USGS, 1982) and procedures established by ADOT&PF, FHWA, and USGS.

7.3.6 Methods

7.3.6.1 Basin Analysis and Field Work

Basin Characteristics

Basin characteristic files were created for each watershed in the study area. The files catalogued information on the physical and climatic nature of each basin. Drainage basin areas were defined for each stream in the study area using USGS topographic maps overlain with watershed boundaries from the Alaska Watershed and Stream Hydrologic Enhanced Datasets (USGS, 2002). Maps were imported into AutoCAD format and enhanced using ArcGIS mapping objects. Watershed maps for each drainage basin included in this study are presented in Appendix 7.3A.

USGS topographic information was supplemented by aerial photography (1978, 2002, and 2003) to create basin characteristic files for each proposed gaging station that included the information summarized in Table 7.3-2. A digital version of the state precipitation map by Jones and Fahl (1994) was used to determine average basin precipitation. The basin characteristic files are used in the USGS regional regression analyses to predict characteristic flows in each stream. Basin characteristic data for each gage station are presented in Appendix 7.3A.

Gage Station Installation

Prior to actual field data collection, a review of available information from sources including the Alaska Department of Fish and Game (ADF&G), the ADNR-OHMP, the ADOT&PF, the U.S. Fish and Wildlife Service (USFWS), the National Oceanographic and Atmospheric Administration (NOAA) River Forecast Center, as well as existing aerial photography from 1978, 2002, and 2003, was used to plan the proposed gaging network.

Field data were collected in accordance with the standards set forth in the *National Handbook of Recommended Methods for Water-Data Acquisition* (USGS, 1977). Crest gages were installed at each selected gaging location to record high water levels occurring between monitoring events. A crest gage is designed to measure the maximum instantaneous flood crest under conditions of transitory or transient flow.

Crest gages installed on this project were constructed of 2-inch galvanized pipe containing a wooden staff held in a fixed position relative to a datum (in this project, an assumed datum of 100 feet was used on all crest gages). Care was taken to ensure the proper placement of intake holes in the bottom of the pipe to minimize the non-hydrostatic drawdown or super elevation of the water levels. A typical crest-gage installation is shown in Photo7.3-1.

The crest gage is a simple device intended to measure peak flow stages. The gage includes granulated cork stored in the bottom of the capped pipe. As a transitory flood wave passes, the water rises in the pipe and the cork floats on the water surface. As the water recedes, the cork adheres to the staff inside the pipe thereby retaining a record of the crest stage of flood. The height of the flood peak is obtained by measuring the elevation of the flood mark relative to an established reference point on the pipe.

During installation of the gage, stream cross-sections were surveyed at the gage location starting at a rebar driven into the bank just beyond the ordinary high-water mark and proceeding across the river perpendicular to the stream channel, as shown on Figure 7.3-3 and in Photo 7.3-2. Survey measurements were generally taken 100 feet upstream and downstream to record the stream channel slope at the crest gage. The types of data collected during installation of the gages are summarized in Table 7.3-3.

Stream Discharge Measurement

Stream discharge data were collected during monthly site visits. For each data collection event, the current water-surface elevation, stream discharge, and hydraulic slope up and downstream were measured at each gaging location. The crest-gage reading was also collected to determine peak flow stages that had occurred between monitoring events.

The mid-section method of computing a cross-section area was used to compute discharges. This method assumes that the velocity measured at each sampling point across the stream represents the mean velocity in the partial rectangular cross-sectional area. The partial area extends laterally from half the distance from the preceding velocity-measurement location to half the distance to the next, and vertically from the water surface to the sounded depth, as depicted on Figure 7.3-4. This method is described in the document *Discharge Measurements at Gaging Stations* (USGS, 1969).

The stream velocities were measured using a Marsh-McBirney Flo-Mate Model 2000 velocity meter, which was calibrated in June 2004 and January 2005. For small streams less than 20 feet in width, velocity was measured at 1-foot intervals across the channel. For the larger streams, the width of the channel was divided into 20 sections controlled by changes in the hydraulic cross-section and changes in velocities. Velocity measurements were taken at the center of each section. Point velocities for all discharge measurements were taken at 0.6 of the measured flow depth unless the depth was greater than 3.0 feet. Where stream depths were greater than 3.0 feet, two measurements were recorded; one at 0.2 and one at 0.8 of the total depth. The mean of the velocity of the two depths was then used as the velocity for that section.

At most gaging stations, streams could be safely waded. A typical wading measurement is shown in Photo 7.3-3. During high-flow events, it was necessary to use a boat to obtain the discharge measurements at some gaging stations. The Iliamna River, Pile River, and Chinkelyes Creek required a boat to conduct the velocity measurements for most events. On a few occasions, the Pile River and Knutson Creek were too dangerous to wade or use a boat. The first attempt to collect measurements on the larger streams used a skiff with a jet outboard motor and outfitted with a fathometer, as this was the only craft that could navigate the shallow water. The skiff was difficult to maneuver and hold in position long enough to collect the measurement in the swift water. Beginning with the September 2004 sampling event, the standard boat method, using a small inflatable boat outfitted with a tag-line and powered with a propeller outboard motor, was used on all streams that could not be waded safely. This method is illustrated in Photo 7.3-4.

Stage-Discharge Rating Curves

The stream discharge measurements were mostly collected during relatively low flow conditions. Stage-discharge rating curves could not be developed due to the limited range of flow conditions measured. Therefore, the crest gage observations cannot be related to rating curves to estimate the corresponding peak discharges. Similarly, the channel cross-section surveys and slope measurements were not used to develop rating curves based on Manning's equation due to the lack of high flow measurements to guide the estimation of Manning's coefficient ("n").

Photographic Documentation

During installation of the crest gages and at seasonal high- and low-flow events, photographic documentation was collected at the crest gage, and upstream and downstream of the gage. High-water marks from past flood events were identified and photographed. The photographs depict conditions that were experienced as the study progressed. The photographs of each gage are shown with the individual gage data in Appendix 7.3A.

Stream Classification

The basin characteristic files contain a row in the spreadsheet with a listing of the "Stream classification at gage site (Montgomery method)". The Montgomery and Buffington method for channel-reach morphology in mountain drainage basins is currently the State of Alaska's preferred method for stream classification (Montgomery and Buffington, 1997). The stream classification used in this analysis is based on a Level 1 assessment. The Level 1 assessment characterizes the types of channels that occur only within the study area corridor and describes the channel morphology near the gage station. The Alaska Highway Drainage Manual describes stream classification in a similar methodology (ADOT&PF, 2004).

7.3.6.2 Regional Analysis

Regional Regression Equations

Regional regression equations published in the USGS publications WRIR 03-4114 (Wiley and Curran, 2003) and WRIR 03-4188 (Curran et al., 2003) are used to estimate characteristic flows in ungaged streams in Alaska. These equations require input of basin characteristic data for each stream of interest. The regional regression equations for Region 4, in which the study area is located, were developed on the basis of USGS streamflow data recorded at a relatively sparse gaging station network within a large region with diverse physiographic and climatic conditions. As such, the regression equations contain considerable uncertainty. The eastern part of the transportation corridor study area lies close to Region 3 and may be better represented by the USGS gaging stations used in the Region 3 regression analysis, so the regression equations for both Regions 3 and 4 have been used to estimate high-duration flows and peak flows in the study area. For low-duration flows, Regions 3 and 4 were combined for the USGS regression analysis, so a single set of equations represents both regions.

The regression equations used to estimate monthly low-duration flows in the months of July, August, and September in Regions 3 and 4 are presented in Table 7.3-4. These are the only months for which these equations are provided by the USGS. Low-duration flows are defined as follows. Low-duration flows represent the daily discharge values that are exceeded for a given fraction of the time in a given month. At any given station with a suitably long record within the region of interest, the low duration flow AUG98 (for example) represents the discharge value that was exceeded 98 percent of the time in the daily discharge record in all months of August in the historical record. As used in the regional estimation procedure, the low-duration flow AUG98 (for the same given station within the region of interest) is also assumed to represent the daily discharge value that will be exceeded on 98 percent of days in August in the future (an assumption that does not consider the potential effects of cyclical or systematic climate change).

The regression equations used to estimate annual high-duration flows in Regions 3 and 4 are presented in Table 7.3-5. A separate set of equations is provided for each region. High-duration flows are defined as follows. High-duration flows represent the daily discharge values that are exceeded for a given fraction of the time, on average, over the course of a water year (October through September, or O-S). At any given station with a suitably long record within the region of interest, the high duration flow O-S1 (for example) represents the discharge value that was exceeded 1 percent of the time in the historical daily discharge record. As used in the regional estimation procedure, the high duration flow O-S1 (for the same given station within the region of interest) is also assumed to represent the daily discharge value that will be exceeded on 1 percent of days in the future (again, an assumption that does not consider the potential effects of cyclical or systematic climate change).

The regression equations used to estimate peak streamflows in Regions 3 and 4 are presented in Table 7.3-6. A separate set of equations is provided for each region. Peak flows represent instantaneous discharge values that are exceeded, on average, once within various specified recurrence intervals. At a station with a suitably long record of annual peaks, Q_{10} (for example) represents the instantaneous discharge value that would be expected to be exceeded once every 10 years, on average, according to a statistical distribution fit through the peaks. As used in the regional estimation procedure, Q_{10} is also assumed to represent the instantaneous discharge value that will be exceeded once every 10 years, on average, in the future (again, an assumption that does not consider the potential effects of cyclical or systematic climate change).

The average standard errors of prediction for all of these regional equations are relatively large, as shown in Tables 7.3-4 through 7.3-6, which reflects the small number of USGS gages used to represent these large, diverse regions. The standard errors for monthly low-duration flows range from around 40 percent to 60 percent in the two regions. The standard errors for annual high-duration flows range from 21 percent to 27 percent in Region 3 and from 30 percent to 34 percent in Region 4. The standard errors for peak flows range from 37 percent to 45 percent in Region 3 and from 38 percent to 52 percent in Region 4. The uncertainty in peak flow estimation is also expressed another way in Table 7.3-6. The right-hand column presents the length of record that would have to be collected at a new gage site to achieve a peak flow estimate with equivalent certainty to the value obtained from the regional equations. These equivalent record lengths are short, ranging from around 1 to 3 years in Region 3, and 1 to 7 years in Region 4, indicating that the regional estimates are highly approximate.

Regional Peak Flow Characteristics

A series of figures has been prepared to graphically present the peak flow prediction equations, using typical physiographic and climatic inputs for the western and eastern parts of the study area.

Figure 7.3-5 presents the Region 4 peak flow predictions for recurrence intervals of 2 years to 500 years for basins with 3 percent lake and pond storage area and 30 inches of annual precipitation, typical of basins in the western part of the study area. Figure 7.3-6 presents the Region 4 peak flow predictions for the same set of recurrence intervals for basins with 1 percent lake and pond storage area and 100 inches of annual precipitation, typical of basins in the extreme eastern part of the study area. For comparison, the Region 3 peak flow predictions for the same set of recurrence intervals and basin characteristics are presented on Figures 7.3-7 and 7.3-8.

The 2-year peak flow estimates from the previous four figures are compared on Figure 7.3-9. The solid lines represent the Region 3 peak flow estimates, and the dashed lines represent the Region 4 estimates. The estimates for the typical basin characteristics in the western part of the study area are represented by green lines, while the estimates for the typical basin characteristics in the eastern part of the study area are represented by red lines. Both regional regression equations predict larger flood magnitudes in the eastern part of the study area as compared to the western part of the study area, as expected. Furthermore, the Region 3 equations predict larger flood magnitudes than the Region 4 equations, primarily for smaller drainage basins. The differences between the regional predictions diminishes for larger basin sizes (i.e., the plotted lines on Figure 7.3-9 converge toward the right-hand side of the chart).

The 500-year peak flow estimates are compared on Figure 7.3-10. Again, the solid lines represent the Region 3 peak flow estimates, and the dashed lines represent the Region 4 estimates. The estimates for the typical basin characteristics in the western part of the study area are represented by green lines, while the estimates for the typical basin characteristics in the eastern part of the study area are represented by red lines. Both regional regression equations predict larger flood magnitudes in the eastern part of the study area as compared to the western part of the study area, as expected, as was the case for the 2-year peak flows. The Region 3 equations predict larger flood magnitudes than the Region 4 equations for basin characteristics typical of the western part of the study area, with no dependence on drainage basin size. The main difference between the comparison of 2-year and 500-year peak flow estimates is that the Region 3 and Region 4 predictions of 500-year flood magnitude are nearly identical for basin characteristics typical of the eastern part of the study area (i.e., the upper pair of lines on Figure 7.3-10 are nearly identical).

Study Area Peak Flow Characteristics

Flood frequency analyses for the two active USGS gages in the study area were compared to the regional regression equations to assess their representativeness of the study area. The results of the published flood frequency analysis for Roadhouse Creek (Curran et al., 2003), based on the period 1973 through 1983, were used for this purpose. A new flood frequency analysis was not performed on the updated Roadhouse Creek record that started again in 2005. Only the mean annual peak instantaneous discharge was calculated using the updated record.

No flood frequency analyses have been published for the Iliamna River. Therefore, a Log Pearson Type III analysis was performed for the Iliamna River using the 10 years of record up to 2005 and following the methodology mandated in Bulletin 17B (USGS, 1982). The “Log Pearson Expected Probability” estimate also includes factors for regional skew. Curves representing the 95 percent confidence interval are also presented. Prior to the analysis, the flow record was reviewed according to procedures in Bulletin 17B to identify any recorded peaks (high or low) that were not consistent with other measurements in the data set and that could abnormally skew the data analysis. No outlier values were identified, so the Log Pearson Type III analysis was performed using the full gaging record for the Iliamna River gaging station.

A flood frequency analysis was not performed on the peak flow record from the Chinkelyes Creek tributary because the crest gage record had not reached 10 years at the time of analysis. Only the mean annual peak instantaneous discharge was calculated.

7.3.7 Results and Discussion

7.3.7.1 Basin Analysis and Field Work

The 2004 through 2005 study program developed information on basin and channel characteristics and limited data on streamflows. The observations and conclusions presented in this report are based on less than 1 year of data for most streams in the study area. Furthermore, based on meteorological records from Iliamna and streamflow records from the mine study area, the autumn rainy season was late arriving in 2004, so the streamflow measurements collected in August and September 2004 were lower than would normally be expected for that time of year.

The basin characteristics data required for input to the USGS regional regression equations are presented in Table 7.3-7. Additional information on each basin is provided in Appendix 7.3A, including tables with additional basin characteristics data, a description of the channel where it crosses the study area, and site photographs.

The instantaneous discharge measurements collected at each gage station are presented in Table 7.3-8. Additional information related to the discharge measurements is provided in Appendix 7.3A, including the method of measurement, the water surface elevation at the time of measurement, and the crest gage readings indicating maximum water level since the previous site visit.

7.3.7.2 Regional Analysis

The estimated monthly low-duration flows at each gage station for the months of July, August, and September – based on the USGS regression equations for Regions 3 and 4 combined – are presented in Table 7.3-9. Measured flows in August 2004 are compared to the regional estimates in Table 7.3-10. Most of the measured flows have exceedence durations of greater than 90 percent, consistent with the expectation that streamflows during August 2004 were below average and should be exceeded most of the time.

The estimated annual high-duration flows at each gage station, based on the USGS Region 4 regression equations, are presented in Table 7.3-11. The table also presents estimated annual high-duration flows at the gage stations in the eastern part of the study area, based on the USGS Region 3 regression equations. The Region 3 equations generally predict larger discharges for specified high-flow durations, ranging from an average of 1.2 times larger than the Region 4 estimates for the 15 percent exceedence duration to 1.6 times greater than the Region 4 estimates for the 1 percent exceedence duration.

The estimated peak streamflow values at each gage station for recurrence intervals of 2 through 500 years, based on the USGS Region 4 regression equations, are presented in Table 7.3-12. The table also presents estimated peak streamflows at the gage stations in the eastern part of the study area, based on the USGS Region 3 regression equations. The basin characteristics summarized in Table 7.3-7 were used as input data for the regression equations, including the precipitation estimates from the state map (Jones and Fahl, 1994), which has been shown to under-represent average precipitation in the Iliamna River watershed and may also under-represent precipitation in neighboring watersheds. The Region 3 equations predict larger discharges than the Region 4 equations. For the three easternmost streams (Chinkelyes Creek, Iliamna River, and Pile River), the Region 3 equations predict flood magnitudes that are approximately 1.2 times greater than the Region 4 predictions. This comparison is based on estimated mean annual precipitation rates of 60 to 70 inches. As shown on Figures 7.3-9 and 7.3-10, the regional equations would produce similar predictions for annual precipitation rates of 100 inches.

7.3.7.3 Study Area Peak Flows

Peak flow estimates for the two active USGS gages in the study area are presented in Table 7.3-13. The results for both gages are based on relatively short periods of record, so only the peak flow estimates for recurrence intervals up to 10 years are presented for comparison to the results of the regional regression equations.

The estimated 2-year and 10-year peak flow values based on the Roadhouse Creek gage record are 106 cfs and 231 cfs, respectively (Curran et al., 2003). The Region 4 peak flow equations over-predict these results by a factor of approximately 1.5 times (based on a comparison of the Q_2 and Q_{10} results for Roadhouse Creek on Tables 7.3-12 and 7.3-13).

The Iliamna River peak flow record is presented on Figure 7.3-11. In most years, the annual peak flow values ranged from around 5,000 cfs to 20,000 cfs. The flood of record occurred in October 2003, when a peak discharge with an estimated value of 53,000 cfs was recorded. Although this flood peak is not considered an "outlier" according to USGS methodology, it does have considerable influence on the flood frequency statistics for the short record, especially for longer return period floods. Interviews with USGS personnel who maintain the gaging site reveal that the water level in the river was at or above low steel on the old Iliamna River Bridge at least three times when they were at the site taking discharge measurements. The new bridge under construction at the start of Pebble field studies is shown in Photo 7.3-5.

The estimated 2-year and 10-year peak flow values based on the Iliamna River gage record are 12,250 cfs and 35,590 cfs, respectively. The Region 3 and Region 4 peak flow equations both under-predict these results by approximate factors of 4 times for the 2-year flood, and 6 times for the 10-year flood. These regional results are based on the estimated mean annual precipitation of 60 inches in the Iliamna River watershed, as determined from the state precipitation map. However, if a more realistic estimate of 100 inches is used (based on mean annual unit runoff at the Iliamna River gage), then the regional estimates are closer to the gage-derived values. The Region 3 and 4 equations under-predict the gage results by approximate factors of 2 times for the 2-year flood, and 4 times for the 10-year flood, when the precipitation value of 100 inches is used. Even when the precipitation value of 100 inches is used, the *10-year* peak flow estimates based on the Region 3 and Region 4 equations are substantially less than the *2-year* peak flows based on the gage record, indicating that the regional equations are not adequate.

The 2-year and 10-year peak flow values based on the Roadhouse Creek gage record have unit-area values of 5.1 cfs/mi^2 and 11.1 cfs/mi^2, respectively, as shown in Table 7.3-13. The peak flows with the same recurrence interval based on the Iliamna Gage record have unit-area values of 95.7 cfs/mi^2 and 309.3 cfs/mi^2, respectively. The unit-area peak flow runoff values at the Iliamna River gage are approximately 19 to 28 times greater than at the Roadhouse Creek gage, which substantially exceeds the ratio of mean annual unit runoff between the two gages (runoff at the Iliamna gage is approximately 5 times greater than at the Roadhouse Creek gage). This illustrates that the eastern part of the study area is not only wetter than the western part, but also has more concentrated runoff response during peak flow events, especially considering that the Iliamna River has a substantially larger drainage basin than Roadhouse Creek, and that peak flow intensity typically decreases with increasing basin area.

An alternate set of peak flow estimates for the Iliamna River, Pile River, Knutson Creek, and Canyon Creek are provided in Appendix 7.3B. These estimates are based on the Region 3 regression equations, with the application of calibration adjustments to make the Iliamna River estimates match the gage analysis. The basin precipitation estimates for all basins, including the Iliamna River, are based on the state precipitation map (Jones and Fahl, 1994).

7.3.8 Summary

The transportation corridor study area within the Bristol Bay drainages varies significantly from east to west, both topographically and climatically. Hydrologic conditions are influenced by local climatic and topographic conditions. The eastern end of the study area has rugged mountainous terrain and a climate influenced by the maritime coastal conditions of Cook Inlet. In the western portion of the study area, the terrain has lower relief, and the climate is transitional between the maritime climate of Cook Inlet and the continental climate of Interior Alaska.

The annual pattern of streamflows in the study area is represented by two USGS gaging stations. Roadhouse Creek, located in the western part of the study area, has a mean annual basin runoff depth of 19 inches. The Iliamna River, located in the eastern part of the study area, has a mean annual basin runoff depth of 96 inches. The annual hydrograph in Roadhouse Creek is dominated by spring snowmelt and autumn rainfall, with low flows in the summer and winter. The autumn rains produce greater runoff volume than spring snowmelt on average, and the winter flows are lower than the summer flows. The annual hydrograph in the Iliamna River is somewhat similar to the Roadhouse Creek hydrograph, except that spring flows in the Iliamna River are greater than autumn flows due to snow accumulation and melt in the higher mountainous basin, and the summer low flow season is not as pronounced as in Roadhouse Creek, due to prolonged snow and glacier melt through the summer.

Basin and channel characteristics and spot discharge measurements were compiled in 2004 and 2005 at 15 sites on 14 streams within the study area, including the two USGS gaging stations discussed above. Crest gages were installed to record instantaneous stage peaks, but stage-discharge rating curves were not developed and peak discharge estimates associated with the stage peaks are not presented.

Streamflow statistics have been estimated at the 15 sites using regional regression equations developed by the USGS. The low-duration estimates indicate that most of the measured flows in August 2004 had exceedence durations of greater than 90 percent, which is consistent with the generally dry conditions experienced in the late summer of 2004. The high-duration flows were not explicitly checked against any field data. The peak flow estimates based on the regional regression equations were compared to the gage records from Roadhouse Creek and the Iliamna River. The regional peak flow estimates appear to over-predict peak flows in the western part of the study area and under-predict peak flows in the eastern part of the study area, even when appropriate values of mean annual precipitation are used in the regression equations. An alternative set of peak flow estimates has been developed for the eastern part of the study area, using the Iliamna River peak flow record to calibrate the regional equations.

7.3.9 References

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TABLES

TABLE 7.1-1
USGS Streamflow Gaging Stations in the Bristol Bay Drainages

Station [a]			Location		Period of Record			Drainage Area	Mean Annual Discharge	Mean Annual Unit Runoff
USGS ID	USGS Name	Pebble ID	Lat. (N)	Long. (W)	Start	End	Length [b] (Year.)	(mi²)	(cfs)	(cfs/mi²)
15303100	East Creek Near Dillingham AK		59°11'32"	158°49'53"	Aug-73	Sep-75	2	2.12	16	7.3
15300100	Bear Creek Near Iliamna AK		59°49'28"	154°52'56"	Jul-05	-	3	2.59	8	3.1
15303011	Wood River Tributary Near Aleknagik AK		59°12'26"	158°40'02"	May-90	Sep-93	0	3.35	-	-
15303010	Silver Salmon Creek Near Aleknagik AK		59°13'34"	158°40'21"	Oct-84	Sep-89	2	4.46	12	2.6
15302840	Elva Lake Outlet Near Aleknagik AK		59°36'15"	159°06'50"	Oct-79	Jun-82	2	9.00	64	7.1
15297900	Eskimo Creek at King Salmon AK		58°41'08"	156°40'08"	Oct-73	Sep-84	10	16.1	14	0.9
15300200	Roadhouse Creek Near Iliamna AK		59°45'26"	154°50'49"	May-05	-	3	20.8	24	1.2
15302800	Grant Lake Outlet Near Aleknagik AK		59°47'43"	158°33'07"	Jul-59	Jul-65	6	34.3	90	2.6
15302200	Koktuli River Near Iliamna AK	SK100 B	59°47'36"	155°31'21"	Aug-04	-	4	69.1	188	2.7
15300250	Upper Talarik Creek Near Iliamna AK	UT100 B	59°47'12"	155°15'11"	Aug-04	-	4	86.6	225	2.6
15302250	North Fork Koktuli River Near Iliamna AK	NK100 A	59°50'35"	155°42'59"	Aug-04	-	4	106	260	2.5
15303150	Snake River Near Dillingham AK		59°08'54"	158°53'14 "	Aug-73	Sep-83	10	113	545	4.8
15300300	Iliamna River Near Pedro Bay AK		59°45'31"	153°50'41"	May-96	-	12	128	889	6.9
15298000	Tanalian River Near Port Alsworth AK		60°11'20"	154°15'30"	Aug-51	Sep-56	5	200	637	3.2

Station [a]			Location		Period of Record			Drainage Area	Mean Annual Discharge	Mean Annual Unit Runoff
USGS ID	USGS Name	Pebble ID	Lat. (N)	Long. (W)	Start	End	Length [b] (Year.)	(mi²)	(cfs)	(cfs/mi²)
15301500	Allen River Near Aleknagik AK		60°09'00"	158°44'00"	Jun-63	Sep-66	3	270	1,420	5.3
15299900	Tazimina River Near Nondalton AK		59°55'05"	154°39'34"	Feb-81	Sep-86	5	327	869	2.7
15300520	Kaskanak Creek Near Igiugig AK		59°20'18"	156°04'31"	Jun-08	-	0	343	-	-
15303000	Wood River Near Aleknagik AK		59°16'30"	158°35'37"	Sep-57	Sep-70	13	1,110	4,823	4.3
15302000	Nuyakuk River Near Dillingham AK		59°56'08"	158°11'16"	Mar-53	-	47	1,490	5,563	3.7
15300000	Newhalen River Near Iliamna AK		59°51'34"	154°52'24"	Jul-51	Sep-86	20	3,478	9,021	2.6
15300500	Kvichak River At Igiugig AK		59°19'44"	155°53'57"	Aug-67	Sep-87	20	6,500	17,180	2.6
15302500	Nushagak River At Ekwok AK		59°20'57"	157°28'23"	Oct-77	Sep-93	16	9,850	23,606	2.4

Notes:

a. Gaging stations are ranked in order of ascending drainage area.

b. Record length refers to the number of complete water years up to September 2008.

c. Yellow shading indicates active gaging stations, including the three USGS stations operated within the Pebble mine study area.

d. Lat (N) = Latitude (North), Long (W) = Longitude (West), cfs = cubic feet per second, mi2= square mile(s), AK = Alaska.

Source: http://waterdata.usgs.gov/usa/nwis/sw; accessed on May 11, 2010.

TABLE 7.1-2
USGS Peak Flow Estimates in the Bristol Bay Drainages

Station [a]		Location		No. of Systematic	Drainage	Peak Flow (cfs) by Return Period (year)		Unit-Area Peak Flow (cfs/mi^2) by Return Period (year)	
USGS ID	USGS Name	Lat. (N)	Long. (W)	Peaks	Area (mi^2)	2 year	200 year	2 year	200 year
15302900	Moody Creek At Aleknagik AK	59°16'34"	158°35'42"	28	1.28	26	76	20.0	59.1
15303011	Wood River Tributary Near Aleknagik AK	59°12'26"	158°40'02"	14	3.35	103	380	30.7	113.4
15303010	Silver Salmon Creek Near Aleknagik AK	59°13'34"	158°40'21"	27	4.46	106	416	23.8	93.3
15297900	Eskimo Creek At King Salmon AK	58°41'08"	156°40'08"	18	16.1	84	510	5.2	31.7
15300200	Roadhouse Creek Near Iliamna AK	59°45'26"	154°50'49"	10	20.8	112	647	5.4	31.1
15303150	Snake River Near Dillingham AK	59°08'54"	158°53'14"	10	113	1,560	3,710	13.8	32.8
15303000	Wood River Near Aleknagik AK	59°16'30"	158°35'37"	13	1,110	13,500	37,000	12.2	33.3
15302000	Nuyakuk River Near Dillingham AK	59°56'08"	158°11'16"	43	1,490	19,600	35,000	13.2	23.5
15300000	Newhalen River Near Iliamna AK	59°51'34"	154°52'24"	31	3,478	25,400	49,200	7.3	14.1
15300500	Kvichak River At Igiugig AK	59°19'44"	155°53'57"	21	6,500	32,700	64,700	5.0	10.0
15302500	Nushagak River At Ekwok AK	59°20'57"	157°28'23"	16	9,850	70,900	158,000	7.2	16.0

Notes:

a. Gaging stations are ranked in order of ascending drainage area.

b. Lat (N) = Latitude (North), Long (W) = Longitude (West), cfs = cubic feet per second, mi^2= square mile(s), AK = Alaska.

Source: Curran et al. (2003).

TABLE 7.1-3
NRCS Snow Courses in the Bristol Bay Drainages, 1993 through 2008

Snow Course [a]		Location		Period of Record			Elevation	Mean SWE [c] (in.)	
ID	Name	Lat. (N)	Long. (W)	Start	End	Length [b] (Year)	(ft asl) [d]	1-Mar	1-Apr
53L02	Upper Twin Lakes			1993	2008	16	2,000	6.0	6.7
54L02	Fishtrap Lake			1992	2008	16	1,800	9.6	10.2
53L01	Telaquana Lake			1992	2008	17	1,550	4.2	4.4
55J02	Three Forks			1996	2008	5	900	2.7	2.6
54L01	Port Alsworth			1992	2008	16	270	3.8	3.2
55J01	Brooks Camp			1996	2008	9	150	2.7	1.6

Notes:

a. Snow courses are ranked in order of descending elevation.

b. Record length refers to the number of years with March and/or April sample data, up to and including Spring 2008.

c. SWE refers to depth of snow water equivalent.

d. Elevation is measured in feet above sea level (ft asl).

e. Lat (N) = Latitude (North), Long (W) = Longitude (West), in = inch.

Source: http://www.wcc.nrcs.usda.gov/snowcourse/sc-data.html; accessed on May 11, 2010

TABLE 7.2-1
Streamflow Gaging Station Characteristics and Results, Bristol Bay Drainages, 2004 through 2008

Watershed	Station	Principal Operator	Period of Record	No. Complete Water Years	Basin Area (mi^2)	Mean Basin Elev. (ft)	Mean Annual Discharge [a] (cfs)	Mean Annual Unit Runoff [a] (cfs/mi^2)	Estimated Baseflow [b] (cfs/mi^2)	200-Year Peak Flow [c] (cfs/mi^2)
South Fork Koktuli River	SK100A	HDR	2004-07	3	106.92	1,115	269.3	2.52	0.7	42
	SK100B	USGS	2004-08	4	69.33	1,255	191.0	2.76	0.7	57
	SK100B1	HDR	2006-07	2	54.41	1,290	113.0	2.08	0.3	-
	SK100C	HDR	2004-08	4	37.50	1,230	52.2	1.39	0.0	40
	SK100F	HDR	2004-07	3	11.91	1,270	28.1	2.36	0.5	61
	SK100G	HDR	2004-07	3	5.49	1,200	14.7	2.68	0.4	82
	SK119A	HDR	2004-08	4	10.73	1,575	36.9	3.44	0.7	293
	SK124A	HDR	2005-08	4	8.52	1,460	19.8	2.32	-	203
North Fork Koktuli River	NK100A	USGS	2004-08	4	105.86	1,280	270.3	2.55	1.0	60
	NK100A1	HDR	2007-08	2	85.34	1,340	203.8	2.39	0.6	-
	NK100B	HDR	2007-08	2	37.32	1,420	86.0	2.31	0.5	-
	NK100C	HDR	2004-08	4	24.35	1,360	52.4	2.15	0.6	48
	NK119A	HDR	2004-08	4	7.76	1,645	24.6	3.17	0.4	209
	NK119B	HDR	2007-08	2	3.97	1,430	4.8	1.21	0.0	-
Upper Talarik Creek	UT100-APC3	APC	2007-08	1	134.16	1,013	382.3	2.85	-	-
	UT100-APC2	APC	2007-08	1	110.16	965	316.9	2.88	-	-
	UT100-APC1	APC	2007-08	1	101.51	881	291.8	2.87	-	-
	UT100B	USGS	2004-08	4	86.24	1,055	231.7	2.69	1.3	43
	UT100C	HDR	2007-08	2	69.47	1,130	162.4	2.34	0.9	-
	UT100C1	HDR	2007-08	2	60.37	1,170	123.3	2.04	0.6	-

Watershed	Station	Principal Operator	Period of Record	No. Complete Water Years	Basin Area (mi^2)	Mean Basin Elev. (ft)	Mean Annual Discharge [a] (cfs)	Mean Annual Unit Runoff [a] (cfs/mi^2)	Estimated Baseflow [b] (cfs/mi^2)	200-Year Peak Flow [c] (cfs/mi^2)
	UT100C2	HDR	2007-08	2	48.26	1,210	107.2	2.22	0.5	-
	UT100D	HDR	2004-08	4	11.96	1,110	29.5	2.47	0.7	69
	UT100E	HDR	2004-08	4	3.10	1,225	10.1	3.27	1.3	77
	UT106-APC1	APC	2008	0	14.14	713	-	-	-	-
	UT119A	HDR	2004-08	4	4.05	882	27.4	6.77	5.5	36
	UT135A	HDR	2007-08	2	20.42	1,170	41.2	2.02	0.5	-
Kaskanak Creek	KC100A	HDR	2004-08	4	25.64	605	36.1	1.41	-	37
Newhalen River	NH100-APC2	APC	2008	0	3,451	-	-	-	-	-
	NH100-APC3	APC	2008	0	3,412	-	-	-	-	-

Notes:

a. Mean annual discharge and unit runoff for the period of record, based on complete water years.

b. Average discharge recorded during late winter baseflow measurement events.

c. 200-year instantaneous peak flows were estimated using a combined local-regional approach for stations with at least 3 years of record.

d. cfs = cubic feet per second, mi^2= square mile(s), ft = feet.

TABLE 7.2-2
Snow Model Results, Bristol Bay Drainages, 2006 through 2008

Watershed	Station	Basin Area (mi^2)	Mean Basin Elev. (ft)	Modeled Mean Snow Water Equivalent for Basin (inches)		
				19-Apr-06	9-Apr-07	6-Apr-08
South Fork Koktuli River	SK100A	106.92	1,115	19.5	4.5	19.3
	SK100B	69.33	1,255	21.3	5.7	21.7
	SK100B1	54.41	1,290	21.5	5.8	22.0
	SK100C	37.50	1,230	21.2	5.5	22.2
	SK100F	11.91	1,270	21.8	6.3	23.7
	SK100G	5.49	1,200	21.4	5.9	23.9
	SK119A	10.73	1,575	23.3	6.9	22.6
	SK124A	8.52	1,460	22.3	6.5	22.7
North Fork Koktuli River	NK100A	105.86	1,280	21.5	6.1	23.8
	NK100A1	85.34	1,340	22.3	6.6	25.1
	NK100B	37.32	1,420	22.8	6.6	25.8
	NK100C	24.35	1,360	22.6	6.3	26.3
	NK119A	7.76	1,645	23.8	7.5	24.8
	NK119B	3.97	1,430	22.3	6.4	25.1
Upper Talarik Creek	UT100-APC3	134.16	1,013	17.6	3.4	16.4
	UT100-APC2	110.16	965	18.4	3.9	18.0
	UT100-APC1	101.51	881	18.9	4.2	18.9
	UT100B	86.24	1,055	19.2	4.4	19.6
	UT100C	69.47	1,130	19.9	5.0	20.9
	UT100C1	60.37	1,170	20.3	5.3	21.3
	UT100C2	48.26	1,210	20.6	5.6	21.9
	UT100D	11.96	1,110	20.5	5.8	22.6
	UT100E	3.10	1,225	21.4	6.3	25.1
	UT106-APC1	14.14	713	-	-	-
	UT119A	4.05	882	18.1	2.0	17.2
	UT135A	20.42	1,170	19.9	4.8	21.5
Kaskanak Creek	KC100A	25.64	605	13.0	0.2	9.3
Newhalen River	NH100-APC2	3451	-	-	-	-
	NH100-APC3	3412	-	-	-	-

Note:

a. mi^2= square mile(s), ft = feet

TABLE 7.3-1
USGS Gaging Stations in the Transportation Corridor Study Area

Station			Location		Period of Record					Mean Annual Discharge		Mean Annual Peak Flow	
USGS ID	USGS Name	Type	Lat. (N)	Long. (W)	Start Year	End Year	No. Complete Water Years	No. Annual Peaks	Drain-age Area (mi²)	Absolute Discharge (cfs)	Unit Discharge (cfs/mi²)	Absolute Discharge (cfs)	Unit Discharge (cfs/mi²)
15300200	Roadhouse Creek Near Iliamna AK	Crest	59°45'26"	154°50'49"	1973	1983	-	10	20.8	-	-	128	6.2
15300200	Roadhouse Creek Near Iliamna AK	Continuous	59°45'26"	154°50'49"	2005	2008	3	4	20.8	29.1	1.4	198	9.5
15300300	Iliamna River Near Pedro Bay AK	Continuous	59°45'31"	153°50'41"	1996	2008	12	13	128	914	7.1	15,900	124.2
15300350	Chinkelyes Creek Tributary Near Pedro Bay AK	Crest	59°44'02"	153°48'40"	1997	2008	-	12	0.40	-	-	84.4	211.0

Note:

a. Lat (N) = Latitude (North), Long (W) = Longitude (West), cfs = cubic feet per second, mi^2= square mile(s), AK = Alaska.

TABLE 7.3-2
Basin Characteristics File Data

Parameter	Variable	Unit
Drainage area	Da	mi^2
Storage area (lakes and ponds)	St	mi^2
Glacier area	Gl	mi^2
Forested area	Fr	mi^2
Mean basin elevation	El	ft
Main channel slope	Sl	%
Main channel length	C	miles
Mean annual precipitation	Pr	inches
Mean minimum January temperature	T	°F

TABLE 7.3-3
Gage Station Installation Data

Parameter	Description	Method
Location	Latitude and longitude in degree, minute, second (ddmmss)	Global Positioning System
Stream cross-section	Hydraulic cross-section perpendicular to flow	Rod and transit survey
Skew of flow	Cosine of the perpendicular to the hydraulic cross-sections in feet	Rod and transit survey
Gage datum	Elevation of reference point on the crest gage	Assumed datum of 100 feet except for Iliamna River station with USGS-established datum
Crest gage reading	Flow height above datum	Measured by gage
Mean velocity	Average velocity through wetted cross-section	In-streamflow meter and Area Average method
Hydraulic slope	Average slope of right and left banks up and downstream of gaging station, or slope between high-water marks used slope area method of computing peak discharge in feet per foot	Rod and transit survey
High-water marks	Evidence of major flood events at a given site	Visual observation
Ordinary high water	Legally defined by AS 16 and Title 41 as the line on the bank established by fluctuations of water and indicated by physical characteristics such as clear, natural line impressed on the bank, shelving, changes in the character of soil, destruction of terrestrial vegetation, the presence of litter and debris, or other appropriate means that consider the characteristics of the surrounding areas	Visual observation
Water temperature	Degrees Fahrenheit	Hand-held thermometer
Photographic documentation	Upstream and downstream conditions, stream bed materials	Digital camera

TABLE 7.3-4
Regression Equations for Estimating Monthly Low-Duration Streamflows in Unregulated Streams in USGS Streamflow Analysis Regions 3 and 4, Alaska

Regression equation [a] for July, JULY*n*, *n* percent low-duration streamflow	Coefficient of determination	Standard error of estimate (%)
$JULY98 = 9.428 \times 10^{-5} A^{1.118} P^{1.211} E^{0.6445}$	0.95	64
$JULY95 = 1.257 \times 10^{-4} A^{1.112} P^{1.226} E^{0.6198}$	0.96	58
$JULY90 = 1.493 \times 10^{-4} A^{1.099} P^{1.213} E^{0.6298}$	0.96	53
$JULY85 = 1.842 \times 10^{-4} A^{1.091} P^{1.212} E^{0.6192}$	0.96	51
$JULY80 = 2.078 \times 10^{-4} A^{1.085} P^{1.215} E^{0.6146}$	0.97	49
$JULY70 = 2.576 \times 10^{-4} A^{1.075} P^{1.222} E^{0.6031}$	0.97	45
$JULY60 = 3.327 \times 10^{-4} A^{1.066} P^{1.224} E^{0.5869}$	0.97	43
$JULY50 = 4.135 \times 10^{-4} A^{1.058} P^{1.221} E^{0.5771}$	0.97	41
Regression equation [a] for August, AUG*n*, *n* percent low-duration streamflow	**Coefficient of determination**	**Standard error of estimate (%)**
$AUG98 = 3.471 \times 10^{-4} A^{1.130} P^{1.054} E^{0.5038}$	0.95	63
$AUG95 = 2.869 \times 10^{-4} A^{1.140} P^{1.103} E^{0.5219}$	0.96	55
$AUG90 = 2.773 \times 10^{-4} A^{1.137} P^{1.139} E^{0.5263}$	0.96	53
$AUG85 = 2.794 \times 10^{-4} A^{1.134} P^{1.168} E^{0.5244}$	0.96	51
$AUG80 = 3.035 \times 10^{-4} A^{1.128} P^{1.179} E^{0.5208}$	0.97	49
$AUG70 = 3.774 \times 10^{-4} A^{1.118} P^{1.199} E^{0.5046}$	0.97	46
$AUG60 = 4.432 \times 10^{-4} A^{1.110} P^{1.227} E^{0.4880}$	0.97	43
$AUG50 = 5.313 \times 10^{-4} A^{1.101} P^{1.246} E^{0.4744}$	0.97	41
Regression equation [a] for September, SEPT*n*, *n* percent low-duration streamflow	**Coefficient of determination**	**Standard error of estimate (%)**
$SEPT98 = 1.655 \times 10^{-2} A^{1.126} P^{0.9572}$	0.96	46
$SEPT95 = 1.474 \times 10^{-2} A^{1.125} P^{1.030}$	0.96	46
$SEPT90 = 1.528 \times 10^{-2} A^{1.110} P^{1.080}$	0.97	44
$SEPT85 = 1.555 \times 10^{-2} A^{1.108} P^{1.109}$	0.97	44
$SEPT80 = 1.599 \times 10^{-2} A^{1.103} P^{1.131}$	0.97	43
$SEPT70 = 1.636 \times 10^{-2} A^{1.094} P^{1.175}$	0.97	41
$SEPT60 = 1.676 \times 10^{-2} A^{1.086} P^{1.214}$	0.97	40
$SEPT50 = 1.745 \times 10^{-2} A^{1.076} P^{1.251}$	0.97	39

Note:

a. MONTH*n* = *n* percent low-duration streamflow, in cubic feet per second

b. A = drainage area, in square miles; P = mean annual precipitation, in inches; E = mean basin elevation, in feet above sea level.

Source: Wiley and Curran, 2003.

TABLE 7.3-5
Regression Equations for Estimating Annual High-Duration Streamflows in Unregulated Streams in USGS Streamflow Analysis Regions 3 and 4, Alaska

Region 3: Regression equation [a] for specified recurrence interval, O-Sn	Coefficient of determination	Standard error of estimate (%)
$O\text{-}S15 = 0.1358\ A^{0.9660}\ P^{1.016}$	0.97	22
$O\text{-}S10 = 0.2145\ A^{0.9472}\ P^{0.9740}$	0.97	21
$O\text{-}S5 = 0.4120\ A^{0.9162}\ P^{0.9179}$	0.96	23
$O\text{-}S4 = 0.4875\ A^{0.9074}\ P^{0.9057}$	0.96	23
$O\text{-}S3 = 0.6039\ A^{0.8963}\ P^{0.8892}$	0.96	24
$O\text{-}S2 = 0.7960\ A^{0.8829}\ P^{0.8697}$	0.95	25
$O\text{-}S1 = 1.279\ A^{0.8637}\ P^{0.8293}$	0.94	27
Region 4: Regression equation [a] for specified recurrence interval, O-Sn	**Coefficient of determination**	**Standard error of estimate (%)**
$O\text{-}S15 = 2.443 \times 10^{-2}\ A^{1.055}\ P^{1.340}$	0.98	30
$O\text{-}S10 = 3.637 \times 10^{-2}\ A^{1.042}\ P^{1.301}$	0.98	31
$O\text{-}S5 = 6.216 \times 10^{-2}\ A^{1.022}\ P^{1.249}$	0.98	32
$O\text{-}S4 = 7.213 \times 10^{-2}\ A^{1.017}\ P^{1.234}$	0.98	32
$O\text{-}S3 = 8.368 \times 10^{-2}\ A^{1.009}\ P^{1.225}$	0.98	32
$O\text{-}S2 = 0.1046\ A^{1.001}\ P^{1.204}$	0.98	32
$O\text{-}S1 = 0.1505\ A^{0.9881}\ P^{1.164}$	0.98	34

Note:

a. O-Sn = daily mean discharge for the water year October-September having an n-percent exceedence probability, in cubic feet per second

b. A = drainage area, in square miles; P = mean annual precipitation, in inches.

Source: Wiley and Curran, 2003.

TABLE 7.3-6
Regression Equations for Estimating Peak Streamflows in Unregulated Streams in USGS Streamflow Analysis Regions 3 and 4, Alaska

Region 3: Regression equation [a, b] for specified recurrence interval, Q_T[2]	**Average standard error of prediction (%)**	**Average equivalent years of record**
$Q_2 = 0.004119\ A^{0.8361}\ (ST+1)^{-0.3590}\ P^{0.9110}\ (J+32)^{1.635}$	38	0.9
$Q_5 = 0.009024\ A^{0.8322}\ (ST+1)^{-0.3670}\ P^{0.8128}\ (J+32)^{1.640}$	37	1.3
$Q_{10} = 0.01450\ A^{0.8306}\ (ST+1)^{-0.3691}\ P^{0.7655}\ (J+32)^{1.622}$	37	1.8
$Q_{25} = 0.02522\ A^{0.8292}\ (ST+1)^{-0.3697}\ P^{0.7165}\ (J+32)^{1.588}$	38	2.4
$Q_{50} = 0.03711\ A^{0.8286}\ (ST+1)^{-0.3693}\ P^{0.6847}\ (J+32)^{1.559}$	40	2.8
$Q_{100} = 0.05364\ A^{0.8281}\ (ST+1)^{-0.3683}\ P^{0.6556}\ (J+32)^{1.527}$	41	3.1
$Q_{200} = 0.07658\ A^{0.8276}\ (ST+1)^{-0.3669}\ P^{0.6284}\ (J+32)^{1.495}$	43	3.4
$Q_{500} = 0.1209\ A^{0.8272}\ (ST+1)^{-0.3646}\ P^{0.5948}\ (J+32)^{1.449}$	45	3.6
Region 4: Regression equation [a, c] for specified recurrence interval, Q_T[2]	**Average standard error of prediction (%)**	**Average equivalent years of record**
$Q_2 = 0.2535\ A^{0.9462}\ (ST+1)^{-0.1981}\ P^{1.201}$	42	1.0
$Q_5 = 0.5171\ A^{0.9084}\ (ST+1)^{-0.2128}\ P^{1.162}$	39	2.2
$Q_{10} = 0.7445\ A^{0.8887}\ (ST+1)^{-0.2204}\ P^{1.147}$	38	3.5
$Q_{25} = 1.091\ A^{0.8686}\ (ST+1)^{-0.2273}\ P^{1.131}$	39	5.0
$Q_{50} = 1.395\ A^{0.8563}\ (ST+1)^{-0.2313}\ P^{1.120}$	41	5.9
$Q_{100} = 1.738\ A^{0.8457}\ (ST+1)^{-0.2347}\ P^{1.109}$	44	6.6
$Q_{200} = 2.124\ A^{0.8363}\ (ST+1)^{-0.2377}\ P^{1.099}$	47	7.1
$Q_{500} = 2.704\ A^{0.8253}\ (ST+1)^{-0.2413}\ P^{1.088}$	52	7.4

Notes:

a. Q_T = T-year peak streamflow, in cubic feet per second;

b. Region 3 equations are developed for basins where A is between 0.72 and 571, ST is between 0 and 26, and P is between 70 and 300, J: 0-32

c. Region 4 equations are developed for basins where A is between 1.07 and 19,400, ST is between 0 and 28, and P is between 20 and 158

d. A = drainage area, in square miles; ST = area of lakes and ponds (storage), as a percentage of drainage area; P = mean annual precipitation, in inches; J = mean minimum January temperature, in degrees Fahrenheit.

Source: Wiley and Curran, 2003.

TABLE 7.3-7
Gage Station Basin Characteristics – Transportation Corridor Study Area

Station [a]	Stream	Period of Record	Drainage Basin Characteristics: Basin Area (mi^2)	Lake & Pond Area (mi^2)	Lake & Pond Area (%)	Mean Basin Elev. (ft)	Mean Annual Precipitation (in)	Mean Minimum January Temp. (°F)
GS-23	Chinkelyes Creek	2004-05	22.55	0.42	1.9	1,616	70	10
GS-3a	Iliamna River	2004-05	128.00	1.03	0.8	2,236	60	10
GS-4a	Pile River	2004-05	152.83	0.86	0.6	1,463	60	10
GS-4b	Unnamed Outlet Creek from Long Lake	2004-05	-	-	-	-	60	10
GS-6a	Unnamed Outlet Creek from Dumbbell Lake	2004-05	2.20	0.13	5.9	1,072	50	10
GS-7a	Unnamed Creek near Pedro Bay Townsite	2004-05	3.36	0.003	0.1	1,176	40	10
GS-8a	Knutson Creek	2004-05	35.70	0.02	0.1	2,300	38	10
GS-11a	Canyon Creek	2004-05	36.20	0.14	0.4	2,257	30	9
GS-12a	Chekok Creek	2004-05	50.48	0.34	0.7	1,764	30	9
GS-14a	Unnamed Creek East of Eagle Bay Creek	2004-05	18.34	0.08	0.4	860	28	9
GS-14b	Unnamed Creek West of Chekok Creek	2004-05	15.91	0.29	1.8	973	28	9
GS-17a	West Fork Eagle Bay Creek	2004-05	10.95	0.02	0.2	1,190	28	9
GS-18a	Unnamed Creek on South Slope of Roadhouse Mountain	2004-05	9.29	0.1	1.1	978	25	9
GS-20 [b]	Roadhouse Creek	2004-05	20.80	1.45	7.0	321	30	8
GS-20a	Upper Roadhouse Creek	2004-05	8.07	0.28	3.5	-	30	8

Notes:

a. The gage stations are listed in order from east to west.

b. The drainage basin characteristics for GS-20 have been adopted from the USGS gage on Roadhouse Creek (Curran et al., 2003).

c. mi^2 = square miles, ft = feet, in = inch, °F = degrees Fahrenheit

TABLE 7.3-8
Instantaneous Discharge Measurement

2004 Instantaneous Discharge Measurements Sample Location (West to East)		July 2004		August 2004		September 2004		October 2004	
		Date	Discharge (cfs)	Date	Discharge (cfs)	Date	Discharge (cfs)	Date	Discharge (cfs)
GS-23	Chinkelyes Creek	-	-	-	-	-	-	-	-
GS-3a	Iliamna River	-	-	19-Aug	338.7	25-Sep	85.7	15-Oct	1200.0
GS-4a	Pile River	-	-	2-Aug	1,533.1	25-Sep	212.4	20-Oct	764.0
				19-Aug	1,375.2				
GS-4b	Unnamed Outlet Creek from Long Lake	-	-	-	-	25-Sep	0.2	15-Oct	20.6
GS-6a	Unnamed Outlet Creek from Dumbbell Lake	21-Jul	4.2	20-Aug	2.2	24-Sep	2.3	15-Oct	6.2
GS-7a	Unnamed Creek near Pedro Bay Townsite	21-Jul	Dry	19-Aug	Dry	-	-	16-Oct	4.7
GS-8a	Knutson Creek	21-Jul	128.6	18-Aug	63.5	24-Sep	69.6	16-Oct	282.4
GS-11a	Canyon Creek	20-Jul	107.9	17-Aug	54.2	23-Sep	92.0	16-Oct	261.1
GS-12a	Chekok Creek	-	-	1-Aug	75.7	22-Sep	111.9	16-Oct	209.0
				17-Aug	43.1				
GS-14a	Unnamed Creek East of Eagle Bay Creek	19-Jul	19.5	17-Aug	12.3	22-Sep	86.1	17-Oct	66.4
GS-14b	Unnamed Creek West of Chekok Creek	20-Jul	7.6	17-Aug	4.0	22-Sep	20.3	16-Oct	27.9
GS-17a	West Fork Eagle Bay Creek	19-Jul	6.6	17-Aug	5.1	22-Sep	10.8	16-Oct	28.9
GS-18a	Unnamed Creek on South Slope of Roadhouse Mountain	19-Jul	1.5	-	-	21-Sep	0.5	16-Oct	0.5
GS-20	Roadhouse Creek	22-Jul	15.0	3-Aug	9.0	26-Sep	38.3	14-Oct	46.4

2005 Winter Instantaneous Discharge Measurements Sample Location (West to East)		February 2005		March 2005		April 2005	
		Date	Discharge (cfs)	Date	Discharge (cfs)	Date	Discharge (cfs)
GS-23	Chinkelyes Creek	-	-	-	-	-	-
GS-3a	Iliamna River	15-Feb	53.8	-	-	-	-
GS-6a	Unnamed Outlet Creek from Dumbbell Lake	16-Feb	3.6	-	-	3-Apr	3.0
GS-7a	Unnamed Creek near Pedro Bay Townsite	-	-	-	-	-	-
GS-8a	Knutson Creek	17-Feb	27.3	-	-	3-Apr	16.0
GS-11a	Canyon Creek	17-Feb	8.8	-		1-Apr	7.7
GS-12a	Chekok Creek	19-Feb	16.9	-	-	1-Apr	14.0
GS-14a	Unnamed Creek East of Eagle Bay Creek	19-Feb	7.5	31-Mar	3.9	-	-
GS-14b	Unnamed Creek West of Chekok Creek	17-Feb	3.1	-	-	-	-
GS-17a	West Fork Eagle Bay Creek	18-Feb	1.1	31-Mar	0.8	-	-
GS-18a	Unnamed Creek on South Slope of Roadhouse Mountain	18-Feb	0.1	31-Mar	0.1	-	-
GS-20	Roadhouse Creek	18-Feb	13.0	-	-	1-Apr	2.8
GS-20a	Upper Roadhouse Creek	18-Feb	0.2	30-Mar	1.8	-	-

2005 Instantaneous Discharge Measurements Sample Location (West to East)		May 2005		June 2005		July 2005		August 2005		September 2005		October 2005	
		Date	Discharge (cfs)	Date	Discharge (cfs)	Date	Discharge (cfs)	Date	Discharge (cfs)	Date	Discharge (cfs)	Date	Discharge (cfs)
GS-23	Chinkelyes Creek	-	-	-	-	14-Jul	295.3	9-Aug	94.5	10-Sep	468.0	6-Oct	151.5
GS-3a	Iliamna River	-	-	14-Jun	2,070.0	15-Jul	1,160.0	10-Aug	500.0	10-Sep	2,530.0	6-Oct	565.0
GS-4a	Pile River	4-May	786.1	14-Jun	1,641.1	15-Jul	1,522.6	10-Aug	1,272.5	10-Sep	-	7-Oct	525.4
GS-4b	Unnamed Outlet Creek from Long Lake	-	-	-	-	-	-	-	-	-	-	-	-
GS-6a	Unnamed Outlet Creek from Dumbbell Lake	-	-	-	-	-	-	-	-	-	-	-	-
GS-7a	Unnamed Creek near Pedro Bay Townsite	-	-	-	-	-	-	-	-	-	-	-	-
GS-8a	Knutson Creek	4-May	247.7	14-Jun	316.9	15-Jul	167.3	9-Aug	116.8	9-Sep	-	7-Oct	167.5

2005 Instantaneous Discharge Measurements Sample Location (West to East)		May 2005		June 2005		July 2005		August 2005		September 2005		October 2005	
		Date	Discharge (cfs)	Date	Discharge (cfs)	Date	Discharge (cfs)	Date	Discharge (cfs)	Date	Discharge (cfs)	Date	Discharge (cfs)
GS-11a	Canyon Creek	3-May	246.7	15-Jun	526.6	16-Jul	196.3	10-Aug	93.2	8-Sep	361.4	7-Oct	183.1
GS-12a	Chekok Creek	-	-	-	-	-	-	-	-	-	-	-	-
GS-14a	Unnamed Creek East of Eagle Bay Creek	-	-	-	-	-	-	-	-	-	-	-	-
GS-14b	Unnamed Creek West of Chekok Creek	3-May	45.3	15-Jun	13.8	15-Jul	3.1	10-Aug	7.2	10-Sep	80.4	7-Oct	56.6
GS-17a	West Fork Eagle Bay Creek	5-May	46.5	15-Jun	14.2	16-Jul	8.4	10-Aug	6.5	10-Sep	62.2	7-Oct	30.2
GS-18a	Unnamed Creek on South Slope of Roadhouse Mountain	-	-	-	-	-	-	-	-	-	-	-	-
GS-20	Roadhouse Creek	24-May	26.0	18-Jun	45.0	2-Jul	33.0	24-Aug	53.0	10-Sep	282.0	8-Oct	110.0
GS-20a	Upper Roadhouse Creek	-	-	-	-	-	-	-	-	-	-	-	-

Note:

a. cfs = cubic feet per second.

TABLE 7.3-9
Estimated Monthly Low-Duration Streamflows at Gage Stations based on USGS Streamflow Analysis Region 3 and 4 Regression Equations

		Low-Duration Flows Estimated from Regression Equations for July (cfs) [a]							
Station	**Stream**	**98%**	**95%**	**90%**	**85%**	**80%**	**70%**	**60%**	**50%**
GS-23	Chinkelyes Creek	61.6	71.6	83.2	92.2	99.9	113.6	127.6	142.1
GS-3a	Iliamna River	438.9	499.5	570.5	621.4	665.3	739.9	814.0	891.3
GS-4a	Pile River	407.1	467.7	530.7	579.8	621.3	693.2	766.6	841.7
GS-4b	Unnamed Outlet Creek from Long Lake	-	-	-	-	-	-	-	-
GS-6a	Unnamed Outlet Creek from Dumbbell Lake	2.3	2.8	3.3	3.8	4.1	4.8	5.6	6.3
GS-7a	Unnamed Creek near Pedro Bay Townsite	3.0	3.6	4.3	4.8	5.3	6.1	7.0	8.0
GS-8a	Knutson Creek	61.7	70.2	82.0	90.3	97.2	109.1	121.3	134.3
GS-11a	Canyon Creek	46.5	52.7	61.8	68.0	73.2	82.1	91.2	101.0
GS-12a	Chekok Creek	57.5	65.5	76.2	83.9	90.3	101.1	112.4	124.6
GS-14a	Unnamed Creek East of Eagle Bay Creek	10.7	12.5	14.7	16.4	17.8	20.3	23.0	25.9
GS-14b	Unnamed Creek West of Chekok Creek	9.9	11.5	13.6	15.2	16.5	18.8	21.3	23.9
GS-17a	West Fork Eagle Bay Creek	7.4	8.6	10.2	11.4	12.4	14.2	16.1	18.1
GS-18a	Unnamed Creek on South Slope of Roadhouse Mountain	4.8	5.5	6.6	7.4	8.0	9.2	10.5	11.8
GS-20	Roadhouse Creek	7.1	8.5	9.8	11.1	12.1	14.0	16.1	18.2
GS-20a	Upper Roadhouse Creek	-	-	-	-	-	-	-	-
		Low-Duration Flows Estimated from Regression Equations for August (cfs) [a]							
Station	**Stream**	**98%**	**95%**	**90%**	**85%**	**80%**	**70%**	**60%**	**50%**
GS-23	Chinkelyes Creek	42.7	51.3	59.1	65.8	71.6	83.3	95.1	108.7
GS-3a	Iliamna River	304.3	371.0	423.6	466.8	501.1	568.6	633.8	707.9
GS-4a	Pile River	300.2	363.9	414.6	456.9	490.7	559.7	627.3	703.6
GS-4b	Unnamed Outlet Creek from Long Lake	-	-	-	-	-	-	-	-
GS-6a	Unnamed Outlet Creek from Dumbbell Lake	1.8	2.0	2.3	2.6	2.8	3.4	3.9	4.5
GS-7a	Unnamed Creek near Pedro Bay Townsite	2.3	2.7	3.0	3.3	3.7	4.3	5.0	5.7
GS-8a	Knutson Creek	45.1	53.1	59.8	65.3	70.3	80.0	88.9	99.6
GS-11a	Canyon Creek	35.3	41.1	46.0	49.9	53.5	60.6	66.9	74.6

		Low-Duration Flows Estimated from Regression Equations for August (cfs) [a]							
Station	**Stream**	**98%**	**95%**	**90%**	**85%**	**80%**	**70%**	**60%**	**50%**
GS-12a	Chekok Creek	45.4	52.8	58.9	63.9	68.5	77.6	85.9	95.7
GS-14a	Unnamed Creek East of Eagle Bay Creek	9.4	10.6	11.8	12.8	13.9	16.0	18.1	20.5
GS-14b	Unnamed Creek West of Chekok Creek	8.5	9.6	10.7	11.6	12.6	14.6	16.4	18.6
GS-17a	West Fork Eagle Bay Creek	6.2	7.0	7.8	8.5	9.2	10.6	11.9	13.5
GS-18a	Unnamed Creek on South Slope of Roadhouse Mountain	4.1	4.6	5.1	5.6	6.0	7.0	7.9	8.9
GS-20	Roadhouse Creek	7.1	7.9	8.8	9.6	10.4	12.2	14.0	16.1
GS-20a	Upper Roadhouse Creek	-	-	-	-	-	-	-	-

		Low-Duration Flows Estimated from Regression Equations for September (cfs) [a]							
Station	**Stream**	**98%**	**95%**	**90%**	**85%**	**80%**	**70%**	**60%**	**50%**
GS-23	Chinkelyes Creek	32.3	39.0	47.7	54.6	60.7	72.8	85.8	101.4
GS-3a	Iliamna River	196.6	234.7	277.7	315.1	346.1	405.9	469.2	541.5
GS-4a	Pile River	240.0	286.6	338.1	383.5	420.8	492.8	568.9	655.3
GS-4b	Unnamed Outlet Creek from Long Lake	-	-	-	-	-	-	-	-
GS-6a	Unnamed Outlet Creek from Dumbbell Lake	1.7	2.0	2.5	2.9	3.2	3.8	4.6	5.4
GS-7a	Unnamed Creek near Pedro Bay Townsite	2.2	2.6	3.2	3.6	3.9	4.7	5.5	6.5
GS-8a	Knutson Creek	30.1	34.9	41.1	46.1	50.5	58.7	67.3	77.4
GS-11a	Canyon Creek	24.4	27.8	32.3	36.1	39.2	45.1	51.3	58.5
GS-12a	Chekok Creek	35.5	40.4	46.8	52.1	56.6	65.0	73.6	83.6
GS-14a	Unnamed Creek East of Eagle Bay Creek	10.6	12.0	14.1	15.7	17.1	19.8	22.6	25.8
GS-14b	Unnamed Creek West of Chekok Creek	9.1	10.3	12.0	13.4	14.7	16.9	19.3	22.1
GS-17a	West Fork Eagle Bay Creek	5.9	6.7	8.0	8.9	9.7	11.3	12.9	14.8
GS-18a	Unnamed Creek on South Slope of Roadhouse Mountain	4.4	5.0	5.9	6.5	7.1	8.2	9.4	10.8
GS-20	Roadhouse Creek	13.1	14.9	17.5	19.5	21.3	24.6	28.1	32.2
GS-20a	Upper Roadhouse Creek	4.5	5.1	6.1	6.8	7.5	8.7	10.1	11.6

Notes:

a. n% refers to n-percent exceedence probability.

b. cfs = cubic feet per second.

TABLE 7.3-10
Flow Duration of Observed Flows, August 2004

Station	Stream	Observed Flow (August 2004)	Approximate Flow Duration [a]
GS-3a	Iliamna River	338.7	95% - 98%
GS-4a	Pile River	1,375.2	<50%
GS-6a	Unnamed Outlet Creek from Dumbbell Lake	2.2	90% - 95%
GS-7a	Unnamed Creek near Pedro Bay Townsite	Dry	>98%
GS-8a	Knutson Creek	63.5	85% - 90%
GS-11a	Canyon Creek	54.2	80%
GS-12a	Chekok Creek	43.1	>98%
GS-14a	Unnamed Creek East of Eagle Bay Creek	12.3	90%
GS-14b	Unnamed Creek West of Chekok Creek	4.0	>98%
GS-17a	West Fork of Eagle Bay Creek	5.1	>98%
GS-20	Roadhouse Creek	9.0	95%
GS-20a	Upper Roadhouse Creek	0.6	>98%

Note:

a. Flow durations estimated from Table 7.3-9.

TABLE 7.3-11
Estimated Annual High-Duration Streamflows at Gage Stations based on USGS Regional Regression Equations

Station	Stream	Annual High-Duration Flows Estimated from Regression Equations for Region 3 (cfs) [a]						
		15%	10%	5%	4%	3%	2%	1%
GS-23	Chinkelyes Creek	206	257	353	386	431	502	639
GS-3a	Iliamna River	944	1,146	1,506	1,624	1,782	2,032	2,521
GS-4a	Pile River	1,121	1,356	1,771	1,907	2,088	2,376	2,938
GS-4b	Unnamed Outlet Creek from Long Lake	-	-	-	-	-	-	-
GS-6a	Unnamed Outlet Creek from Dumbbell Lake	15	20	31	34	40	48	65
GS-7a	Unnamed Creek near Pedro Bay Townsite	19	25	37	41	48	57	78
GS-8a	Knutson Creek	173	219	307	337	378	442	573
GS-11a	Canyon Creek	138	176	251	276	310	365	477

Station	Stream	Annual High-Duration Flows Estimated from Regression Equations for Region 4 (cfs) [a]						
		15%	10%	5%	4%	3%	2%	1%
GS-23	Chinkelyes Creek	195	235	303	324	353	394	459
GS-3a	Iliamna River	993	1,174	1,472	1,568	1,687	1,861	2,135
GS-4a	Pile River	1,197	1,413	1,765	1,878	2,017	2,222	2,544
GS-4b	Unnamed Outlet Creek from Long Lake	-	-	-	-	-	-	-
GS-6a	Unnamed Outlet Creek from Dumbbell Lake	11	13	18	20	22	26	31
GS-7a	Unnamed Creek near Pedro Bay Townsite	12	16	21	23	26	30	37
GS-8a	Knutson Creek	140	171	226	244	266	299	355
GS-11a	Canyon Creek	103	128	170	185	202	228	274
GS-12a	Chekok Creek	147	181	239	259	282	318	380
GS-14a	Unnamed Creek East of Eagle Bay Creek	46	58	78	85	93	106	129
GS-14b	Unnamed Creek West of Chekok Creek	40	50	67	73	81	92	112
GS-17a	West Fork Eagle Bay Creek	27	34	46	50	55	63	77
GS-18a	Unnamed Creek on South Slope of Roadhouse Mountain	19	24	34	37	41	47	58
GS-20	Roadhouse Creek	58	72	97	105	115	131	158
GS-20a	Upper Roadhouse Creek	21	27	37	40	44	51	62

Notes:

a. n% refers to n-percent exceedence probability.

b. cfs = cubic feet per second.

TABLE 7.3-12
Estimated Peak Streamflows at Gage Stations based on USGS Regional Regression Equations

		Peak Flows Estimated from Regression Equations for Region 3 (cfs) [a]							
Station	Stream	Q_2	Q_5	Q_{10}	Q_{20}	Q_{50}	Q_{100}	Q_{200}	Q_{500}
GS-23	Chinkelyes Creek	826	1,190	1,452	1,797	2,070	2,345	2,646	3,053
GS-3a	Iliamna River	3,618	5,276	6,472	8,054	9,311	10,580	11,971	13,860
GS-4a	Pile River	4,419	6,447	7,909	9,840	11,373	12,921	14,614	16,914
GS-4b	Unnamed Outlet Creek from Long Lake	-	-	-	-	-	-	-	-
GS-6a	Unnamed Outlet Creek from Dumbbell Lake	63	94	117	148	173	198	226	264
GS-7a	Unnamed Creek near Pedro Bay Townsite	143	221	278	355	416	479	549	645
GS-8a	Knutson Creek	995	1,531	1,925	2,455	2,881	3,319	3,801	4,466
GS-11a	Canyon Creek	707	1,112	1,413	1,825	2,159	2,507	2,893	3,432

		Peak Flows Estimated from Regression Equations for Region 4 (cfs) [a]							
Station	Stream	Q_2	Q_5	Q_{10}	Q_{20}	Q_{50}	Q_{100}	Q_{200}	Q_{500}
GS-23	Chinkelyes Creek	645	976	1,230	1,571	1,837	2,106	2,388	2,793
GS-3a	Iliamna River	3,038	4,359	5,340	6,621	7,607	8,588	9,609	11,062
GS-4a	Pile River	3,697	5,280	6,453	7,981	9,154	10,321	11,532	13,258
GS-4b	Unnamed Outlet Creek from Long Lake	-	-	-	-	-	-	-	-
GS-6a	Unnamed Outlet Creek from Dumbbell Lake	40	66	87	116	140	165	191	229
GS-7a	Unnamed Creek near Pedro Bay Townsite	66	111	148	199	240	284	330	399
GS-8a	Knutson Creek	583	901	1,144	1,472	1,730	1,993	2,271	2,670
GS-11a	Canyon Creek	421	654	832	1,072	1,261	1,456	1,661	1,955
GS-12a	Chekok Creek	556	850	1,072	1,371	1,605	1,845	2,097	2,459
GS-14a	Unnamed Creek East of Eagle Bay Creek	202	323	417	545	647	752	865	1,026
GS-14b	Unnamed Creek West of Chekok Creek	155	246	316	413	490	569	654	775
GS-17a	West Fork Eagle Bay Creek	129	210	274	362	433	506	585	699
GS-18a	Unnamed Creek on South Slope of Roadhouse Mountain	86	141	184	244	292	342	396	473

Station	Stream	Peak Flows Estimated from Regression Equations for Region 4 (cfs) [a]							
		Q_2	Q_5	Q_{10}	Q_{20}	Q_{50}	Q_{100}	Q_{200}	Q_{500}
GS-20	Roadhouse Creek	176	273	346	445	524	604	689	812
GS-20a	Upper Roadhouse Creek	81	130	169	223	266	311	358	427

Notes:

a. Q_T refers to peak streamflow with average recurrence interval of T years.

b. cfs = cubic feet per second

TABLE 7.3-13
Estimated Peak Flows at USGS Gaging Stations in the Transportation Corridor Study Area

Station		Drainage Area (mi^2)	Peak Flows Estimated from Gage Records (cfs) [a, b, c, d]			Unit-Area Peak Flows from Gage Records (cfs/mi^2) [a]		
USGS ID	USGS Name		Q_2	Q_5	Q_{10}	Q_2	Q_5	Q_{10}
15300200	Roadhouse Creek Near Iliamna AK	20.8	106	173	231	5.1	8.3	11.1
15300300	Iliamna River Near Pedro Bay AK	128.0	12,250	25,100	39,590	95.7	196.1	309.3

Notes:

a. Q_T refers to peak streamflow with average recurrence interval of T years.

b. All peak flow values in this table have been estimated based on Log Pearson Type III analysis of gage records, as opposed to regional regression equations.

c. Peak flows for Roadhouse Creek were calculated by Curran et al. (2003), based on 10 annual peaks from 1973 to 1983.

d. Peak flows for Iliamna River were calculated by BEESC, based on 10 annual peaks from 1996 to 2005.

e. cfs = cubic feet per second, mi^2 = square miles, AK = Alaska

FIGURES

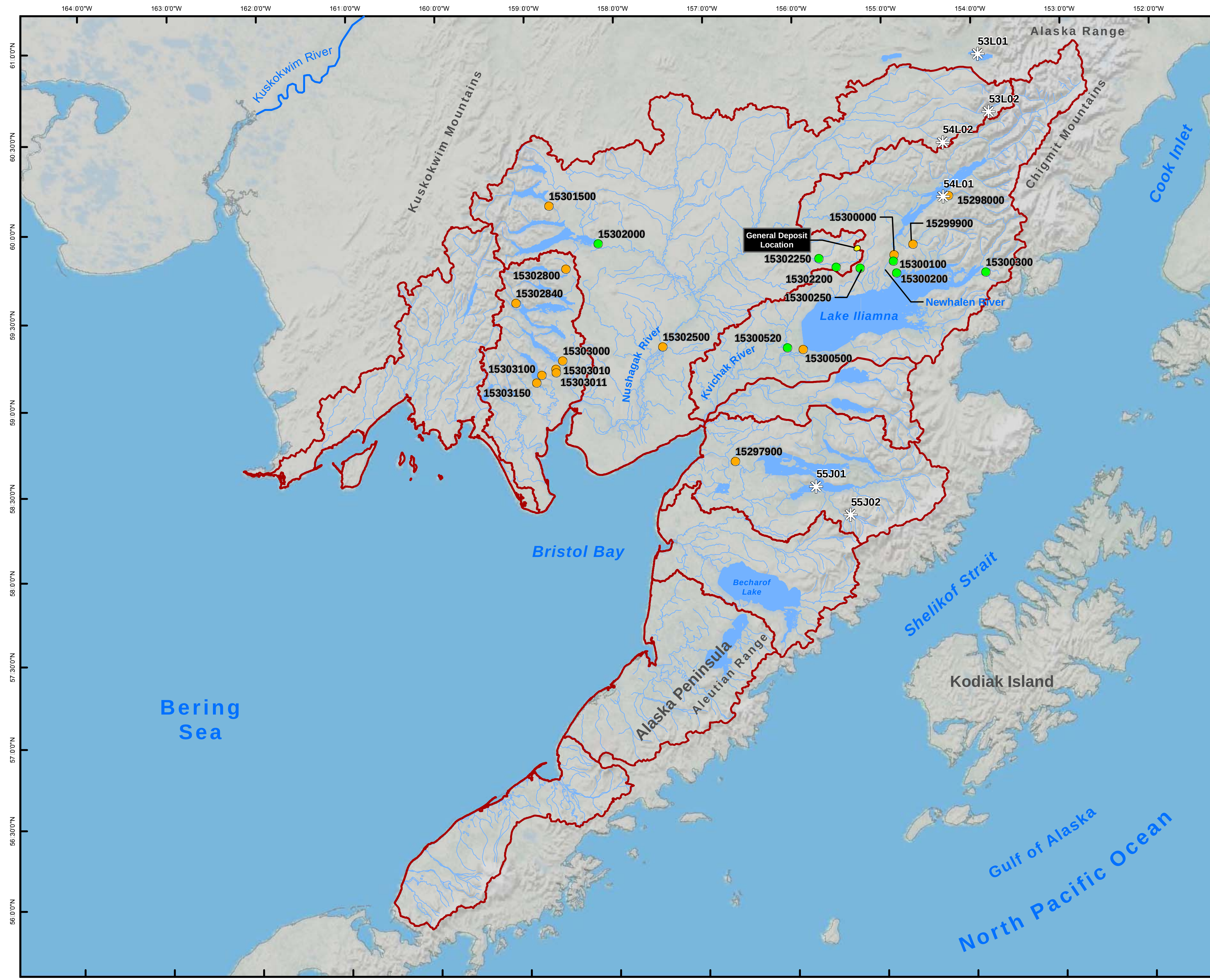


Figure 7.1-1
Regional Hydrology
Bristol Bay Drainages

Legend

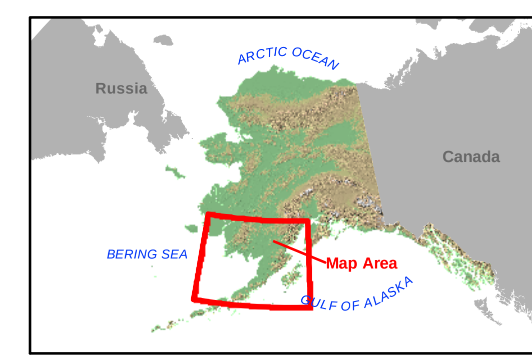
- NRCS Snow Course Site
- Bristol Bay Drainages
- General Deposit Location

USGS Streamflow Gaging Station

- Active
- Discontinued

15303100 : Example of USGS Streamflow Gaging Station Identification Number

55J01 : Example of NRCS Snow Course Site Identification Number



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Kilometers: 0 25 50 75 100
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Alaska State Plane Zone 5 (units feet)
1983 North American Datum

File: HDR_RegionalHydrology.mxd	Date: 30 March 2011
Version: 1	Author: HDR - MC

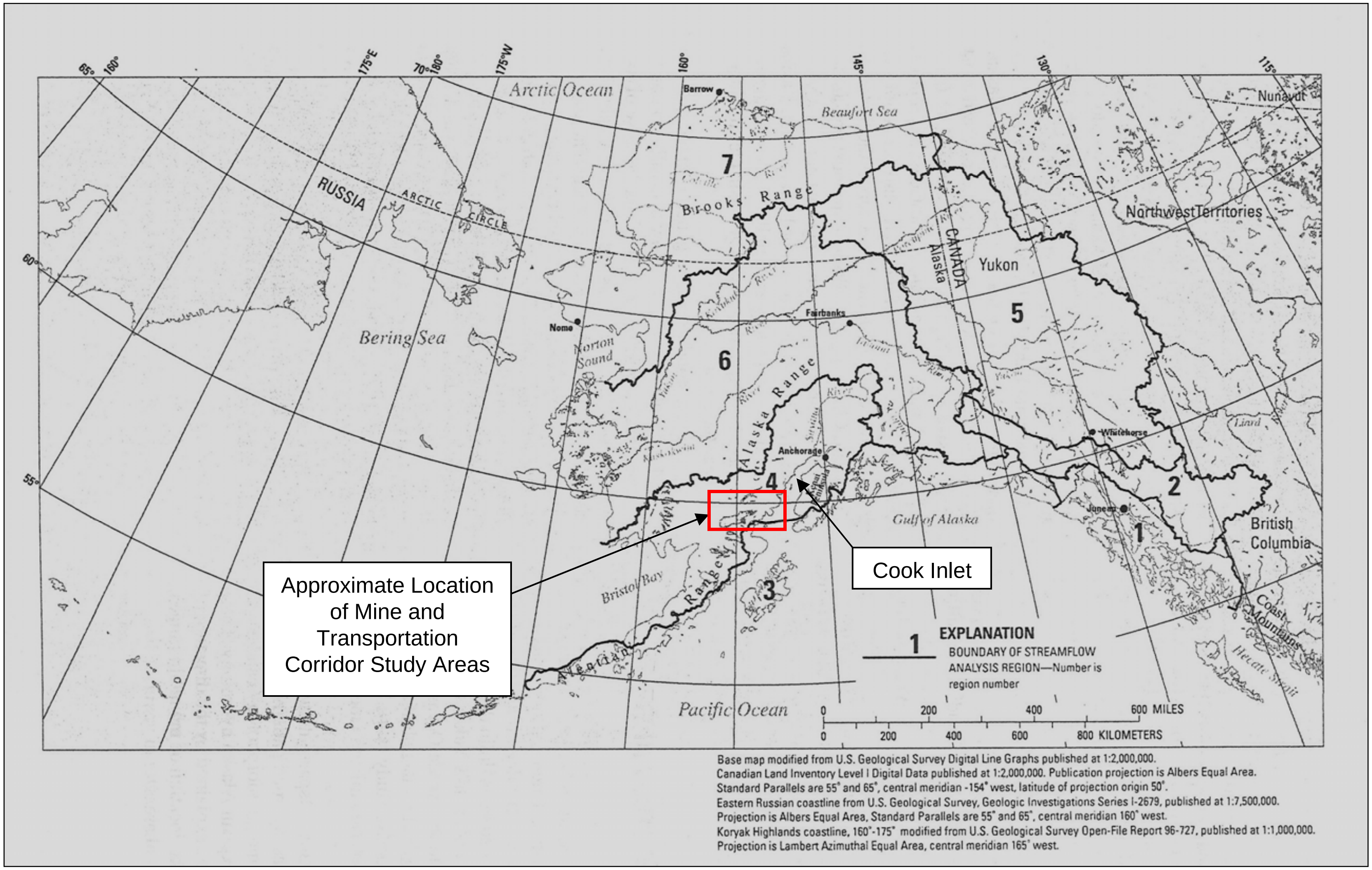


FIGURE 7.1-2
USGS Streamflow Analysis Regions of Alaska

Source: Curran et al., 2003.

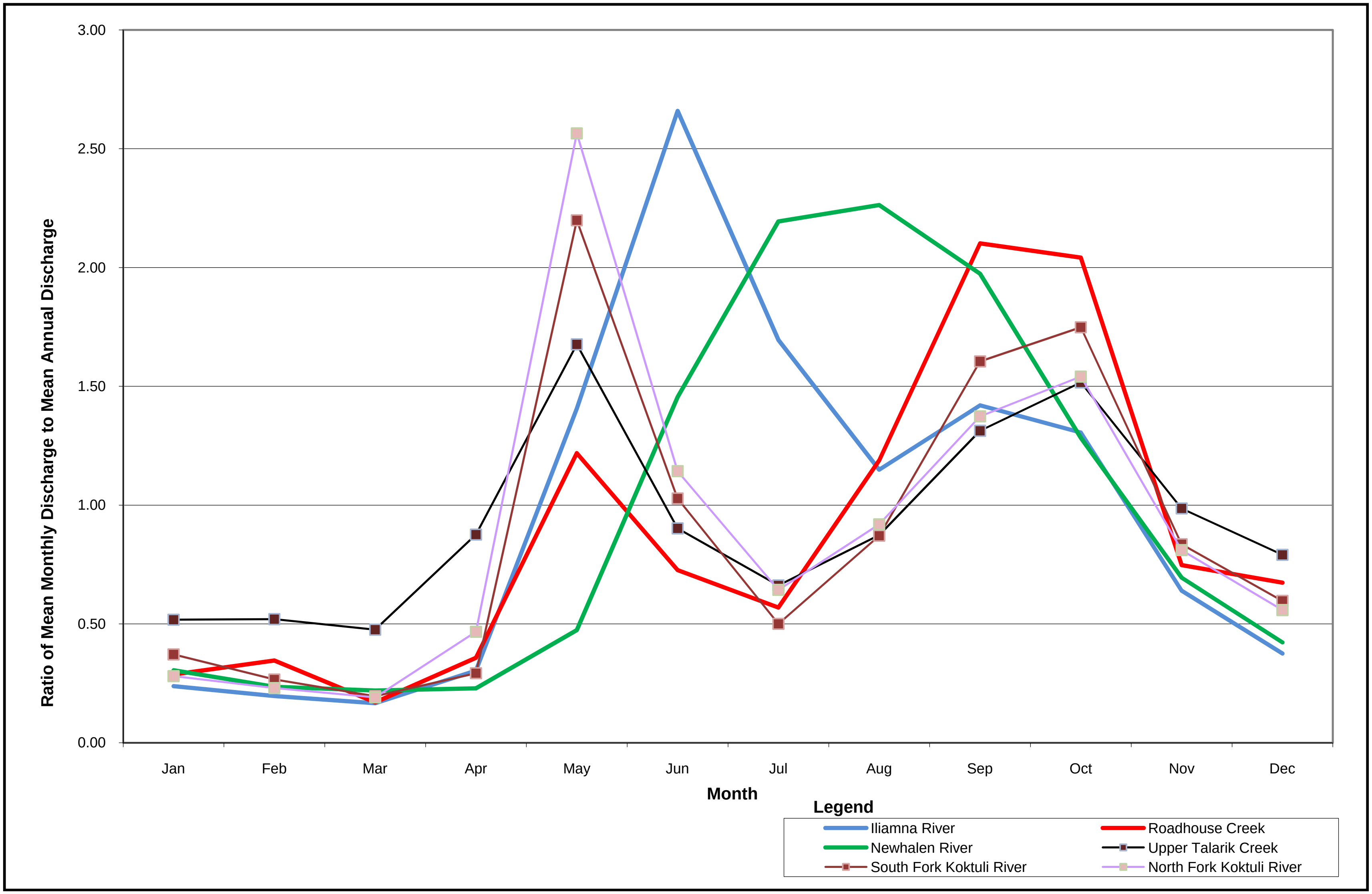
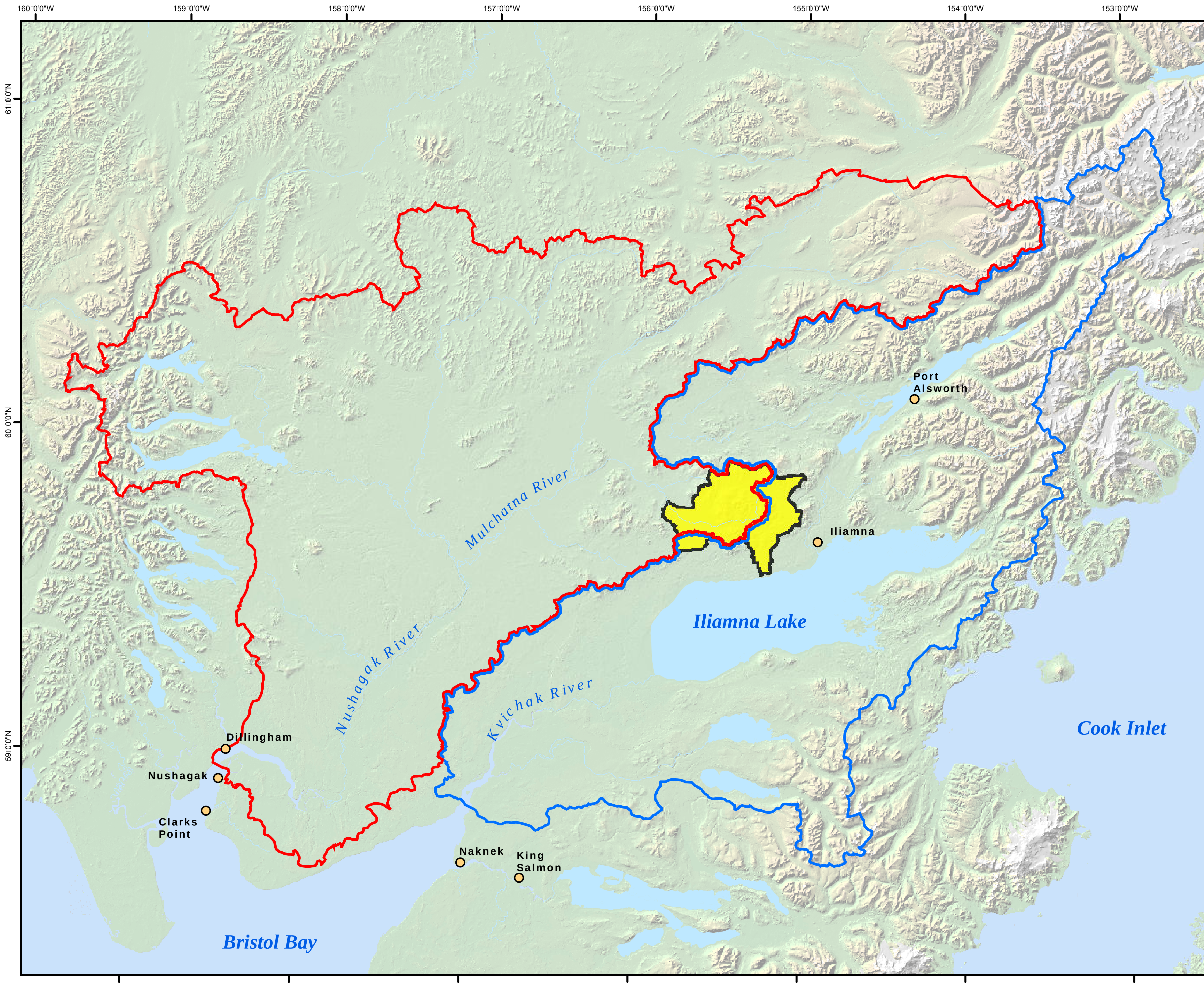


FIGURE 7-1.3
Normalized Mean Annual Hydrographs from Representative USGS Gaging Stations in the Bristol Bay Drainages

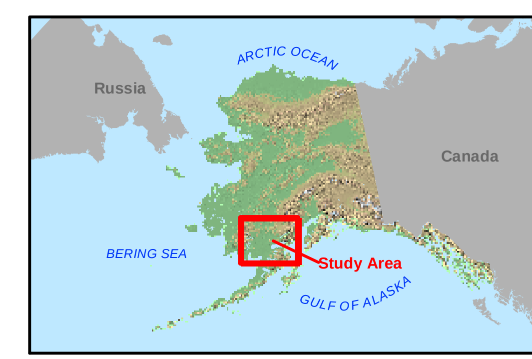


THE pebble PARTNERSHIP

Figure 7.2-1
Surface Hydrology
Study Area Drainages
Mine Study Area

Legend

- Community
- Nushagak River Basin
- Kvichak River Basin
- River
- Waterbody
- Study Area Drainages



Miles: 0, 10, 20, 30, 40
Kilometers: 0, 10, 20, 30, 40
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Scale 1:1,300,000

Alaska State Plane Zone 5 (units feet)
1983 North American Datum

File: synth_fig2.mxd	Date: 05 April 2011
Version: 1	Author: HDR- RB

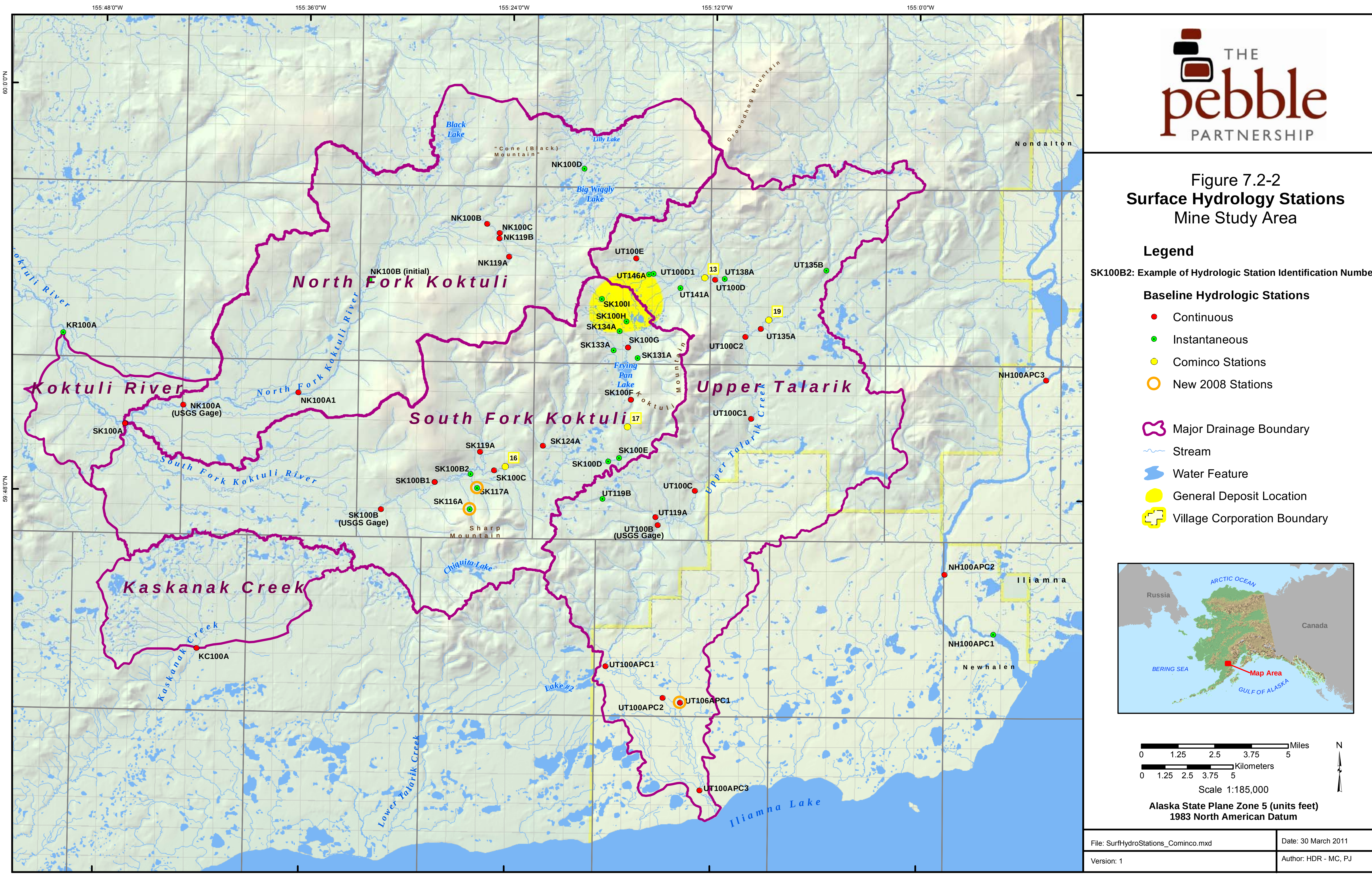


Figure 7.2-2
Surface Hydrology Stations
Mine Study Area

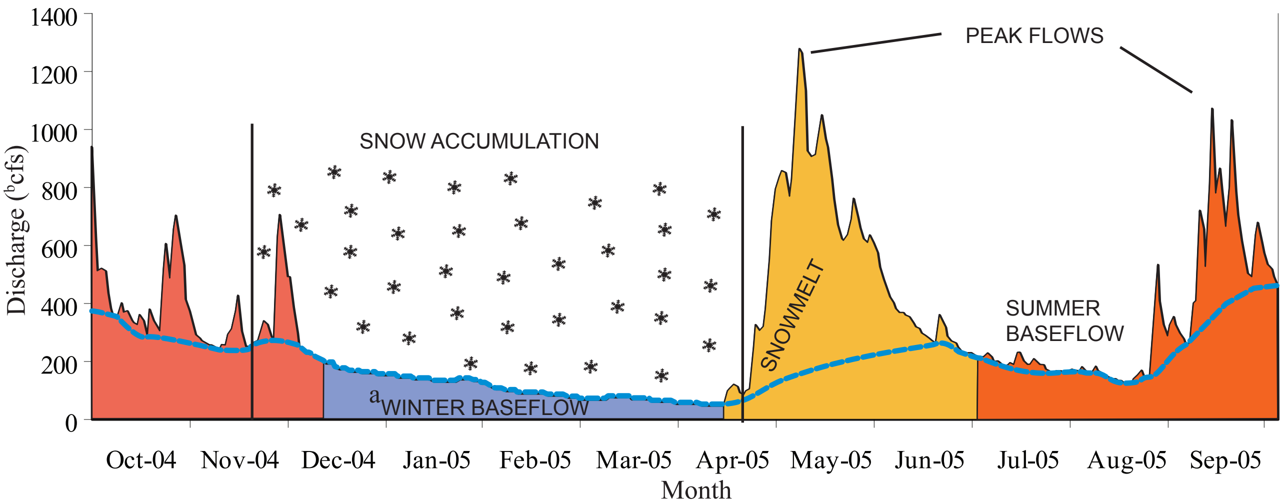


Figure 7.2-3 Annual Hydrograph of the South Fork Koktuli River at SK100B.

Notes:

a. Blue dashed line represents approximated baseflow

b. cfs = cubic feet per second

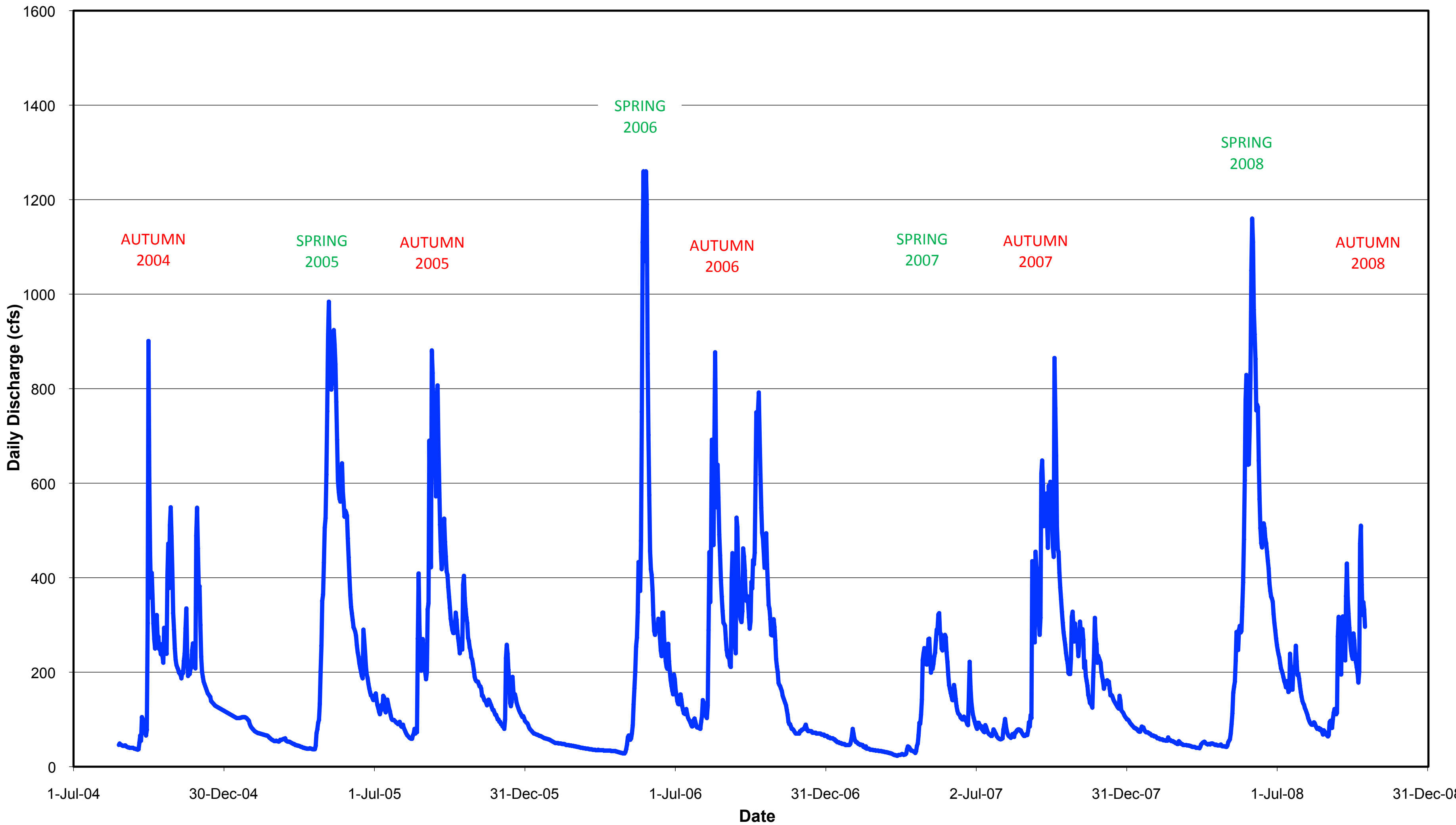


FIGURE 7.2-4
SK100B Hydrograph, 2004-2008

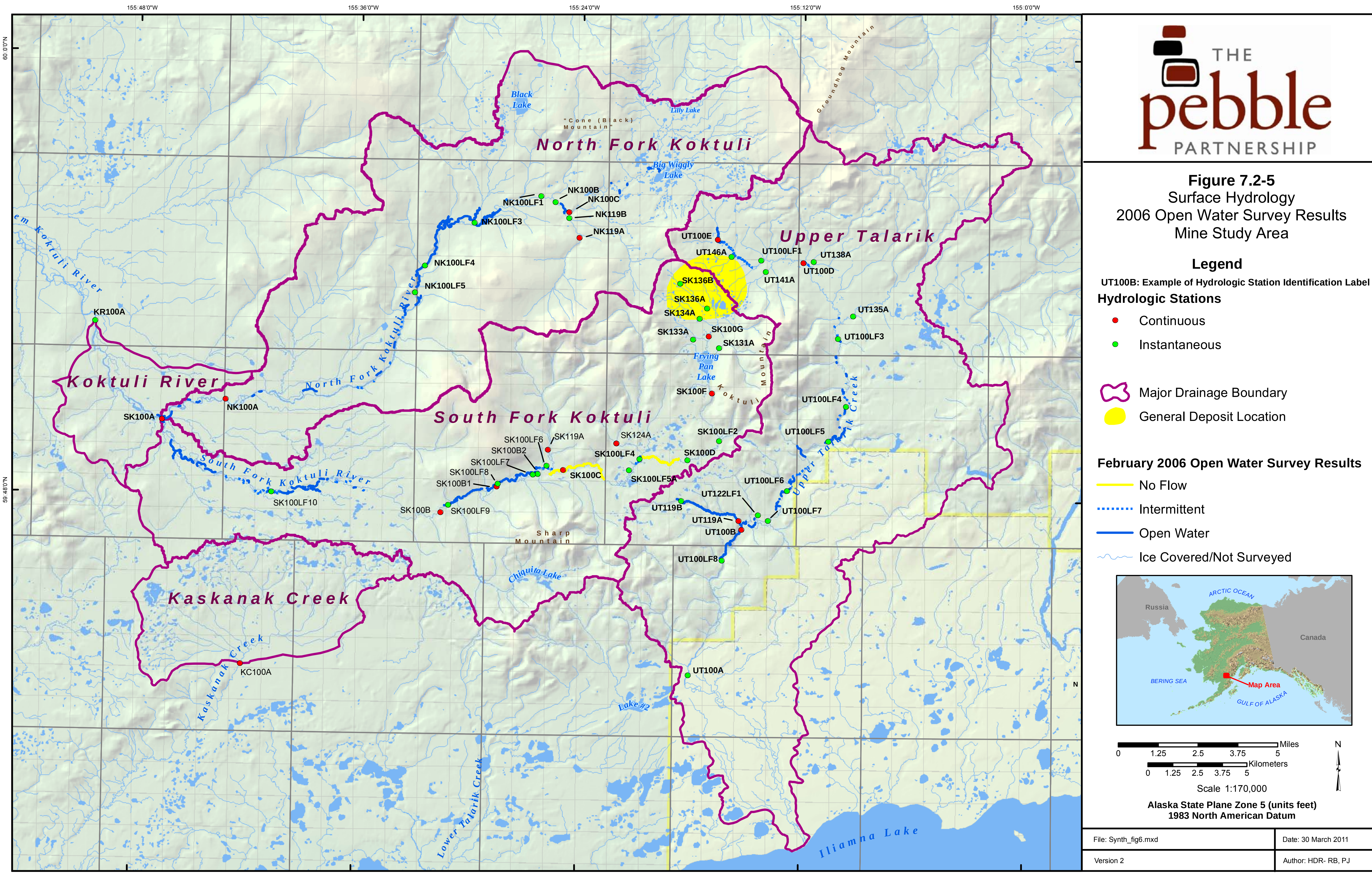
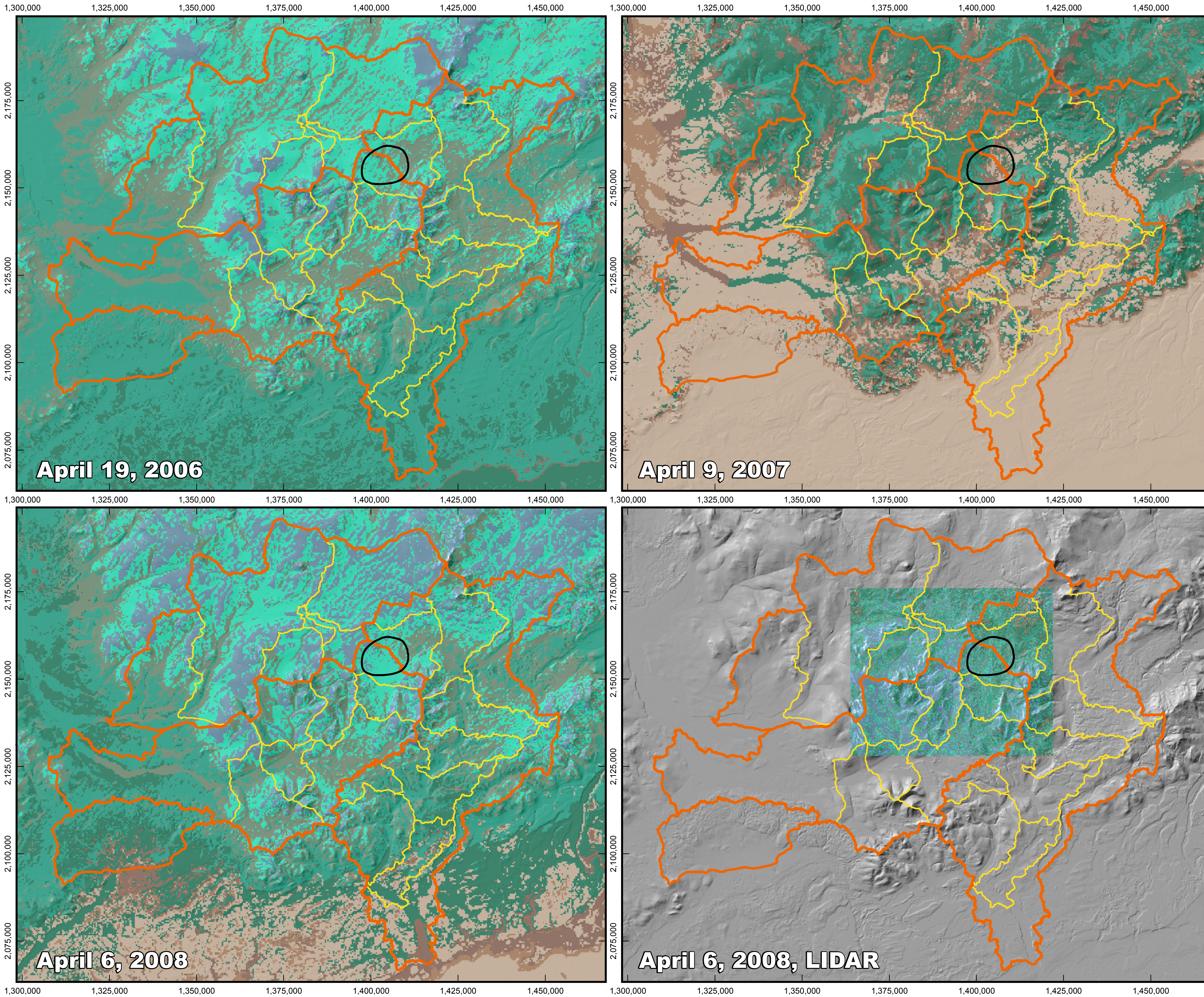


Figure 7.2-5
Surface Hydrology
2006 Open Water Survey Results
Mine Study Area



THE pebble PARTNERSHIP

Figure 7.2-6
Surface Hydrology
Snow Model Output,
April, 2006–2008, Mine Study Area

Legend

Snow Water Equivalent (Inches)

- 0 – 1.00
- 1.01 – 3.00
- 3.01 – 5.00
- 5.01 – 10.00
- 10.01 – 15.00
- 15.01 – 20.00
- 20.01 – 25.00
- 25.01 – 50.00
- 50.01 – 75.00
- 75.01 – 100.00
- 100.01 – 125.00
- 125.01 – 523.00

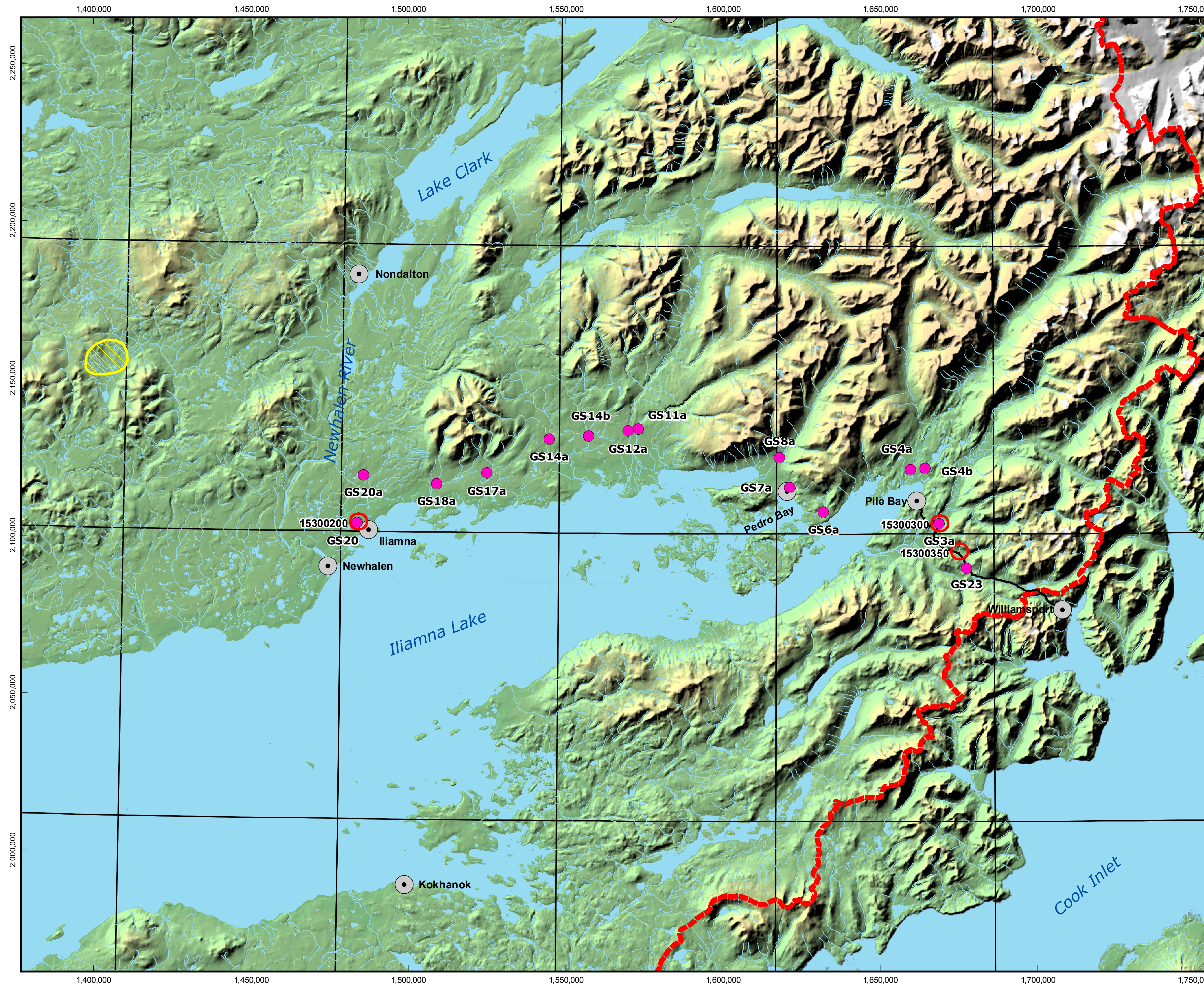
- Basin Boundary
- Monitored Sub-basin Boundary
- General Deposit Location

Russia
ARCTIC OCEAN
Canada
BERING SEA
Map Location
GULF OF ALASKA

Miles: 0 2 4 6 8 10
Kilometers: 0 5 10 15
N
Scale 1:340,000

Alaska State Plane Zone 5 (units feet)
1983 North American Datum

File: 7-2-6_SnowDistModels_06-08_PLP_EBD_v02.mxd	Date: March 16, 2011
Version: 2	Author: ABR-AZC



THE pebble PARTNERSHIP

Figure 7.3-1
Surface Water Gage Stations
Transportation Corridor
Bristol Bay Study Area
2004-2005

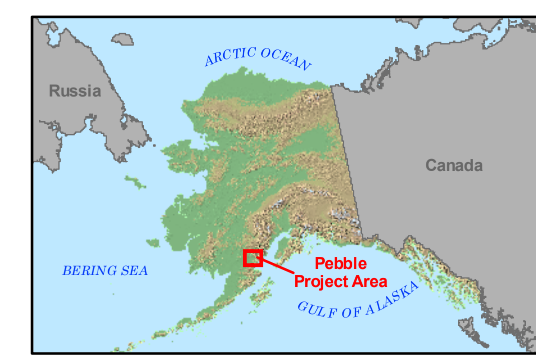
Legend

- Surface Water Gage Station (USGS)
- Surface Water Gage Station (Pebble Project)

GS18a: Example of Pebble Project Surface Water Gage Station Identification Number.

15300300: Example of USGS Surface Water Gage Station Identification Number.

- Communities
- Existing Roads
- General Deposit Location
- Bristol Bay/Cook Inlet Hydrologic Divide



Miles: 0 4 8 12 16

Kilometers: 0 5 10 15 20

N

Scale 1:363,852

Alaska State Plane Zone 5 (units feet)
1983 North American Datum

File: Hydro_EBD1a_V05.mxd	Date: March 28, 2011
Version: 5	Author: BEESC-ME

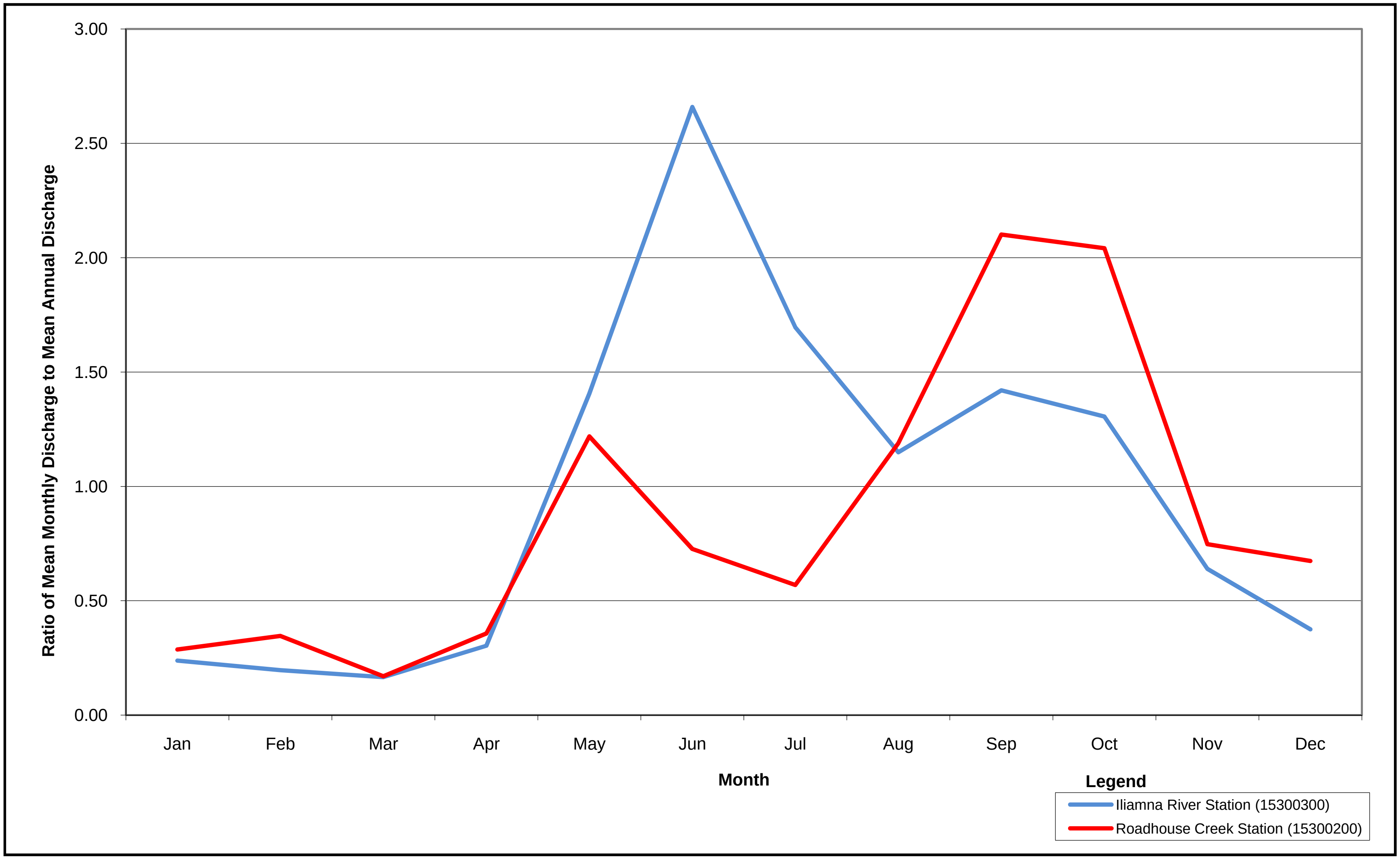


FIGURE 7.3-2
Normalized Mean Annual Hydrographs from USGS Gaging Stations in the Transportation Corridor Study Area

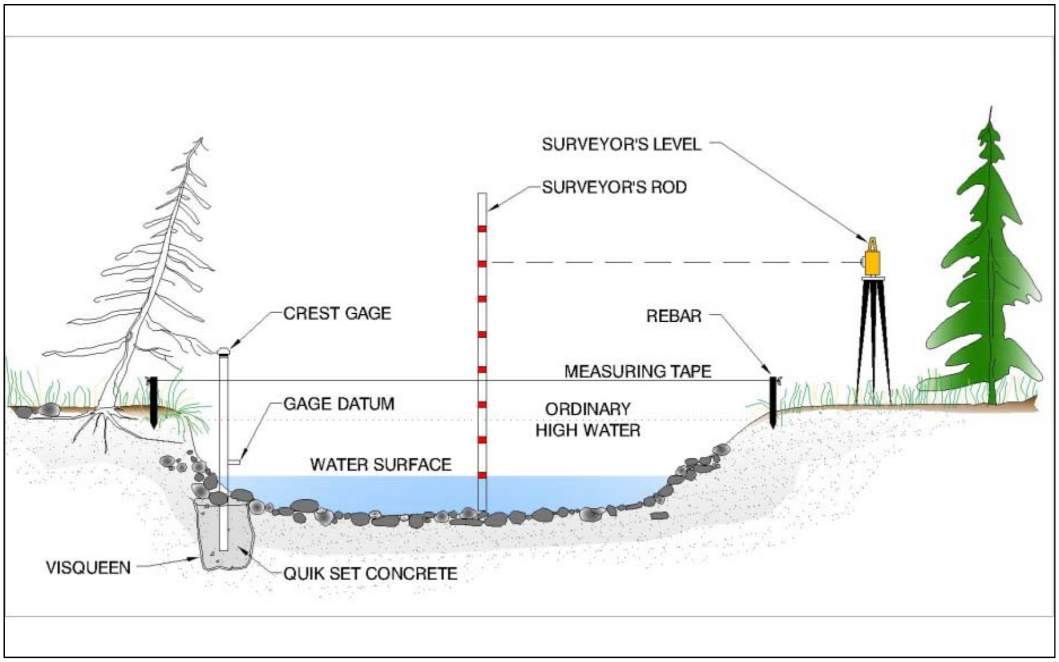


FIGURE 7.3-3
Depiction of Methodology for Stream Cross-Section Surveys

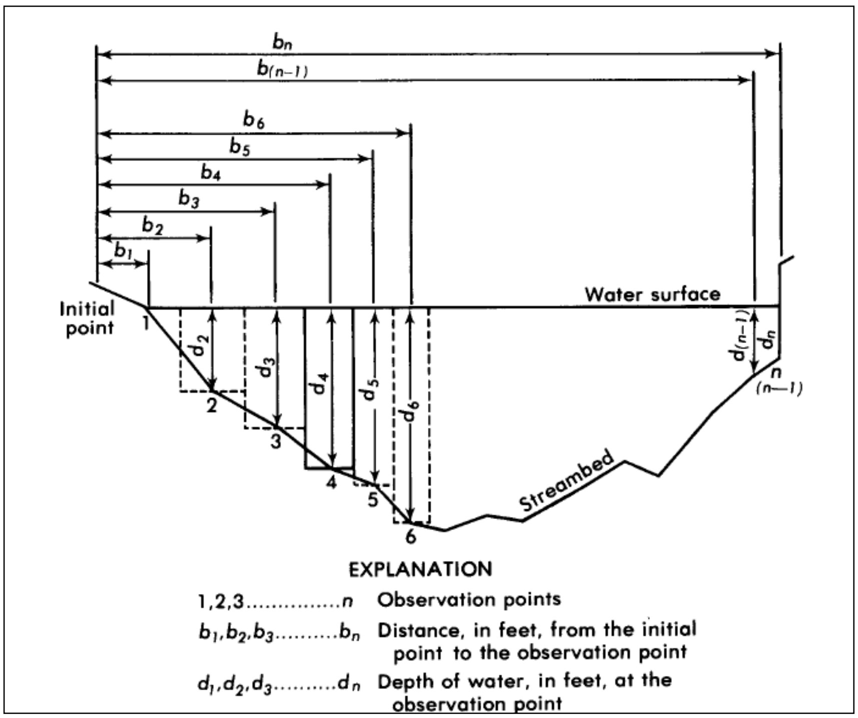


FIGURE 7.3-4
Sketch of the Mid-Section Method of Computing Cross-Sectional Area for Stream Discharge

Source: USGS, 1969.

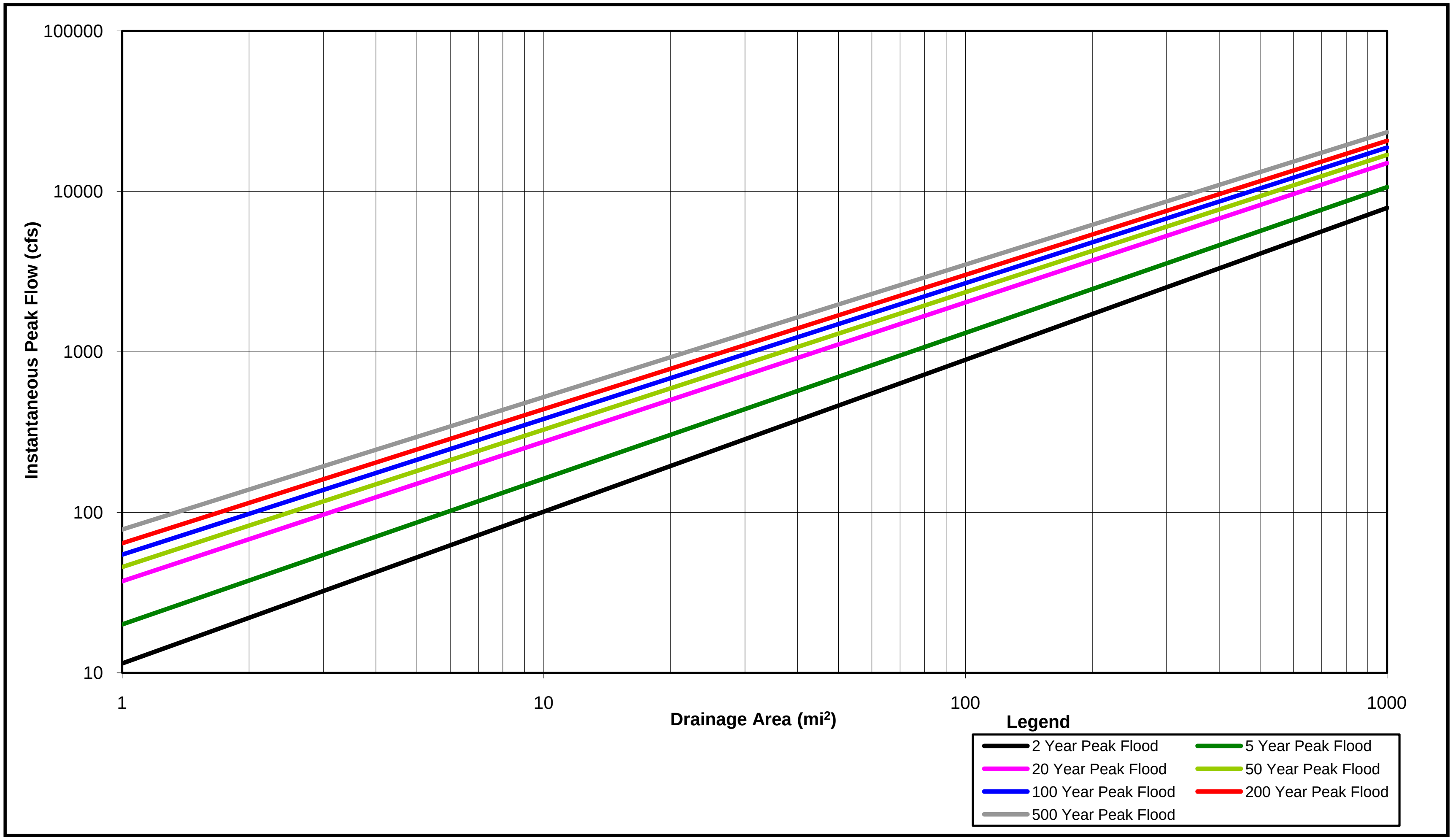


FIGURE 7.3-5

Peak Flows Predicted by USGS Streamflow Analysis Region 4 Regression Equations (Precipitation = 30 Inches)

Notes: a. These curves are applicable for gages with lake storage equal to 3.0 % of drainage area and mean annual precipitation equal to 30 inches.

b. 500 year peak flow equation: $Q = 78 A^{0.83}$

c. 2 year peak flow equation: $Q = 11 A^{0.95}$

d. Q = Discharge (cfs), A = Drainage Area (mi^2).

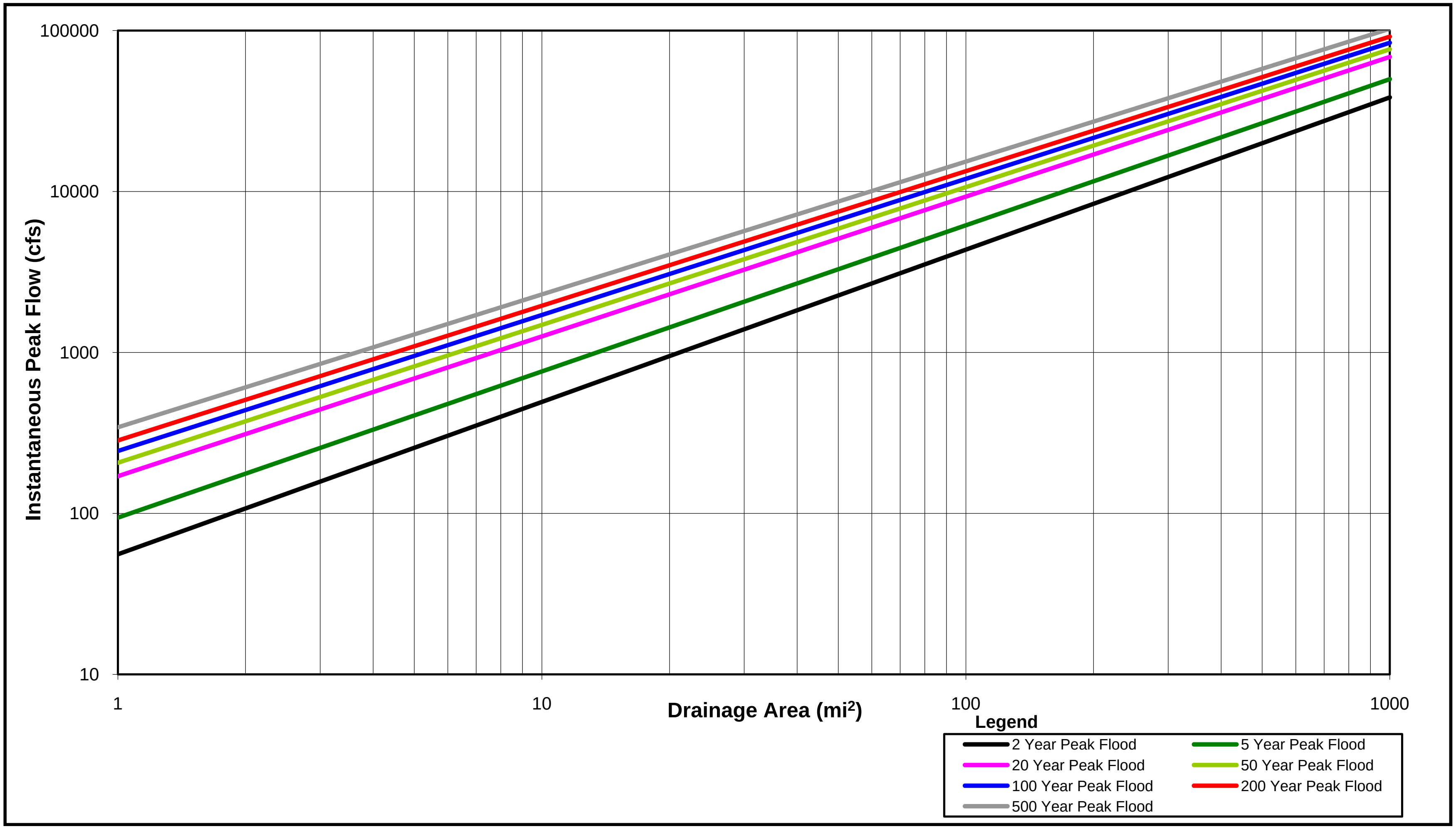


FIGURE 7.3-6

Peak Flows Predicted by USGS Streamflow Analysis Region 4 Regression Equations (Precipitation = 100 Inches)

Notes: a. These curves are applicable for gages with lake storage equal to 1.0 % of drainage area and mean annual precipitation equal to 100 inches.

b. 500 year peak flow equation: $Q = 343 A^{0.83}$

c. 2 year peak flow equation: $Q = 56 A^{0.95}$

d. Q = Discharge (cfs), A = Drainage Area (mi^2).

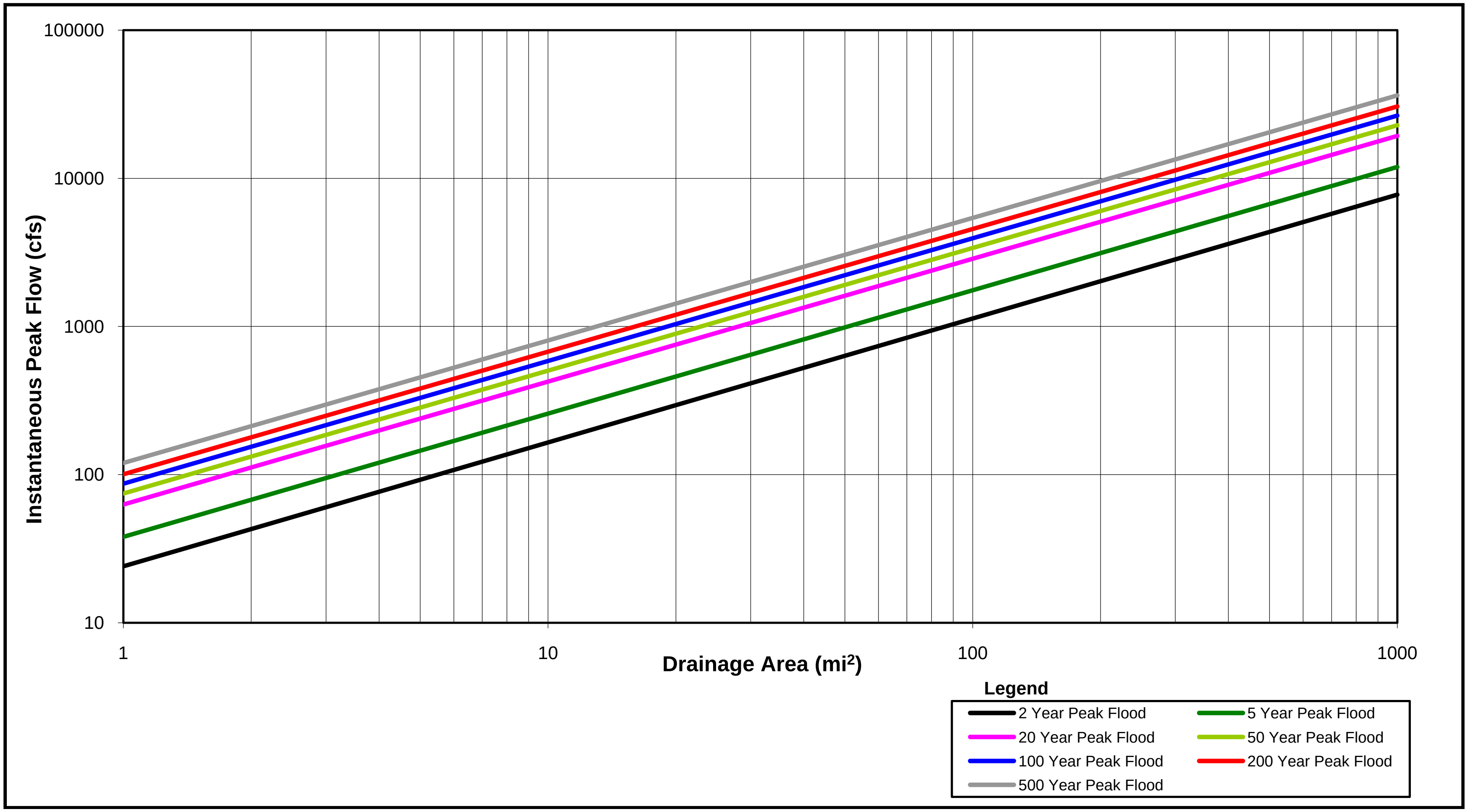


FIGURE 7.3-7

Peak Flows Predicted by USGS Streamflow Analysis Region 3 Regression Equations (Precipitation = 30 Inches)

Notes: a. These curves are applicable for gages with lake storage equal to 3.0 % of drainage area, mean minimum January temperature equal to 9°F and mean annual precipitation equal to 30 inches.

b. 500 year peak flow equation: $Q = 120 A^{0.83}$

c. 2 year peak flow equation: $Q = 24 A^{0.84}$

d. Q = Discharge (cfs), A = Drainage Area (mi^2).

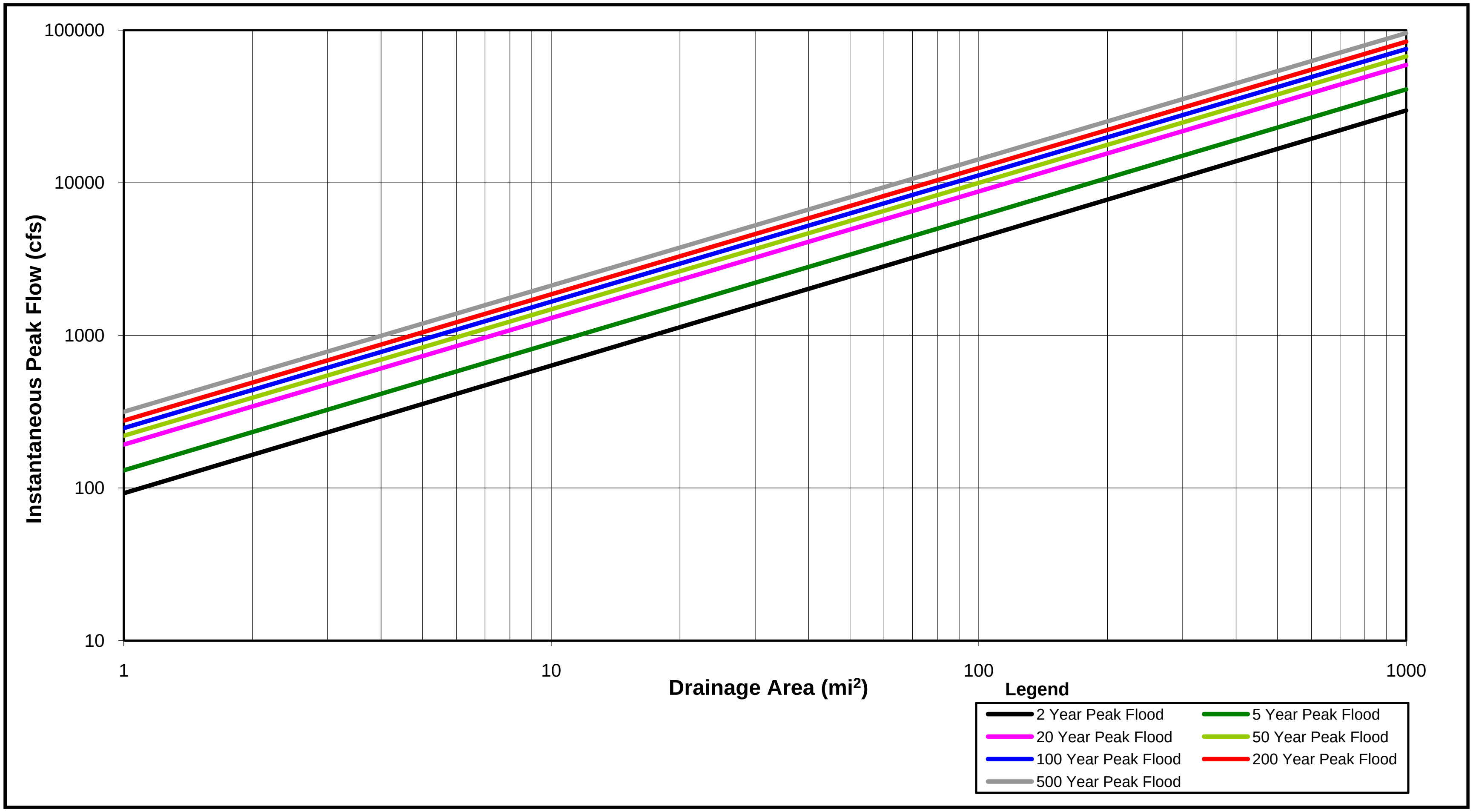


FIGURE 7.3-8

Peak Flows Predicted by USGS Streamflow Analysis Region 3 Regression Equations (Precipitation = 100 Inches)

Notes: a. These curves are applicable for gages with lake storage equal to 1.0 % of drainage area, mean minimum January temperature equal to 9°F and mean annual precipitation equal to 100 inches.

b. 500 year peak flow equation: $Q = 316 A^{0.83}$

c. 2 year peak flow equation: $Q = 92 A^{0.84}$

d. Q = Discharge (cfs), A = Drainage Area (mi^2).

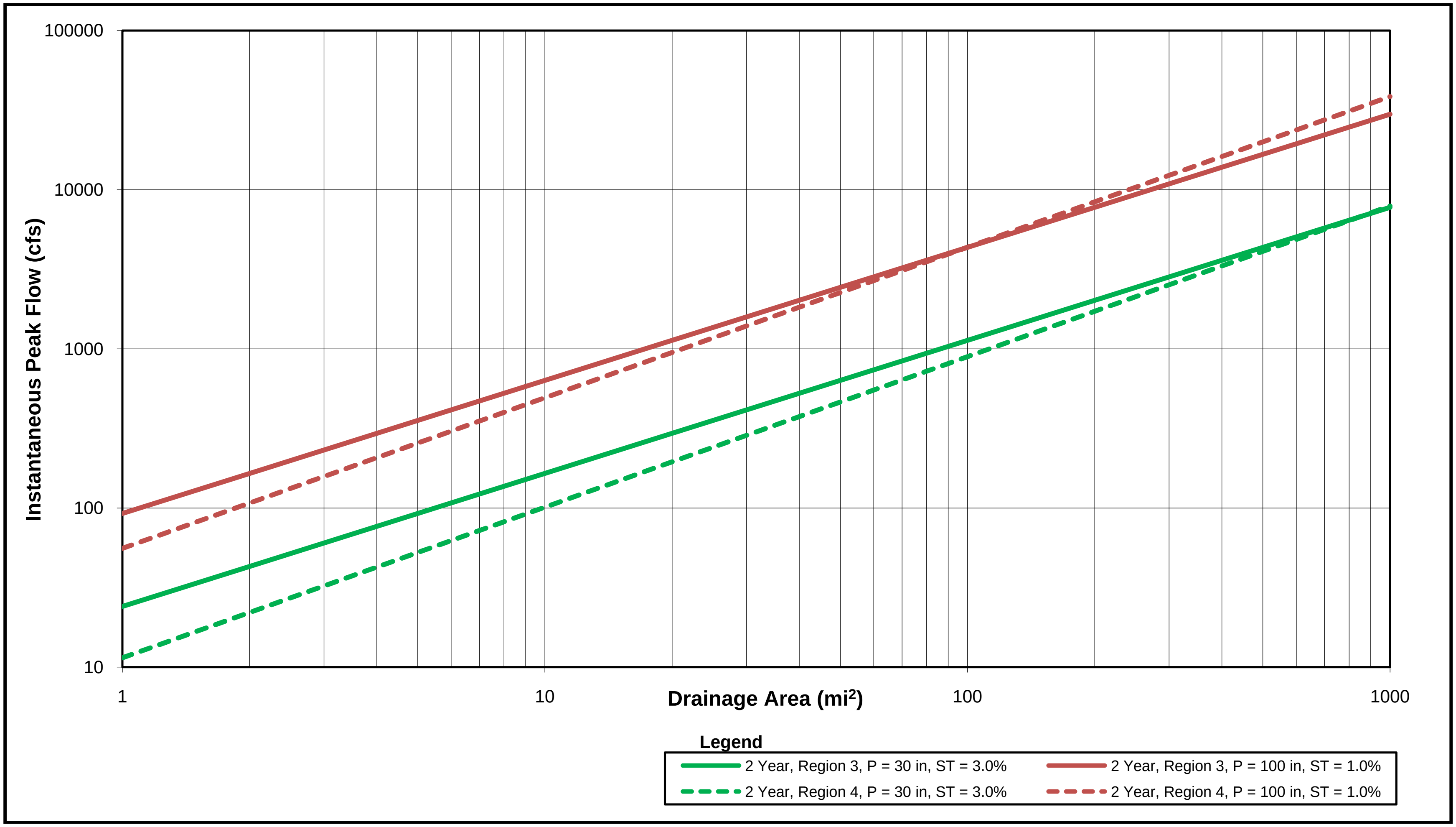


FIGURE 7.3-9

2-Year Peak Flows Predicted by USGS Streamflow Analysis Region 3 and 4 Regression Equations

Notes: a. Region 3 Curve Equation where P = 30 in, ST = 3.0%, J = 9°F: $Q = 24A^{0.84}$

b. Region 3 Curve Equation where P = 100 in, ST = 1.0%, J = 9°F: $Q = 92\ A^{0.84}$

c. Region 4 Curve Equation where P = 30 in, ST = 3.0%: $Q = 11\ A^{0.95}$

d. Region 4 Curve Equation where P = 100 in, ST = 1.0%: $Q = 56\ A^{0.95}$

e. P = Mean Annual Precipitation (in), ST = Lake Storage (%), J = Mean Minimum January Temperature (°F), Q = Discharge (cfs), A = Drainage Area (mi^2).

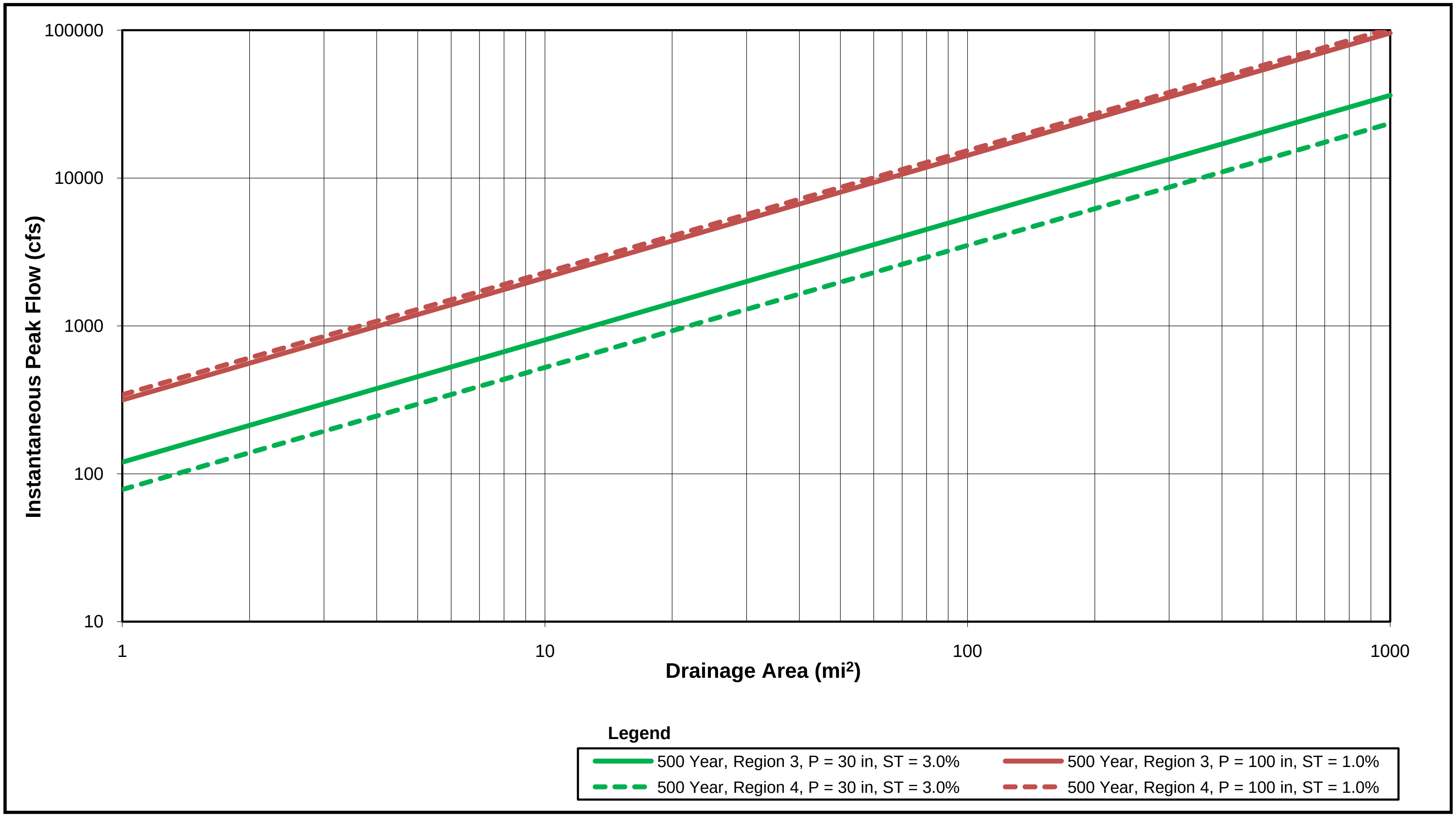


Figure 7.3-10

500-Year Peak Flows Predicted by USGS Streamflow Analysis Region 3 and 4 Regression Equations

Notes: a. Region 3 Curve Equation where P = 30 in, ST = 3.0%, J = 9°F: $Q = 120\ A^{0.83}$

b. Region 3 Curve Equation where P = 100 in, ST = 1.0%, J = 9°F: $Q = 316\ A^{0.83}$

c. Region 4 Curve Equation where P = 30 in, ST = 3.0%: $Q = 78\ A^{0.83}$

d. Region 4 Curve Equation where P = 100 in, ST = 1.0%: $Q = 343\ A^{0.83}$

e. P = Mean Annual Precipitation (in), ST = Lake Storage (%), J = Mean Minimum January Temperature (°F), Q = Discharge (cfs), A = Drainage Area (mi^2).

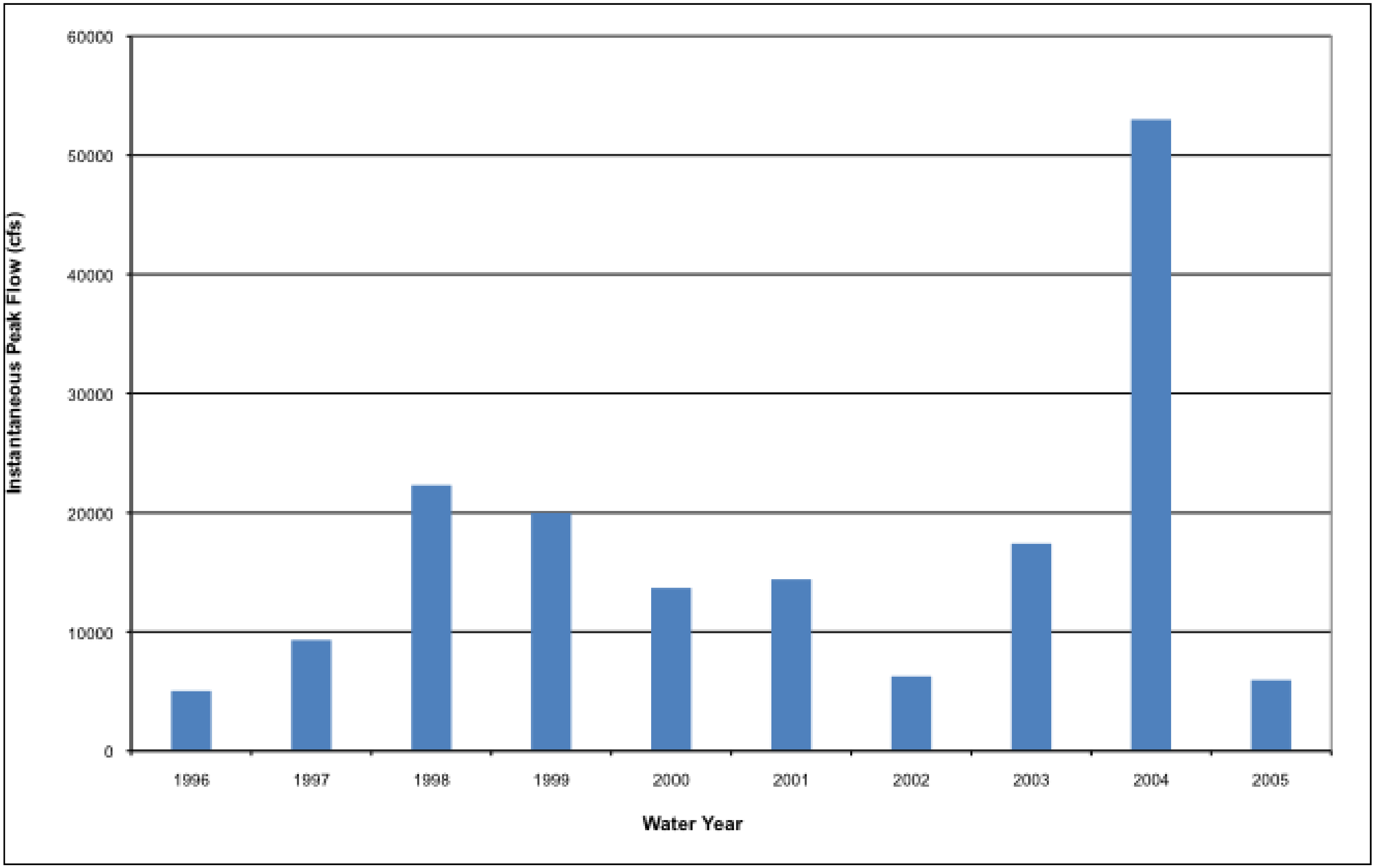


Figure 7.3-11
Iliamna River Peak Discharge 1996 to 2005
Notes: a. Water Year defines a year from October to September

PHOTOGRAPHS

PHOTO 7.3-1: Example of newly installed crest gage.

PHOTO 7.3-2: Example of survey for stream cross section.

PHOTO 7.3-3: Field crew taking a discharge measurement using the wading method on Knutson Creek (Gaging Station GS-8a).

PHOTO 7.3-4: Field crew taking a discharge measurement using a small boat on the Pile River (Gaging Station GS-4a).

PHOTO 7.3-5: View showing new bridge beside the old bridge on the Iliamna River (Gaging Station GS-3a) as seen during the beginning of the Pebble Project studies.

APPENDICES

APPENDIX 7.2A

Hydrologic Analysis

TABLE OF CONTENTS

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LIST OF FIGURES

PHOTOGRAPHS

ACRONYMS AND ABBREVIATIONS

ADCP	Acoustic Doppler Current Profiler
APC	Alaska Peninsula Corporation
cfs	cubic feet per second
Cominco	Teck Cominco Limited
CQ	continuous discharge
EBD	environmental baseline document
HDR	HDR Alaska, Inc.
IQ	instantaneous discharge
KC	Kaskanak Creek
KPL	Knight Piésold Ltd.
mi^2	square mile(s)
NH	Newhalen River
NK	North Fork Koktuli River
PVC	polyvinyl chloride
pzf	point of zero flow
SK	South Fork Koktuli River
TOB	top of bank
USGS	United States Geological Survey
UT	Upper Talarik Creek
WSE	water surface elevation

HYDROLOGIC ANALYSIS

1. INTRODUCTION

This report presents a summary of streamflow data collected between April 2004 and December 2008 in the mine study area, as well as historical streamflow data collected by Cominco Ltd. (Cominco) from 1991 to 1994. In the Pebble Partnership hydrology program (2004 through 2008), continuous streamflow (CQ) data have been collected at 29 gaging stations with varying periods of record. Four of the 29 gaging stations were discontinued at the end of 2007, but the rest remain active. Three of the stations were established in 2008 and do not have fully developed stage-discharge rating curves yet, so continuous discharge results cannot be presented at this time. Three of the gaging stations included as part of the current hydrology program are operated by the U.S. Geological Survey (USGS), while the rest are operated by Pebble Project contractors.

The 26 CQ gaging stations with complete stage-discharge rating curves (including the three USGS gaging stations and the four stations discontinued at the end of 2007) are located in the vicinity of the Pebble Deposit. The station locations are shown on Figure 1, and drainage areas and other basin characteristics are presented in Table 1. The names of the watersheds and the number of gages operated in each watershed as part of the current study are summarized as follows:

- South Fork Koktuli River (SK): 8.
- North Fork Koktuli River (NK): 6.
- Upper Talarik Creek (UT): 11.
- Kaskanak Creek (KC): 1.

Continuous flow data from the three new stations established in 2008 are not presented in this report because of their short records and incomplete stage-discharge rating curves. One of the new stations (UT106-APC1) is located on a UT tributary, and its location is shown on Figure 1. The other two new stations (NH100-APC2 and NH100-APC3) are located on the Newhalen River, approximately 9 miles east of Upper Talarik Creek, beyond the extent of Figure 1. Basin characteristics for all three of the new stations are provided in Table 1.

Instantaneous discharge (IQ) is also measured at a number of other sites as part of the water-quality and baseflow monitoring programs, but no continuous records of discharge are collected at these sites. The data from the IQ measurement sites are not presented in this report but are being stored with the CQ station data. The locations of the water-quality IQ measurement sites are presented on Figure 1. The number of CQ and IQ stations/sites operated in each watershed is summarized by year in Table 2. The locations of the additional baseflow measurement sites are provided in Appendix 7.2B.

This report also includes historical streamflow data collected during a previous study by Cominco from 1991 to 1994, in which two gaging stations were operated in each of the SK and UT watersheds. The locations of the historical Cominco gaging stations are shown on Figure 1. The drainage areas and other basin characteristics are presented in Table 3.

The hydrologic analysis component of the surface hydrology baseline study focused on the development of stream discharge records (hydrographs) from electronically recorded water level (stage) data at each of the CQ gaging stations in the current network and at the four gaging stations in the historical Cominco network. These hydrographs were then analyzed to characterize spatial and temporal variability in streamflow throughout the study area, and were also used in the Low Flow and Peak Flow analyses reported in Appendices 7.2B and 7.2C, respectively.

Each of the SK, NK, and UT watersheds contains one gage that is operated by the USGS. These three gages were installed in August 2004 and remained active beyond the end of 2008, although published data are only available at present up until the end of the 2008 water year (September 30, 2008). Data for the three USGS stations were obtained directly from the USGS website: http://alaska.usgs.gov/science/-water/index.php. The official USGS names and equivalent Pebble Project names of these three gaging stations are as follows:

- South Fork Koktuli River (SK) – USGS: 15302200; Pebble: SK100B.
- North Fork Koktuli River (NK) – USGS: 15302250; Pebble: NK100A.
- Upper Talarik Creek (UT) – USGS: 15300250; Pebble: UT100B.

The remaining gaging stations in the current network were installed and operated by consultants contracted to Pebble Partnership and its corporate predecessors. CH2M Hill installed 11 of the CQ gages in July 2004 and collected data until October 2004. Data collection, data management, and quality assurance responsibilities for these 11 stations were transferred to HDR Alaska, Inc. (HDR) in October 2004. Since then, HDR established two new gaging stations in the SK basin in 2005, and seven new stations in the NK and UT basins in 2007. APC Services, LLP (APC) became involved in the streamflow data collection program starting in 2007, when they established an additional three new gaging stations on the lower part of the UT mainstem. APC also installed the three new gaging stations in 2008. As of 2008, HDR and APC have each been responsible for collecting and managing the data at the stations that they established, and HDR has continued to manage the stations inherited from CH2M Hill. Knight Piésold Ltd. (KPL) has provided technical assistance and data review, developed the stage-discharge rating curves, led the data analysis, and participated in some field data collection. Data preparation and reporting has been a collaborative effort between KPL, HDR, and APC.

Continuous winter discharge records for Alaskan streams are not typically obtainable because stage-discharge relationships are not applicable under ice-affected conditions (Nolan and Jacobson, 2000). The USGS estimates winter hydrographs by using instantaneous discharge measurements in conjunction with meteorological data and drawing on general understanding of hydrograph recession patterns during winter low-flow conditions. USGS personnel estimated winter hydrographs for the three USGS gaging stations in the study area, and these were used as the basis for estimating winter hydrographs for the other Pebble Partnership gaging stations. Winter hydrographs for the Pebble Partnership stations were estimated by scaling USGS station hydrographs based on regression analyses of instantaneous discharge measurements at Pebble Partnership stations versus corresponding daily discharge at USGS stations. This method preserves the expert judgment applied by USGS personnel and uses physical field data to transfer their hydrograph patterns throughout the mine study area.

2. STUDY OBJECTIVES

Objectives of the hydrologic analysis baseline study included data collection for the following:

- Characterization of year-round streamflow throughout the mine study area.
- Calibration of the site-wide water balance model.
- Support for characterization of aquatic resources, fish resources, and wetlands habitat.

Related studies that are referenced in this document are climate and meteorology (Chapter 2), geology and mineralization (Chapter 3), physiography (Chapter 4), groundwater hydrology (Chapter 8), water quality (Chapter 9), and fish and aquatic invertebrates (Chapter 15). All descriptions of surficial materials are based on Hamilton (2007).

3. STUDY AREA

The general deposit location straddles the boundary of the Nushagak and Kvichak River watersheds, both of which drain into Bristol Bay. More specifically, the general deposit location straddles the boundary of the SK and UT basins, and lies close to the headwaters of the NK basin, as shown on Figure 1. The north and south forks of the Koktuli River (abbreviated NK and SK, respectively) join to form the Koktuli River mainstem approximately 17 miles west of the general deposit location. The Koktuli River flows into the Mulchatna River, which in turn flows into the Nushagak River. Upper Talarik Creek (UT) flows into Iliamna Lake, which is drained by the Kvichak River. Kaskanak Creek (KC) is located approximately 16 miles southwest of the deposit and has been included in the study area to investigate the potential for interbasin transfer of groundwater from the SK. KC drains to the Kvichak River below Iliamna Lake. The NK, SK, UT, and KC watersheds encompass a combined area of 373 square miles above the lowermost gaging station on each watercourse, including the mineralized area, and are shown on Figure 1. Two sites on the Newhalen River (NH) were established in 2008. The Newhalen River lies to the east of the mine study area and flows out of Lake Clark into Iliamna Lake. The Newhalen River is much larger than the watercourses on which the other gages are located. The drainage area at the lowermost gage on the Newhalen River is 3,451 square miles, as shown in Table 1.

Streamflows in the mine study area peak in the spring in response to snowmelt, and in the late summer and autumn in response to frequent frontal rainstorms. Flows are typically low in mid-summer and reach their minimum levels in late winter prior to the onset of snowmelt.

Spatial variability in precipitation and snowmelt occurs because of orographic effects in upland areas and extensive redistribution of snow by wind. Glacial and fluvial surficial materials of varying thickness cover most of the study area at elevations below about 1,400 feet, and play an important role in surface-water runoff and groundwater storage and exchange. In several areas, glacial deposits are superimposed on the pre-glacial drainage patterns, forcing surface water in a different direction from that of groundwater flow. These surface geologic features result in the transfer of groundwater across surface-water drainage boundaries. No permafrost has been found in the mine study area.

4. SCOPE OF WORK

The field work for the Pebble Partnership study was conducted from 2004 through 2008. Pressure transducers and dataloggers were installed at stations on the NK, SK, UT, KC, and NH to collect continuous records of water level (stage) throughout the period of unfrozen conditions each year (typically May through October). Manual measurements of instantaneous discharge were made at each site during monthly field visits and were used to develop stage-discharge rating curves. The rating curves were then used to transform the stage records into continuous records of discharge.

Rating curves are not applicable for estimating discharge beneath ice, so the USGS generally applies an expert-based system to estimate discharge between dates of manual discharge measurements. The USGS winter hydrographs at the NK, SK, and UT stations were used as the basis for estimating winter flows at all other gaging stations. The USGS measures instantaneous discharge at its three CQ stations throughout the year with similar frequency to the Pebble Project contractors.

Once computed, the discharge records were analyzed to characterize spatial and temporal variability in streamflow throughout the study area, including the characterization of extreme low flows and peak flows as reported in Appendices 7.2B and 7.2C, respectively.

5. METHODS

5.1 Station Selection and Nomenclature

Data were collected in accordance with the consolidated study program for Pebble Project (a copy of which is provided in Appendix E of this environmental baseline document [EBD]) and quality assurance plans (provided as Appendix G of this EBD). Surface hydrology stations were selected after considering hydrologic criteria, including the following:

- Surface waterbodies that have the potential to be affected by project activities.
- Locations upstream and downstream of the general vicinity of the Pebble Deposit.
- Stations to provide data on groundwater and surface water interactions.
- Streams that could be potential receiving waters for releases from the possible project.
- Stations that coincide with historical Cominco stations and the information obtained from those studies and related literature.
- Waterbodies in areas of potential water supply.

Additionally, selection and development of baseline station locations was a coordinated process involving the engineering design team and other teams, including those studying water quality, fisheries and aquatic resources, and sediment and trace metals. The conceptual-level understanding of surface water and groundwater regimes was used to help define the surface water program. The locations of all surface water stations are shown on Figure 1 (except for the two stations installed on the Newhalen River in 2008) and their respective watershed characteristics are listed in Tables 1 and 3.

The nomenclature for surface water stations is as follows:

- KC = Kaskanak Creek.
- KR = Koktuli River Main Stem.
- NH = Newhalen River.
- NK = North Fork Koktuli River.
- SK = South Fork Koktuli River.
- UT = Upper Talarik Creek.
- Stations on mainstem channels are designated by the two-letter stream code, followed by “100” and a sequential letter identifier for station locations moving upstream from the mouth (A, B, C, etc.).
- Stations that were later placed between existing stations have a number after the letter identifier that increases in the upstream direction.
- Stations on tributary stream channels are designated by the two-letter code for the main receiving stream, followed by the tributary number and a sequential letter identifier for station locations moving upstream along the tributary from the mouth (A, B, C, etc.). Tributary numbers are based on an analysis of the channel network as mapped on USGS quad sheets, with numbers progressing sequentially from 101 for the most downstream tributary in each watershed.

  For example, gaging station “UT119A” refers to the most downstream station (A) on the 19th mapped tributary upstream of the mouth of the UT. Gaging station “SK100B” refers to the second-most downstream station (B) on the main stem of the SK. SK100B1 is located upstream of SK100B and downstream of SK100C.

The stations established by APC in 2007 and 2008 follow a slightly different protocol.

- All stations are designated with an “APC” suffix.
- The three stations established on the lower mainstem of UT are located downstream of UT100A, and are named UT100-APC1, UT100-APC2, and UT100-APC3. The station numbering is reversed from the normal convention, with increasing numbers indicating locations further downstream.
- The station established on the UT tributary in 2008 (UT106-APC1) would have been called UT106A, prior to the APC numbering convention.
- The stations established by APC on the Newhalen River in 2008 have increasing numerical values in the upstream direction, consistent with the Pebble Partnership convention.

5.2 Baseline Data Collection

5.2.1 Continuous Stage Records

5.2.1.1 Equipment and Procedures

Stage was automatically recorded at each of the CQ stations operated by Pebble Project contractors during ice-free months, typically at 15-minute intervals, and at higher frequencies in 2004 and 2005 during periods of rapidly changing stage. The gages were typically established each spring in April or May, and removed each autumn in October or November. No continuous stage records were collected during winter months at these stations due to the effects of ice on stage-discharge relationships.

A local site datum was established for stage measurement at each of the CQ gaging stations operated by Pebble Project contractors. The local datums are arbitrary and are not interconnected to each other or to mean sea level. Multiple (usually three) benchmarks were installed at each site, and the local datum was established by setting the elevation of one benchmark to 100.00 feet. A staff gage was installed at each site (starting in 2005) and tied to the benchmarks by differential survey to provide a physical reference for convenient measurement of stage in terms of a water surface elevation (WSE) relative to the site datum.

Stage was recorded electronically at each CQ station using a vented pressure transducer manufactured by In-Situ, Inc., and an integrated MiniTROLL or LevelTROLL electronic datalogger. Data were periodically downloaded from the dataloggers during site visits without needing to disturb the transducers from their fixed positions. The pressure transducers have a full-scale range of 5 pounds per square inch, which equates to 11.5 feet in water depth. The transducers measured local water depth above the instrument with an accuracy rating of 0.012 foot (0.1 percent of full scale). Each pressure transducer was removed during the freezing period and recalibrated by In-Situ, Inc., prior to reinstallation in the spring. Polyvinyl chloride (PVC) stilling wells for the CQ gages were custom fabricated and installed with each gage. Each CQ gage was set in the stream by securing it to a piece of steel angle iron that was solidly anchored in the streambed. Each staff gage was mounted on a separate piece of angle iron to help detect differential movement of one or the other structure. Photo 1 shows a typical stream installation of a CQ gage.

The transducer stage readings were internally adjustable to the local site datum. Each spring, the transducer datum was calibrated such that the instantaneous stage reading matched the water surface reading on the staff gage, which is linked to the site datum. This procedure did not begin until 2005, so the 2004 stage data were converted to site datums retroactively based on a comparison of simultaneous surveyed water levels and recorded stage values at the time of gage installation.

5.2.1.2 Quality Assurance

Two quality assurance procedures were performed to verify the accuracy of recorded stage data. The first procedure was to compare the instantaneous stage readings from the transducer with simultaneous staff gage readings during site visits. This procedure checked for stability in the electronic stage record and provided a basis for drift or offset adjustments, as required. The second procedure was semi-annual surveys of the staff gage and transducer relative to the site benchmarks to verify the physical stability of the gage equipment. An independent differential survey was performed for each gage following installation in the spring after the ground thawed and before removal in the autumn each year. Additional differential surveys were performed if staff gage or transducer movement was observed or suspected during the gaging period. The results of the quality assurance program for stage data collection are summarized in Table 4 and discussed below.

The difference between a manual staff gage reading or water level survey and the concurrent stage reading on the station datalogger is reported as the manual stage check error. The averages of all manual stage checks at each station are presented in Table 4. At most stations, the average difference between manual stage readings from the staff gage and the simultaneous stage value from the datalogger is around 0.02 foot, which is only about twice the resolution with which the staff gage can be read and twice the specified accuracy of the transducers, and is close to the precision with which the staff gage can be read under many circumstances due to wave action. The water surface is especially rough at Station UT119A, which explains the higher average difference between staff gage and transducer readings at that site. In a few instances, large differences were observed between staff gage and datalogger, typically following a large storm event or during late autumn freeze-up. These observations were used as an indication of gage disturbance, which was investigated further by means of the differential survey results, or else as an indication of transducer malfunction in cases where no physical movement had occurred. Transducer drift was assumed in cases where two or more observations indicated a consistent trend of increasing differences between staff gage and datalogger readings. Drift corrections were applied to the stage record in cases where the differences exceeded 0.10 foot. Drift adjustments were only applied to the records from four stations: SK100F (2004 and 2005), SK100G (2004), SK119A (2008), and NK119B (2008).

The range of surveyed elevations of a staff gage or transducer over the course of a monitoring season is reported as the staff gage or transducer survey error. At most stations, the difference between spring and autumn surveyed elevations for transducer and staff gage apparatus was less than 0.05 foot. Typically, the spring survey was taken as correct and was used to tie recorded stage to the site datum, and the autumn survey was used to assess the stability of equipment. In some cases, the benchmarks were suspected or known to have moved over time, complicating the assessment of gage stability. The rebar stakes used as benchmarks at SK100G and UT135A were prone to frost heave because of the fine-textured soils at those sites, while other benchmarks have moved because of tree fall, bear activity, or other unknown causes. In general, the greatest disturbances occurred in the winter and early spring when the gages were not in place, and the benchmarks were relatively stable within a given stage collection season while the gages were in place. The results of the surveys are presented in Table 4.

5.2.2 Instantaneous Discharge Measurements

5.2.2.1 Equipment and Procedures

Instantaneous discharge (IQ) measurements were collected monthly throughout the year at each gaging station, except in the first two winters when the frequency of measurements was lower. Measurements were occasionally missed because of high water, which was considered too dangerous to wade or boat, or because of equipment malfunctions or extreme weather.

Instantaneous measurements were collected based on the procedures defined by the USGS (Rantz, 1982) and by the Pebble Project quality assurance plans (Appendix G of this EBD). Most discharge measurements were made using the area-velocity method. A salt-dilution slug injection method was also used, starting in May 2006, in small and/or turbulent streams that were not well-suited for the area-velocity method – primarily NK119A, UT100E, and UT119A. A boat-mounted Acoustic Doppler Current Profiler (ADCP) was used at the two Newhalen River stations. Table 5 summarizes the number of IQ measurements taken at each gaging station. Concurrent area-velocity and salt-dilution measurements are counted as single IQ measurements in Table 5, but the IQ values measured by each technique are presented separately on the figures and tables associated with each station.

The area-velocity discharge measurements used top-setting wading rods and three different types of current meter. All USGS measurements used Price AA current meters. Price AA meters were also used in early 2004 on larger streams at gaging stations operated by Pebble Project contractors. Price Pygmy current meters were used for five measurements in 2005 on smaller streams. The remainder of the velocity measurements were made with Marsh-McBirney Flowmate current meters. These became the standard for all streams because they work in the greatest variety of stream reaches and can be used in all seasons. Fulford et al. (1993) showed that under laboratory conditions, Price AA, Price Pygmy, and Marsh-McBirney current meters all have less than 0.8 percent error in repeat velocity measurements, while common field conditions increase the error for each type of meter. Using current meters to measure discharge typically results in a velocity measurement error of approximately 5 percent when dealing with smooth flow conditions in a uniform channel with parallel banks. In more irregular and turbulent flow conditions, the velocity measurement error can rise to approximately 15 percent. For very low flows over a rocky substrate with several small flow paths, the error may increase to 20 percent or more. These error values are typically estimated by comparing several discharge measurements taken on the same day at the same stage.

5.2.2.2 Quality Assurance

The quality assurance procedures for IQ measurements consisted of a line-by-line check of all data entered from field forms into calculation files, further review of field notes for anomalous IQ values, and a comparison of replicate IQ measurements to assess methodological consistency. In the data checking phase, data-entry and calculation mistakes have been identified and corrected, as required, and physical environmental explanations for anomalous values have been compiled. The latter are discussed in Section 6 insofar as they apply to the development of rating curves for each gaging station.

Results of the replicate IQ measurements are presented in Table 6 and are discussed below. Two types of replicates are presented: replicate measurements taken using a consistent technique, for an assessment of technique repeatability or precision; and comparisons of measurements taken using different techniques, for an assessment of technique-related biases. The precision analysis includes replicate area-velocity measurements, replicate salt-dilution measurements, and replicate ADCP measurements. The area-velocity replicates consist of paired measurements taken one after the other. The salt-dilution replicates typically consist of four measurements obtained using two conductivity sensors and two salt injection runs. The ADCP replicates consist of between five and seven repeated transects. The technique comparisons are based on the average values of concurrent area-velocity and salt-dilution measurements. For each comparison (within technique or between techniques), the error was defined as half of the spread between the maximum and minimum replicate values divided by the average of the replicates. A few sets of replicate measurements have been excluded from the analysis because of documented changes in site conditions between replicates, as described in the footnotes of Table 6.

Area-velocity IQ measurements were replicated on 113 occasions at 19 gaging stations, including winter conditions when stage recording equipment was not present. The average station error was 2.3 percent, the maximum station error was 5.0 percent, and the maximum error for any pair of replicates was 9.2 percent (except for the anomalous replicates described in the footnotes of Table 6). For rating curve development, the assumed error for area-velocity IQ measurements was 15 percent, which is greater than the precision-related errors quantified in the above analysis.

Salt dilution IQ measurements were replicated on 91 occasions at five gaging stations, including winter conditions when stage recording equipment was not present. The average station error was 7.7 percent, the maximum station error was 8.5 percent, and the maximum error for any set of replicates was 42.7 percent (excluding the anomalous replicates described in the footnotes of Table 6). All but two of the replicate sets had errors less than 22 percent, and this has been selected as the assumed error for salt dilution IQ measurements for rating curve development.

ADCP IQ measurements were replicated on all four occasions that discharge was measured at the two Newhalen River gaging stations. The average station error was 3.6 percent, the maximum station error was 4.0 percent, and the maximum error for any set of replicates was 4.4 percent. For rating curve development, the assumed error for ADCP IQ measurements was assumed to be 15 percent, which is considerably greater than the precision-related errors quantified in the preliminary analysis above, but the assumed error may be refined in the future based on an updated analysis.

Simultaneous IQ measurements were taken using the area-velocity and salt-dilution techniques on 61 occasions at five gaging stations, including winter conditions when stage recording equipment was not present, but excluding occasions when either of the techniques had within-technique error of greater than 10 percent. Since the maximum error for area-velocity replicates was 9.2 percent, it was always large errors in the salt-dilution replicates that forced some technique pairs to be excluded. In the resulting technique comparison, the average station error was 4.9 percent, the maximum station error was 7.1 percent, and the maximum error for any set of paired values was 17.3 percent. The salt dilution technique tended to yield lower IQ values than the area-velocity technique, and the differences between techniques appeared to be site dependent. At the three gaging stations that accounted for most of the comparative measurements, the average ratios between methods were: UT100E, 83 percent; UT119A, 90 percent; and NK119A, 100 percent (ratio of salt dilution values as a fraction of area-velocity values). These three sites had been chosen for salt dilution because of their poor suitability for area-velocity measurements (shallow, coarse bed material, turbulent flow), but the salt dilution measurements may also be prone to errors related to mixing or adherence of salt to bank materials or ice. Therefore, the values from both sets of measurement techniques have been used for rating curve development, except for cases in which the error between techniques was greater than 10 percent, in which case neither value was used.

5.3 Data Analysis

5.3.1 Rating Curve Development

A stage-discharge rating curve represents the relation between stage and discharge at a particular stream measurement location. A “defining relation” for a rating curve is typically obtained by fitting a mathematical function to a set of concurrently measured stage and discharge values. In general, a single function provides a description of the stage-discharge relation over the range of values bounded by the IQ measurements. In some cases, however, a compound curve consisting of two or more functions is required to properly describe the stage-discharge relation within various stage ranges. This is the case, for example, when an irregular channel bed feature controls the stage-discharge relation under low-flow conditions (i.e., low-flow section control), but the reach-scale channel morphology controls the stage-discharge relation at higher flows once the bed irregularities are sufficiently submerged (i.e., high-flow channel friction control).

An understanding of channel hydraulics can help to extrapolate rating curves to extreme high flows by ensuring that the upper ends of the curves agree with hydraulic theory. This avoids a situation where a compound rating curve should have been developed but was not (e.g., because of an insufficient number or poor distribution of IQ data points) and where a rating curve relation based on a low-flow control feature would otherwise be extrapolated to describe the stage-discharge relation under reach-scale channel friction control at higher flows. The following discussion is from the *Handbook of Hydrology* (Chapter 8, Mosley and McKerchar, 1993).

In a long straight channel where channel friction control dominates, a rating curve has the following form:

$$Q = C(h-a)^N \qquad (1)$$

Where:

Q = discharge,

C, N = constants,

h = stage,

a = stage at which discharge is zero, thus

h-a = depth.

Physically realistic estimates of C and N can be used to check the accuracy of rating curves that are defined by few measured discharges in the range of stage from which extrapolation is reasonable. These values of C and N are estimated using the Manning Equation for open-channel flow, which for high width-depth ratios and Imperial units takes the following form:

$$Q = 1.49 / n \cdot S^{0.5} \cdot A \cdot d^{0.67} = C \cdot d^{N}$$

Where:

n = Manning’s Coefficient.

A = cross-sectional area of channel (for a rectangular cross-section, $A = wd$).

Values of N for different cross-section shapes are as follows:

- Rectangular, 1.67 (assuming width-to-depth ratio > 20).
- Parabolic, 2.17 (assuming width-to-depth ratio > 20).
- Triangular, 2.67.

Natural channels are often approximately rectangular to parabolic in cross section, suggesting that *N* values of about 1.5 to 2.5 are appropriate where there is channel friction control. Sometimes higher values of *N* (up to 3.0) provide a good fit to the measured data even when the channel shape is closer to rectangular than triangular because of the decreasing roughness associated with increasing flows. Where a series of natural controls for different ranges of stage occurs, different values of *C, a*, and *N* may apply for each range of stage.

Estimates of *C* can be found by assuming a value of 0.05 for *n* and substituting a likely range of values for slope. For a slope of 0.01:

$$Q = 2.98 \cdot w \cdot d^{N}$$

For a slope of 0.001:

$$Q = 0.98 \cdot w \cdot d^{N}$$

Thus, in wide, shallow, parabolic-to-rectangular channels, *C* typically has a value that is on the order of 1 to 3 times the average width of the stream (e.g., for a channel width of 10 feet, the value of *C* would be expected to lie between 10 and 30). It is important to recognize that Manning's *n* likely varies both by station and with stage, as does the cross-sectional form of the channel. Thus both *N* and *C* are not hard constraints on rating curves; they are simply a way to cross-check the accuracy of the curve when only a few instantaneous discharge points are used as the basis for extrapolation to much higher flows.

The value of *a*, otherwise known as the point of zero flow (pzf), is estimated in one of three ways: (1) from field surveys of the lowest point in the low flow control section in relation to the stage datum; (2) by fitting a line to Equation 1 and minimizing the error between the curve and IQ measurements by adjusting the value of *a*; or (3) by adjusting the absolute value of *a* to attain reasonable values of *C* and *N* while staying below the lowest recorded value of *h* by some reasonable margin. Generally, the transducer should be installed in a pool at a level below the pzf. Caution must be exercised when using channel survey data to estimate *a*, because often the channel survey is not at the low-flow control section. Estimating *a* from a station visit when zero flow conditions are observed must also be done with caution, because the water in the stream at the time of the visit may actually be lower than the stage at which flow ceases.

The exponential form of the discharge equation suggests that as stage increases, each incremental increase in stage results in a proportionally greater increase in flow. This increased flow occurs for two reasons: (1) the cross-sectional area of each successive layer of water is generally larger than its predecessor, and (2) the velocity of each additional layer of water increases because of reduced friction effects as the distance from the banks and streambed increases.

A transition in the rating curve control, and therefore the equation, is expected at the stage where a noticeable change occurs in the streambed geometry, such as at the bankfull or top-of-bank (TOB) condition, where an increase in depth will cause flow to spill into the overbank or floodplain area. Where a floodplain without vegetation exists, an increase in the value of *N* is expected because the cross-sectional area increases substantially in the floodplain, which results in a proportionately greater increase in flow with each incremental increase in depth. Where densely vegetated ground cover occurs, *N* is not expected to change much. Because the flow in the additional cross-sectional area of the flooded area tends to move very slowly as a result of high bed roughness, the discharge in the overbank region is relatively small. Where substantial overhanging vegetation occurs above TOB, *N* may decrease as water is slowed and the effective cross-sectional area is reduced.

Each stage-discharge point inherently contains error or uncertainty. For the purpose of fitting rating curves, error bars were drawn to represent plus or minus 15 percent for each area-velocity or ADCP discharge measurement, and 22 percent for each salt-dilution discharge measurement. It is worth noting that when developing the rating curve, it is more important that the curve fits through the error bars of each IQ measurement and has a physically realistic defining function than it is to fit the curve precisely through each point. Each point is an estimate of the discharge, rather than a true discharge; the true discharge can be expected to fall anywhere within the range of the error. The goodness of fit between measured stage-discharge points and the derived rating curve function(s) is presented as an overall rating curve error. The rating curve error for each IQ point is calculated as the difference between the measured discharge value and the rating-curve discharge predicted for the measured IQ stage, divided by the average of the two discharge values. The average rating curve error is the average of the errors for each IQ point.

Occasionally, IQ measurements plot far enough away from other points that a single curve cannot be drawn through all error bars. Singular anomalous measurements may have occurred because of equipment error, or may indicate that there has been a temporary shift in channel geometry or stage control because of ice, bank erosion, or beaver activity. Sometimes the cause of anomalies is known from field observations, while at other times it is inferred from the data analysis or cannot be determined at all. Anomalous measurements are not generally used to calibrate the rating curve or calculate rating curve error, but are always reported and will be revisited when the rating curves are updated or as new information becomes available. Multiple, seemingly anomalous points that are taken sequentially may indicate a systematic change in channel geometry or stage control. In these cases, a new rating curve is created. All IQ measurements taken between November and April were assumed to be ice-affected and were not used for rating curve development, regardless of ice observations at the time of measurement. This protocol was adopted to simplify the process of identifying anomalous stage-discharge points. Ice-affected stage in early spring (May) and late autumn (October) was determined on a case-by-case basis by referring to field notes, water temperature data, and the relative plotting position of sequential stage-discharge points.

Table 5 summarizes pertinent information regarding the rating curves developed for the Pebble Partnership and USGS gaging stations, including the number of IQ points used to develop the curves for each station and the number of curves that have been applied at each station because of changes in channel geometry or stage control. Table 5 also presents some comparative information about the maximum discharge on record at each station (based on the maximum recorded stage) that will assist in the evaluation of reliability for peak flow analysis.

5.3.2 Hydrograph Development and Discharge Summary

The continuous stage records were compiled for non-winter periods at each gaging station. The appropriate stage-discharge rating curves were applied to the stage records to produce hydrographs for each station. For the winter months, hydrographs for the Pebble Partnership stations were estimated by scaling USGS station hydrographs based on regression analyses of instantaneous discharge measurements at Pebble Partnership stations versus corresponding daily discharge at USGS stations.

6. RESULTS AND DISCUSSION

6.1 Results

The following section provides additional details about each gaging station in the current data collection network – including local channel characteristics, stage-discharge characteristics and rating curve development – and presents baseline streamflow results for the periods of record up to December 2008. Continuous records are available for Pebble Partnership stations up until the stage recording equipment was removed for the winter in October 2008, after which time only the monthly IQ measurements taken in November and December 2008 are available. USGS has published flow data only until the end of the 2008 water year (September 30, 2008). At the time of this writing, there is no basis for estimating flows at the Pebble Project stations after the equipment was removed in the autumn of 2008.

The number of discharge measurements taken at each station over the entire study period is presented in Table 5, along with the number of those measurements used for rating curve development. Annual discharge data for each station are summarized by water year (October through September) in Table 7.

The following more-detailed information is presented separately for each of the continuous gaging stations, including the three USGS gaging stations, on Figures 2 through 104 and in Tables 8 through 62:

- A channel cross-section figure showing channel topography at the gage control and indicating the bankfull stage and maximum recorded stage (except for the USGS stations).
- A discharge measurement record table presenting all IQ measurement data collected at the gage, including stage-discharge data used for rating curve development.
- Stage-discharge rating curve figures presenting IQ points and rating curves over the full range of recorded stage, and over the smaller range of stage associated with manual discharge measurements (or combined in a single figure where appropriate based on the range in stage).
- A hydrograph figure showing measured and estimated daily discharge for the period of record, along with the concurrent prorated daily discharge data from the USGS gaging station in the same basin to illustrate spatial variability in unit runoff.
- A monthly discharge summary table.

A similar set of information is provided for each of the historical Cominco gaging stations on Figures 105 through 115, and in Tables 63 through 67, except for the gage control cross-sections and hydrograph comparisons to an active USGS station, and the summary of monthly discharge for all four stations is combined in a single table (Table 67).

The comparison of streamflow results between the active Pebble Partnership and USGS gaging stations is an important part of the hydrological analysis. The regression analyses were performed to examine differences in unit runoff throughout the study area, and to provide a means of estimating missing streamflow data at Pebble Partnership stations based on the records of USGS stations. The greatest need for estimating streamflow was in the winter months, but other data gaps also occurred and were filled using regression relationships against one of the USGS gages.

The results of regression analyses between stations are presented on Figures 116 through 125, and are summarized in Tables 68 and 69. Table 68 and Figures 116 and 117 present comparisons of instantaneous discharge measurements taken during the winter months at Pebble Partnership gaging stations versus concurrent daily discharge values from representative USGS gaging stations. Table 69 and Figures 118 through 124 present seasonal comparisons of concurrent daily discharge recorded at Pebble Partnership stations and USGS stations during non-winter months. The May-June regressions encompass most of the snowmelt freshet season, the July-August regressions encompass the summer low-flow season, and the September-October regressions represent most of the autumn rainstorm season (which usually starts in August).

Figure 125 presents a special regression analysis for gaging station UT135A, at which a stable stage-discharge rating curve could not be developed. In this case, instantaneous discharge measurements taken during the normal stage recording period (May through October) were compared against concurrent daily discharges at UT100B, in the same fashion as the winter regression analyses undertaken at all stations. The resulting regression formula was used to estimate May-October flows at UT135A.

6.1.1 South Fork Koktuli River

The SK drains the southern portion of the headwater areas of the Koktuli River catchment. The lowest point in the watershed is at the confluence with the NK at elevation 580 feet, and the highest point is on the northern ridgeline of the watershed divide at elevation 2,600 feet. Winds blow predominantly from the southeast in the winter, resulting in large snow accumulations on leeward slopes, usually the eastern sides of the subcatchments within the SK drainage. The hydrology of the river is characterized by two annual high-flow seasons. The first occurs in response to spring snowmelt in May and June. The second occurs in response to frontal rainfall during the late summer and autumn (typically August through November). The relatively gentle topography, deep deposits of surficial material, and extensive lake and pond coverage of the catchment result in moderately large winter baseflows in lower reaches of the main channel. Lower baseflows (on a unit runoff basis) occur locally along the main channel where it crosses deeper surficial deposits and the water table lies at a lower elevation than the streambed. Tributary channels draining steep upland slopes with shallower surficial deposits than the main valley are generally characterized by more rapid snowmelt and rainfall runoff and lower unit baseflows than the main channel.

Station SK100A is the most downstream gaging station on the SK, located near the confluence with the NK. At this point, the SK drains an area of approximately 107 square miles with a mean basin elevation of approximately 1,115 feet and an average basin slope of 11.8 percent. Five other gaging stations are located at sites further upstream on the main channel of the SK: SK100B, SK100B1, SK100C, SK100F, and SK100G. Two additional gaging stations are located on the lower reaches of SK tributaries: SK119A and SK124A. The two gaged tributaries drain the upland area along the north side of the SK valley, to the west of the deposit location. The drainage areas and basin characteristics of each gaging station are presented in Table 1. SK100B is the USGS-operated station in the SK watershed.

The lower portion of the SK watershed, downstream of SK100B, consists of a broad, unconfined plain with well-developed floodplains, associated low terraces, older glaciofluvial terrace deposits, and abundant wetlands. Upstream of SK100B, the SK valley narrows to a width of 0.5 to 1.5 miles where it is bounded by low but moderately steep-sided hills and ridges. The main channel of the SK generally flows through floodplains and low terraces within this upper part of the watershed, but locally impinges against higher terraces or hillslopes. A large wetland complex is situated in the main valley bottom between SK100C and SK100F, and Frying Pan Lake occupies the valley bottom between SK100F and SK100G. Tributary 1.190 (gaged by SK119A) joins the main SK channel immediately downstream of SK100C; Tributary 1.240 (gaged by SK124A) joins the main SK channel in the wetland complex upstream of SK100C.

6.1.1.1 SK100A

Station SK100A is the most downstream gaging station on the SK. This reach of the river meanders through well-developed floodplains, associated low terraces, and older stream terrace deposits that make up the local topographic relief (Photos 2 and 3). The channel habitat features are dominated by riffles and pools, and the instream sediments are dominated by coarse gravel. The stage record indicates that high flows have exceeded bankfull stage during the study period. The gage control cross-section is shown on Figure 2, with bankfull stage and maximum recorded stage indicated. The banks are covered in grasses and brush, which have high hydraulic roughness characteristics (i.e. high values of Manning’s coefficient, n, relative to the values found in the adjacent stream channel). The vegetation impedes overbank flow during flood conditions. The extent of brush overhanging into the channel is negligible relative to channel width.

Station SK100A was discontinued in late 2007, although instantaneous discharge measurements continued to be collected in 2008. Two stage-discharge rating curves were developed for SK100A based on 18 measurements taken in non-freeze months (May through October) from 2004 through 2007. The rating curve shift was applied starting in the spring of 2006. The stage-discharge measurements are presented in Table 8 and the rating curves are shown on Figures 3 and 4. The average rating curve error is 6.8 percent which is considered good given that the error associated with individual discharge measurements can be up to 15 percent.

Each rating curve for SK100A consists of a single function for main-channel flow over all ranges of stage, with an additional function for flow through a side-channel in which a small portion of flow bypasses the gaging station under high flow conditions. Thus, the composite rating curves for total discharge feature a slight bend to the right above the threshold stage for side-channel flow. The side-channel rating curve was not based on any direct measurements, but rather was estimated based on channel dimensions and only amounts to 8 percent of main-channel discharge at the highest recorded stage.

The rating curve parameters lie within the expected ranges based on channel geometry. The *C* and *N* values are identical for the 2004 through 2005 and 2006 through 2007 main-channel rating curves (only *a* was adjusted). The *C* value for main-channel flow (C = 132) equates to approximately 1.9 times the channel width (70 feet) at the threshold stage for the onset of side-channel flow. The *N* value for main-channel flow (N = 1.72) approximates the value for a rectangular channel, which is appropriate for this site. Rating curve extrapolation above bankfull stage at SK100A is considered to be reasonably accurate because the upper end of the curves are not expected to be influenced significantly by floodplain conveyance or overhanging vegetation, the conveyance of the side channel is low relative to the main channel, and the rating curve functions are in general agreement with hydraulic theory.

The stage-discharge rating curves were applied to the recorded stage data to develop continuous hydrographs for non-freeze periods. Winter flows were estimated using a regression analysis between instantaneous discharge measurements at SK100A and corresponding daily discharge estimates developed by the USGS for SK100B. Discharge was estimated at SK100A for non-freeze data gaps in autumn 2005 (datalogger malfunction) and autumn 2006 (datalogger disturbance) using the seasonal regression analysis of available September and October flows at SK100A versus concurrent flows at SK100B. The resulting hydrograph for SK100A is presented on Figure 5, and a monthly discharge summary is provided in Table 9. The hydrograph includes estimated flows for the period after the gage was discontinued in autumn 2007, based on the seasonal regression analyses against SK100B, but these estimated flows are not included in the monthly discharge summary.

The hydrograph shows the characteristic rises in flow during the spring snowmelt and autumn rainstorm seasons, and the intervening low flow periods during the summer and winter. The SK100A hydrograph matches the prorated hydrograph for SK100B reasonably well, except that SK100A has slightly higher unit runoff in low-flow seasons and slightly lower unit runoff during high-flow periods as would be expected given the storage effects in the lower part of the SK basin between SK100A and SK100B. These patterns are also illustrated in the seasonal regression plots. Unit discharge in the winter months was consistently greater at SK100A than at SK100B, as shown by the position of the instantaneous discharge points that lie above the line of equal unit discharge on Figure 116. However, unit discharge was usually lower at SK100A than at SK100B in the spring, summer, and autumn months, as shown on Figure 118, except during the lowest flow conditions in each season.

6.1.1.2 SK100B

Station SK100B is operated by the USGS. In the USGS system, it is referred to as Station 15302200 (Koktuli River). SK100B is located near the point where the SK emerges from the moderately confined middle part of the watershed onto a wide, flat plain, approximately 14 river miles upstream of SK100A. At this point, the river drains an area of approximately 69 square miles. The river at SK100B cuts through an old cross-valley moraine that separates the unconfined valley downstream from the moderately confined valley upstream. The narrow valley cross-section in the moraine notch near SK100B plays a role in forcing groundwater to the surface as it flows down the SK valley. The channel habitat features in this reach are dominated by riffles and pools, and the instream sediments are dominated by coarse gravel and small cobbles (Photos 4 and 5). The banks are covered in grasses and brush with high hydraulic roughness characteristics (i.e. high values of Manning's coefficient, n, relative to the values found in the adjacent stream channel). The vegetation impedes overbank flow during flood conditions. The extent of brush overhanging into the channel is negligible relative to channel width.

The USGS has developed two stage-discharge rating curves for SK100B based on 33 measurements, including 21 measurements taken in the typical non-freeze months (May through October) from 2004 through 2008. The rating curve shift was applied starting in June 2006, when the gage was moved 30 to 40 feet upstream (Smith, pers. comm. 2008). The stage-discharge measurements are presented in Table 10 and the rating curves are shown on Figures 6 and 7. The average rating curve error is 4.9 percent.

USGS rating curves are provided in the form of a table of stage-discharge points. The SK100B stage-discharge points describe a straight line in log-log space and thus can be represented by a single power function of the form:

$$Q = C(h - a)^N$$

The *C* and *N* values differ substantially between the two rating curves because they describe two different cross-sections. For the first rating curve, the *C* value of 24.3 is only 0.2 times the bankfull width (115 feet), and the *N* value of 3.17 is higher than expected for a rectangular to parabolic channel. For the second rating curve, the *C* value of 66.5 is still only 0.6 times the bankfull width, but the *N* value of 2.16 is more representative of a parabolic channel. The channel at SK100B has a much greater width-depth ratio than the other gaging station sites, as shown in Table 1, so it is not surprising that its stage-discharge relationship has different characteristics than most of the other gaging stations.

The USGS applied its stage-discharge rating curves to the recorded stage data to develop continuous hydrographs for non-freeze periods. Winter flows were estimated using instantaneous discharge measurements in conjunction with meteorological data and drawing on general understanding of hydrograph recession patterns during winter low-flow conditions. The resulting hydrograph for SK100B is presented on Figure 8, and a monthly discharge summary is provided in Table 11.

The hydrograph shows the characteristic rises in flow during the spring snowmelt and autumn rainstorm seasons, and the intervening low flow periods during the summer and winter. The SK100B hydrograph is compared to the prorated hydrograph from NK100A. The two hydrographs are similar in general, indicating the overall hydrologic similarity of the NK and SK watersheds, but significant differences occur for short periods of time.

6.1.1.3 SK100B1

Station SK100B1 is located midway up the SK watershed in an upwelling or gaining reach, approximately 17 miles upstream of SK100A. At this point, the river drains an area of around 54 square miles. The river at SK100B1 is similar to, but slightly less sinuous than, the downstream SK reaches as it meanders through well-developed floodplains and low terraces (Photos 6 and 7). The channel habitat features in this reach are dominated by riffles and runs, and the instream sediments are dominated by medium gravel. The stage record indicates that high flows have exceeded bankfull stage during the study period. The gage control cross-section is shown on Figure 9, with bankfull stage and maximum recorded stage indicated. The banks are covered in grasses and brush, which have high hydraulic roughness characteristics (i.e. high values of Manning's coefficient, n, relative to the values found in the adjacent stream channel). The vegetation impedes overbank flow during flood conditions. The extent of brush overhanging into the channel is negligible relative to channel width.

SK100B1 was installed in the autumn of 2005, more than a year later than most of the other SK stations. It was intended to operate year-round in the unfrozen upwelling reach, but ice effects still limited the usefulness of the recorded winter data. Therefore, the stage record has only been used to estimate discharge starting in late April 2006, at which time the gage was re-installed following ice damage. Station SK100B1 was discontinued in late 2007, although instantaneous discharge measurements continued to be collected in 2008.

Three stage-discharge rating curves were developed for SK100B1, including one for late 2005 that was not used to compute discharge, based on 16 measurements taken in non-freeze months (May through October) from 2005 through 2007. Rating curve shifts were applied starting in the spring of 2006 and spring of 2007. The stage-discharge measurements are presented in Table 12, and the rating curves are shown on Figures 10 and 11. The average rating curve error is 3.9 percent, which is considered good given that the error associated with individual discharge measurements can be up to 15 percent.

Each rating curve for SK100B1 consists of a single function over all ranges of stage. The rating curve parameters lie within the expected ranges based on channel geometry. The *C* and *N* values are similar for each rating curve, with adjustments to *a* representing the main difference. The *C* values of 55 to 58 equate to approximately 1.0 times the bankfull channel width (57 feet). The *N* values of 2.15 to 2.18 approximate the values for a parabolic channel, which is appropriate for this site. Rating curve extrapolation above bankfull stage at SK100B1 is considered to be reasonably accurate because the upper end of the curves are not expected to be influenced substantially by floodplain conveyance or overhanging vegetation and the rating curve functions are in general agreement with hydraulic theory.

The stage-discharge rating curves were applied to the recorded stage data to develop continuous hydrographs for non-freeze periods. Winter flows were estimated using the regression analysis between instantaneous discharge measurements at SK100B1 and corresponding daily discharge estimates developed by the USGS for SK100B. There were no data gaps during non-freeze periods at SK100B1. The resulting hydrograph for SK100B1 is presented on Figure 12, and a monthly discharge summary is provided in Table 13. The hydrograph includes estimated flows for the periods prior to gage re-installation in April 2006 and after gage discontinuation in autumn 2007, based on the seasonal regression analyses against SK100B. Most of these flows are not included in the monthly summary, with the exception of estimated flows from October 2005 through April 2006, which were included to complete the 2006 water year (October 2005 through September 2006).

The hydrograph shows the characteristic rises in flow during the spring snowmelt and autumn rainstorm seasons, and the intervening low flow periods during the summer and winter. The SK100B1 hydrograph matches the prorated hydrograph for SK100B very closely, except that SK100B has slightly higher unit runoff because of upwelling groundwater, which bypasses SK100B1 and reaches the surface upstream of SK100B. This pattern is also illustrated in the seasonal regression plots. Unit discharge was lower at SK100B1 than at SK100B in most seasons, as shown by the position of the instantaneous discharge points that lie below the line of equal unit discharge on Figure 116 (winter) and Figure 118 (summer and autumn). Only on the highest flow dates in the spring (May and June, Figure 118) did SK100B1 record slightly higher unit discharge than SK100B, although absolute discharges at SK100B1 were still slightly lower than at SK100B.

6.1.1.4 SK100C

Station SK100C is located approximately 20 miles upstream of SK100A, just upstream of the Tributary 1.190 confluence and downstream of a large wetland complex. At the SK100C gaging station, the river drains an area of approximately 38 square miles. The river at SK100C is slightly entrenched as it meanders through well-developed floodplains, low terraces, and glacial outwash deposits (Photo 8). The stream channel goes dry during winter and summer low-flow periods when upstream and downstream reaches are still flowing, indicating local losses of surface flow to groundwater (Photo 9). The channel habitat features in this reach are dominated by riffles and pools, and the instream sediments are dominated by coarse gravel. The channel is relatively narrow and entrenched. The stage record indicates that high flows have only exceeded bankfull stage by 0.2 feet during the study period, although greater exceedences have been observed during the breakup period prior to gage installation. Gage installation in the spring has often been hampered by deeply drifted snow and deep water, sometimes impounded by ice.

The gage control cross-section is shown on Figure 13, with bankfull stage and maximum recorded stage indicated. The banks are covered in grasses and brush, which have high hydraulic roughness characteristics (i.e. high values of Manning’s coefficient, n, relative to the values found in the adjacent stream channel). The vegetation would impede overbank flow should flood conditions occur. Brush overhangs into the channel and likely affects channel hydraulics at flows well below bankfull.

One stage-discharge rating curve was developed for SK100C based on 21 measurements taken in non-freeze months (May through October) from 2004 through 2008. Five non-freeze measurements of zero discharge (dry channel) could not be used for rating curve development. The stage-discharge measurements are presented in Table 14 and the rating curve is shown on Figures 14 and 15. The average rating curve error is 7.8 percent, which is considered good given that the error associated with individual discharge measurements can be up to 15 percent.

The SK100C rating curve consists of two functions with a transition at a stage of 93.57 feet. The values of *C* and *N* increase and decrease, respectively, above the transition stage, likely due to the influence of overhanging vegetation and stage-dependent changes to the effective channel geometry. The value of *C* (24.1) for the low-flow rating curve function approximates 1.0 times the wetted width under low-flow conditions, and the value of *N* (2.15) approximates the value for a parabolic channel, which is appropriate for low and moderate flows at this site. The value of *C* (28.5) for the high-flow rating curve function approximates 1.0 times the bankfull channel width, considering the narrower effective width because of overhanging vegetation. The value of *N* (1.86) for the high-flow rating curve lies between the values for rectangular and parabolic channels, which are appropriate for the effective channel shape resulting from overhanging vegetation. Therefore, extrapolation of the high-flow rating curve function to bankfull stage is considered to be reasonably accurate because the form of the curve accounts for the influence of overhanging vegetation and is in general agreement with hydraulic theory.

The stage-discharge rating curve was applied to the recorded stage data to develop continuous hydrographs for non-freeze periods. Winter flows were estimated using the regression analysis between instantaneous discharge measurements at SK100C and corresponding daily discharge estimates developed by the USGS for SK100B. Winter flows were estimated to cease at SK100C whenever flows at SK100B dropped below 50 cubic feet per second (cfs), as shown on Figure 116. Discharge was estimated at SK100C for a non-freeze data gap in late summer 2005 (datalogger malfunction) using the seasonal regression analysis of available August and September flows at SK100C versus concurrent flows at SK100B. In that analysis, flows were estimated to cease at SK100C whenever flows at SK100B dropped below 60 cfs. The resulting hydrograph for SK100C is presented on Figure 16, and a monthly discharge summary is provided in Table 15.

The hydrograph shows the characteristic rises in flow during the spring snowmelt and autumn rainstorm seasons, and the intervening low flow periods during the summer and winter. Flows typically ceased for 1 to 3 months each winter. Flows ceased more briefly during the shorter summer low-flow season. The pattern of the SK100C hydrograph mirrors the prorated hydrograph for SK100B, but SK100C has lower unit runoff throughout the year because of the passage of groundwater beneath SK100C that emerges to the surface further downstream. The seasonal regression plots shown on Figure 116 (winter) and Figure 118 (spring through autumn) indicate that the quantity of flow that bypasses SK100C is flow-dependent (i.e., it increases with overall streamflow). This is illustrated by the slope of the regression line, which is less than the slope of the line of equal unit discharge.

6.1.1.5 SK100F

Station SK100F is located approximately 29 miles upstream of SK100A, just below the outlet of Frying Pan Lake, and drains an area of approximately 12 square miles. The river at SK100F flows in a narrow valley between hillslopes of moraine deposits and weathered bedrock (Photos 10 and 11). The channel habitat features in this reach are riffles and runs, and a large pool. The instream sediments are dominated by very coarse angular gravels and some cobbles. The channel is entrenched and the stage record indicates that high flows have not exceeded bankfull stage during the study period. The gage control cross-section is shown on Figure 17, with bankfull stage and maximum recorded stage indicated. The banks are covered in grasses and brush, which have high hydraulic roughness characteristics (i.e. high values of Manning’s coefficient, n, relative to the values found in the adjacent stream channel). The vegetation would impede overbank flow should flood conditions occur. Brush overhangs into the channel, but the extent of overhang is not significant relative to channel width.

Station SK100F was discontinued in late 2007, although instantaneous discharge measurements continued to be collected in 2008. One stage-discharge rating curve was developed for SK100F based on 20 measurements taken in non-freeze months (May through October) from 2004 through 2007. Two non-freeze measurements taken in the autumn of 2007 were not used for rating curve development because downstream beaver activity had caused elevated stage levels at the gage site. The rating curve does not fit through the error bars of all of the other 20 points, and it is suspected that beaver activity may have been affecting stage throughout the gage record, although to variable and less severe degrees than late 2007. The stage-discharge measurements are presented in Table 16, and the rating curve is shown on Figures 18 and 19. The average rating curve error is 21.3 percent, which is poor compared to most other gages, which typically have errors less than 10 percent.

The SK100F rating curve consists of a single function over all ranges of stage. No sequential pattern could be identified in the scatter of the stage-discharge points that would justify the development of multiple rating curves. The value of *C* (41.4) is less than 1.0 times bankfull width (57 feet), which is to be expected given that flows rarely approach bankfull and that the stage-discharge relation is governed not only by channel friction but also potentially by downstream beaver dams. The value of *N* (2.17) is representative of a parabolic channel that is appropriate for this site. Rating curve extrapolation to bankfull stage at SK100F is considered to be relatively inaccurate because of the variability in downstream control.

The stage-discharge rating curves were applied to the recorded stage data to develop continuous hydrographs for non-freeze periods. Winter flows were estimated using the regression analysis between instantaneous discharge measurements at SK100F and corresponding daily discharge estimates developed by the USGS for SK100B. Discharge was estimated at SK100F for the non-freeze data gap in autumn 2007, when beaver-related backwater effects were most severe using the seasonal regression analysis of available September and October flows at SK100F versus concurrent flows at SK100B. The resulting hydrograph for SK100F is presented on Figure 20, and a monthly discharge summary is provided in Table 17. The hydrograph includes estimated flows for the period after the gage was discontinued in autumn 2007, based on the seasonal regression analyses against SK100B, but these estimated flows are not included in the monthly discharge summary.

The hydrograph shows the characteristic rises in flow during the spring snowmelt and autumn rainstorm seasons, and the intervening low flow periods during the summer and winter. The SK100F hydrograph matches the prorated hydrograph for SK100B reasonably well, except that SK100F has slightly lower unit runoff throughout the year, indicative of groundwater flows bypassing the gage site. This pattern is also illustrated in the seasonal regression plots. Unit discharge was consistently lower at SK100F than at SK100B, as shown by the position of the instantaneous discharge points that lie below the line of equal unit discharge on Figure 116 (winter) and Figure 118 (spring through autumn).

6.1.1.6 SK100G

Station SK100G is located directly upstream of Frying Pan Lake, approximately 32 miles upstream of SK100A. The river at SK100G drains an area of approximately 5 square miles and winds through a flat, poorly-drained basin underlain by glacial lake deposits (Photos 12 and 13). The channel habitat features in this reach are dominated by riffles and pools, and the instream sediments are dominated by fine gravel, coarse sand, and organics. The stage record indicates that high flows have exceeded bankfull stage during the study period. The gage control cross-section is shown on Figure 21, with bankfull stage and maximum recorded stage indicated. The banks are covered mostly with grasses and some brush, which have high hydraulic roughness characteristics (i.e. high values of Manning’s coefficient, n, relative to the values found in the adjacent stream channel). The vegetation impedes overbank flow during flood conditions. The extent of vegetation overhang is not significant relative to channel width. The very low gradient of the channel and proximity to Frying Pan Lake make the stage-discharge relationship sensitive to changes in downstream lake level or local changes in channel geometry.

Station SK100G was discontinued in late 2007, although instantaneous discharge measurements continued to be collected in 2008. Two stage-discharge rating curves were developed for SK100G based on 21 measurements taken in non-freeze months (May through October) from 2004 through 2007. The rating curve shift was applied starting in July 2007, coincident with observations of bank sloughing immediately downstream of the gage site. One non-freeze discharge measurement was not used for rating curve development (May 7, 2005). Channel width was not measured using standard equipment, and the resulting width measurement was anomalously low. The stage-discharge measurements are presented in Table 18 and the rating curves are shown on Figures 22 and 23. The average rating curve error is 15.4 percent, which is poor compared to most other gages, which typically have errors less than 10 percent. The likely explanation is variable lake level during the rising and falling limbs of rainstorm and snowmelt events, which would be difficult to account for in rating curve development.

The rating curve parameters lie within the expected ranges based on channel geometry. The *C* values (21.0 and 24.0) equate to approximately 1.3 to 1.5 times bankfull channel width (16 feet). The *N* values (1.55 and 1.78) are approximately representative of a rectangular channel, which is appropriate for this site with its steep banks of cohesive fine-textured sediment. The shifted rating curve following bank sloughing features higher *a* and *N* values and a lower *C* value than the original rating curve – all consistent with a narrower, shallower, less rectangular channel following bank collapse. Rating curve extrapolation above bankfull stage at SK100G would have been considered reasonably accurate given the form of the rating curves and the nature of the bank vegetation, but the variability in downstream lake levels make estimates of high discharges uncertain.

The stage-discharge rating curves were applied to the recorded stage data to develop continuous hydrographs for non-freeze periods. Winter flows were estimated using the regression analysis between instantaneous discharge measurements at SK100G and corresponding daily discharge estimates developed by the USGS for SK100B. The resulting hydrograph for SK100G is presented on Figure 24, and a monthly discharge summary is provided in Table 19. The hydrograph includes estimated flows for the period after the gage was discontinued in autumn 2007, based on the seasonal regression analyses against SK100B, but these estimated flows are not included in the monthly discharge summary.

The hydrograph shows the characteristic rises in flow during the spring snowmelt and autumn rainstorm seasons, and the intervening low flow periods during the summer and winter. The SK100G hydrograph matches the prorated hydrograph for SK100B reasonably well, except that SK100G has a shorter snowmelt freshet period because of the lower elevation of its drainage basin relative to some of the SK tributaries that enter the main channel further downstream. Apart from the falling limb of the snowmelt freshet, unit runoff is similar at SK100G and SK100B. This pattern is also illustrated in the seasonal regression plots shown on Figure 116 (winter) and Figure 119 (spring through autumn). Unit discharge was similar at SK100G and SK100B in all seasons except spring, when SK100G recorded lower unit discharge than SK100B.

6.1.1.7 SK119A

Station SK119A is located on SK tributary 1.190, the mouth of which is located approximately 21 miles upstream of SK100A. The creek at the gaging station drains approximately 11 square miles near the outlet of a relatively steep, narrow tributary valley. At the gage site, the creek flows within a narrow alluvial plain bounded by low terraces and colluvial hillslopes. The channel habitat features in this reach are riffles and runs, and the instream sediments are dominated by coarse gravels and cobbles. The stage record indicates that high flows have exceeded bankfull stage during the study period. The gage control cross-section is shown on Figure 25, with bankfull stage and maximum recorded stage indicated. The banks are primarily covered in brush, including 4- to 6-inch diameter willow, which overhangs into the stream channel (Photos 14 and 15). The brush has high hydraulic roughness characteristics (i.e. high values of Manning’s coefficient, n, relative to the values found in the adjacent stream channel) and impedes overbank flow during floods. Vegetation overhang potentially reduces *N* values in the rating curve equation at stages that exceed the bankfull condition.

Three stage-discharge rating curves were developed for SK119A based on 21 measurements taken in non-freeze months (May through October) from 2004 through 2008. The rating curve shifts were applied starting in the spring of 2006 and spring of 2007. The stage-discharge measurements are presented in Table 20 and the rating curves are shown on Figures 26 and 27. The average rating curve error is 4.8 percent, which is considered good given that the error associated with individual discharge measurements can be up to 15 percent.

The rating curves applicable from 2004 through 2005 and in 2006 consist of compound curves consisting of two functions, while the 2007 through 2008 curve is a single function. The three curves differ in their values of *a*, *C*, and *N*, although all three constants consistently decrease with time. The values of *C* and *N* lie within the expected ranges based on channel geometry. The values of *C* (54.0 to 45.4) equate to approximately 1.8 to 1.5 times bankfull channel width (30 feet). The values of *N* (2.36 to 2.05) are approximately representative of a parabolic channel, which is appropriate for this site. Recorded stage peaks have exceeded bankfull stage by up to 2.0 feet during the study period. The overbank flows are mostly constrained to a narrow vegetated bench along the left bank, which is comparable in width to the channel. The maximum estimated discharge, based on rating curve extrapolation with no adjustments above bankfull stage, is 5.7 times greater than the estimated bankfull discharge (as compared to ratios of 1.0 to 2.5 times at most other gages). This is due in part to the flashy storm hydrographs in the small upland watershed, which are difficult to capture in a manual measurement program, but it is also likely that the peak discharges estimated by rating curve extrapolation are over-estimated due to the unaccounted effects of vegetation overhang.

The stage-discharge rating curves were applied to the recorded stage data to develop continuous hydrographs for non-freeze periods. Winter flows were estimated using the regression analysis between instantaneous discharge measurements at SK119A and corresponding daily discharge estimates developed by the USGS for SK100B. Discharge was estimated at SK119A for non-freeze data gaps because of gage disturbance in October 2004, and May and June 2006, using seasonal regression analyses of available flows at SK119A versus concurrent flows at SK100B. The resulting hydrograph for SK119A is presented on Figure 28, and a monthly discharge summary is provided in Table 21.

The hydrograph shows the characteristic rises in flow during the spring snowmelt and autumn rainstorm seasons, and the intervening low flow periods during the summer and winter. The SK119A hydrograph features higher unit runoff than SK100B throughout the non-freeze periods, with much greater peak daily flows during spring snowmelt and autumn rainstorms. This is to be expected given the higher elevation and steep topography of the SK119A subcatchment, but the problem with estimation of high flows at SK119A must also be kept in mind. Unit runoff at SK119A during summer and winter baseflow periods is slightly lower at SK119A than SK100B. These patterns are also illustrated in the seasonal regression plots. Unit discharge was consistently lower at SK119A than at SK100B in the winter months, as shown on Figure 116. Unit discharge was greater at SK119A than at SK100B in the non-freeze periods, especially in May and June, as shown on Figure 119.

6.1.1.8 SK124A

Station SK124A is located on SK tributary 1.240, which lies to the east of tributary 1.190. The mouth of the tributary is located approximately 25 miles upstream of SK100A. The creek at the gaging station drains approximately 9 square miles below the outlet of a relatively steep, narrow tributary valley. At the gage site, the creek flows across gravelly to sandy outwash and moraine deposits in the broad central part of the main SK valley. The channel habitat features in this reach are riffles and pools, and the instream sediments are dominated by coarse gravels. The stage record indicates that high flows have exceeded bankfull stage during the study period. The gage control cross-section is shown on Figure 29, with bankfull stage and maximum recorded stage indicated. The banks are primarily covered in brush that overhangs the stream above bankfull conditions (Photos 16 and 17). The brush has high hydraulic roughness characteristics (i.e. high values of Manning's coefficient, n, relative to the values found in the adjacent stream channel) and impedes overbank flow during floods. Vegetation overhang potentially reduces *N* values in the rating curve equation at stages that exceed the bankfull condition.

SK124A was installed in June 2005, nearly 1 year later than most of the other SK stations. Four stage-discharge rating curves were developed for SK124A based on 19 measurements taken in non-freeze months (May through October) from 2005 through 2008. The rating curve shifts were applied starting in the spring of 2006, the spring of 2007, and the spring of 2008. The stage-discharge measurements are presented in Table 22, and the rating curves are shown on Figures 30 and 31. The average rating curve error is 7.2 percent, which is considered good given that the error associated with individual discharge measurements can be up to 15 percent.

Each rating curve for SK124A consists of a single function over all ranges of stage. The four curves differ in their values of *a* and *C*, while *N* is constant for all four curves. The values of *C* and *N* lie within the expected ranges based on channel geometry. The values of *C* range from 22.3 to 28.0, which equates to approximately 1.5 to 1.9 times bankfull channel width (15 feet). The value of *N* (2.00) is representative of a rectangular to parabolic channel, which is appropriate for this site. Rating curve extrapolation up to bankfull discharge at SK124A relies on the hydraulic reasonableness of the curve parameters because the highest directly measured discharge is less than 50 percent of the bankfull discharge estimate (based on rating curve extrapolation). Recorded peak stage has exceeded bankfull stage by 1.0 feet, but rating curve extrapolation above bankfull stage is somewhat uncertain because the value of *N* should probably be reduced to account for overhanging vegetation.

The stage-discharge rating curves were applied to the recorded stage data to develop continuous hydrographs for non-freeze periods. Winter flows were estimated using the regression analysis between instantaneous discharge measurements at SK124A and corresponding daily discharge estimates developed by the USGS for SK100B. The resulting hydrograph for SK124A is presented on Figure 32, and a monthly discharge summary is provided in Table 23. The hydrograph includes estimated flows for the period prior to gage installation in June 2005, based on the seasonal regression analyses against SK100B, and these flows are included in the monthly discharge summary from October 2004 onward to complete the record for the 2005 water year.

The hydrograph shows the characteristic rises in flow during the spring snowmelt and autumn rainstorm seasons, and the intervening low flow periods during the summer and winter. The SK124A hydrograph features higher unit runoff than SK100B only during peak events in non-freeze periods and lower unit runoff than SK100B during moderate and baseflow periods throughout the year. These patterns are also illustrated in the seasonal regression plots. Unit discharge was consistently lower at SK124A than at SK100B in the winter months, as shown on Figure 116. Unit discharge was also lower at SK124A than at SK100B in the non-freeze periods, except during the highest flows in each season, as shown on Figure 119.

The higher peak flows in SK124A are to be expected given the higher elevation and steep topography of the SK124A subcatchment, but the problem with estimation of high flows at SK124A must also be kept in mind. The lower unit runoff throughout most other periods is explained by the lack of groundwater storage in the upland subcatchment of SK tributary 1.240 and by surface flow losses to groundwater in the lower reaches of the tributary as the channel crosses the deep valley fills upstream of SK100C. Figure 119 also presents a regression analysis between SK124A and SK119A indicating the consistently lower unit runoff in SK124A, presumably because of surface flow losses in the lower reaches of tributary 1.240.

6.1.2 North Fork Koktuli River

The NK drains the northern portion of the headwater areas of the Koktuli River catchment. The lowest point in the watershed is at the confluence with the SK at elevation 580 feet, and the highest point is on the southern ridgeline of the watershed divide at elevation 2,600 feet. In the winter, winds blow predominantly from the southeast, resulting in large snow accumulations on leeward slopes along the southern side of the catchment. The hydrology of the river is characterized by two annual high-flow seasons. The first occurs in response to spring snowmelt in May and June. The second occurs in response to frontal rainfall during the late summer and autumn (typically August through November). The relatively gentle topography, deep deposits of surficial material, and presence of headwater lakes in the catchment result in moderately large winter baseflows in the main channel. Tributary channels draining steep upland slopes with shallower surficial deposits than the main valley are generally characterized by more rapid snowmelt and rainfall runoff and lower unit baseflows than the main channel.

Station NK100A (operated by USGS) is the most downstream gaging station on the NK, located approximately 3 miles upstream from the confluence with the SK. At this point, the NK drains an area of approximately 106 square miles with a mean basin elevation of approximately 1,280 feet and an average basin slope of 9.2 percent. Five other gaging stations are located further upstream within the NK watershed. NK100A1, NK100B, and NK100C are located on the main NK channel, and NK119A and NK119B are located on tributaries. The two gaged tributaries drain the upland area along the south side of the NK valley, to the west of the deposit location. The drainage areas and basin characteristics of each gaging station are presented in Table 1.

The lower portion of the NK watershed, in the vicinity of NK100A, consists of a broad, unconfined plain consisting of well-developed floodplains, associated low terraces, and older glaciofluvial terrace deposits. Further upstream in the middle part of the watershed, the NK valley narrows to a width of around 0.5 miles where it is bounded by gently sloping hills and ridges. The main channel of the NK generally flows through floodplains and low terraces within this part of the watershed, but locally impinges on higher terraces or hillslopes, creating bluffs. Lakes and wetlands are located in undulating headwater areas in the northwestern part of the watershed.

6.1.2.1 NK100A

Station NK100A is operated by the USGS. In the USGS system, it is referred to as Station 15302250 (North Fork Koktuli River). NK100A is located approximately 3 miles upstream of the confluence of the NK and SK. At this point, the river drains an area of approximately 106 square miles. NK100A is at a location where the river meanders through well-developed floodplains and associated low terraces. The channel habitat features in this reach are dominated by riffles and pools, and the instream sediments are dominated by coarse gravel and small cobbles. The banks are covered in brush (Photos 18 and 19), which has high hydraulic roughness characteristics (i.e. high values of Manning’s coefficient, n, relative to the values found in the adjacent stream channel). The vegetation impedes overbank flow during flood conditions. The extent of brush overhanging into the channel is negligible relative to channel width.

The USGS has developed one stage-discharge rating curve for NK100A based on 29 measurements, including 21 measurements taken in the typical non-freeze months (May through October) from 2004 through 2008. Seven of the eight discharge measurements taken during the non-freeze months of 2007 and 2008 plot above the rating curve, but a rating curve shift has not been applied. The stage-discharge measurements are presented in Table 24, and the rating curves are shown on Figures 33 and 34. The average rating curve error is 11.1 percent. The average rating curve error for 2004 through 2006 is 6.0 percent, and for 2007 and 2008 is 19.6 percent.

USGS rating curves are provided in the form of a table of stage-discharge points. The NK100A stage-discharge points describe a straight line in log-log space and thus can be represented by a single power function of the form:

$$Q = C(h-a)^N$$

The *C* and *N* values for the NK100A rating lie within the expected ranges based on channel geometry. The value of *C* (208) is 2.8 times bankfull width (75 feet). The value of *N* (1.80) is representative of a rectangular to parabolic channel, which is appropriate for this site.

The USGS applied its stage-discharge rating curve to the recorded stage data to develop continuous hydrographs for non-freeze periods. Winter flows were estimated using instantaneous discharge measurements in conjunction with meteorological data and drawing on general understanding of hydrograph recession patterns during winter low-flow conditions. The resulting hydrograph for NK100A is presented on Figure 35, and a monthly discharge summary is provided in Table 25.

The hydrograph shows the characteristic rises in flow during the spring snowmelt and autumn rainstorm seasons, and the intervening low flow periods during the summer and winter. The NK100A hydrograph is compared to the prorated hydrograph from SK100B. The two hydrographs are similar in general, indicating the overall hydrologic similarity of the NK and SK watersheds, but considerable differences occur for short periods of time.

6.1.2.2 NK100A1

Station NK100A1 is located approximately 4 miles upstream of NK100A. At this station, the river drains an area of approximately 85 square miles. Similar to NK100A, NK100A1 is at a location where the river meanders through well-developed floodplains and associated low terraces. The gage control cross-section is shown on Figure 36, with bankfull stage and maximum recorded stage indicated. The maximum recorded stage has exceeded bankfull by 0.9 feet. The banks are covered in grasses and brush (Photos 20 and 21), which have high hydraulic roughness characteristics (i.e. high values of Manning’s coefficient, n, relative to the values found in the adjacent stream channel). The vegetation impedes overbank flow during flood conditions. The extent of brush overhanging into the channel is negligible relative to channel width.

Station NK100A1 was established in May 2007, almost 3 years after the initial batch of gaging stations. One stage-discharge rating curve was developed for NK100A1 based on nine measurements taken in non-freeze months (May through October) from 2007 through 2008. The stage-discharge measurements are presented in Table 26, and the rating curve is shown on Figures 37 and 38. The average rating curve error is 4.2 percent, which is considered good given that the error associated with individual discharge measurements can be up to 15 percent.

The NK100A1 rating curve consists of a single function over all ranges of stage. The values of *C* and *N* lie within the expected ranges based on channel geometry. The value of *C* (80.0) is 0.9 times bankfull width (87 feet). The value of *N* (2.19) is representative of a roughly parabolic channel, which is appropriate for this site. Rating curve extrapolation up to and beyond bankfull stage at NK100A1 is considered to be reasonably accurate because the upper end of the curve is not expected to be influenced substantially by floodplain conveyance or overhanging vegetation, and the rating curve function is in general agreement with hydraulic theory.

The stage-discharge rating curve was applied to the recorded stage data to develop a continuous hydrograph for non-freeze periods. Winter flows were estimated using the regression analysis between instantaneous discharge measurements at NK100A1 and corresponding daily discharge estimates developed by the USGS for NK100A. Discharge was estimated at NK100A1 for two periods of gage disturbance in spring 2008 and autumn 2008 using the seasonal regression analyses of available flows at

NK100A1 versus concurrent flows at NK100A. The resulting hydrograph for NK100A1 is presented on Figure 39, and a monthly discharge summary is provided in Table 27. The hydrograph includes estimated flows for the period prior to gage installation in May 2007, based on the seasonal regression analyses against NK100A; these flows are included in the monthly discharge summary from October 2006 onward to complete the record for the 2006 through 2007 water year.

The hydrograph shows the characteristic rises in flow during the spring snowmelt and autumn rainstorm seasons, and the intervening low flow periods during the summer and winter. The NK100A1 hydrograph closely matches the prorated hydrograph for NK100A. Unit discharge at the two stations is similar in all seasons, as shown by the proximity of concurrent flows to the line of equal unit discharge on Figure 116 (winter) and Figure 120 (spring through autumn).

6.1.2.3 NK100B

Station NK100B is located in the upper reaches of the NK approximately 16 miles upstream of NK100A and just downstream of the confluence of NK tributary 1.190. At this station, the river drains an area of approximately 37 square miles, including a large complex of lakes and wetlands in the upper NK basin and the upland terrain of tributary 1.190. The river at NK100B flows through glacial outwash and drift deposits. The gage control cross-section is shown on Figure 40, with bankfull stage and maximum recorded stage indicated. The maximum recorded stage has exceeded bankfull by 0.7 feet. The banks are covered in grasses and brush (Photos 22 and 23), which have high hydraulic roughness characteristics (i.e. high values of Manning’s coefficient, n, relative to the values found in the adjacent stream channel). The vegetation impedes overbank flow during flood conditions. The extent of brush overhanging into the channel is negligible relative to channel width.

Station NK100B was established in May 2007, almost 3 years after the initial batch of gaging stations. One stage-discharge rating curve was developed for NK100B based on nine measurements taken in non-freeze months (May through October) from 2007 through 2008. The stage-discharge measurements are presented in Table 28, and the rating curve is shown on Figures 41 and 42. The average rating curve error is 2.7 percent, which is considered good given that the error associated with individual discharge measurements can be up to 15 percent.

The NK100B rating curve consists of a single function over all ranges of stage. The values of *C* and *N* lie within the expected ranges based on channel geometry. The value of *C* (50.0) is 1.0 times bankfull width (51 feet). The value of *N* (2.47) is representative of a parabolic channel, which is appropriate for this site. Rating curve extrapolation up to and beyond bankfull stage at NK100B is considered to be reasonably accurate because the upper end of the curve is not expected to be influenced substantially by floodplain conveyance or overhanging vegetation, and the rating curve function is in general agreement with hydraulic theory. However, the maximum discharge estimated from the stage record is 4.2 times greater than the largest IQ measurement used for rating curve development, so the extent of extrapolation causes some concern about the accuracy of high flows.

The stage-discharge rating curves were applied to the recorded stage data to develop continuous hydrographs for non-freeze periods. Winter flows were estimated using the regression analysis between instantaneous discharge measurements at NK100B and corresponding daily discharge estimates developed by the USGS for NK100A. Discharge was estimated at NK100B for a period of gage disturbance in May 2008 using the seasonal regression analysis of available flows at NK100B versus concurrent flows at NK100A. The resulting hydrograph for NK100B is presented on Figure 43, and a monthly discharge summary is provided in Table 29. The hydrograph includes estimated flows for the period prior to gage installation in May 2007, based on the seasonal regression analyses against NK100A; these flows are included in the monthly discharge summary from October 2006 onward to complete the record for the 2006 through 2007 water year.

The hydrograph shows the characteristic rises in flow during the spring snowmelt and autumn rainstorm seasons, and the intervening low flow periods during the summer and winter. The NK100B hydrograph closely matches the prorated hydrograph for NK100A. Unit discharge at the two stations is similar in all seasons, as shown by the proximity of concurrent flows to the line of equal unit discharge on Figure 116 (winter) and Figure 120 (spring through autumn).

6.1.2.4 NK100C

Station NK100C is located in the upper reaches of the NK approximately 17 miles upstream of NK100A and just upstream of the confluence of Tributary 1.190. At this station, the river drains an area of approximately 24 square miles, including a large complex of lakes and wetlands. The river at NK100C flows through a narrow valley cut through glacial outwash and drift deposits. The channel habitat features in this reach are dominated by riffles and runs, and the instream sediments are dominated by coarse gravel. Flows at this site are buffered by upstream lake and wetland storage, and the maximum recorded stage has only exceeded bankfull by 0.06 feet. The gage control cross-section is shown on Figure 44, with bankfull stage and maximum recorded stage indicated. The banks are covered in grasses and brush (Photos 24 and 25), which have high hydraulic roughness characteristics (i.e. high values of Manning's coefficient, n, relative to the values found in the adjacent stream channel). The vegetation impedes overbank flow during flood conditions. The extent of brush overhanging into the channel is negligible relative to channel width.

One stage-discharge rating curve was developed for NK100C based on 20 measurements taken in non-freeze months (May through October) from 2004 through 2008. Two non-freeze measurements taken in May 2006 were not used due their anomalous plotting position, which is likely explained by the rapidly rising stage during discharge measurement. Two other non-freeze measurements taken in the autumn of 2007 were not used for rating curve development because downstream beaver activity had caused elevated stage levels at the gage site. Two other discharge measurements, taken on October 28, 2005, and October 19, 2008, were affected by ice prior to complete freeze-up and were not used for rating curve development.

The single rating curve could not be fitted through the error bars of all of the other 20 points, particularly in the lower flow range, and it is suspected that downstream beaver activity may have affected low-flow stage at other times in the gage record, although to variable and less severe degrees than late 2007. The only other observation of beaver activity recorded by field crews was in August 2006, although that stage-discharge point fits the rating curve well, indicating that beaver dams may have provided downstream control throughout the period of record, with changes in control because of phases of dam construction and failure. The stage-discharge measurements are presented in Table 30, and the rating curve is shown on Figures 45 and 46. The average rating curve error is 7.4 percent, which is considered good given that the error associated with individual discharge measurements can be up to 15 percent, and considering the potential beaver problems described above.

The NK100C rating curve consists of a single function over all ranges of stage. The values of *C* and *N* lie within the expected ranges based on channel geometry. The value of *C* (90.0) is 2.4 times bankfull width (38 feet). The value of *N* (1.69) is representative of a roughly rectangular channel, which, over the majority of the stage range, is appropriate for this site. Rating curve extrapolation up to and beyond bankfull stage at NK100C is considered to be reasonably accurate because the upper end of the curve is not expected to be influenced substantially by floodplain conveyance or overhanging vegetation and the rating curve function is in general agreement with hydraulic theory.

The stage-discharge rating curves were applied to the recorded stage data to develop continuous hydrographs for non-freeze periods. Winter flows were estimated using a regression analysis between instantaneous discharge measurements at NK100C and corresponding daily discharge estimates developed by the USGS for NK100A. Flow data during the period of beaver-dam backwater in autumn 2007 were estimated using the seasonal regression analysis of available September and October flows at NK100C versus concurrent flows at NK100A. The resulting hydrograph for NK100C is presented on Figure 47, and a monthly discharge summary is provided in Table 31.

The hydrograph shows the characteristic rises in flow during the spring snowmelt and autumn rainstorm seasons, and the intervening low flow periods during the summer and winter. Unit discharge tended to be similar at NK100C and NK100A in the winter months, but lower at NK100C than at NK100A in the non-winter months. These patterns are also illustrated in the seasonal regression plots. In the winter, concurrent discharges between the two stations are clustered around the line of equal unit discharge on Figure 116. In the other seasons, NK100C flows generally lie below the line of equal unit discharge on Figure 120.

The lower unit discharge at NK100C compared with NK100A during non-winter periods is explained by the relative lack of higher elevation terrain and orographic precipitation effects upstream of NK100C, and possibly because of a rain shadow effect on the lee (northwest) side of the upland areas along the NK-SK and NK-UT watershed boundaries. The lower precipitation is offset by aquifer and lake storage in the winter to provide similar winter flows at both stations.

6.1.2.5 NK119A

Station NK119A measures flows in the western fork of NK tributary 1.190, a relatively steep, upland stream. The headwaters of this tributary abut the headwaters of SK tributaries 1.190 and 1.240, which are gaged by Stations SK119A and SK124A, respectively. The mouth of NK tributary 1.190 is located approximately 17 miles upstream of NK100A. The creek at NK119A drains approximately 8 square miles. The creek is relatively steep and flows through moraine and colluvial deposits. The channel habitat features in this reach are dominated by short rapids with irregular scour pools, and the instream sediments are dominated by coarse gravels, some cobble, and numerous boulders. The stage record indicates that high flows have exceeded bankfull stage during the study period. The gage control cross-section is shown on Figure 48, with bankfull stage and maximum recorded stage indicated. The banks are primarily covered in brush that overhangs the stream and influence flows over a range of flow conditions (Photos 26 and 27). The brush has high hydraulic roughness characteristics (i.e. high values of Manning’s coefficient, n, relative to the values found in the adjacent stream channel), impedes overbank flow during floods, and potentially reduces *N* values in the rating curve equation at stages that approach or exceed the bankfull condition.

Discharge was measured at NK119A using both the area-velocity and salt dilution methods, due to the coarse bed material and turbulent flow conditions. One rating curve was developed for NK119A based on 31 measurements taken in non-freeze months (May through October) from 2004 through 2008. The stage-discharge measurements are presented in Table 32, and the rating curve is shown on Figures 49 and 50. Each stage-discharge point presented on the rating curve figures represents the average value of a series of replicates using one of the two techniques; therefore, the points are typically paired, with one point representing the average value obtained using the area-velocity method and the other point representing the average value obtained using the salt dilution method. Discharge measurements in which the error between replicates within a given technique exceeded 10 percent were not used for rating curve development. Similarly, pairs of measurements in which the average values obtained using the two different techniques had errors exceeding 10 percent were also not used. The average rating curve error, based on the stage-discharge points used for rating curve development, is 9.6 percent.

The rating curve for NK119A consists of a single function over all ranges of stage. The values of *C* and *N* lie within the expected ranges based on channel geometry. The value of *C* (18.0) equates to 1.0 times bankfull channel width (18 feet). The value of *N* (2.30) is approximately representative of a parabolic channel, which is appropriate for this site. Rating curve extrapolation above bankfull stage at NK119A is somewhat uncertain because the value of *N* should probably be reduced to account for overhanging vegetation, but there are no discharge measurements at suitably high flows to guide the estimation of *N*. NK119A experiences flashy high flows in which recorded peak stage has exceeded bankfull stage by up to 1.8 feet during the study period. The maximum estimated discharge, based on rating curve extrapolation with no adjustments above bankfull stage, is 3.6 times greater than the estimated bankfull discharge, so consideration of rating curve extrapolation is important at NK119A. The peak discharge estimates based on current rating curve extrapolation may be somewhat too high.

The stage-discharge rating curves were applied to the recorded stage data to develop continuous hydrographs for non-freeze periods. Winter flows were estimated using the regression analysis between instantaneous discharge measurements at NK119A and corresponding daily discharge estimates developed by the USGS for NK100A. Discharge was estimated at NK119A for a period of gage disturbance in October 2004 using the seasonal regression analysis of available September and October flows at NK119A versus concurrent flows at NK100A. The resulting hydrograph for NK119A is presented on Figure 51, and a monthly discharge summary is provided in Table 33.

The hydrograph shows the characteristic rises in flow during the spring snowmelt and autumn rainstorm seasons, and the intervening low flow periods during the summer and winter. The NK119A hydrograph features higher unit runoff than NK100A throughout the non-freeze periods, with much greater peak daily flows during spring snowmelt and autumn rainstorms. This is to be expected given the higher elevation and steep topography of the NK119A subcatchment, but the problem with estimation of high flows at NK119A must also be kept in mind. Unit runoff at NK119A during summer and winter baseflow periods is lower at NK119A than at NK100A, as expected given the lack of groundwater storage in the upland subcatchment above NK119A. These patterns are also illustrated in the seasonal regression plots. Unit discharge was typically lower at NK119A than at NK100A in the winter months, as shown on Figure 116. Unit discharge was similar at NK119A and NK100A during low to moderate flow conditions in the non-freeze periods, but higher at NK119A than at NK100A during high flow conditions, as shown on Figure 121. Figure 121 also presents a regression analysis between NK119A and SK119A indicating slightly lower unit runoff in NK119A, which may reflect a rain shadow effect on the lee (northwest) side of the upland area along the NK-SK watershed boundary.

6.1.2.6 NK119B

Station NK119B measures flows in the eastern fork of NK tributary 1.190. The headwaters of this tributary abut the headwaters of the SK mainstem and SK tributary 1.240, which are gaged by Stations SK100G and SK124A, respectively. The mouth of NK tributary 1.190 is located approximately 17 miles upstream of NK100A. The creek at NK119B drains approximately 4 square miles. The creek is relatively steep and flows through glacial drift deposits. The stream channel goes dry during winter and summer low-flow periods due to the small drainage area, steep terrain, and lack of ponds or other storage features in the subcatchment. This topographic subcatchment also loses groundwater to the upper mainstem of NK to the north, which contributes to the dry channel during low-flow periods. The stage record indicates that high flows have exceeded bankfull stage during the study period. The gage control cross-section is shown on Figure 52, with bankfull stage and maximum recorded stage indicated. The banks are densely vegetated with brush that overhangs the stream and influences flows over a range of flow conditions (Photos 28 and 29). The brush has high hydraulic roughness characteristics (i.e. high values of Manning's coefficient, n, relative to the values found in the adjacent stream channel), impedes overbank flow during floods, and potentially reduces *N* values in the rating curve equation at stages that approach or exceed the bankfull condition.

Station NK119B was established in May 2007, almost 3 years after the initial batch of gaging stations. One stage-discharge rating curve was developed for NK119B based on six measurements taken in non-freeze months (May through October) from 2007 through 2008. The stage-discharge measurements are presented in Table 34, and the rating curve is shown on Figures 53 and 54. The average rating curve error is 13.9 percent, which is considered fair given that the error associated with individual discharge measurements can be up to 15 percent.

The rating curve for NK119B consists of a single function over all ranges of stage. The values of *C* and *N* lie within the expected ranges based on channel geometry. The value of *C* (6.2) equates to 1.3 times bankfull channel width (5 feet). The value of *N* (2.50) is representative of a parabolic to triangular channel cross-section, which is appropriate for this site. Rating curve extrapolation above bankfull stage at NK119B is somewhat uncertain because the value of *N* should probably be reduced to account for overhanging vegetation, but there are no discharge measurements at suitably high flows to guide the estimation of *N*. The peak discharge estimates based on current rating curve extrapolation may be somewhat too high.

The stage-discharge rating curves were applied to the recorded stage data to develop continuous hydrographs for non-freeze periods. Winter flows were estimated using the regression analysis between instantaneous discharge measurements at NK119B and corresponding daily discharge estimates developed by the USGS for NK100A. Discharge was estimated at NK119B for a period of gage disturbance in spring 2008 using the seasonal regression analysis of available May and June flows at NK119B versus concurrent flows at NK100A. The resulting hydrograph for NK119B is presented on Figure 55, and a monthly discharge summary is provided in Table 35. The hydrograph includes estimated flows for the period prior to gage installation in May 2007, based on the seasonal regression analyses against NK100A; these flows are included in the monthly discharge summary from October 2006 onward to complete the record for the 2006 through 2007 water year.

The hydrograph shows the characteristic rises in flow during the spring snowmelt and autumn rainstorm seasons, and the intervening low flow periods during the summer and winter. Flows typically ceased for 1 to 3 months each winter. Flows ceased more briefly during the shorter summer low-flow season. The NK119B hydrograph features lower unit runoff than NK100A throughout the winter and non-winter periods, with similar unit runoff only during peak events in the spring snowmelt and autumn rainstorm seasons. These patterns are also illustrated in the seasonal regression plots. Unit discharge was consistently lower at NK119B than at NK100A in the winter season, as shown on Figure 116. Unit discharge was also less at NK119B than at NK100A in the non-freeze periods, except during some high flow events when unit discharge was similar at the two stations, as shown on Figure 121. The low runoff during baseflow periods is to be expected given the lack of storage features in the upland subcatchment above NK119B. The relatively low baseflows at NK119B are not balanced by greater unit discharge during high flow periods because the subcatchment above NK119B probably experiences a rain shadow effect on the lee (northwest) side of the upland area along the NK-SK watershed boundary, and it also loses groundwater across the topographic divide into the upper NK mainstem basin.

6.1.3 Upper Talarik Creek

The UT watershed is adjacent to the NK and SK headwaters and drains into Iliamna Lake. The highest point in the watershed is at an elevation of approximately 2,200 feet. The hydrology of the creek is characterized by two annual high-flow seasons. The first occurs in response to spring snowmelt in May and June. The second occurs in response to frontal rainfall during the late summer and autumn (typically August through November). The relatively gentle topography, deep deposits of surficial material, and abundance of ponds and wetlands result in moderate winter baseflows in the middle and upper sections of the mainstem channel. Interbasin transfer of groundwater from the SK watershed results in large winter baseflows in UT tributary 1.190 and in the mainstem channel downstream of the tributary confluence.

Station UT100-APC3 is the most downstream gaging station on the UT, located approximately 1 mile upstream of the creek mouth at Iliamna Lake. At UT100-APC3, the UT drains an area of approximately 134 square miles with a mean basin elevation of approximately 1,013 feet and an average basin slope of 14.9 percent. Eight other gaging stations are located at sites further upstream on the main channel of the UT: UT100-APC2, UT100-APC1, UT100B, UT100C, UT100C1, UT100C2, UT100D, and UT100E. Three additional gaging stations are located on the lower reaches of UT tributaries: UT106-APC1, UT119A, and UT135A. The drainage areas and basin characteristics of each gaging station are presented in Table 1. UT100B is the USGS-operated station in the UT watershed.

The UT watershed consists primarily of a broad lowland, 2 to 3 miles in width, bounded by low, but locally steep-sided hills and ridges. The lowland consists of a well-developed floodplain, associated low terraces, and older glaciofluvial terrace deposits. The main channel of the UT generally flows through these floodplains and low terraces, but locally impinges on higher terraces or hillslopes. Short bedrock canyon sections are located above and below Station UT100B.

6.1.3.1 UT100-APC3

Station UT100-APC3 is located approximately 1 mile upstream of the creek mouth, where the drainage area is approximately 134 square miles. At this site, the creek is unconfined as it meanders across a gently sloping plain of relict beach deposits (Photos 30 and 31). The gage control cross-section is shown on

Figure 56, with bankfull stage and maximum recorded stage indicated. The maximum recorded stage has exceeded bankfull stage during the period of record. The banks are densely vegetated with brush that has high hydraulic roughness characteristics (i.e. high values of Manning's coefficient, n, relative to the values found in the adjacent stream channel). The vegetation impedes overbank flow during flood conditions. The extent of brush overhanging into the channel is negligible relative to channel width.

Station UT100-APC3 was established in August 2007, 3 years after the initial batch of gaging stations. One stage-discharge rating curve was developed for UT100-APC3 based on six measurements taken in non-freeze months (May through October) from 2007 through 2008. The stage-discharge measurements are presented in Table 36, and the rating curve is shown on Figures 57 and 58. The average rating curve error is 6.8 percent, which is considered good given that the error associated with individual discharge measurements can be up to 15 percent.

The UT100-APC3 rating curve consists of a single function over all ranges of stage. The values of *C* and *N* lie within the expected ranges based on channel geometry. The value of *C* (142) is 1.4 times bankfull width (100 feet). The value of *N* (1.71) is representative of a roughly rectangular channel, which is appropriate for this site. Rating curve extrapolation up to and beyond bankfull stage at UT100-APC3 is considered to be reasonably accurate because there is one discharge measurement above bankfull stage, and because floodplain conveyance and vegetation overhang likely have little influence on the value of *N* at this site.

The stage-discharge rating curve was applied to the recorded stage data to develop continuous hydrographs for non-freeze periods. Winter flows were estimated using the regression analysis between instantaneous discharge measurements at UT100-APC3 and corresponding daily discharge estimates developed by the USGS for UT100B. Discharge was estimated at UT100-APC3 for a period of gage disturbance in spring 2008 by drainage area pro-ration from UT100B, because there were not enough May and June data available to perform a suitable seasonal regression analysis. The two stations located between UT100-APC3 and UT100B displayed similar unit runoff patterns to UT100B in May and June, which supports the adopted approach. The resulting hydrograph for UT100-APC3 is presented on Figure 59, and a monthly discharge summary is provided in Table 37. The hydrograph includes estimated flows for the period prior to gage installation in August 2007, based on the seasonal regression analyses against UT100B, but these flows are not included in the monthly discharge summary.

The hydrograph shows the characteristic rises in flow during the spring snowmelt and autumn rainstorm seasons, and the intervening low flow periods during the summer and winter. Unit discharge is similar at UT100-APC3 and UT100B throughout the year, during most flow conditions. This pattern is illustrated in the seasonal regression plots, in which the concurrent flows lie close to the line of equal unit discharge in the winter (Figure 117), autumn (Figure 122), and during low to moderate flow conditions in the summer (Figure 122). The record of spring data at this station is short. At higher flow conditions in the summer, unit discharge tended to be lower at UT100-APC3 than at UT100B, possibly due to the moderating influence of aquifers, wetlands, and gentle topography in the lower UT basin. This effect was not observed in the autumn, when the highest flows were recorded at this station (due to the late start of data collection in Spring 2008).

6.1.3.2 UT100-APC2

Station UT100-APC2 is located approximately 3 miles upstream of UT100-APC3, where the drainage area is approximately 110 square miles. At this site, the creek is partially confined by low bedrock bluffs (Photos 32 and 33). The gage control cross-section is shown on Figure 60, with bankfull stage and maximum recorded stage indicated. The maximum recorded stage during the period of record is approximately equal to the bankfull stage. The banks are densely forested with vegetation that has high hydraulic roughness characteristics (i.e. high values of Manning's coefficient, n, relative to the values found in the adjacent stream channel). The vegetation would impede overbank flow during flood conditions. The extent of brush overhanging into the channel is negligible relative to channel width.

Station UT100-APC2 was established in August 2007, 3 years after the initial batch of gaging stations. One stage-discharge rating curve was developed for UT100-APC2 based on seven measurements taken in non-freeze months (May through October) from 2007 through 2008. The stage-discharge measurements are presented in Table 38, and the rating curve is shown on Figures 61 and 62. The average rating curve error is 4.3 percent, which is considered good given that the error associated with individual discharge measurements can be up to 15 percent.

The UT100-APC2 rating curve consists of a single function over all ranges of stage. The values of *C* and *N* lie within the expected ranges based on channel geometry. The value of *C* (90.0) is 1.3 times bankfull width (71 feet). The value of *N* (2.57) is representative of a parabolic to triangular channel, which is appropriate for this site. Rating curve extrapolation up to and beyond bankfull stage at UT100-APC2 is considered to be reasonably accurate because the upper end of the curve is not expected to be influenced substantially by floodplain conveyance or overhanging vegetation and the rating curve function is in general agreement with hydraulic theory.

The stage-discharge rating curve was applied to the recorded stage data to develop continuous hydrographs for non-freeze periods. Winter flows were estimated using the regression analysis between instantaneous discharge measurements at UT100-APC2 and corresponding daily discharge estimates developed by the USGS for UT100B. Discharge was estimated at UT100-APC2 for a period of gage disturbance in autumn 2007 by drainage area pro-ration from UT100B because there were not enough September and October data available to perform a suitable seasonal regression analysis. The next stations upstream and downstream of UT100-APC2 displayed similar unit runoff patterns to UT100B in September and October, which supports the adopted approach. The resulting hydrograph for UT100-APC2 is presented on Figure 63, and a monthly discharge summary is provided in Table 39. The hydrograph includes estimated flows for the period prior to gage installation in August 2007, based on the seasonal regression analyses against UT100B, but these flows are not included in the monthly discharge summary.

The hydrograph shows the characteristic rises in flow during the spring snowmelt and autumn rainstorm seasons, and the intervening low flow periods during the summer and winter. Unit discharge is similar at UT100-APC2 and UT100B throughout the year. This pattern is also illustrated in the seasonal regression plots, in which the concurrent flows lie close to the line of equal unit discharge on Figure 117 (winter) and Figure 122 (spring through autumn). During the highest flow conditions in the spring and autumn, unit discharge tended to be slightly greater at UT100-APC2 than at UT100B, while the opposite was true during lower flow conditions (Figure 122).

6.1.3.3 UT100-APC1

Station UT100-APC1 is located approximately 6 miles upstream of UT100-APC3, where the drainage area is approximately 102 square miles. At this site, the creek is partially confined (Photos 34 and 35). The gage control cross-section is shown on Figure 64, with bankfull stage and maximum recorded stage indicated. The maximum recorded stage during the period of record has exceeded bankfull stage. The banks are densely forested with vegetation that has high hydraulic roughness characteristics (i.e. high values of Manning’s coefficient, n, relative to the values found in the adjacent stream channel). The vegetation impedes overbank flow during flood conditions. The extent of brush overhanging into the channel is negligible relative to channel width.

Station UT100-APC1 was established in August 2007, 3 years after the initial batch of gaging stations. One stage-discharge rating curve was developed for UT100-APC1 based on seven measurements taken in non-freeze months (May through October) from 2007 through 2008. The stage-discharge measurements are presented in Table 40, and the rating curve is shown on Figures 65 and 66. The average rating curve error is 5.4 percent, which is considered good given that the error associated with individual discharge measurements can be up to 15 percent.

The UT100-APC1 rating curve consists of a single function over all ranges of stage. The values of *C* and *N* lie within the expected ranges based on channel geometry. The value of *C* (70.5) is 0.9 times bankfull width (80 feet). The value of *N* (2.42) is representative of a parabolic to triangular channel, which is appropriate for this site. Rating curve extrapolation up to and beyond bankfull stage at UT100-APC1 is considered to be reasonably accurate because the curve is not expected to be influenced substantially by floodplain conveyance or overhanging vegetation, and because two measurements were recorded above bankfull stage.

The stage-discharge rating curve was applied to the recorded stage data to develop continuous hydrographs for non-freeze periods. Winter flows were estimated using the regression analysis between instantaneous discharge measurements at UT100-APC1 and corresponding daily discharge estimates developed by the USGS for UT100B. There were no periods of missing data during non-freeze periods that required infilling based on seasonal regression analysis against UT100B. The resulting hydrograph for UT100-APC1 is presented on Figure 67, and a monthly discharge summary is provided in Table 41. The hydrograph includes estimated flows for the period prior to gage installation in August 2007, based on the seasonal regression analyses against UT100B, but these flows are not included in the monthly discharge summary.

The hydrograph shows the characteristic rises in flow during the spring snowmelt and autumn rainstorm seasons, and the intervening low flow periods during the summer and winter. Unit discharge is similar at UT100-APC1 and UT100B throughout the year. This pattern is also illustrated in the seasonal regression plots, in which the concurrent flows lie close to the line of equal unit discharge on Figure 117 (winter) and Figure 122 (spring through autumn).

6.1.3.4 UT100B

Station UT100B is operated by the USGS. In the USGS system, it is referred to as Station 1530250 (Upper Talarik Creek). UT100B is located approximately 11 miles upstream of UT100-APC3 and immediately downstream of the confluence with UT tributary 1.190, which receives the large groundwater transfer from the SK watershed. At Station UT100B, the creek drains a surface area of approximately 86 square miles. The creek meanders through well-developed floodplains, associated low terraces, and abandoned channel deposits (Photos 36 and 37). The channel habitat features in this reach are dominated by riffles and pools, and the instream sediments are dominated by coarse gravel and small cobbles. The banks are covered in grasses and brush, which have high hydraulic roughness characteristics (i.e. high values of Manning's coefficient, n, relative to the values found in the adjacent stream channel). The vegetation impedes overbank flow during flood conditions. The extent of brush overhanging into the channel is negligible relative to channel width.

The USGS has developed two stage-discharge rating curves for UT100B based on 33 measurements, including 22 measurements taken in the typical non-freeze months (May through October) from 2004 through 2008. The rating curve shift was applied starting in October 2006, when changes in the channel cross-section changed the stage-discharge relationship. The stage-discharge measurements are presented in Table 42, and the rating curves are shown on Figures 68 and 69. The average rating curve error is 9.2 percent.

USGS rating curves are provided in the form of a table of stage-discharge points. The UT100B stage-discharge points describe a straight line in log-log space and thus can be represented by a single power function of the form:

$$Q = C(h - a)^N$$

The *C* and *N* values are similar for the two rating curves. The values of *C* (25.0 and 31.0) are approximately 0.5 to 0.6 times the bankfull channel width, slightly lower than expected. The values of *N* (2.89 and 3.05) are slightly higher than expected for a rectangular to parabolic channel.

The USGS applied its stage-discharge rating curves to the recorded stage data to develop continuous hydrographs for non-freeze periods. Winter flows were estimated using instantaneous discharge measurements in conjunction with meteorological data and drawing on general understanding of hydrograph recession patterns during winter low-flow conditions. The resulting hydrograph for UT100B is presented on Figure 70, and a monthly discharge summary is provided in Table 43.

The hydrograph shows the characteristic rises in flow during the spring snowmelt and autumn rainstorm seasons, and the intervening low flow periods during the summer and winter. The UT100B hydrograph is compared to the prorated hydrograph from SK100B. The UT100B hydrograph is characterized by substantially higher unit discharge during winter and summer baseflow periods, because of extensive aquifer storage along the east side of the middle UT basin upstream of UT100B, pond and wetland storage in the upper UT basin, and cross-basin groundwater contributions from the SK watershed via tributary UT 1.190. Unit discharge in high flow periods is generally lower at UT100B than at SK100B because of the smaller amount of high elevation terrain in the UT basin. These patterns are also shown in the seasonal regression plots on Figure 122.

6.1.3.5 UT100C

Station UT100C is located approximately 12 miles upstream of UT100-APC3. At this site, the creek drains an area of approximately 69 square miles and flows through a floodplain and associated low terraces (Photos 38 and 39). The stage record indicates that high flows have slightly exceeded bankfull stage during the study period. The gage control cross-section is shown on Figure 71, with bankfull stage and maximum recorded stage indicated. The banks are covered in grasses and brush, which have high hydraulic roughness characteristics (i.e. high values of Manning's coefficient, n, relative to the values found in the adjacent stream channel). The vegetation impedes overbank flow during flood conditions. The extent of brush overhanging into the channel is negligible relative to channel width.

Station UT100C was established in spring 2007, almost 3 years after the initial batch of gaging stations. Two stage-discharge rating curves were developed for UT100C based on 12 measurements taken in non-freeze months (May through October) from 2007 through 2008. The rating curve shift was applied starting in the spring of 2008. The stage-discharge measurements are presented in Table 44, and the rating curves are shown on Figures 72 and 73. The average rating curve error is 5.2 percent, which is considered good given that the error associated with individual discharge measurements can be up to 15 percent.

Each rating curve for UT100C consists of a single function over all ranges of stage. The two curves differ in their values of *a* and *N*, while *C* is constant for both curves. The values of *C* and *N* lie within the expected ranges based on channel geometry. The value of *C* (91.0) equates to approximately 1.3 times bankfull channel width (70 feet). The values of *N* (2.65 and 2.70) are representative of a triangular channel, which is appropriate for this site. Rating curve extrapolation above bankfull stage at UT100C is considered to be reasonably accurate because the upper ends of the curves are not expected to be influenced substantially by floodplain conveyance or overhanging vegetation, and because the rating curve functions are in general agreement with hydraulic theory.

The stage-discharge rating curves were applied to the recorded stage data to develop continuous hydrographs for non-freeze periods. Winter flows were estimated using the regression analysis between instantaneous discharge measurements at UT100C and corresponding daily discharge estimates developed by the USGS for UT100B. Discharge was estimated at UT100C for a period of gage disturbance in spring 2008 and a period of missing data in autumn 2008 using the seasonal regression analyses of available flows at UT100C versus concurrent flows at UT100B. The resulting hydrograph for UT100C is presented on Figure 74, and a monthly discharge summary is provided in Table 45. The hydrograph includes estimated flows for the period prior to gage installation in spring 2007, based on the seasonal regression analyses against UT100B; these flows are included in the monthly discharge summary from October 2006 onward to complete the record for the 2006 through 2007 water year.

The hydrograph shows the characteristic rises in flow during the spring snowmelt and autumn rainstorm seasons, and the intervening low flow periods during the summer and winter. The UT100C hydrograph features similar unit runoff to UT100B during high-flow periods and lower unit runoff during baseflow periods, when the interbasin transfer of groundwater from the SK watershed via UT tributary 1.190 becomes apparent. These patterns are also indicated in the seasonal regression plots provided on Figure 117 (winter) and Figure 123 (spring through autumn).

6.1.3.6 UT100C1

Station UT100C1 is located approximately 15 miles upstream of UT100-APC3. At this site, the creek drains an area of approximately 60 square miles and flows through a narrow floodplain and high terraces (Photos 40 and 41). An ancient landslide deposit constricts the valley a short distance downstream. The stage record indicates that high flows have slightly exceeded bankfull stage during the study period. The gage control cross-section is shown on Figure 75, with bankfull stage and maximum recorded stage indicated. The banks are covered in grasses and brush, which have high hydraulic roughness characteristics (i.e. high values of Manning's coefficient, n, relative to the values found in the adjacent stream channel). The vegetation impedes overbank flow during flood conditions. The extent of brush overhanging into the channel is negligible relative to channel width.

Station UT100C1 was established in spring 2007, almost 3 years after the initial batch of gaging stations. One stage-discharge rating curve was developed for UT100C1 based on 11 measurements taken in non-freeze months (May through October) from 2007 through 2008. The stage-discharge measurements are presented in Table 46, and the rating curves are shown on Figures 76 and 77. The average rating curve error is 5.2 percent, which is considered good given that the error associated with individual discharge measurements can be up to 15 percent.

The rating curve for UT100C1 consists of a single function over all ranges of stage. The values of *C* and *N* lie within the expected ranges based on channel geometry. The value of *C* (50.0) equates to approximately 1.0 times bankfull channel width (50 feet). The value of *N* (2.20) is representative of a parabolic channel, which is appropriate for this site. Rating curve extrapolation above bankfull stage at UT100C1 is considered to be reasonably accurate because the upper end of the curve is not expected to be influenced substantially by floodplain conveyance or overhanging vegetation and the rating curve function is in general agreement with hydraulic theory.

The stage-discharge rating curve was applied to the recorded stage data to develop a continuous hydrograph for non-freeze periods. Winter flows were estimated using the regression analysis between instantaneous discharge measurements at UT100C1 and corresponding daily discharge estimates developed by the USGS for UT100B. Discharge was estimated at UT100C1 for period of low flow in August 2008, when the water level dropped below the transducer, using a seasonal regression analysis of available July and August flows at UT100C1 versus concurrent flows at UT100B. The resulting hydrograph for UT100C1 is presented on Figure 78, and a monthly discharge summary is provided in Table 47. The hydrograph includes estimated flows for the period prior to gage installation in spring 2007, based on the seasonal regression analyses against UT100B; these flows are included in the monthly discharge summary from October 2006 onward to complete the record for the 2006 through 2007 water year.

The hydrograph shows the characteristic rises in flow during the spring snowmelt and autumn rainstorm seasons, and the intervening low flow periods during the summer and winter. The UT100C1 hydrograph features similar unit runoff to UT100B during high-flow periods and lower unit runoff during baseflow periods, when the interbasin transfer of groundwater from the SK watershed via UT tributary 1.190 becomes apparent. These patterns are also indicated in the seasonal regression plots provided on Figure 117 (winter) and Figure 123 (spring through autumn).

6.1.3.7 UT100C2

Station UT100C2 is located approximately 18 miles upstream of UT100-APC3 and immediately downstream of the confluence of UT tributary 1.350. At this site, the creek drains an area of approximately 48 square miles and flows through a floodplain and associated low terraces within a glacio-lacustrine basin (Photos 42 and 43). The stage record indicates that high flows have slightly exceeded bankfull stage during the study period. The gage control cross-section is shown on Figure 79, with bankfull stage and maximum recorded stage indicated. The banks are covered in grasses and brush, which have high hydraulic roughness characteristics (i.e. high values of Manning's coefficient, n, relative to the values found in the adjacent stream channel). The vegetation impedes overbank flow during flood conditions. The extent of brush overhanging into the channel is negligible relative to channel width.

Station UT100C2 was established in spring 2007, almost 3 years after the initial batch of gaging stations. One stage-discharge rating curve was developed for UT100C2 based on 11 measurements taken in non-freeze months (May through October) from 2007 through 2008. The stage-discharge measurements are presented in Table 48 and the rating curves are shown on Figures 80 and 81. The average rating curve error is 3.0 percent, which is considered good given that the error associated with individual discharge measurements can be up to 15 percent.

The UT100C2 rating curve consists of two functions with a transition at a stage of 95.91 feet. Both *C* and *N* increase above the transition stage. The value of *C* (103.0) for the low-flow rating curve function is approximately 2.3 times the wetted width at the rating curve transition, and the value of N (1.75) approximates the value for a rectangular channel, which is appropriate for low and moderate flows at this site. The value of *C* (77.0) for the high-flow rating curve function is approximately 1.5 times the bankfull channel width (50 feet). The value of *N* (2.16) for the high-flow rating curve approximates the value for a parabolic channel, which is appropriate for the effective channel shape at high flows. Therefore, extrapolation of the high-flow rating curve function up to and beyond bankfull stage is considered to be reasonably accurate because the form of the curve is in general agreement with hydraulic theory, and the effects of floodplain conveyance and overhanging vegetation are not expected to be substantial.

The stage-discharge rating curve was applied to the recorded stage data to develop a continuous hydrograph for non-freeze periods. Winter flows were estimated using the regression analysis between instantaneous discharge measurements at UT100C2 and corresponding daily discharge estimates developed by the USGS for UT100B. There were no periods of missing data during non-freeze periods that required infilling based on seasonal regression analysis against UT100B. The resulting hydrograph for UT100C2 is presented on Figure 82, and a monthly discharge summary is provided in Table 49. The hydrograph includes estimated flows for the period prior to gage installation in spring 2007, based on the seasonal regression analyses against UT100B; these flows are included in the monthly discharge summary from October 2006 onward to complete the record for the 2006 through 2007 water year.

The hydrograph shows the characteristic rises in flow during the spring snowmelt and autumn rainstorm seasons, and the intervening low flow periods during the summer and winter. The UT100C2 hydrograph features similar unit runoff to UT100B during high-flow periods and lower unit runoff during baseflow periods. UT100C2 is located at the upstream end of an extensive aquifer along the east side of the UT basin, which contributes baseflow between UT100C2 and UT100B. These patterns are also indicated in the seasonal regression plots provided on Figure 117 (winter) and Figure 123 (spring through autumn).

6.1.3.8 UT100D

Station UT100D is located in the upper reaches of the UT, 25 miles upstream of UT100-APC3. The creek here drains approximately 12 square miles of mostly low-gradient wetlands and some adjacent upland, including the general deposit location. The creek meanders through floodplains and associated low terraces within a glacio-lacustrine basin (Photos 44 and 45). Channel habitat features in this reach are dominated by riffles and pools, and the instream sediments are dominated by medium gravel. The stage record indicates that high flows have exceeded bankfull stage during the study period. The gage control cross-section is shown on Figure 83, with bankfull stage and maximum recorded stage indicated. The banks are covered in grasses and brush, which have high hydraulic roughness characteristics (i.e. high values of Manning's coefficient, n, relative to the values found in the adjacent stream channel). The vegetation impedes overbank flow during flood conditions. The extent of brush overhanging into the channel is negligible relative to channel width.

Four stage-discharge rating curves were developed for UT100D based on 22 measurements taken in non-freeze months (May through October) from 2004 through 2008. The rating curve shifts were applied starting in the spring of 2005, 2007, and 2008. One non-freeze measurement taken in September 2006 was not used for rating-curve development because of beaver activity immediately downstream of the gage site. The beaver debris was gone in 2007. The stage-discharge measurements are presented in Table 50, and the rating curves are shown on Figure 84 and 85. The average rating curve error is 6.7 percent, which is considered good given that the error associated with individual discharge measurements can be up to 15 percent. It is not known whether the need for multiple rating curves at this site reflects changes in channel morphology or phases of downstream beaver dam construction and decay. Regardless, the relatively low rating error indicates that stage-discharge relations tend to remain stable within the non-freeze gaging period each year.

Each rating curve for UT100D consists of a single function over all ranges of stage. The four curves differ in their values of *a* and *C*, while *N* is constant for all but the 2004 curve. The values of *C* and *N* lie within the expected ranges based on channel geometry. The values of *C* (23.9 to 38.3) equate to approximately 1.2 to 1.9 times the bankfull channel width (20 feet). The values of *N* (1.86 to 1.90) are representative of a rectangular to parabolic channel, which is appropriate for this site. Rating curve extrapolation above bankfull stage at UT100D is considered to be reasonably accurate because the upper ends of the curves are not expected to be influenced substantially by floodplain conveyance or overhanging vegetation and the rating curve functions are in general agreement with hydraulic theory.

The stage-discharge rating curves were applied to the recorded stage data to develop continuous hydrographs for non-freeze periods. Winter flows were estimated using the regression analysis between instantaneous discharge measurements at UT100D and corresponding daily discharge estimates developed by the USGS for UT100B. Discharge was estimated at UT100D for the period in which a beaver dam caused noticeable backwater influence at the gage in autumn 2006, using the seasonal regression analysis of available September and October flows at UT100D versus concurrent flows at UT100B. The resulting hydrograph for UT100D is presented on Figure 86, and a monthly discharge summary is provided in Table 51.

The hydrograph shows the characteristic rises in flow during the spring snowmelt and autumn rainstorm seasons, and the intervening low flow periods during the summer and winter. The UT100D hydrograph features similar unit runoff to UT100B during high-flow periods and lower unit runoff during baseflow periods, due to the relatively smaller amount of aquifer storage upstream of UT100D. These patterns are also indicated in the seasonal regression plots provided on Figure 117 (winter) and Figure 123 (spring through autumn).

6.1.3.9 UT100E

Station UT100E is located near the headwaters of the UT watershed approximately 29 miles upstream of UT100-APC3. The creek at UT100E drains a relatively small area of low-gradient wetlands covering approximately 3 square miles, upstream of the general deposit location. The creek at UT100E flows through floodplains and associated low terraces, within a complex set of moraine and outwash deposits (Photos 46 and 47). The channel habitat features in this reach are dominated by riffles and pools, and the instream sediments are dominated by coarse gravel. The stage record indicates that flows have barely exceeded bankfull stage (by only 0.1 foot) during the study period. The gage control cross-section is shown on Figure 87, with bankfull stage and maximum recorded stage indicated. The banks are covered mainly with grasses and some brush, which have high hydraulic roughness characteristics (i.e. high values of Manning's coefficient, n, relative to the values found in the adjacent stream channel). The vegetation would impede overbank flow should flood conditions occur. The extent of vegetation overhang is negligible relative to channel width.

Discharge was measured at UT100E using both the area-velocity and salt dilution methods, due to the coarse bed material and turbulent flow conditions. Two stage-discharge rating curves were developed for UT100E based on 29 measurements taken in non-freeze months (May through October) from 2004 through 2008. The rating curve shift was applied starting in the spring of 2007. The stage-discharge measurements are presented in Table 52, and the rating curves are shown on Figures 88 and 89. Each stage-discharge point presented on the rating curve figures represents the average value of a series of replicates using one of the two techniques; therefore, the points are typically paired, with one point representing the average value obtained using the area-velocity method and the other point representing the average value obtained using the salt dilution method. Discharge measurements in which the error between replicates within a given technique exceeded 10 percent were not used for rating curve development. Similarly, pairs of measurements in which the average values obtained using the two different techniques had errors exceeding 10 percent were also not used. The average rating curve error, based on the stage-discharge points used for rating curve development, is 8.4 percent.

Each rating curve for UT100E consists of a single function over all ranges of stage. The two curves differ only in their values of *a*, while *C* and *N* are constant for both. The values of *C* and *N* lie within the expected ranges based on channel geometry. The value of *C* (33.0) equates to 3.0 times bankfull channel width (11 feet). The value of *N* (2.31) is approximately representative of a parabolic channel, which is appropriate for this site. Rating curve extrapolation up to and above bankfull stage at UT100E is considered to be reasonably accurate because the upper ends of the curves are not expected to be influenced substantially by floodplain conveyance or overhanging vegetation and the rating curve functions are in general agreement with hydraulic theory.

The stage-discharge rating curves were applied to the recorded stage data to develop continuous hydrographs for non-freeze periods. Winter flows were estimated using a regression analysis between instantaneous discharge measurements at UT100E and corresponding daily discharge estimates developed by the USGS for UT100B. The winter IQ measurement taken on January 19, 2006, is not consistent with the estimated winter hydrograph. The IQ point indicates a lower discharge than the regression-based estimate for that date. This measurement was taken during a very cold period when anchor ice had formed in the stream, introducing additional error into flow measurement. There were no periods of missing data during non-freeze periods that required infilling based on the seasonal regression analyses against UT100B. The resulting hydrograph for UT100E is presented on Figure 90, and a monthly discharge summary is provided in Table 53.

The hydrograph shows the characteristic rises in flow during the spring snowmelt and autumn rainstorm seasons, and the intervening low flow periods during the summer and winter. The UT100E hydrograph features similar unit discharge to UT100B throughout the year, unlike the stations downstream of UT100E, which tend to have lower unit discharge than UT100B in low flow periods. The similarity in unit discharge between UT100E and UT100B is also shown in the seasonal regression plots provided on Figures 117 (winter) and Figure 124 (spring through autumn). Baseflows at UT100E are sustained by a number of sources: aquifer storage in the outwash deposits, pond and wetland storage, an interbasin groundwater transfer from a downstream UT tributary that feeds the springs upstream of UT100E, and a potential interbasin transfer of groundwater from NK to UT at the UT headwaters.

6.1.3.10 UT106-APC1

Station UT106-APC1 is located on UT tributary 1.060. The mouth of the tributary is located approximately 2 miles upstream of UT100-APC3. At UT106-APC1, tributary 1.060 drains an area of approximately 14 square miles, comprised primarily of low-gradient wetlands and some adjacent uplands. The creek at UT106-APC1 flows through floodplains and associated low terraces (Photos 48 and 49). The channel habitat features in this reach are dominated by riffles and pools, and the instream sediments are dominated by gravel and cobbles. The stage record indicates that flows have not exceeded bankfull stage during the short period of record. The gage control cross-section is shown on Figure 91, with bankfull stage and maximum recorded stage indicated. The banks are covered mainly with grasses, brush, and forest vegetation, which have high hydraulic roughness characteristics (i.e. high values of Manning’s coefficient, n, relative to the values found in the adjacent stream channel). The vegetation would impede overbank flow should flood conditions occur. The extent of vegetation overhang is negligible relative to channel width.

Station UT106-APC1 was established in May 2008. Seven stage-discharge points have been collected as of the end of 2008, five of which were collected during ice-free conditions and will be used for rating curve development at a later date. The stage-discharge measurements are presented in Table 54 and shown on Figure 92.

6.1.3.11 UT119A

Station UT119A is located on UT tributary 1.190 approximately 0.5 miles upstream of the confluence with the mainstem UT. The mouth of the tributary is located immediately upstream of UT100B. The surface drainage area at the gage is approximately 4 square miles, but the creek also receives a substantial groundwater contribution from the SK basin. The valley of UT tributary 1.190 consists of an underfit, former meltwater channel that drained the SK basin during a period when the SK valley was dammed by a moraine. Subsequent landscape erosion and deposition have altered the surface topography and drainage divides, but the meltwater valley/channel continues to drain a substantial portion of groundwater flow from the middle part of the SK basin. Because of the groundwater influence from SK, UT119A has relatively high and constant flows.

The channel habitat features in the gage reach are dominated by riffles and pools, and the instream sediments are dominated by coarse gravels, some cobble, and a few small boulders. The range of recorded stage at UT119A during the study period was only 0.6 feet because of the dominant influence of groundwater, and the maximum recorded stage was 0.2 feet below bankfull. The gage control cross-section is shown on Figure 93, with bankfull stage and maximum recorded stage indicated. The banks are primarily covered in brush that overhangs the stream above bankfull conditions (Photos 50 and 51). The vegetation has high hydraulic roughness characteristics (i.e. high values of Manning's coefficient, n, relative to the values found in the adjacent stream channel) and would impede overbank flow should flood conditions occur.

The discharge measurements used for rating-curve development at UT119A were collected within a far narrower range of flow conditions than at the other gaging stations because of the large baseflow at this site. The range of measured IQs at UT119A was only 21 cfs to 37 cfs, whereas measured IQs at other gages typically covered a range of at least one order of magnitude. The creek at UT119A is also steep, with coarse bed material, and the water surface is always wavy. Therefore, the measurement of stage is more difficult at this site than most others, and the relation between stage and discharge is less consistent. However, the total range of recorder stage at this site was relatively low, so the stage-discharge rating curve did not require much extrapolation to high or low flow conditions.

Discharge was measured at UT119A using both the area-velocity and salt dilution methods, due to the coarse bed material and turbulent flow conditions. Two stage-discharge rating curves were developed for UT119A based on 31 measurements taken in non-freeze months (May through October) from 2004 through 2008. The rating curve shift was applied starting in the spring of 2005. The stage-discharge measurements are presented in Table 55, and the rating curves are shown on Figure 94.

The discharge values presented on the rating curve figure represent the average value of a series of replicates using one of the two techniques; therefore, the points are typically paired, with one point representing the average value obtained using the area-velocity method and the other point representing the average value obtained using the salt dilution method. Discharge measurements in which the error between replicates within a given technique exceeded 10 percent were not used for rating curve development. Similarly, pairs of measurements in which the average values obtained using the two different techniques had errors exceeding 10 percent were also not used.

The average rating curve error, based on the stage-discharge points used for rating curve development, is 8.4 percent, which is considered good given that the error associated with individual discharge measurements can be up to 15 percent for current-meter measurements and 22 percent for salt-dilution measurements, and that a 0.10-foot error in stage equates to a 20 percent error in discharge according to the derived rating curves.

Each rating curve for UT119A consists of a single function over all ranges of stage. The two curves differ only in their values of a, while C and N are constant for both. The values of C and N lie within the expected ranges based on channel geometry. The value of C (45.0) equates to 2.3 times bankfull channel width (20 feet). The value of N (1.67) is representative of a rectangular channel, which is appropriate for this site. Rating curve extrapolation is not a major consideration at this site because of the narrow range of flows.

The stage-discharge rating curves were applied to the recorded stage data to develop continuous hydrographs for non-freeze periods. Winter flows were estimated using the regression analysis between instantaneous discharge measurements at UT119A and corresponding daily discharge estimates developed by the USGS for UT100B. Discharge was also estimated at UT119A for a non-freeze data gap in October 2004 using a seasonal regression analysis of available flows at UT119A versus concurrent flows at UT100B. Two winter IQ measurements are not consistent with the estimated winter hydrograph.

The two IQ points were taken on January 19, 2006, and December 11, 2006, and indicate much lower discharge than the regression-based estimates for those dates. These measurements were taken during very cold periods when anchor ice had formed in the stream, introducing additional error into flow measurement. It is also possible that anchor ice temporarily blocked some of the upwelling springs that feed into UT119A. The resulting hydrograph for UT119A is presented on Figure 95, and a monthly discharge summary is provided in Table 56.

The hydrograph shows muted rises in flow during the spring snowmelt and autumn rainstorm seasons, and high baseflows in the intervening summer and winter periods. The winter baseflow is approximately 24 to 25 cfs. The seasonal regression plots provided on Figures 117 (winter) and Figure 124 (spring through autumn) indicate the much greater unit discharge at UT119A as compared to UT100B. Figure 124 also indicates that UT119A has lower unit discharge than UT100B during high flow periods, despite the groundwater influx, because of the relatively low terrain and thick, permeable surficial materials in the UT119A subcatchment.

6.1.3.12 UT135A

Station UT135A is located on UT tributary 1.350 approximately 0.4 miles upstream of the confluence with the mainstem UT. The mouth of the tributary is located approximately 18 miles upstream of UT100-APC3. The surface drainage area at the gage is approximately 20 square miles. The creek at UT135A meanders across a wide, low-gradient glacio-lacustrine plain (Photos 52 and 53). The channel habitat features in this reach are dominated by slow-moving pools with abundant aquatic vegetation, and the bed sediments are dominated by sands overlying non-alluvial silts and clays. The gage control cross-section is shown on Figure 96, with bankfull stage and maximum recorded stage indicated. The banks are primarily covered in tall grasses that have high hydraulic roughness characteristics (i.e. high values of Manning's coefficient, n, relative to the values found in the adjacent stream channel). The vegetation impedes overbank flow during flood conditions.

Station UT135A was established in May 2007, almost 3 years after the initial batch of gaging stations. Ten stage-discharge measurements were taken in non-freeze months (May through October) in 2007 and 2008. The stage-discharge measurements are presented in Table 57 and on Figure 97. There is no clear relationship between stage and discharge at this site, and a rating curve has not been developed as a result. The unstable stage-discharge relationship is likely due to the low channel gradient, which causes the effects of downstream channel changes, bank slumping, or water levels in the UT mainstem to propagate far upstream. The seasonal growth and decay of aquatic vegetation may also contribute to the variability in the stage-discharge relationship.

Instantaneous discharge measurements have been collected at the UT135A gage site since 2004. Forty-six IQ measurements are available for seasonal regression analysis against UT100B. The entire hydrograph for Station UT135A has been estimated on this basis, instead of using the stage record and a rating curve. The resulting hydrograph for UT135A is presented on Figure 98, and a monthly discharge summary is provided in Table 58. The monthly discharge summary presents flows for the period that would be expected to be shown if the station stage record had been used.

The hydrograph shows the characteristic rises in flow during the spring snowmelt and autumn rainstorm seasons, and the intervening low flow periods during the summer and winter. The UT135A hydrograph features consistently lower unit discharge compared to UT100B throughout the year. This pattern can also be seen in the seasonal regression plots provided on Figure 117 (winter) and Figure 125 (spring through autumn). The relatively low unit runoff at UT135A can be attributed to the general lack of high elevation terrain in the basin, which limits orographic enhancement of precipitation. The topographic basin of UT135A includes some closed depressions from which the subsurface drainage pathways are not well known. Some of these pathways may drain into the Newhalen River basin.

6.1.4 Kaskanak Creek

6.1.4.1 KC100A

Station KC100A is located on the mainstem of KC immediately below the morainal headwaters where numerous small tributaries coalesce to form the main KC channel. This station was installed for the purpose of investigating potential interbasin transfer of water from the SK watershed, which is situated directly to the north. The lack of a distinct topographic divide and the probable presence of a deep overburden fill led to this investigation. However, the relatively low unit runoff measured in KC is not consistent with an interbasin transfer from the SK watershed.

At the gaging station, the creek meanders across a broad, low-gradient plain of relict beach deposits. The drainage area above KC100A is approximately 26 square miles; the mean basin elevation is approximately 605 feet; and the average basin slope is 4.3 percent. The channel habitat features in this reach are dominated by runs and pools with some aquatic vegetation, and the instream sediments are dominated by medium gravels. The stage record indicates that high flows have exceeded bankfull stage by up to 2.0 feet during the study period. The gage control cross-section is shown on Figure 99, with bankfull stage and maximum recorded stage indicated. The banks are covered in tall grasses and brush (Photos 54 and 55), which have high hydraulic roughness characteristics (i.e. high values of Manning’s coefficient, n, relative to the values found in the adjacent stream channel). The vegetation impedes overbank flow during flood conditions. The extent of brush overhanging into the channel is negligible relative to channel width. The banks are composed of fine-textured sediments and are prone to slump failures. The low gradient of the channel (0.001 foot per foot) makes the stage-discharge relation sensitive to changes in downstream channel geometry.

Two stage-discharge rating curves were developed for KC100A based on 24 measurements taken in non-freeze months (May through October) from 2004 through 2008. The rating curve shift was applied starting in the spring of 2006. Although the 2004 through 2005 rating curve is well defined, the stability of the stage-discharge relationship appears to degrade from 2006 onwards. The specific physical causes underlying this change are not clear but are likely related to the low channel gradient and unstable banks. The stage-discharge measurements are presented in Table 59, and the rating curves are shown on Figures 100 and 101. The average rating curve error is 9.4 percent, which is considered fair given that the error associated with individual discharge measurements can be up to 15 percent and the overall uncertainty of the stage-discharge relationship at KC100A.

Each rating curve for KC100A consists of a single function over all ranges of stage. The two curves differ in their values of a and C, while N remains constant for both. The values of C and N lie within the expected ranges based on channel geometry. The values of C (21.5 to 26.0) equate to approximately 0.9 to 1.1 times bankfull channel width (23 feet). The value of N (2.10) is approximately representative of a parabolic channel, which is appropriate for this site. Rating curve extrapolation above bankfull stage at

KC100A is considered to be reasonably accurate. Maximum recorded stage has exceeded bankfull stage by 2.0 feet, but the overbank flows are mostly constrained to a vegetated bench along the left bank, which is comparable in width to the channel. The maximum estimated discharge, based on rating curve extrapolation with no adjustments above bankfull stage, is 4.8 times greater than the estimated bankfull discharge (as compared to ratios of 1.0 to 2.5 times at most other gages).

The stage-discharge rating curves were applied to the recorded stage data to develop continuous hydrographs for non-freeze periods. Winter flows were estimated using a regression analysis between instantaneous discharge measurements at KC100A and corresponding daily discharge estimates developed by the USGS for UT100B. UT100B provided a better comparison than SK100B for KC100A because of the large baseflows and muted seasonal flows at KC100A. The resulting hydrograph for KC100A is presented on Figure 102, and a monthly discharge summary is provided in Table 60.

The hydrograph shows the characteristic rises in flow during the spring snowmelt and autumn rainstorm seasons, and the intervening low flow periods during the summer and winter. The KC100A hydrograph approximately mirrors the UT100B hydrograph, but the KC100A hydrograph features lower unit runoff than UT100B in all seasons. The seasonal regression plots provided on Figure 117 (winter) and Figure 124 (spring through autumn) also show the lower unit discharge at KC100A as compared to UT100B under most flow conditions. The lower unit runoff at KC100A can be attributed to lower precipitation on the low-elevation terrain, and possibly to groundwater losses from the channel through the deep surficial materials.

6.1.5 Newhalen River

The Newhalen River flows in a southwesterly direction from Lake Clark into Iliamna Lake. The mouth of the river is located approximately 3 miles southwest of the town of Iliamna and 12 miles northeast of the mouth of Upper Talarik Creek. The watershed contains high mountains and glaciers. A large portion of the annual runoff occurs during the spring and summer period of snow and glacial melt. A secondary hydrograph peak occurs in response to frontal rainfall during the late summer and early autumn (typically August through October). Unlike the smaller watercourses draining the area around the deposit location (SK, NK, and UT), the Newhalen River lacks a distinct low flow period in the summer due to the effects of summer snow and glacier melt and storage in Lake Clarke and several other large lakes. Winter flows in the Newhalen River are fed by the upstream lakes and baseflows remain significant through the winter.

A USGS gaging station was operated on the Newhalen River between Lake Clark and Iliamna Lake from 1951 to 1986 (gage number 15300000). Station NH100-APC3 was established in spring 2008 at the historic USGS gage site, where the drainage area is 3,412 square miles. This drainage area value has been updated from the value published previously by the USGS to account for a change in drainage pattern in the Lake Clark Pass area due to glacier recession. The NH100-APC3 site is shown in Photos 56 and 57. Station NH100-APC2 was established approximately 8 miles downstream of NH100-APC3, just upstream of Petrof Falls, where the drainage area is approximately 3,451 square miles. The site is shown in Photos 58 and 59.

Three ADCP discharge measurements were collected at NH100-APC2 in 2008, and one was collected at NH100-APC3. The measurement information is presented in Tables 61 and 62, and the stage-discharge points are displayed on Figures 103 and 104. No rating curve has been developed for NH100-APC2. The stage-discharge point collected at NH100-APC3 has been overlain on the rating curve from the discontinued USGS station, and it lies right on the curve. However, it is not known if the old rating curve still describes the stage-discharge relationship at this site over the full range of flow conditions. As a result, the stage records collected at the two Newhalen River gages in 2008 have not been used to develop continuous hydrographs.

6.1.6 Streamflow Data for Historical Cominco Stations

Cominco field technicians collected both IQ and CQ measurements at four stream locations in the mine study area for various periods between 1991 and 1994. These stream locations are identified on Figure 1 as Stations 13, 16, 17, and 19. Stations 13 and 19 were located in the UT watershed, while stations 16 and 17 were located in the SK watershed. The Cominco stations were all located near current CQ stations. KPL received the raw Cominco data in 2004 and compiled the most complete rating curves and hydrographs possible from the limited data. Discharge measurement records for the four gaging stations are provided in Tables 63 through 66. Stage-discharge rating curves and daily discharge hydrographs for each station are presented on Figures 105 through 115. Monthly discharge summaries are provided in Table 67, along with mean monthly unit discharge from the most representative stations in the current gaging program for general comparative purposes.

The Cominco stations initially used float gages with strip charts, but these were later replaced with pressure transducers and dataloggers. Some gages were operated in the winter months, but discharge cannot be estimated for these periods because of the invalidity of stage-discharge rating curves in ice conditions. Several problems affected the recorded data within the ice-free season as well. Two strip-chart recorders were fitted with the wrong scale of graph paper and inappropriately sized drums, resulting in strip chart records that had little or no variation in stage height. These only captured events in which stage increased or decreased substantially. The pressure transducer records indicated instrument drift, so the datalogger records were adjusted to known IQ measurements taken manually at several times during the recording period.

The Cominco data are presented in the interest of providing the most complete dataset available for the mine study area, with the understanding that the 1991 through 1994 data were not collected to the same standards as the 2004 through 2008 data and are not believed to be as accurate or as useful for understanding the hydrologic regime in the study area.

6.1.6.1 Station 13

Station 13 was located on the main channel of UT, just upstream from the current location of UT100D and approximately 25 miles upstream of UT100-APC3. The creek at the gaging station drains approximately 12 square miles. A strip-chart stage recorder recorded data from August 27, 1991, until September 19, 1991, and from June 6, 1992, until October 14, 1992. A pressure transducer then recorded stage from October 6, 1993, until February 8, 1994. Stage data were affected by ice from November 1993 onward, thus no discharge could be calculated for this period. KPL reviewed the 14 IQ measurements taken during the period of 1991 through 1993 and developed a rating curve. The IQ measurements are listed in Table 63, and the rating curve is shown on Figures 105 and 106. The resulting daily hydrograph is shown on Figure 107, and corresponding monthly unit discharge values are summarized in Table 67.

Mean monthly unit discharge at UT100D (2004 through 2008) is also presented in Table 67 for comparison.

6.1.6.2 Station 16

Station 16 was located on the main channel of the SK, just upstream from the current location of SK100C and approximately 20 miles upstream of SK100A. The creek at the gaging station drains approximately 38 square miles. The six stage-discharge points measured in 1991 (one measurement) and 1993 (five measurements) were reviewed and used to develop a rating curve. A continuous gage measured stage at the station from July 1, 1993, to October 7, 1993. The IQ measurements are listed in Table 64, and the rating curve is shown on Figure 108. The resulting daily hydrograph is shown on Figure 109, and corresponding monthly unit discharge values are summarized in Table 67. Mean monthly unit discharge at SK100C (2004 through 2008) is also presented in Table 67 for comparison. Similar to Station SK100C, Station 16 went dry during the summer that it was gaged.

6.1.6.3 Station 17

Station 17 was located approximately 1 mile downstream from the outlet of Frying Pan Lake and Station SK100F, and approximately 28 miles upstream of SK100A. A datalogger recorded stage from August 28, 1991, until September 19, 1991, and from June 6, 1992, until October 14, 1992. The creek at the gaging station drains approximately 14 square miles. The 13 stage-discharge points measured in 1991 and 1992 were reviewed and used to develop a rating curve. The IQ measurements are listed in Table 65, and the rating curve is shown on Figures 110 and 111. The resulting daily hydrograph is shown on Figure 112, and corresponding monthly unit discharge values are summarized in Table 67. Mean monthly unit discharge at SK100F (2004-07) is also presented in Table 67 for comparison.

6.1.6.4 Station 19

Station 19 was located on the "Northeast Tributary of the Upper Talarik," near the location of Station UT135A. The tributary at the Cominco gaging station drains approximately 19 square miles. Dataloggers recorded stage from August 1, 1993, until September 9, 1994. The five stage-discharge points measured during 1993 were reviewed and used to develop a rating curve. The IQ measurements are listed in Table 66, and the rating curve is shown on Figures 113 and 114. The resulting daily hydrograph is shown on Figure 115, and corresponding monthly unit discharge values are summarized in Table 67. Mean monthly unit discharge at UT135A (2007 through 2008) is also presented in Table 67 for comparison.

6.2 Discussion

The following discussion summarizes the spatial and temporal patterns in streamflow that have been identified on a station-by-station basis in the previous section. Figures 126 through 135 present hydrographs of monthly unit runoff for various combinations of stations to illustrate the points discussed. The monthly discharge and unit runoff data for each station are provided in Table 7. The key patterns are as follows:

- The mean annual runoff at the USGS gages on the lower reaches of the SK, NK, and UT watersheds (Stations SK100B, NK100A, and UT100B, respectively) over the period of record was 2.6 to 2.8 cubic feet per second per square mile (cfs/mi^2). The mean annual runoff at the lone KC gage (KC100A) was 1.4 cfs/mi^2.

- These annual runoff rates translate to depths of 35 to 38 inches at the SK, NK, and UT gages, and 19 inches at the KC gage. By comparison, the mean annual precipitation at the Iliamna Airport during the study period was 25 inches.
- The Iliamna Airport is located on low elevation terrain near Iliamna Lake. This meteorological station is probably more representative of conditions in the KC basin, which lacks high elevation terrain, than in the SK, NK, and UT basins, which contain small mountains that rise over 2,500 feet above Iliamna Lake.
- Higher unit runoff was recorded in the upland tributary subcatchments of SK119A and NK119A, where mean annual runoff ranged from 3.2 to 3.4 cfs/mi^2, reflecting higher annual precipitation rates due to orographic influence.
- Anomalously high unit runoff was recorded in a tributary of UT (at UT119A), where groundwater crosses the surface-drainage divide and results in elevated flows in the receiving stream. Mean annual unit runoff was 6.8 cfs/mi^2 at UT119A, although it is potentially confusing to consider this in terms of runoff per unit area of surface drainage since most of the flow is contributed via subsurface pathways from outside the surface drainage basin. A large portion of the interbasin flow enters the stream in a localized geographic section of the tributary.
- Anomalously low unit runoff was recorded in the middle reach of SK, especially at SK100C (1.4 cfs/mi^2), where surface flow is lost to ground. Unit runoff is strongly dependent on the point of measurement along the middle reach of SK as subsurface flow re-emerges to the surface further downstream of SK100C.
- The streams in the study area experience distinct high-flow seasons in spring due to snowmelt and in autumn due to frequent frontal rainstorms.
- The period of record has included a range of hydrologic conditions, including large snowmelt freshets in 2006 and 2008, and a small snowmelt freshet in 2007.
- The average volume of runoff in the autumn rainstorm seasons exceeded the volume of runoff in the spring snowmelt seasons over the period of record. At most gaging stations, approximately 30 percent to 35 percent of the annual runoff occurred in the months of April through June, while 40 percent to 60 percent of the annual runoff occurred during the months of August through November.
- The duration of snowmelt is shorter than the rainstorm season, so average monthly flows at most gaging stations are highest in May, followed by September and October. Annual maximum daily and instantaneous flows have occurred in either season.
- In low-elevation catchments, snowmelt runoff typically starts in early to mid-April, flows rise rapidly to peak in late April or early May, then flows recede until the end of May. In higher-elevation catchments, the start of snowmelt is typically delayed until late April or early May, the freshet peak is delayed until mid- to late May, and the duration of the freshet is prolonged with flows receding until the end of June. The SK and NK watersheds contain more high-elevation terrain than the UT and KC, and so have correspondingly later and larger snowmelt freshets, in general. However, the headwater subcatchments of the SK and NK basins contain lower terrain

than some of the tributaries in the middle parts of the basins, which is reflected in the relatively muted snowmelt freshet characteristics at the upper mainstem stations (NK100C and SK100G).

- The spatial redistribution of snow by wind throughout the winter also plays a role in the local variability of snowmelt timing and magnitude. Winter winds are predominantly southeasterly, so snow accumulates preferentially in leeward areas on the northwestern sides of ridges.
- The rainy season is less well-defined than the snowmelt season, and the timing varies from year to year, but frequent rainstorms typically begin between mid-August and mid-September and taper off in November. The end of the rainy season is indistinct. Rainstorms occasionally occur in early December but are rare from late December onward through the rest of the winter.
- The timing of the rainstorm season is uniform within the study area in any given year, but local runoff responses vary because of orographic enhancement of precipitation in higher-elevation terrain and rain shadow effects in leeward areas situated northwest of high terrain.
- Daily and seasonal rainstorm runoff is also affected by catchment topography and depth and characteristics of surficial materials. Steep catchments with shallow depths of unconsolidated material generate greater and more rapid rainfall runoff (SK119A, SK124A, and NK119A).
- All streams in the study area experience their lowest flows in late winter, prior to the onset of snowmelt, and in mid- to late summer, prior to the onset of frequent rainstorms.
- Winter flows typically exhibit a steady decline from December to April, with extreme minimum flows occurring around late March to mid-April.
- Summer low flows typically occur between late July and early August. The duration of summer low-flow conditions in any given year depends on the timing of snowmelt hydrograph recession and the onset of autumn rains.
- Aquifers, lakes, and wetlands govern the magnitude of winter and summer baseflows. A large aquifer is located along the east side of the UT watershed between Stations UT100C2 and UT100B. Lakes and wetlands are located in the middle part of the SK watershed between SK100C and SK100G, in the lower part of the SK watershed between SK100A and SK100B, in the upper part of the NK watershed above NK100C, in the middle part of the UT watershed between UT100B and UT100D, and throughout the headwaters of the KC watershed upstream of KC100A.
- Unusually high baseflows are recorded at Station UT119A on UT tributary 1.190. The surface drainage area at the gage is approximately 4 square miles, but the creek also receives a substantial groundwater contribution from the SK basin. The valley of UT tributary 1.190 consists of an underfit, former meltwater channel that drained the SK basin during a period when the SK valley was dammed by a moraine. Subsequent landscape erosion and deposition have altered the surface topography and drainage divides, but the meltwater valley/channel continues to drain a substantial portion of groundwater flow from the middle part of the SK basin. Because of the groundwater influence from SK, UT119A has relatively high and constant flows.
- The average rate of groundwater transfer from SK to UT via UT Tributary 1.190 is approximately 22 cfs, which represents a loss of approximately 8 percent of the mean annual runoff from the SK watershed, as gaged near the watershed outlet at SK100A. At the USGS gaging station SK100B, the loss amounts to 10 percent of the mean annual runoff. The groundwater transfer into the UT watershed accounts for 10 percent of the average annual runoff at Station UT100B.

- Assuming that these groundwater transfers did not occur, the average annual runoff at SK100B would increase from 2.8 cfs/mi^2 to 3.1 cfs/mi^2. The average annual runoff at UT100B would decrease from 2.7 cfs/mi^2 to 2.4 cfs/mi^2. These artificial runoff values indicate that orographic effects and snow drifting, which would otherwise produce higher runoff rates in the SK basin, are almost equally counteracted by the interbasin groundwater transfer.
- Local losses and gains in surface flow along mainstem and tributary channels are associated with the characteristics of underlying surficial materials. The most notable losing reach occurs in the middle part of the SK watershed, where surface flows at Station SK100C always cease in the winter and often cease for part of the summer, while surface flows re-emerge in the channel downstream year-round.
- Surface flows in KC watershed are not consistent with an inter-basin transfer of flow from the SK watershed. The annual runoff at KC100A is consistent with expectations based on the surface drainage basin and precipitation rates recorded at the Iliamna Airport.

6.2.1 Regional Analysis of South Fork Koktuli River Basins

Monthly unit runoff hydrographs for the gaging stations in the SK watershed are presented on Figures 126 through 128.

Figure 126 presents the hydrographs for the four lowermost gages on the main SK channel: SK100A, SK100B, SK100B1, and SK100C. This figure illustrates the trend of increasing unit runoff in a downstream direction (from SK100C to SK100A) during months of low to moderate flow conditions. This is attributed to the passage of flows beneath the upstream gages through the deep surficial materials, and the upwelling of these flows into the channel further downstream. SK100B has the highest unit runoff in the spring and autumn months of high flow conditions because it is situated downstream of the main upwelling reach, but upstream of the broad lowlands of the lower SK watershed where precipitation and snowmelt are less substantial than in the upper part of the watershed.

Figure 127 presents the hydrographs for four gages on the main SK channel that bracket the lake and wetlands in the middle part of the watershed: SK100B, SK100C, SK100F, and SK100G. This figure illustrates the trend of decreasing unit runoff in a downstream direction from SK100G to SK100C, which is attributed to the loss of surface flow to groundwater. The SK100B hydrograph illustrates the re-emergence of upwelling groundwater to the surface. The mean annual unit runoff at SK100G and SK100B are both approximately 2.7 cfs/mi^2, as shown in Table 7. The mean annual unit runoff at SK100C is only 1.4 cfs/mi^2, suggesting that up to 50 percent of the expected surface flow at SK100C bypasses the gage via subsurface flow.

Figure 128 presents the hydrographs for SK100B and the three upland tributaries in the SK and NK watersheds: SK119A, SK124A, and NK119A. SK119A records the highest unit runoff during the snowmelt and rainstorm seasons, which is attributed to its steep catchment, full exposure to incoming storms, and lack of surface flow losses to ground in its lower reaches. High flows at SK119A are likely overestimated because of rating curve uncertainties, which may exaggerate the differences between SK119A and the other gages. SK124A has similar catchment characteristics to SK119A except that a portion of the surface flow is lost to ground in the lower reaches, upstream of SK124A. This partially accounts for the lower unit runoff in SK124A as compared to SK119A. Unit runoff tends to be greater at all three tributary gages than at SK100B in the high flow months, and lower in the baseflow-dominated months. This reflects the greater amount of precipitation in the higher terrain of the tributary catchments, the more rapid runoff from the steep terrain with shallow cover of surficial materials, and the relative lack of storage to sustain baseflows. However, it is important to note the significant influence of surface flow losses to ground at SK124A, which indicates that local exchanges between surface and subsurface flow can overwhelm the influence of catchment characteristics on flow conditions.

6.2.2 Regional Analysis of North Fork Koktuli River Basins

Monthly unit runoff hydrographs for the gaging stations in the NK watershed are presented on Figures 129 and 130. The NK119A hydrograph was also compared to similar upland tributary gages in the SK watershed on Figure 128, as discussed in the previous section.

Figure 129 presents the hydrographs for the four stations on the NK mainstem: NK100A, NK100A1, NK100B, and NK100C. The catchment above NK100C consists of moderate elevation terrain with abundant wetlands. As a result, unit runoff at NK100C is generally lower than at the downstream gages, except in winter when the wetlands sustain baseflows. Downstream of NK100C, unit runoff tends to increase, primarily in the spring and autumn high flow seasons, due to inflows from the higher elevation terrain along the sides of the middle NK basin.

Figure 130 presents the hydrographs for NK100A and the two gages on upland tributaries: NK119A and NK119B. NK119A records substantially higher unit runoff than NK100A during the snowmelt and rainstorms seasons, and lower unit runoff during the winter baseflow period, due to the higher annual precipitation and lack of storage features in the upland subcatchment above NK119A. NK119B records lower unit runoff than NK100A or NK119A due to its lower elevation subcatchment and a rain shadow effect caused by high terrain to the east.

6.2.3 Regional Analysis of Upper Talarik Creek Basins

Monthly unit runoff hydrographs for the gaging stations in the UT watershed are presented on Figures 131 to 134.

Figure 131 shows the hydrographs of UT100B and the three mainstem gages located downstream of UT100B: UT100-APC1, UT100-APC2, and UT100-APC3. The unit runoff at these four gages is similar in all seasons.

Figure 132 compares the hydrographs of UT100B and the three mainstem gages located in the middle part of the UT mainstem: UT100C, UT100C1, and UT100C2. Unit discharge increases in the downstream direction along this reach, due to surface flow gains from the aquifer along the east side of the UT basin, and the interbasin groundwater transfer from the SK basin to the west via UT tributary 1.190.

Figure 133 presents a comparison of the UT100B, UT100D, and UT100E hydrographs. The aquifer and wetland storage and the potential interbasin groundwater transfers upstream of UT100E result in similar baseflow unit runoff compared to UT100B. Station UT100D has lower unit runoff during baseflow periods due to the lower abundance of such features between UT100E and UT100D.

Figure 134 presents the hydrographs recorded at the UT tributary gages and at UT100B. The hydrograph for UT119A stands out because of its high unit runoff and muted seasonal variability. The mean annual unit runoff at UT119A is 6.8 cfs/mi^2, or approximately 2.7 times greater than NK100A, SK100A, or UT100B. The high runoff at UT119A is sustained by subsurface flow transfer from the SK watershed at a steady rate of around 22 cfs, which equates to a unit runoff of 5.4 cfs/mi^2 at UT119A. The muted seasonal fluctuations above this baseflow rate are generated from the low-elevation catchment, which has gentle terrain and a deep cover of permeable surficial materials. The hydrograph at UT135A shows a similar pattern to UT100B, but with consistently lower unit runoff in all seasons. This may be explained by the moderate elevation terrain and potential interbasin transfers of groundwater out of the basin.

6.2.4 Regional Analysis of Kaskanak Creek Basin

The monthly unit runoff hydrograph for KC100A is compared to UT100B and UT119A on Figure 135. Similar to UT119A, the KC100A hydrograph exhibits a pattern of steady baseflows and muted seasonal variability. The main difference is the much lower unit runoff at KC100A. This is likely because of the low elevation, gentle terrain and deep surficial materials in the KC100A catchment, and the apparent lack of subsurface flow transfer from the SK watershed. The mean annual unit runoff at KC100A is consistent with expectations based on the precipitation record at the Iliamna Airport.

7. SUMMARY

This report presents a summary of the hydrologic data collected from 29 continuous streamflow gaging stations currently or recently operated within the mine study area on behalf of Pebble Partnership, and four historical gaging stations operated by Cominco from 1991 until 1994. The Pebble Partnership stations are located in five watersheds in the general vicinity of the Pebble Deposit: the SK (eight gages), NK (six gages), UT (12 gages), KC (one gage), and NH (two gages). The SK, NK, and UT watersheds each contain one gage that is operated year-round by the USGS. The remaining 26 Pebble Partnership gages were established and operated by consultants contracted to Pebble Partnership. The historical gages were located in the SK and UT watersheds, with two gages in each watershed.

The 26 gages operated by Pebble Project contractors were maintained with a similar level of effort as the USGS gages. Over 40 instantaneous discharge measurements have been collected at each of the Pebble Partnership-operated gages installed in 2004, as compared to 29 to 33 at the USGS gages. The Pebble Partnership gages were operated only during non-freeze months, typically from May through October, but instantaneous discharge measurements were collected throughout the winter. USGS personnel use expert judgment to estimate winter flows at their gages, since standard rating-curve techniques are not applicable under ice conditions. Winter flows at the Pebble Partnership-operated gages were estimated by comparing instantaneous winter discharge measurements to the USGS winter hydrographs and applying regression-based transfer functions.

Quality assurance procedures were followed at the Pebble Partnership-operated gages to provide checks on the recorded stage data and the instantaneous discharge measurements. The average stage error identified by regular manual staff gage readings was typically 0.01 to 0.02 feet. The exceptions were UT119A and SK100F. The water surface is always wavy at UT119A, and the average error was 0.04 feet. The average error at SK100F was 0.05 feet, but a drift pattern was identified in 2004 and 2005 and has since been compensated. Most discharge measurements were made by the area-velocity method, but the salt-dilution method was applied at sites with shallow and/or highly turbulent flow – primarily NK119A, UT100E, and UT119A. A series of replicate discharge measurements resulted in an average error of 2.3 percent for 113 area-velocity replicates, 7.7 percent for 91 salt-dilution replicates, and 3.6 percent for 4 ADCP replicates. The average error between 61 concurrent area-velocity and salt-dilution measurements was 4.9 percent.

Stage-discharge rating curves were developed for each gaging station, and the reliability of curve extrapolation to estimate high flows was carefully considered. The steep upland tributaries gaged by SK119A, SK124A, and NK119A experience flashy runoff in which flows greatly exceed those that have been measured manually. It is likely that overhanging vegetation impedes channel flows during high flow conditions, and that the extrapolated rating curves at these stations somewhat overestimate high flow values based on recorded stage. The average rating curve error at each station – which represents the error between the rating curve and individual instantaneous stage-discharge measurements – was typically 10 percent or less. The exceptions were SK100F, where beavers have caused irregularly fluctuating water levels; SK100G, where variable lake levels and a recent bank collapse have resulted in variable stage-discharge relations; NK100A (a USGS station), where a stage-discharge shift appears to have occurred but has not been reflected by a rating curve shift; and NK119B, which has a steep, narrow channel with rough bed material. At other stations, occasional discrete shifts in stage-discharge relations have been identified requiring the development of multiple rating curves. The USGS has developed two rating curves each for SK100B and UT100B, and their third station (NK100A) may require a new curve, as mentioned above. The Pebble Partnership-operated gages have required between one and four rating curves each over the study period.

The current gaging program began in 2004 and has now recorded four complete water years of streamflow results from October 2004 through September 2008. The key findings of this report are summarized as follows:

- The mean annual runoff at the USGS gages on the lower reaches of the SK, NK, and UT basins (Stations SK100B, NK100A, and UT100B, respectively) was 2.6 to 2.8 cfs/mi^2 over the period of record. Elsewhere, annual unit runoff varied from gage to gage because of catchment topography and precipitation, surface and subsurface flow exchanges along stream channels, and interbasin transfers of groundwater.
- The annual hydrographs for each gage show that large portions of the annual runoff occurred during the spring snowmelt period (30 percent to 35 percent of the annual runoff volume) and during frontal rainstorms in the late summer and autumn (40 percent to 60 percent of the annual runoff volume).
- Groundwater plays a prominent role in the flow patterns of all the creeks and rivers that were studied, but its role was especially notable at SK100C, which goes dry seasonally because of upstream losses of surface flow to groundwater, and at UT119A, which gains substantial flow from the SK to the extent that its hydrograph is dominated by baseflow.
- The highest mean annual unit runoff value was recorded at UT119A (6.8 cfs/mi^2) because of the groundwater transfer from the SK basin. An anomalously low mean annual unit runoff value was recorded at SK100C (1.4 cfs/mi^2) due to upstream losses of groundwater to the UT watershed,

and the bypassing of additional groundwater beneath the gage prior to upwelling into the channel further downstream.

- High annual unit runoff values were recorded at SK119A (3.4 cfs/mi^2) and NK119A (3.2 cfs/mi^2) because of the high catchment elevations and orographic enhancement of precipitation. SK124A recorded considerably lower annual unit runoff (around 2.3 cfs/mi^2), despite having similar basin characteristics because of losses of surface flow to ground just upstream of the gage.
- The low annual unit runoff value recorded at KC100A (1.4 cfs/mi^2) was due to the low elevation of the gage drainage basin and is consistent with expectations based on the precipitation record at the Iliamna Airport.

8. REFERENCES

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TABLES

TABLE 1
Basin and Channel Characteristics at Pebble Partnership and USGS Streamflow Gaging Stations

Watershed	Station [a]	Period of Record	No. of Complete Water Years	Drainage Basin Characteristics				Channel Characteristics		
				Basin Area (mi^2)	Lake & Pond Area	Mean Basin Elev. (ft.)	Mean Basin Slope	Bankfull Width (ft.)	Bankfull Width/Depth	Channel Slope
South Fork Koktuli River	SK100A	2004-07	3	106.92	1.74%	1,115	11.8%	110	37	0.2%
	SK100B	2004-08	4	69.33	1.67%	1,255	15.5%	115	83	0.3%
	SK100B1	2006-07	2	54.41	1.59%	1,290	15.8%	71	24	0.06%
	SK100C	2004-08	4	37.50	2.20%	1,230	14.8%	32	7	0.2%
	SK100F	2004-07	3	11.91	4.16%	1,270	13.7%	42	20	0.2%
	SK100G	2004-07	3	5.49	3.83%	1,200	10.6%	19	5	0.05%
	SK119A	2004-08	4	10.73	0.03%	1,575	19.4%	33	17	0.2%
	SK124A	2005-08	4	8.52	0.12%	1,460	20.5%	17	6	0.2%
North Fork Koktuli River	NK100A	2004-08	4	105.86	1.71%	1,280	9.2%	75	37	0.8%
	NK100A1	2007-08	2	85.34	2.02%	1,340	13.0%	90	32	0.1%
	NK100B	2007-08	2	37.32	3.30%	1,420	11.2%	51	19	0.6%
	NK100C	2004-08	4	24.35	4.96%	1,360	7.4%	37	14	0.4%
	NK119A	2004-08	4	7.76	0.02%	1,645	14.3%	23	9	3.0%
	NK119B	2007-08	2	3.97	0.48%	1,430	11.0%	5	3	2.0%
Upper Talarik Creek	UT100-APC3	2007-08	1	134.16	1.65%	1,013	14.9%	101	49	0.3%
	UT100-APC2	2007-08	1	110.16	1.62%	965	14.3%	77	22	0.3%
	UT100-APC1	2007-08	1	101.51	1.72%	881	11.0%	81	38	0.2%
	UT100B	2004-08	4	86.24	1.77%	1,055	11.1%	55	20	
	UT100C	2007-08	2	69.47	1.92%	1,130	15.1%	71	36	0.2%
	UT100C1	2007-08	2	60.37	1.87%	1,170	14.7%	50	18	0.3%
	UT100C2	2007-08	2	48.26	2.14%	1,210	13.8%	50	20	0.2%
	UT100D	2004-08	4	11.96	1.08%	1,110	10.1%	24	11	0.05%
	UT100E	2004-08	4	3.10	0.98%	1,225	8.7%	15	9	0.3%
	UT106-APC1	2008	0	14.14	1.53%	713	13.1%	35	31	1.2%
	UT119A	2004-08	4	4.05	2.13%	882	8.8%	20	17	2.0%
	UT135A	2007-08	2	20.42	3.60%	1,170	12.9%	37	10	0.1%
Kaskanak Creek	KC100A	2004-08	4	25.64	6.23%	605	4.3%	21	9	0.1%
Newhalen River	NH100-APC2	2008	0	3451						
	NH100-APC3	2008	0	3412						

TABLE 2
Streamflow Gaging Summary by Watershed and Year

Watershed	Year	No. of Stations Continuous	Instantaneous	Total
South Fork Koktuli River	2004	6	7	13
	2005	7	7	14
	2006	8	7	15
	2007	8	7	15
	2008	4	13	17
North Fork Koktuli River	2004	3	2	5
	2005	3	2	5
	2006	3	2	5
	2007	6	0	6
	2008	6	0	6
Koktuli River Main	2004	0	1	1
	2005	0	1	1
	2006	0	1	1
	2007	0	1	1
	2008	0	1	1
Upper Talarik Creek	2004	4	7	11
	2005	4	7	11
	2006	4	9	13
	2007	11	5	16
	2008	12	5	17
Kaskanak Creek	2004	1	0	1
	2005	1	0	1
	2006	1	0	1
	2007	1	0	1
	2008	1	0	1
Newhalen River	2004	0	0	0
	2005	0	0	0
	2006	0	0	0
	2007	0	0	0
	2008	2	0	2
TOTALS	2004	**14**	**17**	**31**
	2005	**14**	**17**	**31**
	2006	**16**	**19**	**35**
	2007	**26**	**13**	**39**
	2008	**25**	**19**	**44**

TABLE 3
Basin Area at Historical Streamflow Gaging Stations

Watershed	Station	Period of Record	Basin Area (mi^2)
South Fork Koktuli River	16	1993	38.1
	17	1991-92	14.1
Upper Talarik Creek	13	1991-93	11.9
	19	1993-94	18.6

TABLE 4
Quality Assurance Results for Stage Records

			Manual Stage Checks [a,b,c]		Annual Surveys to Benchmarks [d]														
					Staff Gage Error (ft.)					Transducer Error (ft.)					Net Error (ft.) [e]				
Watershed	Station	Start Date	Total (no.)	Average Error (ft.)	2004	2005	2006	2007	2008	2004	2005	2006	2007	2008	2004	2005	2006	2007	2008
South Fork Koktuli River	SK100A	12-Jul-04	20	0.02	-	0.01	0.02	0.00	-	-	0.01	0.01	0.00		-	0.01	0.03	0.00	
	SK100B	25-Aug-04	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	SK100B1	23-Apr-06	19	0.02	-	-	0.03	0.15	-	-	-	0.03	0.16	-	-	-	0.00	0.01	-
	SK100C	10-Jul-04	25	0.01	0.01	0.02	0.00	0.07	0.00	-	0.00	0.00	0.05	0.01	-	0.02	0.00	0.02	0.01
	SK100F	14-Jul-04	22	0.05	-	0.06	0.01	0.00	-	-	0.02	0.00	0.01	-	-	0.05	0.01	0.01	-
	SK100G	11-Jul-04	25	0.02	-	0.11	0.03	0.03	-	-	0.11	0.00	0.03	-	-	0.02	0.03	0.00	-
	SK119A	11-Jul-04	27	0.03	0.10	0.02	0.00	0.01	0.01	-	0.10	0.01	0.02	0.00	-	0.10	0.01	0.01	0.01
	SK124A	6-Jun-05	27	0.03	-	0.02	0.01	0.00	0.01	-	0.04	0.34	0.00	0.01	-	0.03	0.33	0.00	0.02
North Fork Koktuli River	NK100A	25-Aug-04	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	NK100A1	17-May-07	13	0.01	-	-	-	0.22	0.02	-	-	-	0.01	0.04	-	-	-	0.21	0.02
	NK100B	17-May-07	14	0.02	-	-	-	0.01	0.01	-	-	-	0.00	0.01	-	-	-	0.01	0.00
	NK100C	11-Jul-04	22	0.01	0.00	0.05	-	-	-	-	0.06	-	-	-	-	0.03	-	-	-
	NK119A	11-Jul-04	22	0.02	0.06	0.01	-	0.01	0.04	-	0.02	-	0.01	0.03	-	0.01	-	0.00	0.01
	NK119B	16-Jun-07	9	0.04	-	-	-	0.04	0.01	-	-	-	0.01	0.02	-	-	-	0.05	0.01
Upper Talarik Creek	UT100-APC3	21-Aug-07	10	0.01	-	-	-	0.01	-	-	-	-	0.00	-	-	-	-	0.01	-
	UT100-APC2	21-Aug-07	11	0.03	-	-	-	0.11	0.07	-	-	-	0.04	0.00	-	-	-	0.15	0.07
	UT100-APC1	20-Aug-07	18	0.02	-	-	-	0.00	0.03	-	-	-	0.06	0.06	-	-	-	0.06	0.09
	UT100B	25-Aug-04	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	UT100C	24-Apr-07	12	0.03	-	-	-	0.00	0.02	-	-	-	0.00	0.03	-	-	-	0.00	0.01
	UT100C1	16-May-07	10	0.02	-	-	-	0.00	0.00	-	-	-	0.01	0.01	-	-	-	0.00	0.01
	UT100C2	16-May-07	11	0.01	-	-	-	0.07	0.03	-	-	-	0.03	0.03	-	-	-	0.04	0.00
	UT100D	12-Jul-04	22	0.02	0.02	0.13	0.06	0.06	0.19	-	0.14	1.29	0.06	0.18	-	0.08	1.23	0.00	0.01
	UT100E	12-Jul-04	24	0.01	0.04	0.01	-	0.01	0.02	-	0.01	-	0.02	0.31	-	0.01	-	0.01	0.33
	UT106-APC1	15-May-08	8	0.02	-	-	-	-	0.45	-	-	-	-	0.38	-	-	-	-	0.07
	UT119A	12-Jul-04	25	0.04	0.02	0.03	0.00	0.07	0.01	-	0.05	0.03	0.04	0.00	-	0.03	0.03	0.03	0.01
	UT135A	16-May-07	11	0.02	-	-	-	0.36	0.29	-	-	-	0.29	0.05	-	-	-	0.07	0.24
Kaskanak Creek	KC100A	10-Jul-04	20	0.02	0.01	0.11	0.00	0.00	0.01	-	0.49	0.01	0.01	0.01	-	0.38	0.01	0.01	0.01
Newhalen River	NH100-APC2	16-May-08	5	0.03	-	-	-	-	0.02	-	-	-	-	0.03	-	-	-	-	0.05
	NH100-APC3	19-Aug-08	2	0.01	-	-	-	-	0.07	-	-	-	-	0.08	-	-	-	-	0.15

Notes:

a. Manual stage checks are comparisons of instantaneous staff gage readings or water level surveys to concurrent stage readings on a station datalogger. A single error value corresponds to the difference between a manual reading and the simultaneous reading on the datalogger.

b. Manual stage checks include readings at the time of datum calibration (i.e. when the error is forced to 0.00 ft as the datalogger is programmed).

c. Manual stage check errors refer to errors prior to drift adjustments of data (NK119B, SK100F, SK100G, and SK119A).

d. Annually surveyed staff gage and transducer errors represent the range of surveyed elevations to top of staff gage plate and transducer bolt, respectively, over the course of a monitoring season (typically May through October).

e. Net errors for the annual benchmark surveys represent the range in surveyed elevation differences between staff gage and transducer over the course of a monitoring season.

TABLE 5
Stage-Discharge Rating Curve Summary

Watershed	Station	IQ Measurements [a, b] Total (no.)	IQ Measurements [a, b] Rating Curve (no.)	Rating Curves No. of Curves	Rating Curves Average Error	Max. Recorded Stage Relative to Bankfull (ft.)
South Fork Koktuli River	SK100A	32	18	2	6.8%	1.0
	SK100B	33	21	2	4.9%	-
	SK100B1	29	16	3	3.9%	1.3
	SK100C	47	21	1	7.8%	0.2
	SK100F	39	20	1	21.2%	-0.1
	SK100G	38	21	2	15.4%	1.4
	SK119A	46	21	3	5.7%	2.0
	SK124A	35	19	4	7.2%	1.0
North Fork Koktuli River	NK100A	29	21	1	11.1%	-
	NK100A1	23	9	1	3.9%	0.9
	NK100B	44	9	1	2.7%	0.7
	NK100C	49	20	1	7.4%	0.1
	NK119A	76	31	1	9.6%	1.8
	NK119B	32	6	1	13.9%	0.8
Upper Talarik Creek	UT100-APC3	16	6	1	6.7%	1.1
	UT100-APC2	15	5	1	3.0%	-0.1
	UT100-APC1	16	7	1	5.7%	0.8
	UT100B	33	22	2	9.2%	-
	UT100C	24	12	2	5.2%	0.1
	UT100C1	25	11	1	5.2%	0.2
	UT100C2	23	11	1	3.0%	0.7
	UT100D	50	22	4	6.7%	1.2
	UT100E	79	29	2	8.4%	0.1
	UT106-APC1	7	-	-	-	-0.1
	UT119A	82	37	2	7.4%	-0.2
	UT135A	43	-	-	-	-
Kaskanak Creek	KC100A	44	24	2	9.2%	2.0
Newhalen River	NH100-APC2	3	-	-	-	-
	NH100-APC3	1	-	-	-	-

Notes:
a. IQ measurments are manually measured instantaneous discharge measurements.
b. Concurrent area-velocity and salt-dilution discharge measurements are both counted as separate measurements.

TABLE 6
Quality Assurance Results for Discharge Measurements

Watershed	Station	Area-Velocity Replicates [a, b] No.	Area-Velocity Replicates [a, b] Avg. Error	Salt-Dilution Replicates [c] No.	Salt-Dilution Replicates [c] Avg. Error	ADCP Replicates No.	ADCP Replicates Avg. Error	Technique Comparisons No.	Technique Comparisons Avg. Error
South Fork Koktuli River	SK100A	1	1.9%	-	-	-	-	-	-
	SK100B	-	-	-	-	-	-	-	-
	SK100B1	3	1.5%	-	-	-	-	-	-
	SK100C	-	-	-	-	-	-	-	-
	SK100F	7	2.9%	1	8.1%	-	-	1	4.4%
	SK100G	2	3.7%	-	-	-	-	-	-
	SK119A	5	1.8%	-	-	-	-	-	-
	SK124A	4	0.7%	1	7.6%	-	-	1	2.6%
North Fork Koktuli River	NK100A1	1	0.5%	-	-	-	-	-	-
	NK100A	-	-	-	-	-	-	-	-
	NK100B	1	0.1%	-	-	-	-	-	-
	NK100C	4	3.3%	-	-	-	-	-	-
	NK119A	21	2.8%	30	8.5%	-	-	17	5.0%
	NK119B	4	5.0%	-	-	-	-	-	-
Upper Talarik Creek	UT100-APC3	-	-	-	-	-	-	-	-
	UT100-APC2	-	-	-	-	-	-	-	-
	UT100-APC1	-	-	-	-	-	-	-	-
	UT100B	5	2.3%	-	-	-	-	-	-
	UT100C	3	3.9%	-	-	-	-	-	-
	UT100C1	4	0.9%	-	-	-	-	-	-
	UT100C2	2	2.6%	-	-	-	-	-	-
	UT100D	1	2.1%	-	-	-	-	-	-
	UT100E	20	2.4%	30	7.5%	-	-	18	7.1%
	UT106-APC1	-	-	-	-	-	-	-	-
	UT119A	19	2.8%	29	6.9%	-	-	24	5.7%
	UT135A	-	-	-	-	-	-	-	-
Kaskanak Creek	KC100A	6	3.3%	-	-	-	-	-	-
Newhalen River	NH100-APC2	-	-	-	-	3	3.2%	-	-
	NH100-APC3	-	-	-	-	1	4.0%	-	-
All Stations		113	2.3%	91	7.7%	4	3.6%	61	4.9%

Notes:

a. SK100F, 11/1/2006: Duplicate area-velocity measurements not used, error > 50%. Anchor ice along left bank, ice broken up to take IQ measurements, SG differs by 0.27 ft between measurements.

b. SK00G, 9/16/2007: Duplicate area-velocity measurements not used, error > 50%. First measurement affected by aquatic vegetation, second measurement (higher discharge) was taken in different section lacking vegetation.

c. UT100E, 2/20/2007: Duplicate salt-dilution measurements not used, error > 50%. Salt dilution affected by ice dam release and calibration problems. Run #2 considered better measurement and closer to simultaneous current meter value.

TABLE 7
Annual Discharge Summary

Watershed	Station	Basin Area (mi^2)	Annual Discharge by Water Year (cfs) [a]					Annual Unit Runoff by Water Year (cfs/mi^2)				
			2004-05	2005-06	2006-07	2007-08	Mean	2004-05	2005-06	2006-07	2007-08	Mean
South Fork Koktuli River	SK100A	106.92	306.5	282.4	218.9	-	269.3	2.87	2.64	2.05	-	2.52
	SK100B	69.33	229.0	190.0	145.4	199.7	191.0	3.30	2.74	2.10	2.88	2.76
	SK100B1	54.41	-	128.7	97.4	-	113.0	-	2.36	1.79	-	2.08
	SK100C	37.50	68.2	50.8	33.6	56.2	52.2	1.82	1.35	0.90	1.50	1.39
	SK100F	11.91	32.3	29.0	22.9	-	28.1	2.71	2.44	1.92	-	2.36
	SK100G	5.49	17.4	14.1	12.6	-	14.7	3.17	2.57	2.30	-	2.68
	SK119A	10.73	48.9	35.3	26.6	36.8	36.9	4.56	3.29	2.48	3.43	3.44
	SK124A	8.52	25.3	18.5	14.8	20.6	19.8	2.97	2.17	1.74	2.41	2.32
North Fork Koktuli River	NK100A	105.86	316.5	262.6	201.8	300.4	270.3	2.99	2.48	1.91	2.84	2.55
	NK100A1	85.34	-	-	172.3	235.4	203.8	-	-	2.02	2.76	2.39
	NK100B	37.32	-	-	68.9	103.2	86.0	-	-	1.85	2.77	2.31
	NK100C	24.35	60.8	50.9	39.8	58.0	52.4	2.50	2.09	1.64	2.38	2.15
	NK119A	7.76	32.1	22.0	20.0	24.2	24.6	4.13	2.84	2.58	3.11	3.17
	NK119B	3.97	-	-	3.5	6.1	4.8	-	-	0.88	1.53	1.21
Upper Talarik Creek	UT100-APC3	134.16	-	-	-	382.3	382.3	-	-	-	2.85	2.85
	UT100-APC2	110.16	-	-	-	316.9	316.9	-	-	-	2.88	2.88
	UT100-APC1	101.51	-	-	-	291.8	291.8	-	-	-	2.87	2.87
	UT100B	86.24	242.6	243.2	190.0	251.0	231.7	2.81	2.82	2.20	2.91	2.69
	UT100C	69.47	-	-	140.5	184.3	162.4	-	-	2.02	2.65	2.34
	UT100C1	60.37	-	-	103.1	143.5	123.3	-	-	1.71	2.38	2.04
	UT100C2	48.26	-	-	92.6	121.8	107.2	-	-	1.92	2.52	2.22
	UT100D	11.96	30.2	31.5	24.0	32.2	29.5	2.53	2.64	2.01	2.69	2.47
	UT100E	3.10	10.0	10.6	8.6	11.3	10.1	3.22	3.43	2.78	3.66	3.27
	UT106-APC1	14.14	-	-	-	-	-	-	-	-	-	-
	UT119A	4.05	28.9	28.2	25.5	27.0	27.4	7.15	6.97	6.29	6.67	6.77
	UT135A	20.42	-	-	34.6	47.9	41.2	-	-	1.70	2.34	2.02
Kaskanak Creek	KC100A	25.64	37.2	40.4	34.9	31.9	36.1	1.45	1.57	1.36	1.24	1.41
Newhalen River	NH100-APC2	3451	-	-	-	-	-	-	-	-	-	-
	NH100-APC3	3412	-	-	-	-	-	-	-	-	-	-

Note:
a. The annual average discharges for USGS gaging stations (SK100B, NK100A and UT100B) presented above are based on published daily data.

TABLE 8
SK100A Discharge Measurement Record

Date	Time	Stage (ft)	Measured Discharge (cfs) [a]	Rating Curve Discharge (cfs)	Rating Curve Error	Notes
28-Apr-04	12:01	-	*329.4*	-	-	-
15-Jun-04	13:00	-	*272.8*	-	-	-
14-Jul-04	9:30	97.86	131.6	123.0	6.7%	-
24-Aug-04	9:40	97.71	86.9	91.9	5.5%	-
14-Sep-04	8:55	97.63	84.9	76.8	9.9%	-
17-Oct-04	11:00	98.54	341.7	309.1	10.0%	-
28-Jan-05	16:20	-	*147.6*	-	-	-
19-Mar-05	10:00	-	*125.0*	-	-	-
2-Jun-05	17:17	98.87	476.7	423.7	11.8%	-
9-Jul-05	10:00	98.13	180.1	188.5	4.6%	-
17-Aug-05	12:48	97.95	125.6	143.6	13.3%	-
16-Sep-05	12:10	100.14	993.6	1035.6	4.1%	Bankfull stage.
29-Oct-05	15:50	98.51	306.5	299.4	2.3%	Beaver influence upstream.
8-Feb-06	10:25	-	*76.4*	-	-	-
14-Mar-06	16:00	-	*83.7*	-	-	-
4-Apr-06	9:40	-	*79.7*	-	-	-
20-May-06	14:55	99.06	529.2	536.6	1.4%	Ice-free conditions; small side channel bypasses gage.
18-Jun-06	9:35	98.70	419.2	398.1	5.2%	-
22-Jul-06	9:34	97.95	151.9	167.9	10.0%	-
17-Aug-06	11:08	99.27	603.5	625.7	3.6%	-
13-Sep-06	10:40	98.53	370.3	338.9	8.9%	-
31-Oct-06	11:18	98.61	388.3	366.3	5.8%	-
10-Dec-06	11:08	-	*166.2*	-	-	-
15-Jan-07	13:30	-	*89.2*	-	-	-
17-Feb-07	10:50	-	*120.4*	-	-	-
15-Mar-07	11:15	-	*51.6*	-	-	-
31-Mar-07	9:55	-	*69.0*	-	-	-
20-Apr-07	15:30	-	*188.9*	-	-	-
16-Jun-07	14:00	97.94	174.1	165.4	5.2%	-
12-Jul-07	11:10	97.77	135.8	125.3	8.1%	-
13-Oct-07	10:50	98.80	463.2	434.9	6.3%	-
8-Dec-07	11:20	*98.31*	*360.4*	-	-	-
				Average	6.8%	

Note:

a. Italicized values were not used in rating curve development.

TABLE 9
SK100A Monthly Discharge Summary

	Monthly Discharge (cfs)						Monthly Unit Runoff (cfs/mi^2)					
Month	**2003-04**	**2004-05**	**2005-06**	**2006-07**	**2007-08**	**Mean**	**2003-04**	**2004-05**	**2005-06**	**2006-07**	**2007-08**	**Mean**
Oct		435.5	367.2	599.4		467.4		4.07	3.43	5.61		4.37
Nov		337.2	214.3	191.4		247.6		3.15	2.00	1.79		2.32
Dec		237.1	208.3	144.1		196.5		2.22	1.95	1.35		1.84
Jan		163.4	127.9	112.1		134.5		1.53	1.20	1.05		1.26
Feb		133.1	103.8	100.7		112.5		1.24	0.97	0.94		1.05
Mar		110.1	86.1	73.9		90.0		1.03	0.80	0.69		0.84
Apr		211.3	84.9	159.8		152.0		1.98	0.79	1.49		1.42
May		760.5	678.4	329.6		589.5		7.11	6.35	3.08		5.51
Jun		302.1	376.1	194.3		290.8		2.83	3.52	1.82		2.72
Jul		188.7	200.0	134.2		174.3		1.76	1.87	1.26		1.63
Aug	106.6	207.1	483.5	120.6		229.5	1.00	1.94	4.52	1.13		2.15
Sep	146.4	581.3	441.0	459.5		407.0	1.37	5.44	4.12	4.30		3.81
Mean		306.5	282.4	218.9		269.3		2.87	2.64	2.05		2.52

TABLE 10
SK100B Discharge Measurement Record

Date	Time	Stage (ft)	Measured Discharge (cfs) [a]	Rating Curve Discharge (cfs)	Rating Curve Error	Notes
25-Aug-04	9:35	17.13	45.0	46.8	4.0%	-
13-Sep-04	12:40	17.06	37.8	38.9	2.9%	-
18-Oct-04	17:00	17.89	222.0	215.3	3.1%	-
28-Oct-04	12:35	18.48	488.0	490.3	0.5%	-
2-Feb-05	16:50	19.45	*130.0*	-	-	-
3-Feb-05	13:15	19.33	*81.1*	-	-	-
6-Mar-05	16:05	17.19	*52.0*	-	-	-
27-Apr-05	11:09	17.81	*172.0*	-	-	-
25-May-05	12:50	18.56	526.0	540.1	2.6%	-
20-Jul-05	14:45	17.54	113.0	116.6	3.1%	-
12-Aug-05	9:50	17.26	66.0	64.4	2.4%	-
6-Oct-05	12:05	18.03	284.0	267.0	6.2%	-
9-Dec-05	11:30	18.04	*294.0*	-	-	-
20-Feb-06	17:00	17.14	*49.0*	-	-	-
16-May-06	9:10	17.98	266.0	247.7	7.1%	-
20-Jun-06	11:52	18.04	222.0	220.0	0.9%	-
14-Aug-06	17:00	18.85	497.0	502.3	1.1%	-
4-Oct-06	11:55	18.66	432.0	424.9	1.7%	-
26-Oct-06	10:23	18.24	279.0	278.3	0.3%	-
5-Dec-06	13:00	19.28	*79.0*	-	-	-
13-Feb-07	13:27	17.14	*45.8*	-	-	-
3-Apr-07	13:39	17.23	*26.7*	-	-	-
15-May-07	16:30	18.06	268.0	225.5	17.2%	-
26-Jun-07	10:30	17.59	138.0	115.3	18.0%	-
8-Aug-07	15:30	17.36	79.0	75.4	4.6%	-
3-Oct-07	13:44	18.75	438.0	460.7	5.1%	-
5-Dec-07	12:15	17.86	*171.0*	-	-	-
12-Mar-08	11:30	18.28	*46.4*	-	-	-
13-May-08	14:41	18.12	279.0	242.4	14.0%	-
23-Jul-08	15:41	17.97	211.0	201.3	4.7%	-
4-Sep-08	12:21	17.49	94.7	96.8	2.2%	-
3-Oct-08	11:51	18.20	272.0	266.0	2.2%	-
10-Dec-08	12:30	17.60	*64.9*	-	-	-
				Average	4.9%	

Notes:

a. Italicized values were not used in rating curve error assessment.

TABLE 11
SK100B Monthly Discharge Summary

	Monthly Discharge (cfs)						Monthly Unit Runoff (cfs/mi^2)					
Month	**2003-04**	**2004-05**	**2005-06**	**2006-07**	**2007-08**	**Mean**	**2003-04**	**2004-05**	**2005-06**	**2006-07**	**2007-08**	**Mean**
Oct		337.9	282.5	456.5	374.9	363.0		4.87	4.08	6.59	5.41	5.24
Nov		255.9	139.1	119.5	222.6	184.3		3.69	2.01	1.72	3.21	2.66
Dec		158.7	135.1	73.6	147.0	128.6		2.29	1.95	1.06	2.12	1.85
Jan		105.9	69.5	53.5	80.8	77.5		1.53	1.00	0.77	1.17	1.12
Feb		69.4	48.3	46.4	57.9	55.5		1.00	0.70	0.67	0.84	0.80
Mar		52.6	38.5	29.5	44.9	41.4		0.76	0.56	0.43	0.65	0.60
Apr		82.6	32.6	64.9	47.0	56.8		1.19	0.47	0.94	0.68	0.82
May		672.8	436.0	245.5	362.3	429.1		9.70	6.29	3.54	5.23	6.19
Jun		237.0	271.3	124.8	557.8	297.7		3.42	3.91	1.80	8.05	4.29
Jul		119.2	113.7	75.1	197.6	126.4		1.72	1.64	1.08	2.85	1.82
Aug		129.3	365.4	71.4	92.2	164.6		1.86	5.27	1.03	1.33	2.37
Sep	89.0	516.7	334.6	377.4	209.9	305.5	1.28	7.45	4.83	5.44	3.03	4.41
Mean		229.0	190.0	145.4	200.1	191.1		3.30	2.74	2.10	2.89	2.76

TABLE 12
SK100B1 Discharge Measurement Record

Date	Time	Stage (ft)	Measured Discharge (cfs) [a]	Rating Curve Discharge (cfs)	Rating Curve Error	Notes
17-Sep-05	14:05	97.16	453.6	469.1	3.4%	-
28-Oct-05	17:05	96.01	151.5	143.1	5.7%	-
29-Oct-05	15:25	95.98	136.3	137.2	0.7%	-
31-Oct-05	14:44	95.80	105.4	104.9	0.5%	-
7-Feb-06	11:15	-	*25.6*	-	-	-
21-Feb-06	16:15	-	*22.7*	-	-	-
14-Mar-06	12:55	-	*20.5*	-	-	-
4-Apr-06	11:42	-	*14.5*	-	-	-
24-Apr-06	15:25	-	*13.1*	-	-	-
21-May-06	13:36	96.39	259.6	271.5	4.5%	-
18-Jun-06	11:05	96.05	195.3	182.1	7.0%	-
22-Jul-06	11:35	95.33	49.2	54.3	9.7%	-
17-Aug-06	13:40	96.48	309.4	298.4	3.6%	-
13-Sep-06	12:45	95.95	166.8	159.4	4.5%	-
31-Oct-06	14:25	96.03	172.8	177.4	2.6%	-
10-Dec-06	12:40	-	*50.3*	-	-	-
15-Jan-07	15:15	-	*29.8*	-	-	-
17-Feb-07	13:00	-	*24.0*	-	-	-
15-Mar-07	15:10	-	*18.7*	-	-	-
31-Mar-07	12:30	-	*16.3*	-	-	-
20-Apr-07	15:07	-	*13.7*	-	-	-
11-May-07	12:15	95.68	132.2	136.3	3.1%	-
17-Jun-07	9:55	95.22	63.7	60.6	5.0%	-
12-Jul-07	13:15	95.05	42.5	40.7	4.3%	-
15-Aug-07	10:20	95.06	42.6	41.7	2.1%	-
15-Sep-07	14:00	96.11	235.9	237.7	0.8%	-
13-Oct-07	13:05	96.04	231.4	219.1	5.5%	-
9-Nov-07	12:20	-	*128.5*	-	-	-
8-Dec-07	12:40	-	*121.5*	-	-	-
				Average	3.9%	

Note:

a. Italicized values were not used in rating curve development.

TABLE 13
SK100B1 Monthly Discharge Summary

	Monthly Discharge (cfs)						Monthly Unit Runoff (cfs/mi^2)					
Month	**2003-04**	**2004-05**	**2005-06**	**2006-07**	**2007-08**	**Mean**	**2003-04**	**2004-05**	**2005-06**	**2006-07**	**2007-08**	**Mean**
Oct			187.2	322.3		254.7			3.44	5.92		4.68
Nov			75.1	65.2		70.2			1.38	1.20		1.29
Dec			73.0	39.8		56.4			1.34	0.73		1.04
Jan			37.6	28.9		33.2			0.69	0.53		0.61
Feb			26.1	25.0		25.5			0.48	0.46		0.47
Mar			20.8	15.9		18.4			0.38	0.29		0.34
Apr			17.8	41.0		29.4			0.33	0.75		0.54
May			365.2	179.1		272.1			6.71	3.29		5.00
Jun			184.4	82.5		133.5			3.39	1.52		2.45
Jul			73.0	48.5		60.8			1.34	0.89		1.12
Aug			250.5	48.7		149.6			4.60	0.90		2.75
Sep			222.9	267.5		245.2			4.10	4.92		4.51
Mean			128.7	97.4		113.0			2.36	1.79		2.08

TABLE 14
SK100C Discharge Measurment Record

Date	Time	Stage (ft)	Measured Discharge (cfs) [a]	Rating Curve Discharge (cfs)	Rating Curve Error	Notes
15-Jun-04	15:30	-	*56.6*	-	-	-
13-Jul-04	15:10	92.66	7.6	7.8	1.6%	-
23-Aug-04	13:20	91.51	*0.0*	-	-	Dry channel.
14-Sep-04	-	91.50	*0.0*	-	-	Dry channel.
16-Oct-04	15:40	93.72	66.4	67.4	1.5%	-
28-Jan-05	16:30	-	*17.5*	-	-	-
18-Mar-05	-	-	*0.0*	-	-	Dry channel.
8-May-05	18:00	96.49	340.8	339.7	0.3%	Above bankfull stage.
4-Jun-05	12:30	94.41	114.3	119.4	4.3%	-
8-Jul-05	17:20	93.02	22.1	21.6	2.4%	-
15-Aug-05	-	-	*0.0*	-	-	Dry channel.
14-Sep-05	15:17	95.12	183.2	184.4	0.6%	-
29-Oct-05	13:55	93.65	57.9	62.8	8.1%	-
8-Feb-06	-	-	*0.0*	-	-	Dry channel.
14-Mar-06	-	-	*0.0*	-	-	Dry channel.
23-May-06	-	-	*111.5*	-	-	-
18-Jun-06	13:30	94.00	91.3	87.1	4.7%	-
22-Jul-06	13:00	92.49	2.6	3.7	37.2%	-
17-Aug-06	15:15	94.47	121.1	124.4	2.8%	-
13-Sep-06	14:15	93.64	61.3	62.2	1.5%	-
31-Oct-06	15:35	94.03	93.4	89.3	4.5%	-
10-Dec-06	14:40	-	*12.0*	-	-	-
17-Feb-07	-	-	*0.0*	-	-	Dry channel.
15-Mar-07	-	-	*0.0*	-	-	Dry channel.
31-Mar-07	-	-	*0.0*	-	-	Dry channel.
20-Apr-07	-	-	*0.0*	-	-	Dry channel.
11-May-07	14:30	93.57	60.4	57.7	4.6%	-
17-Jun-07	12:10	92.78	14.0	11.5	19.1%	-
12-Jul-07	-	-	*0.0*	-	-	Dry channel.
16-Jul-07	12:20	92.25	0.8	0.6	25.8%	-
15-Aug-07	-	-	*0.0*	-	-	Dry channel.
15-Sep-07	14:15	94.19	96.3	101.6	5.3%	-
13-Oct-07	14:16	94.27	114.4	107.9	5.8%	-
9-Nov-07	13:40	-	*83.0*	-	-	-
21-Jan-08	-	-	*0.0*	-	-	Dry channel.
19-Feb-08	-	-	*0.0*	-	-	Dry channel.
12-Mar-08	-	-	*0.0*	-	-	Dry channel.
28-Mar-08	-	-	*0.0*	-	-	Dry channel.
19-Apr-08	-	-	*0.0*	-	-	Dry channel.
28-May-08	-	-	*222.7*	-	-	Above bankfull stage.
16-Jun-08	9:12	-	190.2	187.4	1.5%	-
19-Jul-08	8:02	-	52.5	59.0	11.7%	-
20-Aug-08	10:14	-	7.9	9.5	19.0%	-
16-Sep-08	13:00	-	48.7	48.9	0.5%	-
18-Oct-08	13:30	-	*73.3*	-	-	No staff gage reading because gage is iced in.
18-Nov-08	12:43	-	*13.3*	-	-	-
6-Dec-08	13:25	-	*3.9*	-	-	-
				Average	7.8%	

Notes:
a. Italicized values were not used in rating curve development.

TABLE 15
SK100C Monthly Discharge Summary

	Monthly Discharge (cfs)						Monthly Unit Runoff (cfs/mi^2)					
Month	**2003-04**	**2004-05**	**2005-06**	**2006-07**	**2007-08**	**Mean**	**2003-04**	**2004-05**	**2005-06**	**2006-07**	**2007-08**	**Mean**
Oct		108.7	91.4	154.7	118.6	118.4		2.90	2.44	4.13	3.16	3.16
Nov		80.8	34.8	27.8	67.7	52.8		2.16	0.93	0.74	1.81	1.41
Dec		42.5	33.2	9.0	37.7	30.6		1.13	0.89	0.24	1.01	0.82
Jan		21.7	7.4	1.7	5.1	9.0		0.58	0.20	0.04	0.14	0.24
Feb		7.3	0.2	1.1	0.0	2.1		0.20	0.00	0.03	0.00	0.06
Mar		1.2	0.0	0.0	0.0	0.3		0.03	0.00	0.00	0.00	0.01
Apr		15.6	0.0	10.7	0.0	6.6		0.42	0.00	0.29	0.00	0.18
May		240.0	150.4	70.5	121.0	145.5		6.40	4.01	1.88	3.23	3.88
Jun		83.6	82.4	21.7	202.2	97.5		2.23	2.20	0.58	5.39	2.60
Jul		26.3	14.6	1.9	60.2	25.7		0.70	0.39	0.05	1.61	0.69
Aug	0.9	24.3	97.3	1.3	13.2	27.4	0.02	0.65	2.60	0.04	0.35	0.73
Sep	12.0	163.2	93.0	100.6	48.5	83.4	0.32	4.35	2.48	2.68	1.29	2.22
Mean		68.2	50.8	33.6	56.4	52.3		1.82	1.35	0.90	1.50	1.39

TABLE 16
SK100F Discharge Measurement Record

Date	Time	Stage (ft)	Measured Discharge (cfs) [a]	Rating Curve Discharge (cfs)	Rating Curve Error	Notes
18-May-04	10:26	-	*129.7*	-	-	-
16-Jun-04	13:00	-	*33.2*	-	-	-
14-Jul-04	16:00	98.84	7.5	7.1	5.6%	-
24-Aug-04	16:04	98.86	2.5	7.7	101.1%	-
14-Sep-04	14:30	98.84	6.7	7.0	3.8%	-
16-Oct-04	14:15	99.23	43.1	27.8	42.9%	-
26-Jan-05	13:00	-	*14.6*	-	-	-
19-Mar-05	16:30	-	*8.3*	-	-	-
4-May-05	10:10	100.02	137.1	117.9	15.0%	-
5-Jun-05	12:30	99.46	36.7	47.0	24.6%	-
9-Jul-05	16:50	99.09	14.6	18.5	23.3%	-
13-Jul-05	16:15	99.23	28.7	27.6	3.9%	-
18-Aug-05	16:00	99.12	15.6	20.3	26.1%	-
15-Sep-05	11:50	99.88	67.9	96.9	35.3%	-
29-Oct-05	10:30	99.34	35.2	35.8	1.5%	-
18-Jan-06	14:00	-	*4.2*	-	-	-
7-Feb-06	13:45	-	*6.6*	-	-	-
14-Mar-06	10:20	-	*4.4*	-	-	-
4-Apr-06	16:32	-	*5.1*	-	-	-
4-Apr-06	0:00	-	*5.6*	-	-	-
22-May-06	12:20	100.14	121.9	137.7	12.2%	Ice flows in channel
18-Jun-06	15:10	99.45	54.7	46.0	17.2%	-
22-Jul-06	14:40	99.00	12.6	13.4	6.5%	Sediment erosion affecting flow
17-Aug-06	16:25	99.68	76.2	70.7	7.4%	-
13-Sep-06	15:58	99.26	28.1	29.8	6.0%	-
1-Nov-06	11:00	*99.38*	*23.5*	-	-	Ice conditions; replicate discharge measurement error > 25%.
11-Dec-06	12:00	-	*13.1*	-	-	-
19-Jan-07	11:25	-	*7.0*	-	-	-
18-Feb-07	10:40	-	*10.4*	-	-	-
16-Mar-07	12:25	-	*1.2*	-	-	-
21-Apr-07	10:00	-	*6.9*	-	-	-
11-May-07	16:50	99.26	37.8	29.8	23.6%	-
17-Jun-07	14:20	99.18	32.0	24.1	28.0%	-
12-Jul-07	16:47	98.95	14.1	11.3	21.7%	-
15-Aug-07	12:40	99.00	16.1	13.4	18.4%	-
15-Sep-07	16:35	*99.82*	*60.1*	-	-	Beaver activity downstream
13-Oct-07	16:57	*99.66*	*54.9*	-	-	Beaver activity downstream
9-Nov-07	15:30	*99.45*	*28.4*	-	-	-
8-Dec-07	14:43	-	*40.8*	-	-	-
				Average	21.2%	

Note:

a. Italicized values were not used in rating curve development.

TABLE 17
SK100F Monthly Discharge Summary

	Monthly Discharge (cfs)						Monthly Unit Runoff (cfs/mi^2)					
Month	**2003-04**	**2004-05**	**2005-06**	**2006-07**	**2007-08**	**Mean**	**2003-04**	**2004-05**	**2005-06**	**2006-07**	**2007-08**	**Mean**
Oct		45.3	49.1	76.0		56.8		3.81	4.12	6.38		4.77
Nov		32.2	18.1	14.9		21.8		2.71	1.52	1.25		1.83
Dec		20.0	17.0	9.3		15.4		1.68	1.43	0.78		1.30
Jan		13.3	8.8	6.7		9.6		1.12	0.74	0.57		0.81
Feb		8.7	6.1	5.8		6.9		0.73	0.51	0.49		0.58
Mar		6.6	4.9	3.7		5.1		0.56	0.41	0.31		0.43
Apr		10.4	4.1	8.2		7.6		0.87	0.35	0.69		0.64
May		95.1	66.4	36.3		65.9		7.98	5.57	3.05		5.53
Jun		37.7	44.9	25.4		36.0		3.17	3.77	2.13		3.02
Jul		19.8	20.0	14.8		18.2		1.66	1.68	1.24		1.53
Aug	9.4	22.8	56.0	13.0		25.3	0.79	1.91	4.70	1.10		2.12
Sep	15.8	74.4	50.8	58.9		49.9	1.32	6.24	4.27	4.94		4.19
Mean		32.3	29.0	22.9		28.1		2.71	2.44	1.92		2.36

TABLE 18
SK100G Discharge Measurement Record

Date	Time	Stage (ft)	Measured Discharge (cfs) [a]	Rating Curve Discharge (cfs)	Rating Curve Error	Notes
28-Apr-04	14:39	-	*23.3*	-	-	-
18-May-04	12:30	-	*48.2*	-	-	-
16-Jun-04	9:15	-	*12.9*	-	-	-
15-Jul-04	16:40	97.92	6.2	3.2	64.9%	-
25-Aug-04	8:35	97.92	3.5	3.2	9.4%	-
14-Sep-04	16:10	97.89	1.9	2.6	33.4%	Submerged vegetation.
16-Oct-04	13:30	98.30	15.8	12.3	25.0%	-
26-Jan-05	14:50	-	*9.3*	-	-	-
17-Mar-05	15:30	-	*6.0*	-	-	-
7-May-05	12:30	*99.28*	*29.9*	-	-	Channel width measurement error.
5-Jun-05	10:00	98.37	19.0	14.4	27.3%	-
11-Jul-05	16:00	98.21	10.1	9.8	3.5%	Submerged vegetation.
15-Jul-05	15:15	98.21	9.5	9.8	2.8%	Submerged vegetation.
15-Aug-05	16:45	98.08	4.7	6.5	31.2%	Submerged vegetation.
12-Sep-05	16:59	99.23	42.4	48.8	14.0%	-
29-Oct-05	10:20	98.30	13.6	12.3	10.2%	-
18-Jan-06	10:50	-	*5.7*	-	-	-
9-Feb-06	11:20	-	*1.2*	-	-	-
14-Mar-06	10:15	-	*3.6*	-	-	-
22-May-06	11:10	99.16	52.9	45.5	15.2%	-
18-Jun-06	15:08	98.38	19.0	14.7	25.5%	-
22-Jul-06	14:10	98.05	7.6	5.7	29.1%	-
17-Aug-06	16:30	98.87	33.0	32.7	1.1%	Submerged vegetation.
13-Sep-06	15:05	98.40	15.9	15.4	3.4%	-
1-Nov-06	11:10	*98.34*	*24.2*	-	-	-
10-Dec-06	15:05	-	*7.9*	-	-	-
19-Jan-07	12:30	-	*5.6*	-	-	-
17-Feb-07	10:45	-	*5.1*	-	-	-
31-Mar-07	14:20	-	*2.1*	-	-	-
21-Apr-07	12:00	-	*15.8*	-	-	-
11-May-07	16:00	98.40	15.0	15.4	2.3%	-
17-Jun-07	14:35	98.27	11.5	11.4	0.7%	-
13-Jul-07	9:50	98.36	9.4	8.7	7.7%	Left bank sloughed into channel downstream of
15-Aug-07	15:40	98.29	6.8	7.0	2.7%	Submerged vegetation.
16-Sep-07	10:15	98.67	16.7	18.1	7.9%	First run affected by aquatic vegetation; used second run.
13-Oct-07	16:30	98.71	20.6	19.5	5.2%	-
9-Nov-07	15:25	*98.79*	*23.0*	-	-	-
8-Dec-07	14:30	-	*16.6*	-	-	-
				Average	15.4%	

Note:

a. Italicized values were not used in rating curve development.

TABLE 19
SK100G Monthly Discharge Summary

	Monthly Discharge (cfs)						Monthly Unit Runoff (cfs/mi²)					
Month	**2003-04**	**2004-05**	**2005-06**	**2006-07**	**2007-08**	**Mean**	**2003-04**	**2004-05**	**2005-06**	**2006-07**	**2007-08**	**Mean**
Oct		25.1	23.7	35.3		28.0		4.56	4.32	6.43		5.10
Nov		24.6	13.4	11.0		16.3		4.48	2.43	2.01		2.97
Dec		15.2	13.0	7.1		11.8		2.77	2.36	1.29		2.14
Jan		10.2	6.7	5.1		7.3		1.85	1.22	0.94		1.33
Feb		6.7	4.6	4.5		5.2		1.21	0.84	0.81		0.96
Mar		5.1	3.7	2.8		3.9		0.92	0.67	0.52		0.70
Apr		18.8	3.1	6.2		9.4		3.43	0.57	1.13		1.71
May		35.6	29.2	19.0		27.9		6.49	5.32	3.46		5.09
Jun		12.1	13.7	12.5		12.7		2.20	2.49	2.27		2.32
Jul		10.0	7.8	7.9		8.6		1.82	1.41	1.44		1.56
Aug	4.1	12.3	25.9	7.9		12.6	0.75	2.25	4.72	1.43		2.29
Sep	8.5	33.0	23.8	31.6		24.2	1.56	6.01	4.33	5.75		4.41
Mean		17.4	14.1	12.6		14.7		3.17	2.57	2.30		2.68

TABLE 20
SK119A Discharge Measurement Record

Date	Time	Stage (ft)	Measured Discharge (cfs) [a]	Rating Curve Discharge (cfs)	Rating Curve Error	Notes
30-Apr-04	12:10	-	*8.6*	-	-	-
19-May-04	9:37	-	*101.9*	-	-	-
16-Jun-04	9:07	-	*26.5*	-	-	-
13-Jul-04	17:09	98.05	10.4	11.3	7.7%	-
23-Aug-04	14:17	97.94	7.8	-	-	-
14-Sep-04	11:00	97.87	5.2	-	-	-
29-Jan-05	12:00	-	*11.5*	-	-	-
20-Mar-05	12:50	-	*7.6*	-	-	-
3-May-05	16:00	98.81	97.9	96.7	1.3%	-
7-Jun-05	13:28	98.57	57.1	59.2	3.8%	-
9-Jul-05	12:05	98.23	20.3	23.3	13.5%	-
18-Aug-05	11:40	98.09	12.2	13.7	11.6%	-
14-Sep-05	14:05	98.78	92.6	91.4	1.2%	-
30-Oct-05	9:48	98.28	27.6	27.4	0.7%	-
7-Feb-06	17:05	-	*4.7*	-	-	-
15-Mar-06	11:15	-	*2.5*	-	-	-
21-May-06	16:40	-	*131.0*	-	-	Gage disturbed prior to June survey.
22-May-06	9:33	-	*165.9*	-	-	Gage disturbed prior to June survey.
19-Jun-06	9:40	98.26	37.8	36.8	2.7%	-
23-Jul-06	10:10	97.95	12.6	12.9	2.3%	-
16-Aug-06	15:25	98.81	112.1	110.8	1.1%	-
1-Nov-06	14:00	*99.10*	*30.0*	-	-	Ice conditions.
11-Dec-06	13:40	-	*7.3*	-	-	-
18-Feb-07	14:40	-	*5.6*	-	-	-
21-Apr-07	10:50	-	*3.9*	-	-	-
12-May-07	10:30	-	*52.5*	-	-	Ice conditions.
17-Jun-07	16:54	97.88	24.5	23.8	2.6%	-
13-Jul-07	11:56	97.88	25.9	23.8	8.5%	-
15-Aug-07	17:35	97.78	16.9	17.6	3.9%	-
16-Sep-07	13:58	98.30	66.7	60.5	9.8%	-
14-Oct-07	13:10	98.04	36.2	35.8	1.3%	-
10-Nov-07	10:37	-	*27.7*	-	-	-
9-Dec-07	11:30	-	*19.3*	-	-	-
23-Jan-08	13:06	-	*0.9*	-	-	-
19-Feb-08	12:05	-	*4.5*	-	-	-
14-Mar-08	12:11	-	*4.3*	-	-	-
19-Apr-08	16:00	-	*2.6*	-	-	-
28-May-08	14:03	-	119.0	123.6	3.8%	-
14-Jun-08	16:08	-	136.7	143.0	4.5%	-
20-Jul-08	8:50	-	22.9	27.3	17.6%	-
19-Aug-08	16:21	-	12.7	13.8	8.6%	-
18-Sep-08	9:28	-	114.1	107.1	6.3%	-
16-Oct-08	15:15	-	43.5	46.3	6.3%	-
22-Nov-08	11:00	-	*10.5*	-	-	-
6-Dec-08	11:15	-	*14.9*	-	-	-
27-Mar-08	14:40	-	*1.8*	-	-	-
				Average	5.7%	

Note:
a. Italicized values were not used in rating curve development.

TABLE 21
SK119A Monthly Discharge Summary

	Monthly Discharge (cfs)						Monthly Unit Runoff (cfs/mi^2)					
Month	**2003-04**	**2004-05**	**2005-06**	**2006-07**	**2007-08**	**Mean**	**2003-04**	**2004-05**	**2005-06**	**2006-07**	**2007-08**	**Mean**
Oct		68.2	43.5	76.3	48.0	59.0		6.35	4.06	7.11	4.47	5.50
Nov		33.4	17.1	14.3	28.8	23.4		3.12	1.59	1.34	2.68	2.18
Dec		19.8	16.5	7.9	18.2	15.6		1.85	1.54	0.74	1.70	1.46
Jan		12.4	7.3	5.1	8.9	8.5		1.16	0.68	0.48	0.83	0.79
Feb		7.3	4.4	4.1	5.7	5.4		0.68	0.41	0.38	0.53	0.50
Mar		5.0	3.0	1.7	3.9	3.4		0.46	0.28	0.16	0.36	0.32
Apr		21.0	2.2	9.0	4.2	9.1		1.95	0.20	0.84	0.39	0.85
May		189.8	109.0	58.8	82.0	109.9		17.69	10.16	5.48	7.65	10.24
Jun		45.1	58.4	24.8	128.2	64.1		4.20	5.45	2.31	11.94	5.98
Jul		22.0	18.6	14.4	38.4	23.4		2.05	1.74	1.34	3.58	2.18
Aug	6.8	35.4	81.4	17.7	18.7	32.0	0.64	3.30	7.59	1.65	1.74	2.98
Sep	31.7	124.4	59.0	83.9	56.8	71.2	2.95	11.59	5.50	7.82	5.29	6.63
Mean		48.9	35.3	26.6	36.9	36.9		4.56	3.29	2.48	3.44	3.44

TABLE 22
SK124A Discharge Measurement Record

Date	Time	Stage (ft)	Measured Discharge (cfs) [a]	Rating Curve Discharge (cfs)	Rating Curve Error	Notes
29-Jan-05	11:30	-	*5.2*	-	-	-
19-Mar-05	14:00	-	*3.0*	-	-	-
9-May-05	11:00	97.04	105.2	116.5	10.2%	Stage reading surveyed from benchmarks.
5-Jun-05	15:00	-	*42.9*	-	-	No stage reading.
9-Jul-05	14:20	95.68	10.9	12.9	17.1%	-
14-Jul-05	16:30	95.64	12.0	11.5	4.2%	-
18-Aug-05	14:40	95.40	5.6	4.5	22.8%	-
14-Sep-05	12:07	96.55	71.2	67.3	5.7%	-
29-Oct-05	13:25	95.83	18.3	19.3	5.3%	-
19-Jan-06	11:10	-	*2.0*	-	-	-
7-Feb-06	15:00	-	*0.9*	-	-	-
14-Mar-06	17:10	-	*0.5*	-	-	-
19-Jun-06	11:15	95.79	25.7	21.9	16.0%	-
19-Jun-06	11:15	95.79	24.4	21.9	10.9%	-
23-Jul-06	9:45	95.14	1.5	1.7	12.1%	-
16-Aug-06	14:25	96.41	60.9	62.4	2.4%	-
1-Nov-06	13:11	*96.69*	*26.3*	-	-	-
11-Dec-06	12:40	-	*2.3*	-	-	-
17-Jan-07	15:30	-	*0.2*	-	-	-
18-Feb-07	12:45	-	*0.4*	-	-	-
12-May-07	10:30	-	*28.9*	-	-	-
18-Jun-07	9:30	95.26	7.3	7.5	3.2%	-
13-Jul-07	9:10	94.85	0.5	0.5	1.6%	-
16-Aug-07	9:55	94.94	1.3	1.4	6.8%	-
16-Sep-07	15:10	95.95	40.0	37.5	6.4%	-
17-Oct-07	10:30	95.68	21.6	23.0	6.3%	-
10-Nov-07	12:19	*95.54*	*14.6*	-	-	-
9-Dec-07	14:30	*95.47*	*6.6*	-	-	-
15-Jun-08	8:50	96.56	89.0	89.2	0.2%	-
20-Jul-08	9:45	95.26	11.5	10.9	5.2%	-
19-Aug-08	14:51	94.89	2.4	2.4	0.2%	-
18-Sep-08	12:07	95.93	41.7	41.9	0.4%	-
17-Oct-08	15:04	*95.94*	*36.8*	-	-	Possible ice interference.
19-Nov-08	14:55	-	*2.2*	-	-	-
6-Dec-08	13:00	-	*5.0*	-	-	-
				Average	7.2%	

Note:

a. Italicized values were not used in rating curve development.

TABLE 23
SK124A Monthly Discharge Summary

	Monthly Discharge (cfs)						Monthly Unit Runoff (cfs/mi^2)					
Month	**2003-04**	**2004-05**	**2005-06**	**2006-07**	**2007-08**	**Mean**	**2003-04**	**2004-05**	**2005-06**	**2006-07**	**2007-08**	**Mean**
Oct		37.0	19.8	61.3	38.5	39.1		4.34	2.32	7.19	4.52	4.59
Nov		20.8	9.1	7.1	17.5	13.6		2.44	1.07	0.84	2.05	1.60
Dec		11.1	8.7	2.6	9.9	8.1		1.30	1.02	0.30	1.16	0.95
Jan		5.8	2.2	0.6	1.4	2.5		0.68	0.25	0.07	0.16	0.29
Feb		2.1	0.1	0.4	0.0	0.7		0.25	0.02	0.04	0.00	0.08
Mar		0.5	0.0	0.0	0.0	0.1		0.06	0.00	0.00	0.00	0.01
Apr		5.9	0.0	3.9	0.0	2.4		0.70	0.00	0.45	0.00	0.29
May		103.5	63.9	31.9	50.9	62.6		12.15	7.50	3.74	5.97	7.34
Jun		28.1	32.0	11.0	84.8	39.0		3.30	3.76	1.30	9.95	4.57
Jul		12.1	4.9	1.4	19.2	9.4		1.42	0.57	0.16	2.26	1.10
Aug		12.6	47.6	2.5	3.4	16.5		1.47	5.59	0.29	0.40	1.94
Sep		62.9	32.1	54.2	21.1	42.6		7.38	3.77	6.37	2.47	5.00
Mean		25.3	18.5	14.8	20.6	19.8		2.97	2.17	1.74	2.42	2.33

TABLE 24
NK100A Discharge Measurement Record

Date	Time	Stage (ft)	Measured Discharge (cfs) [a]	Rating Curve Discharge (cfs)	Rating Curve Error	Notes
24-Aug-04	18:20	17.23	62.6	66.3	5.8%	-
13-Sep-04	11:25	17.22	64.2	64.1	0.2%	-
18-Oct-04	15:25	17.78	243.0	238.9	1.7%	-
27-Oct-04	16:05	18.65	694.0	692.0	0.3%	-
2-Feb-05	13:25	*19.72*	*73.0*	-	-	-
7-Mar-05	10:05	*19.59*	*68.3*	-	-	-
27-Apr-05	9:15	*18.69*	*686.0*	-	-	-
25-May-05	14:35	18.66	841.0	698.4	18.5%	-
20-Jul-05	16:05	17.66	187.0	193.3	3.3%	-
12-Aug-05	11:20	17.47	108.0	129.9	18.4%	-
6-Oct-05	13:35	18.01	332.0	338.2	1.8%	-
21-Feb-06	10:41	*19.86*	*66.6*	-	-	-
16-May-06	11:45	18.89	849.0	852.8	0.5%	-
20-Jun-06	14:20	17.98	312.0	324.4	3.9%	-
14-Aug-06	15:30	18.58	672.0	648.0	3.6%	-
4-Oct-06	10:29	18.59	680.0	654.2	3.9%	-
26-Oct-06	11:26	18.07	310.0	366.6	16.7%	-
6-Dec-06	11:42	*20.36*	*86.7*	-	-	-
3-Apr-07	12:20	*20.60*	*40.4*	-	-	-
15-May-07	14:15	18.34	444.0	506.7	13.2%	-
26-Jun-07	9:11	17.88	224.0	280.2	22.3%	-
8-Aug-07	12:56	17.65	141.0	189.7	29.4%	-
3-Oct-07	10:30	18.35	435.0	512.3	16.3%	-
5-Dec-07	11:00	*18.47*	*245.0*	-	-	-
11-Mar-08	14:45	*19.29*	*84.5*	-	-	-
13-May-08	13:05	18.83	929.0	811.2	13.5%	-
23-Jul-08	13:38	18.05	291.0	357.0	20.4%	-
4-Sep-08	10:39	17.90	231.0	288.8	22.2%	-
3-Oct-08	10:43	18.10	322.0	381.1	16.8%	-
				Average	11.1%	

Note:
a. Italicized values were not used in rating curve error assessment.

TABLE 25
NK100A Monthly Discharge Summary

	Monthly Discharge (cfs)						Monthly Unit Runoff (cfs/mi^2)					
Month	**2003-04**	**2004-05**	**2005-06**	**2006-07**	**2007-08**	**Mean**	**2003-04**	**2004-05**	**2005-06**	**2006-07**	**2007-08**	**Mean**
Oct		389.0	330.1	583.2	417.7	430.0		3.67	3.12	5.51	3.95	4.06
Nov		384.7	166.0	134.3	350.4	258.8		3.63	1.57	1.27	3.31	2.45
Dec		217.4	173.2	80.9	203.4	168.7		2.05	1.64	0.76	1.92	1.59
Jan		82.2	95.8	58.9	132.6	92.4		0.78	0.91	0.56	1.25	0.87
Feb		71.2	69.7	53.3	103.0	74.3		0.67	0.66	0.50	0.97	0.70
Mar		66.4	57.2	37.8	78.9	60.1		0.63	0.54	0.36	0.75	0.57
Apr		238.2	47.2	109.6	67.7	115.7		2.25	0.45	1.04	0.64	1.09
May		1049.4	718.9	399.5	772.1	735.0		9.91	6.79	3.77	7.29	6.94
Jun		364.8	382.8	218.5	710.9	419.3		3.45	3.62	2.06	6.72	3.96
Jul		192.3	205.6	145.7	284.0	206.9		1.82	1.94	1.38	2.68	1.95
Aug		216.5	471.5	131.9	146.3	241.5		2.04	4.45	1.25	1.38	2.28
Sep	167.1	509.7	413.5	457.4	334.1	376.4	1.58	4.81	3.91	4.32	3.16	3.56
Mean		316.5	262.6	201.8	301.0	270.5		2.99	2.48	1.91	2.84	2.56

TABLE 26
NK100A1 Discharge Measurement Record

Date	Time	Stage (ft)	Measured Discharge (cfs) [a]	Rating Curve Discharge (cfs)	Rating Curve Error	Notes
16-Feb-07	15:15	-	*91.0*	-	-	-
17-Mar-07	12:45	-	*17.8*	-	-	-
30-Mar-07	14:31	-	*43.0*	-	-	-
24-Apr-07	12:30	-	*223.0*	-	-	-
12-May-07	14:00	-	*308.8*	-	-	-
18-Jun-07	12:25	95.08	165.3	167.2	1.1%	-
14-Jul-07	9:05	95.02	154.6	151.9	1.8%	-
17-Aug-07	10:45	94.78	101.2	98.6	2.6%	-
17-Sep-07	9:40	95.34	229.7	242.7	5.5%	-
15-Oct-07	13:09	95.30	214.4	230.1	7.1%	-
11-Nov-07	12:25	-	*221.4*	-	-	-
10-Dec-07	14:00	-	*205.2*	-	-	-
25-Jan-08	11:30	-	*52.5*	-	-	-
20-Feb-08	14:05	-	*71.8*	-	-	-
17-Mar-08	10:48	-	*45.3*	-	-	-
18-Apr-08	11:15	-	*54.4*	-	-	-
19-May-08	11:14	96.29	*613.7*	-	-	Staff gage damaged prior to survey; estimated datum.
13-Jun-08	12:18	95.88	472.0	449.8	4.8%	-
17-Jul-08	16:10	95.51	312.4	300.5	3.9%	-
19-Aug-08	9:25	94.79	99.3	100.5	1.3%	-
19-Oct-08	10:41	95.38	238.7	255.7	6.9%	-
8-Dec-08	12:12	-	*122.9*	-	-	-
25-Mar-08	15:20	-	*55.3*	-	-	-
				Average	3.9%	

Note:
a. Italicized values were not used in rating curve development.

TABLE 27
NK100A1 Monthly Discharge Summary

	Monthly Discharge (cfs)						Monthly Unit Runoff (cfs/mi^2)					
Month	**2003-04**	**2004-05**	**2005-06**	**2006-07**	**2007-08**	**Mean**	**2003-04**	**2004-05**	**2005-06**	**2006-07**	**2007-08**	**Mean**
Oct				471.7	338.2	404.9				5.53	3.96	4.74
Nov				114.8	281.1	197.9				1.34	3.29	2.32
Dec				73.7	167.9	120.8				0.86	1.97	1.42
Jan				56.7	113.4	85.1				0.66	1.33	1.00
Feb				52.3	90.6	71.5				0.61	1.06	0.84
Mar				40.4	72.1	56.3				0.47	0.84	0.66
Apr				95.7	63.4	79.6				1.12	0.74	0.93
May				346.8	573.2	460.0				4.06	6.72	5.39
Jun				197.3	515.9	356.6				2.31	6.04	4.18
Jul				120.6	224.6	172.6				1.41	2.63	2.02
Aug				112.2	110.9	111.6				1.31	1.30	1.31
Sep				377.1	269.8	323.5				4.42	3.16	3.79
Mean				172.3	235.8	204.0				2.02	2.76	2.39

TABLE 28
NK100B Discharge Measurement Record

Date	Time	Stage (ft)	Measured Discharge (cfs) [a]	Rating Curve Discharge (cfs)	Rating Curve Error	Notes
29-Apr-04	10:10	-	275.7	-	-	-
24-Aug-04	14:16	-	23.8	-	-	-
15-Sep-04	13:15	-	22.0	-	-	-
18-Oct-04	14:00	-	*93.0*	-	-	-
29-Jan-05	15:30	-	*40.8*	-	-	-
20-Mar-05	12:30	-	*65.0*	-	-	-
7-May-05	13:20	-	*401.8*	-	-	-
4-Jun-05	12:00	-	*100.9*	-	-	-
9-Jul-05	16:30	-	*92.8*	-	-	-
17-Aug-05	12:30	-	*39.8*	-	-	-
13-Sep-05	15:45	-	*191.8*	-	-	-
28-Oct-05	12:00	-	*85.9*	-	-	-
9-Feb-06	16:40	-	*22.4*	-	-	-
13-Mar-06	13:30	-	*18.9*	-	-	-
1-Apr-06	-	-	*18.5*	-	-	-
20-May-06	11:54	-	*190.8*	-	-	-
15-Jun-06	12:20	-	*99.5*	-	-	-
23-Jul-06	13:30	-	*51.1*	-	-	-
16-Aug-06	11:15	-	*180.2*	-	-	-
3-Nov-06	14:35	-	*83.4*	-	-	-
13-Dec-06	11:00	-	*36.3*	-	-	-
16-Feb-07	11:45	-	*34.0*	-	-	-
30-Mar-07	16:40	-	*12.9*	-	-	-
12-May-07	15:00	-	*115.4*	-	-	-
18-Jun-07	12:00	97.23	64.3	61.9	3.9%	-
14-Jul-07	11:44	97.14	51.2	50.0	2.3%	-
16-Aug-07	16:09	97.06	39.7	40.7	2.4%	-
17-Sep-07	9:55	97.45	95.5	97.4	2.0%	-
15-Oct-07	12:10	97.51	106.6	108.8	2.1%	-
11-Nov-07	12:50	-	*86.3*	-	-	-
10-Dec-07	12:55	-	*91.1*	-	-	-
25-Jan-08	13:40	-	*16.2*	-	-	-
20-Feb-08	13:45	-	*20.0*	-	-	-
17-Mar-08	13:00	-	*14.3*	-	-	-
25-Mar-08	11:00	-	*25.5*	-	-	-
18-Apr-08	11:57	-	*12.3*	-	-	-
19-May-08	10:10	98.34	298.04	-	-	Staff gage damaged prior to survey; estimated datum.
13-Jun-08	14:28	97.89	195.6	199.2	1.8%	-
17-Jul-08	15:20	97.54	114.3	114.8	0.4%	-
19-Aug-08	12:04	97.04	42.4	38.5	9.5%	-
18-Sep-08	15:37	-	*188.7*	*188.1*	*0.3%*	-
19-Oct-08	12:26	-	*98.2*	-	-	Ice interference.
22-Nov-08	13:50	-	*42.0*	-	-	-
8-Dec-08	12:15	-	*61.4*	-	-	-
				Average	2.7%	

Note:
a. Italicized values were not used in rating curve development.

TABLE 29
NK100B Monthly Discharge Summary

	Monthly Discharge (cfs)						Monthly Unit Runoff (cfs/mi^2)					
Month	**2003-04**	**2004-05**	**2005-06**	**2006-07**	**2007-08**	**Mean**	**2003-04**	**2004-05**	**2005-06**	**2006-07**	**2007-08**	**Mean**
Oct				194.6	146.9	170.8				5.22	3.94	4.58
Nov				46.2	110.3	78.2				1.24	2.96	2.10
Dec				31.2	65.5	48.4				0.84	1.76	1.30
Jan				25.0	45.7	35.4				0.67	1.22	0.95
Feb				23.5	37.4	30.4				0.63	1.00	0.82
Mar				19.1	30.6	24.9				0.51	0.82	0.67
Apr				39.2	27.5	33.4				1.05	0.74	0.89
May				129.2	267.5	198.3				3.46	7.17	5.32
Jun				71.4	232.7	152.0				1.91	6.24	4.08
Jul				46.7	101.3	74.0				1.25	2.72	1.98
Aug				44.8	52.8	48.8				1.20	1.42	1.31
Sep				152.4	118.3	135.4				4.09	3.17	3.63
Mean				68.9	103.4	86.1				1.85	2.77	2.31

TABLE 30
NK100C Discharge Measurement Record

Date	Time	Stage (ft)	Measured Discharge (cfs) [a]	Rating Curve Discharge (cfs)	Rating Curve Error	Notes
30-Apr-04	12:20	-	*105.4*	-	-	-
19-May-04	16:00	-	*127.9*	-	-	-
15-Jun-04	9:22	-	*51.5*	-	-	-
14-Jul-04	14:10	97.44	29.4	30.8	4.7%	-
24-Aug-04	15:00	97.32	15.4	19.9	25.9%	-
15-Sep-04	15:20	97.29	15.5	17.5	12.6%	-
18-Oct-04	11:50	97.60	56.0	48.1	15.2%	-
25-Jan-05	12:11	-	*38.7*	-	-	-
17-Mar-05	15:30	-	*21.5*	-	-	-
6-May-05	11:45	-	*429.1*	-	-	Ice conditions.
9-May-05	17:25	98.54	207.5	205.5	1.0%	Ice-free conditions.
5-Jun-05	18:15	97.84	81.3	79.6	2.1%	-
11-Jul-05	13:20	97.59	47.5	46.9	1.3%	-
16-Aug-05	17:20	97.35	23.2	22.5	3.0%	-
13-Sep-05	11:55	97.96	92.8	97.7	5.2%	-
28-Oct-05	13:34	*98.02*	*63.3*	-	-	Ice conditions.
9-Feb-06	14:17	-	*13.5*	-	-	-
13-Mar-06	11:30	-	*12.6*	-	-	-
20-May-06	13:10	*98.39*	*125.3*	-	-	Rapidly rising stage.
21-May-06	10:44	*98.49*	*168.0*	-	-	Rapidly rising stage.
15-Jun-06	14:35	97.60	52.8	48.1	9.5%	-
23-Jul-06	12:01	97.43	32.0	29.8	7.2%	-
16-Aug-06	9:50	98.02	107.9	107.4	0.5%	Beaver activity downstream.
15-Sep-06	13:39	98.09	114.2	119.0	4.2%	-
3-Nov-06	10:55	-	*43.3*	-	-	-
13-Dec-06	11:45	-	*30.4*	-	-	-
16-Feb-07	13:45	-	*22.4*	-	-	-
31-Mar-07	13:00	-	*10.5*	-	-	-
12-May-07	14:25	-	*55.0*	-	-	-
18-Jun-07	14:00	97.47	34.9	33.8	3.3%	-
14-Jul-07	13:28	97.37	31.7	24.2	26.7%	-
16-Aug-07	11:22	97.42	28.5	28.8	1.1%	-
17-Sep-07	14:20	97.72	49.1	-	-	Beaver activity downstream.
15-Oct-07	15:00	97.86	65.0	-	-	Beaver activity downstream.
11-Nov-07	12:18	-	*56.2*	-	-	-
10-Dec-07	14:20	-	*62.1*	-	-	-
25-Jan-08	14:15	-	*15.4*	-	-	-
21-Feb-08	11:00	-	*12.7*	-	-	-
17-Mar-08	16:06	-	*14.2*	-	-	-
25-Mar-08	17:15	-	*14.9*	-	-	-
18-Apr-08	15:51	-	*8.9*	-	-	-
19-May-08	15:45	-	188.4	-	-	Ice conditions.
13-Jun-08	15:58	-	98.7	104.1	5.4%	-
18-Jul-08	14:50	-	54.1	51.7	4.7%	-
19-Aug-08	12:10	-	27.2	25.1	7.9%	-
18-Sep-08	15:20	-	*92.0*	*97.7*	*6.0%*	-
19-Oct-08	13:56	-	*85.6*	-	-	Ice conditions.
19-Nov-08	12:10	-	*34.1*	-	-	-
8-Dec-08	14:35	-	*44.0*	-	-	-
				Average	7.4%	

Note:
a. Italicized values were not used in rating curve development.

TABLE 31
NK100C Monthly Discharge Summary

	Monthly Discharge (cfs)						Monthly Unit Runoff (cfs/mi^2)					
Month	**2003-04**	**2004-05**	**2005-06**	**2006-07**	**2007-08**	**Mean**	**2003-04**	**2004-05**	**2005-06**	**2006-07**	**2007-08**	**Mean**
Oct		75.3	71.4	122.2	79.9	87.2		3.09	2.93	5.02	3.28	3.58
Nov		77.1	35.5	29.5	70.6	53.2		3.17	1.46	1.21	2.90	2.18
Dec		45.3	36.9	19.4	42.6	36.1		1.86	1.52	0.80	1.75	1.48
Jan		19.6	22.2	15.2	29.2	21.6		0.81	0.91	0.62	1.20	0.89
Feb		17.5	17.2	14.1	23.6	18.1		0.72	0.71	0.58	0.97	0.74
Mar		16.6	14.9	11.2	19.0	15.4		0.68	0.61	0.46	0.78	0.63
Apr		49.3	13.0	24.8	16.9	26.0		2.02	0.53	1.02	0.69	1.07
May		179.3	140.5	63.7	159.4	135.7		7.37	5.77	2.62	6.55	5.57
Jun		69.7	60.2	37.7	114.7	70.6		2.86	2.47	1.55	4.71	2.90
Jul		42.6	39.7	25.0	52.7	40.0		1.75	1.63	1.03	2.16	1.64
Aug	21.8	39.3	77.3	28.1	28.7	39.0	0.89	1.61	3.17	1.15	1.18	1.60
Sep	30.2	95.8	78.3	85.2	57.8	69.5	1.24	3.93	3.22	3.50	2.38	2.85
Mean		60.8	50.9	39.8	58.1	52.4		2.50	2.09	1.64	2.39	2.15

TABLE 32
NK119A Discharge Measurement Record

Date	Time	Stage (ft)	Measured Discharge (cfs) [a]	Rating Curve Discharge (cfs)	Rating Curve Error	Notes
30-Apr-04	13:58	-	*44.9*	-	-	-
15-Jun-04	11:13	-	*18.1*	-	-	-
15-Jul-04	14:45	96.69	8.9	9.0	0.8%	-
24-Aug-04	10:10	96.53	6.4	5.1	21.3%	-
15-Sep-04	17:00	96.49	5.1	4.4	15.9%	-
17-Oct-04	16:10	*97.07*	*24.6*	-	-	Datalogger disturbed, no staff gage for stage verification.
26-Jan-05	16:00	-	*5.9*	-	-	-
20-Mar-05	15:15	-	*3.7*	-	-	-
3-May-05	15:35	-	*77.6*	-	-	-
4-Jun-05	13:45	97.37	33.3	40.3	19.2%	-
11-Jul-05	14:40	96.95	17.2	18.0	4.7%	-
16-Aug-05	15:30	96.64	8.6	7.7	11.5%	-
13-Sep-05	9:00	97.77	72.7	71.4	1.8%	-
28-Oct-05	11:35	96.95	16.6	18.0	7.8%	-
19-Jan-06	12:35	*96.70*	*5.0*	-	-	-
9-Feb-06	12:40	*96.48*	*4.7*	-	-	-
13-Mar-06	10:45	*96.41*	*3.9*	-	-	-
1-Apr-06	17:45	*96.39*	*2.8*	-	-	-
1-Apr-06	17:45	*96.39*	*2.8*	-	-	-
21-May-06	12:40	97.59	48.9	56.2	13.8%	-
15-Jun-06	16:42	97.14	28.2	26.9	4.9%	-
15-Jun-06	16:42	97.14	32.1	26.9	17.7%	-
23-Jul-06	13:45	96.74	10.5	10.5	0.7%	-
23-Jul-06	13:45	96.74	10.8	10.5	3.2%	-
16-Aug-06	11:50	97.57	52.8	54.6	3.3%	-
16-Aug-06	11:50	97.57	50.4	54.6	7.9%	-
15-Sep-06	10:45	97.59	53.3	56.2	5.2%	-
15-Sep-06	10:45	97.59	49.5	56.2	12.5%	-
3-Nov-06	10:55	*96.81*	*11.8*	-	-	-
3-Nov-06	10:55	*96.81*	*12.1*	-	-	-
13-Dec-06	12:55	-	*6.4*	-	-	-
13-Dec-06	12:55	-	*5.8*	-	-	-
17-Feb-07	11:30	*96.43*	*4.7*	-	-	-
17-Feb-07	11:30	*96.43*	*3.4*	-	-	-
17-Mar-07	14:38	-	*3.0*	-	-	-
17-Mar-07	14:38	-	*2.6*	-	-	-
30-Mar-07	0:00	-	*2.4*	-	-	-
22-Apr-07	13:05	*96.50*	*6.3*	-	-	-
22-Apr-07	13:05	*96.50*	*4.9*	-	-	-
13-May-07	11:36	97.30	36.4	35.9	1.4%	-
13-May-07	11:36	97.30	30.5	35.9	16.2%	-
18-Jun-07	17:22	96.95	20.5	18.0	12.9%	-
18-Jun-07	17:22	96.95	15.9	-	-	Error between salt dilution measurement runs > 10%
13-Jul-07	10:55	97.01	21.4	20.6	3.9%	-
13-Jul-07	10:55	97.01	20.4	-	-	Error between salt dilution measurement runs > 10%
16-Aug-07	13:33	96.78	10.4	11.7	11.6%	-

Date	Time	Stage (ft)	Measured Discharge (cfs) [a]	Rating Curve Discharge (cfs)	Rating Curve Error	Notes
16-Aug-07	13:33	96.78	10.1	-	-	Error between salt dilution measurement runs > 10%
17-Sep-07	11:42	97.19	28.3	29.5	4.2%	-
17-Sep-07	11:42	97.19	27.1	-	-	Error between salt dilution measurement runs > 10%
14-Oct-07	15:20	96.98	15.3	19.3	23.0%	-
14-Oct-07	15:20	96.98	20.1	-	-	Error between salt dilution measurement runs > 10%
10-Nov-07	10:55	*96.87*	*15.4*	-	-	-
10-Nov-07	10:55	*96.87*	*14.9*	-	-	-
9-Dec-07	12:23	-	*14.1*	-	-	-
9-Dec-07	12:23	-	*12.9*	-	-	-
25-Jan-08	15:39	*96.46*	*4.5*	-	-	-
25-Jan-08	14:20	*96.46*	*4.5*	-	-	-
20-Feb-08	15:07	-	*4.0*	-	-	-
17-Mar-08	15:49	-	*3.6*	-	-	-
25-Mar-08	12:30	-	*2.9*	-	-	-
18-Apr-08	14:23	-	*3.0*	-	-	-
19-May-08	14:38	*97.62*	*66.7*	-	-	Snow drifts on both banks; intermittent current meter problems.
14-Jun-08	15:00	97.57	59.9	54.6	9.3%	-
14-Jun-08	14:44	97.57	62.8	-	-	Error between salt dilution measurement runs > 10%.
18-Jul-08	10:40	97.10	25.9	24.8	4.2%	-
18-Jul-08	11:12	97.10	31.0	24.8	22.1%	-
19-Aug-08	14:52	96.67	9.2	8.5	8.8%	-
19-Aug-08	14:43	96.67	9.5	8.5	11.9%	-
19-Sep-08	13:10	97.63	60.8	59.4	2.4%	-
19-Sep-08	13:45	97.63	68.7	59.4	14.6%	-
19-Oct-08	13:45	97.02	18.7	-	-	Error between salt dilution and area-velocity measurements > 10%.
19-Oct-08	13:40	97.02	23.5	-	-	Error between salt dilution and area-velocity measurements > 10%.
20-Nov-08	0:00	-	*6.9*	-	-	-
20-Nov-08	10:52	-	*6.8*	-	-	-
8-Dec-08	14:10	*96.69*	*11.0*	-	-	-
8-Dec-08	14:35	*96.69*	*8.5*	-	-	-
				Average	9.6%	

Note:

a. Italicized values were not used in rating curve development.

TABLE 33
NK119A Monthly Discharge Summary

	Monthly Discharge (cfs)						Monthly Unit Runoff (cfs/mi^2)					
Month	**2003-04**	**2004-05**	**2005-06**	**2006-07**	**2007-08**	**Mean**	**2003-04**	**2004-05**	**2005-06**	**2006-07**	**2007-08**	**Mean**
Oct		41.3	30.4	52.5	30.1	38.6		5.33	3.92	6.77	3.88	4.97
Nov		18.2	9.0	6.8	15.3	12.3		2.35	1.16	0.87	1.97	1.59
Dec		10.0	8.2	4.5	9.4	8.0		1.28	1.06	0.58	1.21	1.03
Jan		4.5	5.1	3.6	6.6	5.0		0.59	0.66	0.47	0.85	0.64
Feb		4.1	4.0	3.4	5.4	4.2		0.53	0.52	0.44	0.69	0.55
Mar		3.9	3.5	2.8	4.4	3.7		0.50	0.46	0.36	0.57	0.47
Apr		23.1	3.1	8.3	4.0	9.6		2.98	0.41	1.07	0.51	1.24
May		124.0	69.1	45.1	78.1	79.1		15.99	8.90	5.82	10.07	10.19
Jun		35.3	34.1	24.5	69.6	40.9		4.55	4.39	3.16	8.97	5.27
Jul		20.8	14.8	12.9	25.1	18.4		2.69	1.90	1.66	3.23	2.37
Aug	6.5	26.1	45.1	13.5	9.8	20.2	0.84	3.36	5.82	1.75	1.26	2.60
Sep	29.9	71.2	35.9	61.3	31.9	46.0	3.85	9.18	4.62	7.90	4.10	5.93
Mean		32.1	22.0	20.0	24.2	24.6		4.13	2.84	2.58	3.12	3.17

TABLE 34
NK119B Discharge Measurement Record

Date	Time	Stage (ft)	Measured Discharge (cfs) [a]	Rating Curve Discharge (cfs)	Rating Curve Error	Notes
21-May-04	13:12	-	*25.8*	-	-	-
15-Jun-04	13:13	-	*5.1*	-	-	-
14-Jul-04	16:13	-	*1.2*	-	-	-
24-Aug-04	12:55	-	*0.3*	-	-	-
15-Sep-04	18:00	-	*4.9*	-	-	-
18-Oct-04	10:45	-	*7.2*	-	-	-
9-May-05	14:00	-	*40.4*	-	-	-
4-Jun-05	10:45	-	*8.5*	-	-	-
9-Jul-05	18:15	-	*0.8*	-	-	-
19-Aug-05	12:15	-	*0.8*	-	-	-
13-Sep-05	13:04	-	*21.1*	-	-	-
28-Oct-05	10:30	-	*4.4*	-	-	-
9-Feb-06	-	-	*0.0*	-	-	Dry channel
16-Feb-07	-	-	*0.0*	-	-	Dry channel
16-Mar-07	-	-	*0.0*	-	-	Dry channel
31-Mar-07	-	-	*0.0*	-	-	Dry channel
22-Apr-07	-	-	*1.1*	-	-	-
12-May-07	-	-	*18.1*	-	-	-
18-Jun-07	14:40	89.90	0.4	0.4	18.0%	-
14-Jul-07	-	-	*0.0*	-	-	Dry channel
17-Aug-07	-	-	*0.0*	-	-	Dry channel
18-Sep-07	10:00	90.38	3.8	3.5	5.7%	-
15-Oct-07	13:27	90.48	5.7	4.8	18.4%	-
10-Nov-07	12:55	90.51	*3.5*	-	-	-
9-Dec-07	-	-	*3.9*	-	-	-
28-Mar-08	-	-	*0.0*	-	-	Dry channel
14-Jun-08	13:03	91.00	14.7	14.9	1.5%	-
18-Jul-08	12:51	90.22	1.5	2.0	30.4%	-
19-Aug-08	-	-	*0.0*	-	-	Dry channel
18-Sep-08	16:27	90.85	10.2	11.3	9.6%	-
19-Oct-08	15:09	90.72	*3.0*	-	-	Snow-covered vegetation interfering with flow.
20-Nov-08	-	-	*0.0*	-	-	Dry channel
				Average	13.9%	

Note:
a. Italicized values were not used in rating curve development.

TABLE 35
NK119B Monthly Discharge Summary

	Monthly Discharge (cfs)						Monthly Unit Runoff (cfs/mi²)					
Month	2003-04	2004-05	2005-06	2006-07	2007-08	Mean	2003-04	2004-05	2005-06	2006-07	2007-08	Mean
Oct				17.9	10.5	14.2				2.30	1.35	1.83
Nov				1.4	5.7	3.6				0.18	0.74	0.46
Dec				0.6	2.4	1.5				0.08	0.30	0.19
Jan				0.3	1.4	0.9				0.04	0.18	0.11
Feb				0.3	1.0	0.6				0.03	0.12	0.08
Mar				0.0	0.6	0.3				0.01	0.08	0.04
Apr				1.1	0.5	0.8				0.14	0.06	0.10
May				6.3	23.0	14.6				0.81	2.96	1.89
Jun				0.5	19.3	9.9				0.06	2.49	1.28
Jul				0.0	2.5	1.3				0.00	0.33	0.16
Aug				0.2	0.0	0.1				0.02	0.00	0.01
Sep				13.1	6.0	9.5				1.69	0.77	1.23
Mean				3.5	6.1	4.8				0.45	0.79	0.62

TABLE 36
UT100-APC3 Discharge Measurement Record

Date	Time	Stage (ft)	Measured Discharge (cfs) [a]	Rating Curve Discharge (cfs)	Rating Curve Error	Notes
21-Aug-07	16:05	98.57	*232.2*	240.2	3.4%	-
21-Sep-07	13:43	100.06	*851.2*	851.3	0.0%	-
18-Oct-07	15:15	99.03	*423.3*	395.4	6.8%	-
16-Nov-07	12:30	98.80	*180.3*	-	-	-
12-Dec-07	14:45	99.01	*344.8*	-	-	-
29-Jan-08	-	-	*220.4*	-	-	-
15-Feb-08	-	-	*193.6*	-	-	-
27-Mar-08	-	-	*166.4*	-	-	-
23-Apr-08	-	-	*215.0*	-	-	-
16-May-08	14:01	-	*1070.5*	-	-	- Unverified staff gauge datum.
24-Jun-08	13:25	99.10	*406.5*	421.7	3.7%	-
29-Jul-08	13:21	98.70	*324.7*	280.8	14.5%	-
20-Aug-08	14:16	98.63	*230.1*	258.6	11.7%	-
28-Oct-08	15:48	98.93	*314.5*	-	-	- Shore ice present.
19-Nov-08	-	-	*184.7*	-	-	-
10-Dec-08	-	-	*227.1*	-	-	-
				Average	6.7%	

Note:

a. Italicized values were not used in rating curve development.

TABLE 37
UT100-APC3 Monthly Discharge Summary

	Monthly Discharge (cfs)						Monthly Unit Runoff (cfs/mi^2)					
Month	**2003-04**	**2004-05**	**2005-06**	**2006-07**	**2007-08**	**Mean**	**2003-04**	**2004-05**	**2005-06**	**2006-07**	**2007-08**	**Mean**
Oct					533.2						3.97	
Nov					474.5						3.54	
Dec					337.2						2.51	
Jan					230.0						1.71	
Feb					183.0						1.36	
Mar					144.1						1.07	
Apr					192.9						1.44	
May					937.6						6.99	
Jun					579.8						4.32	
Jul					289.9						2.16	
Aug					255.1						1.90	
Sep				511.5	421.9	466.7				3.81	3.14	3.48
Mean					382.8						2.85	

TABLE 38
UT100-APC2 Discharge Measurement Record

Date	Time	Stage (ft)	Measured Discharge (cfs) [a]	Rating Curve Discharge (cfs)	Rating Curve Error	Notes
21-Aug-07	10:20	98.20	*172.2*	176.6	2.5%	-
22-Sep-07	10:35	-	*585.9*	-	-	- Staff gage datum uncertain.
18-Oct-07	13:17	-	*318.5*	-	-	- Staff gage datum uncertain.
15-Nov-07	13:45	-	*271.2*	-	-	-
12-Dec-07	13:10	-	*262.2*	-	-	-
29-Jan-08	-	-	*143.9*	-	-	-
13-Feb-08	-	-	*129.5*	-	-	-
27-Mar-08	-	-	*114.0*	-	-	-
23-Apr-08	-	-	*156.9*	-	-	-
14-May-08	11:53	99.32	*906.2*	872.3	3.8%	-
24-Jun-08	10:00	98.59	*346.1*	346.7	0.2%	-
29-Jul-08	10:30	98.33	*228.9*	225.7	1.4%	-
20-Aug-08	11:59	98.17	*178.1*	166.3	6.8%	-
28-Oct-08	12:52	98.62	*251.8*	-	-	- Anchor ice, slush in creek, shore ice.
10-Dec-08	-	-	*185.0*	-	-	-
				Average	3.0%	

Note:

a. Italicized values were not used in rating curve development.

TABLE 39
UT100-APC2 Monthly Discharge Summary

	Monthly Discharge (cfs)						Monthly Unit Runoff (cfs/mi^2)					
Month	**2003-04**	**2004-05**	**2005-06**	**2006-07**	**2007-08**	**Mean**	**2003-04**	**2004-05**	**2005-06**	**2006-07**	**2007-08**	**Mean**
Oct					441.4						4.01	
Nov					389.6						3.54	
Dec					276.9						2.51	
Jan					188.8						1.71	
Feb					150.2						1.36	
Mar					118.3						1.07	
Apr					158.4						1.44	
May					800.8						7.27	
Jun					474.8						4.31	
Jul					225.2						2.04	
Aug					180.6						1.64	
Sep				451.9	392.0	421.9				4.10	3.56	3.83
Mean					317.4						2.88	

TABLE 40
UT100-APC1 Discharge Measurement Record

Date	Time	Stage (ft)	Measured Discharge (cfs) [a]	Rating Curve Discharge (cfs)	Rating Curve Error	Notes
20-Aug-07	11:07	-	*160.0*	151.0	5.8%	-
21-Sep-07	10:15	-	*718.2*	752.3	4.6%	-
18-Oct-07	10:00	-	*297.2*	280.7	5.7%	-
15-Nov-07	11:35	-	*246.2*	-	-	-
12-Dec-07	11:40	-	*234.8*	-	-	-
29-Jan-08	11:00	-	*160.3*	-	-	-
13-Feb-08	12:05	-	*125.1*	-	-	-
27-Mar-08	10:05	-	*93.9*	-	-	-
23-Apr-08	9:00	-	*140.3*	-	-	-
14-May-08	13:23	-	*917.0*	874.0	4.8%	-
23-Jun-08	15:50	-	*332.0*	316.5	4.8%	-
29-Jul-08	8:39	-	*207.7*	223.2	7.2%	-
20-Aug-08	9:23	-	*163.1*	173.3	6.0%	-
27-Oct-08	14:35	-	*225.6*	-	-	- Slush in creek and shore ice present.
20-Nov-08	10:15	-	*68.6*	-	-	-
9-Dec-08	14:30	-	*200.6*	-	-	-
				Average	5.6%	

Note:

a. Italicized values were not used in rating curve error assessment.

TABLE 41
UT100-APC1 Monthly Discharge Summary

	Monthly Discharge (cfs)						Monthly Unit Runoff (cfs/mi^2)					
Month	**2003-04**	**2004-05**	**2005-06**	**2006-07**	**2007-08**	**Mean**	**2003-04**	**2004-05**	**2005-06**	**2006-07**	**2007-08**	**Mean**
Oct					396.8						3.91	
Nov					353.5						3.48	
Dec					255.1						2.51	
Jan					174.0						1.71	
Feb					138.4						1.36	
Mar					109.0						1.07	
Apr					146.0						1.44	
May					701.4						6.91	
Jun					434.1						4.28	
Jul					237.7						2.34	
Aug					188.9						1.86	
Sep				423.3	361.4	392.4				4.17	3.56	3.86
Mean					292.3						2.88	

TABLE 42
UT100B Discharge Measurement Record

Date	Time	Stage (ft)	Measured Discharge (cfs) [a]	Rating Curve Discharge (cfs)	Rating Curve Error	Notes
25-Aug-04	14:30	16.91	111.0	106.8	3.8%	-
13-Sep-04	14:10	16.89	103.0	102.8	0.1%	-
19-Oct-04	8:55	17.63	317.0	329.9	4.0%	-
28-Oct-04	9:35	17.92	471.0	471.8	0.2%	-
3-Feb-05	11:10	19.33	*122.0*	-	-	-
7-Mar-05	12:10	17.00	*135.0*	-	-	-
27-Apr-05	12:41	18.00	*563.0*	-	-	-
25-May-05	10:50	17.64	386.0	334.2	14.4%	-
20-Jul-05	12:35	17.06	169.0	140.2	18.6%	-
12-Aug-05	8:20	16.92	130.0	108.9	17.7%	-
6-Oct-05	10:23	17.47	294.0	265.5	10.2%	-
8-Dec-05	15:45	17.76	*425.0*	-	-	-
20-Feb-06	15:50	16.99	*134.0*	-	-	-
16-May-06	14:07	17.94	491.0	482.9	1.7%	-
1-Jun-06	15:40	17.59	339.0	312.9	8.0%	-
20-Jun-06	18:30	17.30	245.0	207.1	16.8%	-
14-Aug-06	13:15	17.64	374.0	334.2	11.2%	-
4-Oct-06	13:49	17.79	428.0	432.9	1.1%	-
26-Oct-06	12:28	17.42	261.0	271.9	4.1%	-
5-Dec-06	11:00	17.09	*155.0*	-	-	-
13-Feb-07	14:38	16.91	*113.0*	-	-	-
3-Apr-07	14:51	16.81	*98.8*	-	-	-
15-May-07	9:30	17.29	242.0	226.5	6.6%	-
26-Jun-07	13:00	17.01	172.0	146.1	16.3%	-
8-Aug-07	17:10	16.97	142.0	136.5	4.0%	-
3-Oct-07	14:50	17.68	385.0	379.9	1.3%	-
5-Dec-07	13:45	17.27	*237.0*	-	-	-
12-Mar-08	10:27	16.84	*89.2*	-	-	-
13-May-08	16:00	18.60	954.0	976.9	2.4%	-
23-Jul-08	10:25	17.18	255.0	192.2	28.1%	-
4-Sep-08	14:19	17.13	209.0	177.8	16.2%	-
3-Oct-08	12:58	17.36	293.0	250.3	15.7%	-
10-Dec-08	13:42	16.95	*154.0*	-	-	-
				Average	9.2%	

Note:

a. Italicized values were not used in rating curve error assessment.

TABLE 43
UT100B Monthly Discharge Summary

	Monthly Discharge (cfs)						Monthly Unit Runoff (cfs/mi^2)					
Month	**2003-04**	**2004-05**	**2005-06**	**2006-07**	**2007-08**	**Mean**	**2003-04**	**2004-05**	**2005-06**	**2006-07**	**2007-08**	**Mean**
Oct		340.7	312.6	431.0	345.5	357.4		3.95	3.63	5.00	4.01	4.14
Nov		311.2	220.3	173.6	305.0	252.5		3.61	2.55	2.01	3.54	2.93
Dec		198.3	232.5	135.0	216.7	195.6		2.30	2.70	1.57	2.51	2.27
Jan		121.6	134.0	114.9	147.8	129.6		1.41	1.55	1.33	1.71	1.50
Feb		121.1	123.3	127.8	117.6	122.5		1.40	1.43	1.48	1.36	1.42
Mar		126.6	119.1	94.5	92.6	108.2		1.47	1.38	1.10	1.07	1.25
Apr		278.7	130.6	217.1	124.0	187.6		3.23	1.51	2.52	1.44	2.18
May		445.1	531.6	222.2	602.6	450.4		5.16	6.16	2.58	6.99	5.22
Jun		221.6	266.0	157.4	389.8	258.7		2.57	3.08	1.82	4.52	3.00
Jul		171.7	174.3	127.4	209.7	170.8		1.99	2.02	1.48	2.43	1.98
Aug		163.6	345.6	134.9	162.6	201.7		1.90	4.01	1.56	1.89	2.34
Sep	187.6	407.3	314.9	342.0	292.7	308.9	2.18	4.72	3.65	3.97	3.39	3.58
Mean		242.6	243.2	190.0	251.3	231.8		2.81	2.82	2.20	2.91	2.69

TABLE 44
UT100C Discharge Measurement Record

Date	Time	Stage (ft)	Measured Discharge (cfs) [a]	Rating Curve Discharge (cfs)	Rating Curve Error	Notes
19-Feb-07	-	-	*67.3*	-	-	-
13-Mar-07	-	-	*44.0*	-	-	-
1-Apr-07	-	-	*48.5*	-	-	-
23-Apr-07	11:20	-	*193.1*	-	-	-
13-May-07	12:30	96.07	152.1	157.5	3.5%	-
19-Jun-07	11:25	95.91	111.5	108.9	2.4%	-
15-Jul-07	9:55	95.87	107.8	98.4	9.1%	-
18-Aug-07	-	95.81	77.2	83.9	8.4%	-
18-Sep-07	-	96.10	175.8	167.9	4.6%	-
16-Oct-07	-	96.15	188.6	186.1	1.3%	-
11-Nov-07	14:10	-	*176.2*	-	-	-
11-Dec-07	11:15	-	*166.0*	-	-	-
22-Feb-08	11:10	-	*68.7*	-	-	-
13-Mar-08	12:50	-	*82.0*	-	-	-
27-Mar-08	11:50	-	*78.5*	-	-	-
21-Apr-08	10:11	-	*66.4*	-	-	-
17-May-08	17:10	96.76	484.6	458.4	5.6%	-
12-Jun-08	14:10	96.50	271.8	302.3	10.6%	-
16-Jul-08	12:45	96.11	133.1	139.0	4.4%	-
21-Aug-08	11:08	95.97	104.2	98.6	5.6%	-
20-Sep-08	11:20	96.56	327.3	334.8	2.2%	-
20-Oct-08	12:22	96.26	201.3	192.6	4.4%	-
23-Nov-08	12:50	-	*112.8*	-	-	-
9-Dec-08	14:10	-	*94.7*	-	-	-
				Average	5.2%	

Note:

a. Italicized values were not used in rating curve development.

TABLE 45
UT100C Monthly Discharge Summary

	Monthly Discharge (cfs)						Monthly Unit Runoff (cfs/mi^2)					
Month	**2003-04**	**2004-05**	**2005-06**	**2006-07**	**2007-08**	**Mean**	**2003-04**	**2004-05**	**2005-06**	**2006-07**	**2007-08**	**Mean**
Oct				335.1	249.2	292.2				4.82	3.59	4.21
Nov				114.0	198.0	156.0				1.64	2.85	2.25
Dec				89.3	141.6	115.4				1.28	2.04	1.66
Jan				76.4	97.4	86.9				1.10	1.40	1.25
Feb				84.6	78.1	81.4				1.22	1.12	1.17
Mar				63.3	62.1	62.7				0.91	0.89	0.90
Apr				151.4	83.6	117.5				2.18	1.20	1.69
May				173.8	468.2	321.0				2.50	6.74	4.62
Jun				125.5	321.5	223.5				1.81	4.63	3.22
Jul				102.1	156.7	129.4				1.47	2.26	1.86
Aug				98.7	115.5	107.1				1.42	1.66	1.54
Sep				269.4	236.6	253.0				3.88	3.41	3.64
Mean				140.5	184.6	162.6				2.02	2.66	2.34

TABLE 46
UT100C1 Discharge Measurement Record

Date	Time	Stage (ft)	Measured Discharge (cfs) [a]	Rating Curve Discharge (cfs)	Rating Curve Error	Notes
19-Feb-07	14:30	-	*48.6*	-	-	-
15-Mar-07	11:40	-	*28.5*	-	-	-
1-Apr-07	10:38	-	*32.4*	-	-	-
23-Apr-07	13:55	-	*184.9*	-	-	-
13-May-07	13:55	-	*115.8*	-	-	-
19-Jun-07	11:45	91.42	84.9	77.4	9.2%	-
15-Jul-07	9:25	91.34	71.6	66.7	7.1%	-
18-Aug-07	13:50	91.30	61.7	61.7	0.1%	-
18-Sep-07	12:03	91.72	139.6	125.6	10.5%	-
16-Oct-07	12:26	91.74	140.8	129.3	8.6%	-
12-Nov-07	11:55	-	*120.4*	-	-	-
11-Dec-07	11:30	-	*121.7*	-	-	-
18-Jan-08	12:24	-	*58.8*	-	-	-
22-Feb-08	11:30	-	*66.9*	-	-	-
13-Mar-08	13:15	-	*50.4*	-	-	-
27-Mar-08	13:00	-	*43.2*	-	-	-
21-Apr-08	11:12	-	*48.6*	-	-	-
17-May-08	10:36	92.70	374.5	375.4	0.2%	-
12-Jun-08	15:05	92.16	228.4	219.8	3.9%	-
16-Jul-08	10:14	91.61	97.3	106.5	9.0%	-
21-Aug-08	12:29	91.41	71.3	76.0	6.5%	-
20-Sep-08	14:00	92.32	255.1	261.2	2.3%	-
20-Oct-08	13:15	91.86	152.7	152.5	0.2%	-
22-Nov-08	14:00	-	*73.5*	-	-	-
9-Dec-08	13:40	-	*86.8*	-	-	-
				Average	5.2%	

Note:

a. Italicized values were not used in rating curve development.

TABLE 47
UT100C1 Monthly Discharge Summary

	Monthly Discharge (cfs)						Monthly Unit Runoff (cfs/mi^2)					
Month	**2003-04**	**2004-05**	**2005-06**	**2006-07**	**2007-08**	**Mean**	**2003-04**	**2004-05**	**2005-06**	**2006-07**	**2007-08**	**Mean**
Oct				258.1	187.3	222.7				4.27	3.10	3.69
Nov				89.8	171.2	130.5				1.49	2.83	2.16
Dec				65.9	116.5	91.2				1.09	1.93	1.51
Jan				53.4	73.8	63.6				0.88	1.22	1.05
Feb				61.4	55.1	58.2				1.02	0.91	0.96
Mar				40.7	39.6	40.2				0.67	0.66	0.66
Apr				116.8	59.0	87.9				1.93	0.98	1.46
May				127.9	350.5	239.2				2.12	5.80	3.96
Jun				83.9	253.7	168.8				1.39	4.20	2.79
Jul				69.6	126.4	98.0				1.15	2.09	1.62
Aug				67.8	90.3	79.1				1.12	1.50	1.31
Sep				200.8	196.4	198.6				3.32	3.25	3.29
Mean				103.1	143.8	123.4				1.71	2.38	2.04

TABLE 48
UT100C2 Discharge Measurement Record

Date	Time	Stage (ft)	Measured Discharge (cfs) [a]	Rating Curve Discharge (cfs)	Rating Curve Error	Notes
22-Feb-07	13:14	-	*32.5*	-	-	-
1-Apr-07	15:35	-	*18.9*	-	-	-
13-May-07	15:35	-	*105.9*	-	-	-
19-Jun-07	15:10	95.54	66.5	67.1	0.9%	-
15-Jul-07	13:43	95.49	57.1	58.6	2.6%	-
18-Aug-07	10:12	95.41	44.7	46.2	3.4%	-
19-Sep-07	9:45	96.94	364.8	380.0	4.1%	Overflow conditions. Two overflow side channels w/ ~.13-.22 CFS.
16-Oct-07	11:45	95.80	120.5	121.6	0.9%	-
12-Nov-07	12:45	97.12	*99.6*	-	-	-
11-Dec-07	14:00	-	*101.5*	-	-	-
18-Jan-08	14:50	-	*47.0*	-	-	-
23-Feb-08	13:00	-	*40.1*	-	-	-
13-Mar-08	15:00	-	*34.6*	-	-	-
27-Mar-08	13:30	-	*25.3*	-	-	-
21-Apr-08	13:53	-	*27.3*	-	-	-
17-May-08	13:45	96.64	315.5	303.6	3.9%	-
12-Jun-08	16:03	96.16	188.4	196.9	4.4%	-
16-Jul-08	12:15	95.64	86.2	86.0	0.2%	-
21-Aug-08	11:48	95.46	57.6	53.7	6.9%	-
20-Sep-08	13:08	96.28	228.3	221.7	2.9%	-
20-Oct-08	13:29	95.88	146.3	141.9	3.0%	-
23-Nov-08	10:50	-	*55.9*	-	-	-
9-Sep-08	14:30	-	*70.8*	-	-	-
				Average	3.0%	

Note:

a. Italicized values were not used in rating curve development.

TABLE 49
UT100C2 Monthly Discharge Summary

	Monthly Discharge (cfs)						Monthly Unit Runoff (cfs/mi^2)					
Month	**2003-04**	**2004-05**	**2005-06**	**2006-07**	**2007-08**	**Mean**	**2003-04**	**2004-05**	**2005-06**	**2006-07**	**2007-08**	**Mean**
Oct				253.1	181.0	217.1				5.24	3.75	4.49
Nov				68.9	139.9	104.4				1.43	2.90	2.16
Dec				48.1	92.2	70.2				1.00	1.91	1.45
Jan				37.2	55.0	46.1				0.77	1.14	0.95
Feb				44.2	38.7	41.5				0.92	0.80	0.86
Mar				26.2	25.2	25.7				0.54	0.52	0.53
Apr				92.5	49.4	70.9				1.91	1.02	1.47
May				127.2	308.6	217.9				2.63	6.39	4.51
Jun				82.6	226.6	154.6				1.71	4.69	3.20
Jul				64.3	106.0	85.1				1.33	2.19	1.76
Aug				59.7	64.1	61.9				1.24	1.33	1.28
Sep				204.6	172.9	188.8				4.24	3.58	3.91
Mean				92.6	122.0	107.3				1.92	2.53	2.22

TABLE 50
UT100D Discharge Measurement Record

Date	Time	Stage (ft)	Measured Discharge (cfs) [a]	Rating Curve Discharge (cfs)	Rating Curve Error	Notes
30-Apr-04	-	-	*112.0*	-	-	-
20-May-04	-	-	*55.6*	-	-	-
17-Jun-04	-	-	*47.5*	-	-	-
15-Jul-04	11:15	97.91	12.9	12.6	2.2%	-
25-Aug-04	12:50	97.82	7.8	9.0	15.2%	-
17-Sep-04	16:00	97.77	7.9	7.3	7.9%	-
18-Oct-04	10:25	98.15	25.5	24.7	3.3%	-
27-Jan-05	-	-	*15.2*	-	-	-
19-Mar-05	-	-	*10.5*	-	-	-
2-May-05	-	-	*118.2*	-	-	-
4-Jun-05	16:45	98.11	30.6	34.7	12.6%	-
11-Jul-05	9:15	97.81	19.2	19.2	0.1%	-
15-Jul-05	11:50	97.75	16.9	16.6	2.1%	-
16-Aug-05	10:21	97.62	8.4	11.6	31.4%	-
13-Sep-05	14:55	98.36	49.7	51.0	2.6%	-
30-Oct-05	14:15	98.07	*27.9*	-	-	Ice conditions.
10-Feb-06	-	-	*8.5*	-	-	-
15-Mar-06	-	-	*8.8*	-	-	-
15-Mar-06	-	-	*8.4*	-	-	-
2-Apr-06	-	-	*8.3*	-	-	-
19-May-06	11:45	98.34	62.3	49.6	22.7%	-
17-Jun-06	14:20	98.36	51.4	51.0	0.8%	-
24-Jul-06	11:30	97.86	21.0	21.4	2.1%	-
15-Aug-06	11:50	99.21	125.5	128.0	2.0%	-
12-Sep-06	12:45	98.17	*30.0*	-	-	Beaver activity downstream.
12-Dec-06	-	-	*12.5*	-	-	-
12-Jan-07	-	-	*9.8*	-	-	-
19-Feb-07	-	-	*9.3*	-	-	-
1-Apr-07	-	-	*6.4*	-	-	-
13-May-07	-	-	*28.2*	-	-	-
19-Jun-07	14:00	97.45	16.7	17.2	2.9%	-
15-Jul-07	14:15	97.42	16.7	16.0	4.3%	-
18-Aug-07	12:13	97.34	13.7	13.1	4.1%	-
19-Sep-07	10:40	98.87	111.6	112.5	0.8%	-
16-Oct-07	-	-	*35.7*	-	-	Ice conditions.
12-Nov-07	-	-	*27.0*	-	-	-
11-Dec-07	-	-	*29.0*	-	-	-
19-Jan-08	-	-	*12.6*	-	-	-
23-Feb-08	-	-	*9.9*	-	-	-
13-Mar-08	-	-	*9.2*	-	-	-
27-Mar-08	-	-	*10.0*	-	-	-
22-Apr-08	-	-	*8.7*	-	-	-
17-May-08	-	-	*95.7*	-	-	-
13-Jun-08	9:08	98.30	48.9	50.5	3.2%	-
16-Jul-08	16:17	97.84	19.5	21.3	9.0%	-
21-Aug-08	14:05	97.65	13.3	12.7	4.2%	-
19-Sep-08	16:13	98.57	79.6	72.9	8.7%	-
20-Oct-08	15:00	97.97	30.0	28.4	5.5%	-
21-Nov-08	-	-	*13.5*	-	-	-
9-Dec-08	-	-	*18.5*	-	-	-
				Average	6.7%	

Note:
a. Italicized values were not used in rating curve development.

TABLE 51
UT100D Monthly Discharge Summary

	Monthly Discharge (cfs)						Monthly Unit Runoff (cfs/mi^2)					
Month	**2003-04**	**2004-05**	**2005-06**	**2006-07**	**2007-08**	**Mean**	**2003-04**	**2004-05**	**2005-06**	**2006-07**	**2007-08**	**Mean**
Oct		40.7	38.7	62.1	49.9	47.9		3.40	3.24	5.19	4.17	4.00
Nov		40.2	26.5	19.5	39.2	31.4		3.36	2.22	1.63	3.28	2.62
Dec		23.2	28.4	13.7	26.0	22.8		1.94	2.37	1.15	2.17	1.91
Jan		11.7	13.6	10.7	15.7	12.9		0.98	1.14	0.90	1.31	1.08
Feb		11.7	12.0	12.7	11.1	11.9		0.97	1.00	1.06	0.93	0.99
Mar		12.5	11.4	7.7	7.4	9.7		1.04	0.95	0.64	0.62	0.81
Apr		35.3	13.1	27.5	12.1	22.0		2.95	1.09	2.30	1.01	1.84
May		71.8	78.3	29.6	90.9	67.7		6.01	6.55	2.47	7.60	5.66
Jun		26.6	38.1	20.3	55.1	35.0		2.23	3.19	1.70	4.60	2.93
Jul		17.4	22.7	16.7	26.7	20.9		1.45	1.90	1.40	2.23	1.75
Aug	9.5	17.6	52.1	16.8	16.0	22.4	0.79	1.47	4.35	1.41	1.34	1.87
Sep	25.3	53.2	41.6	50.7	34.8	41.1	2.12	4.45	3.48	4.24	2.91	3.44
Mean		30.2	31.5	24.0	32.2	29.5		2.53	2.64	2.01	2.69	2.47

TABLE 52
UT100E Discharge Measurement Record

Date	Time	Stage (ft)	Measured Discharge (cfs) [a]	Rating Curve Discharge (cfs)	Rating Curve Error	Notes
30-Apr-04	10:40	-	*20.6*	-	-	-
20-May-04	12:10	-	*20.2*	-	-	-
17-Jun-04	12:48	-	*16.1*	-	-	-
15-Jul-04	12:45	98.07	6.3	6.1	3.0%	-
25-Aug-04	10:20	98.02	4.6	4.6	0.0%	-
17-Sep-04	9:45	97.99	3.9	4.1	4.5%	-
18-Oct-04	16:30	98.14	8.5	8.2	3.3%	-
25-Jan-05	14:00	-	*7.1*	-	-	-
18-Mar-05	13:20	-	*4.3*	-	-	-
23-Mar-05	12:10	-	*4.6*	-	-	-
2-May-05	12:45	98.61	40.0	34.5	14.6%	-
4-Jun-05	15:45	98.20	7.8	-	-	Left bank undercut, fast flow against right bank.
11-Jul-05	11:20	98.11	7.9	7.3	8.6%	-
16-Aug-05	13:40	98.05	4.5	5.5	19.6%	-
12-Sep-05	15:08	98.33	17.4	16.5	5.3%	-
30-Oct-05	11:47	98.21	10.1	10.9	8.4%	-
19-Jan-06	11:50	98.08	*1.6*	-	-	-
7-Feb-06	12:25	-	*4.5*	-	-	-
15-Mar-06	10:40	-	*3.9*	-	-	-
18-May-06	15:05	98.40	21.9	20.3	7.7%	-
17-Jun-06	16:45	98.28	13.3	14.0	5.2%	-
24-Jul-06	13:30	98.18	9.2	9.8	6.1%	-
24-Jul-06	13:30	98.18	10.9	9.8	10.9%	-
15-Aug-06	14:25	98.51	27.4	27.2	0.5%	-
15-Aug-06	14:25	98.51	23.0	27.2	16.8%	-
12-Sep-06	15:13	98.26	11.6	13.1	12.3%	-
12-Sep-06	15:13	98.26	11.9	13.1	9.5%	-
2-Nov-06	13:40	98.26	*13.3*	-	-	-
2-Nov-06	13:35	98.26	*10.6*	-	-	-
12-Dec-06	13:10	98.11	*6.2*	-	-	-
12-Dec-06	11:56	98.11	*6.8*	-	-	-
14-Jan-07	11:32	97.91	*5.3*	-	-	-
14-Jan-07	11:05	97.91	*4.5*	-	-	-
20-Feb-07	14:00	98.56	*5.7*	-	-	-
20-Feb-07	13:48	98.56	*4.2*	-	-	-
14-Mar-07	14:38	-	*3.4*	-	-	-
14-Mar-07	13:55	-	*3.6*	-	-	-
1-Apr-07	13:41	-	*3.5*	-	-	-
23-Apr-07	13:25	98.19	*15.3*	-	-	-
23-Apr-07	13:17	98.19	*11.7*	-	-	-
14-May-07	11:58	98.07	9.4	8.6	7.9%	-
14-May-07	10:08	98.07	*7.9*	-	-	Error between salt dilution measurent runs > 10%.
19-Jun-07	17:00	97.99	6.0	6.1	0.8%	-
19-Jun-07	17:35	97.99	5.3	6.1	12.9%	-
15-Jul-07	15:15	98.00	6.2	6.4	2.9%	-
15-Jul-07	16:03	98.00	5.1	6.4	21.4%	-
18-Aug-07	14:12	98.01	5.8	6.7	13.9%	-
19-Sep-07	14:17	98.38	*21.7*	-	-	Error between salt dilution and area-velocity measurents > 10%.
19-Sep-07	12:55	98.38	*17.7*	-	-	Error between salt dilution and area-velocity measurents > 10%.

Date	Time	Stage (ft)	Measured Discharge (cfs) [a]	Rating Curve Discharge (cfs)	Rating Curve Error	Notes
16-Oct-07	15:05	98.20	14.8	14.0	5.7%	-
16-Oct-07	15:40	98.20	11.6	-	-	Error between salt dilution measurent runs > 10%.
12-Nov-07	14:20	98.13	*11.2*	-	-	-
12-Nov-07	14:20	98.13	*9.4*	-	-	-
11-Dec-07	14:32	98.18	*14.2*	-	-	-
11-Dec-07	13:46	98.18	*8.3*	-	-	-
18-Jan-08	13:21	98.01	*6.3*	-	-	-
18-Jan-08	13:15	98.01	*6.0*	-	-	-
22-Feb-08	15:15	97.96	*5.4*	-	-	-
22-Feb-08	14:15	97.96	*4.5*	-	-	-
14-Mar-08	13:25	97.93	*4.6*	-	-	-
14-Mar-08	13:20	97.93	*4.2*	-	-	-
27-Mar-08	14:20	-	*4.0*	-	-	-
27-Mar-08	14:20	-	*4.3*	-	-	-
21-Apr-08	13:15	97.91	*4.1*	-	-	-
21-Apr-08	13:21	97.91	*3.9*	-	-	-
18-May-08	9:35	98.41	*27.8*	-	-	Error between salt dilution and area-velocity measurents > 10%.
18-May-08	8:42	98.41	*19.6*	-	-	Error between salt dilution and area-velocity measurents > 10%.
13-Jun-08	13:59	98.26	17.5	17.0	3.0%	-
13-Jun-08	13:53	98.26	*16.1*	-	-	Error between salt dilution measurent runs > 10%.
16-Jul-08	15:40	98.08	8.4	9.0	6.9%	-
21-Aug-08	14:06	98.21	15.4	14.5	6.4%	-
21-Aug-08	13:34	98.21	*9.4*	-	-	Error between salt dilution measurent runs > 10%.
20-Sep-08	14:39	98.22	*14.1*	-	-	Error between salt dilution and area-velocity measurents > 10%.
20-Sep-08	15:00	98.22	*11.0*	-	-	Error between salt dilution and area-velocity measurents > 10%.
20-Oct-08	16:08	98.18	12.4	13.1	5.3%	-
20-Oct-08	16:00	98.18	10.7	13.1	19.6%	-
20-Nov-08	13:19	0.00	*6.4*	-	-	Slush, frazzle ice, and anchor ice may impact velocity measurements.
20-Nov-08	13:19	0.00	*8.1*	-	-	Slush, frazzle ice, and anchor ice may impact velocity measurements.
10-Dec-08	10:30	98.01	*6.4*	-	-	-
				Average	8.4%	

Note:

a. Italicized values were not used in rating curve development.

TABLE 53
UT100E Monthly Discharge Summary

	Monthly Discharge (cfs)						Monthly Unit Runoff (cfs/mi^2)					
Month	**2003-04**	**2004-05**	**2005-06**	**2006-07**	**2007-08**	**Mean**	**2003-04**	**2004-05**	**2005-06**	**2006-07**	**2007-08**	**Mean**
Oct		11.2	12.5	20.5	16.5	15.2		3.63	4.04	6.63	5.33	4.91
Nov		12.7	11.3	8.6	16.4	12.3		4.11	3.64	2.78	5.28	3.95
Dec		9.4	12.0	6.2	11.1	9.7		3.04	3.88	1.99	3.57	3.12
Jan		5.4	6.1	5.0	6.9	5.8		1.73	1.97	1.60	2.24	1.89
Feb		5.3	5.5	5.7	5.1	5.4		1.72	1.76	1.85	1.65	1.75
Mar		5.7	5.2	3.7	3.6	4.6		1.83	1.68	1.21	1.17	1.47
Apr		8.6	4.9	10.9	5.2	7.4		2.79	1.58	3.51	1.68	2.39
May		25.0	19.8	9.0	24.0	19.5		8.07	6.40	2.89	7.75	6.28
Jun		8.9	11.5	6.8	17.4	11.2		2.86	3.72	2.20	5.60	3.60
Jul		7.0	8.7	6.6	9.6	8.0		2.25	2.80	2.14	3.11	2.57
Aug	5.0	6.6	14.3	6.7	7.6	8.1	1.62	2.14	4.62	2.16	2.46	2.60
Sep	6.1	13.5	15.3	13.5	12.2	12.1	1.98	4.37	4.92	4.35	3.95	3.92
Mean		10.0	10.6	8.6	11.3	10.1		3.22	3.43	2.78	3.66	3.27

TABLE 54
UT106-APC1 Discharge Measurement Record

Date	Time	Stage (ft)	Measured Discharge (cfs)	Rating Curve Discharge (cfs) [a]	Rating Curve Error	Notes
15-May-08	16:33	98.70	86.7	-	-	-
25-Jun-08	10:10	98.52	45.5	-	-	-
29-Jul-08	15:15	98.46	37.7	-	-	-
21-Aug-08	13:14	98.46	36.8	-	-	-
24-Sep-08	15:45	98.76	86.1	-	-	-
29-Oct-08	10:26	99.46	35.2	-	-	- Ice dam
10-Dec-08	-	-	29.2	-	-	-

Note:

a. Rating curve not developed at this time.

TABLE 55
UT119A Discharge Management Record

Date	Time	Stage (ft)	Measured Discharge (cfs)[a]	Rating Curve Discharge (cfs)	Rating Curve Error	Notes
30-Apr-04	10:15	-	*35.9*	-	-	-
20-May-04	10:03	-	*34.9*	-	-	-
17-Jun-04	11:00	-	*35.0*	-	-	-
15-Jul-04	9:45	96.51	27.3	29.9	9.1%	-
26-Aug-04	12:37	96.45	25.5	25.8	1.3%	-
16-Sep-04	16:40	96.44	25.2	25.4	0.9%	-
17-Oct-04	10:50	96.36	*23.6*	-	-	Data logger erroneous, no manual stage measurement
26-Jan-05	11:46	0.00	*29.9*	-	-	-
18-Mar-05	12:07	0.00	*24.7*	-	-	-
2-May-05	14:00	96.43	28.2	31.7	11.4%	-
2-Jun-05	11:30	96.44	32.4	32.3	0.4%	-
10-Jul-05	10:03	96.44	27.3	32.3	16.7%	-
15-Jul-05	11:00	96.41	28.0	30.4	7.9%	-
17-Aug-05	16:47	96.44	28.7	32.3	12.0%	-
14-Sep-05	10:15	96.45	37.1	33.0	11.7%	-
30-Oct-05	11:55	96.47	33.4	34.3	2.6%	-
19-Jan-06	17:05	-	*8.6*	-	-	-
8-Feb-06	16:12	-	*28.4*	-	-	-
14-Mar-06	12:00	-	*29.1*	-	-	-
2-Apr-06	12:48	96.62	*27.5*	-	-	-
2-Apr-06	12:48	96.62	*21.9*	-	-	-
19-May-06	13:35	96.44	36.4	32.3	11.9%	-
17-Jun-06	12:10	96.37	30.7	27.8	9.7%	-
17-Jun-06	12:10	96.37	30.4	-	-	Error between salt dilution measurent runs > 10%
24-Jul-06	8:45	96.35	24.4	26.6	8.5%	-
24-Jul-06	8:45	96.35	25.7	26.6	3.3%	-
15-Aug-06	9:45	96.37	33.4	27.8	18.1%	-
15-Aug-06	9:45	96.37	29.5	27.8	5.9%	-
12-Sep-06	10:43	96.44	*32.1*	-	-	Error between salt dilution and area-velocity measurents > 10%
12-Sep-06	10:43	96.44	*25.7*	-	-	Error between salt dilution and area-velocity measurents > 10%
2-Nov-06	10:48	96.50	*33.0*	-	-	-
2-Nov-06	10:48	96.50	*28.2*	-	-	-
11-Dec-06	15:20	96.43	*9.9*	-	-	-
12-Jan-07	12:40	96.25	*29.2*	-	-	-
12-Jan-07	12:40	96.25	*25.3*	-	-	-
21-Feb-07	14:15	96.33	*28.7*	-	-	-
21-Feb-07	14:15	96.33	*19.5*	-	-	-
13-Mar-07	15:45	-	*24.4*	-	-	-
13-Mar-07	15:45	-	*21.4*	-	-	-
2-Apr-07	0:00	-	*22.9*	-	-	-
23-Apr-07	10:52	96.29	*30.0*	-	-	-
23-Apr-07	11:19	96.29	*26.7*	-	-	-
13-May-07	15:45	96.30	25.0	23.6	5.5%	-
13-May-07	16:29	96.30	23.0	23.6	2.7%	-
20-Jun-07	10:05	96.29	25.6	23.1	10.5%	-

Date	Time	Stage (ft)	Measured Discharge (cfs) [a]	Rating Curve Discharge (cfs)	Rating Curve Error	Notes
20-Jun-07	10:05	96.29	*22.4*	-	-	Error between salt dilution measurent runs > 10%
16-Jul-07	8:32	96.29	*26.3*	-	-	Error between salt dilution and area-velocity measurents > 10%
16-Jul-07	8:32	96.29	*21.4*	-	-	Error between salt dilution and area-velocity measurents > 10%
17-Aug-07	10:57	96.28	22.4	22.5	0.4%	-
17-Aug-07	10:57	96.28	21.0	22.5	6.9%	-
19-Sep-07	16:40	96.37	31.3	27.8	11.8%	-
19-Sep-07	16:40	96.37	27.2	27.8	2.4%	-
15-Oct-07	15:25	96.35	31.8	26.6	17.6%	-
15-Oct-07	15:25	96.35	30.8	26.6	14.7%	-
12-Nov-07	12:10	96.30	*30.9*	-	-	-
12-Nov-07	12:10	96.30	*27.3*	-	-	-
12-Dec-07	11:14	96.36	*29.5*	-	-	-
12-Dec-07	11:14	96.36	*24.6*	-	-	-
18-Aug-08	12:00	96.35	*30.0*	-	-	-
23-Feb-08	14:26	96.31	*26.0*	-	-	-
23-Feb-08	14:05	96.31	*25.6*	-	-	-
15-Mar-08	14:45	96.38	*25.1*	-	-	-
15-Mar-08	14:50	96.38	*25.1*	-	-	-
28-Mar-08	10:34	96.44	*28.4*	-	-	-
28-Mar-08	10:17	96.44	*21.6*	-	-	-
22-Apr-08	9:24	96.34	*27.0*	-	-	-
22-Apr-08	9:23	96.34	*24.9*	-	-	-
18-May-08	13:45	96.39	32.9	29.1	12.3%	-
18-May-08	12:31	96.39	27.5	29.1	5.5%	-
13-Jun-08	11:09	96.40	33.3	29.7	11.5%	-
13-Jun-08	11:04	96.40	30.2	29.7	1.7%	-
17-Jul-08	10:15	96.38	28.9	28.5	1.6%	-
17-Jul-08	11:02	96.38	28.5	28.5	0.3%	-
21-Aug-08	15:05	96.38	27.8	28.5	2.3%	-
21-Aug-08	15:28	96.38	26.2	28.5	8.4%	-
21-Sep-08	13:25	96.40	28.5	29.7	4.2%	-
21-Sep-08	14:04	96.40	26.2	29.7	12.7%	-
20-Oct-08	10:28	96.39	30.2	29.1	3.8%	-
20-Oct-08	10:10	96.39	27.5	29.1	5.7%	-
21-Nov-08	11:15	-	*27.8*	-	-	Shelf ice
21-Nov-08	0:00	-	*29.8*	-	-	Shelf ice
10-Dec-08	11:54	96.48	*29.3*	-	-	-
				Average	7.4%	

Note:

a. Italicized values were not used in rating curve development.

TABLE 56

UT119A Monthly Discharge Summary

	Monthly Discharge (cfs)						Monthly Unit Runoff (cfs/mi^2)					
Month	**2003-04**	**2004-05**	**2005-06**	**2006-07**	**2007-08**	**Mean**	**2003-04**	**2004-05**	**2005-06**	**2006-07**	**2007-08**	**Mean**
Oct		27.3	35.0	34.7	26.7	30.9		6.75	8.64	8.58	6.59	7.64
Nov		28.7	27.7	27.6	28.6	28.2		7.09	6.85	6.82	7.05	6.95
Dec		26.4	27.1	24.9	26.8	26.3		6.53	6.70	6.15	6.62	6.50
Jan		24.9	25.2	24.8	25.4	25.1		6.15	6.21	6.12	6.28	6.19
Feb		24.9	24.9	25.0	24.8	24.9		6.15	6.16	6.18	6.13	6.15
Mar		25.0	24.9	24.4	24.3	24.6		6.17	6.14	6.01	6.01	6.08
Apr		28.3	27.5	26.1	25.1	26.8		6.98	6.80	6.45	6.20	6.61
May		33.1	33.7	23.3	29.4	29.9		8.17	8.31	5.76	7.26	7.37
Jun		32.2	26.9	23.0	28.6	27.7		7.95	6.65	5.67	7.06	6.83
Jul		30.7	25.5	23.3	27.3	26.7		7.57	6.29	5.75	6.73	6.58
Aug	26.2	30.8	28.1	23.0	28.2	27.3	6.46	7.61	6.95	5.68	6.97	6.73
Sep	25.4	34.9	31.8	25.6	28.8	29.3	6.26	8.63	7.86	6.33	7.11	7.24
Mean		28.9	28.2	25.5	27.0	27.4		7.15	6.97	6.29	6.67	6.77

TABLE 57
UT135A Discharge Measurement Record

Date	Time	Stage (ft)	Measured Discharge (cfs)	Rating Curve Discharge (cfs) [a]	Rating Curve Error	Notes
20-May-04	17:02	-	86.7	-	-	-
17-Jun-04	16:00	-	66.2	-	-	-
15-Jul-04	13:55	-	16.0	-	-	-
25-Aug-04	17:05	-	14.9	-	-	-
16-Sep-04	17:35	-	12.2	-	-	-
15-Oct-04	15:00	-	40.9	-	-	-
28-Jan-05	12:10	-	17.4	-	-	-
19-Mar-05	17:46	-	22.3	-	-	-
3-May-05	10:30	-	139.6	-	-	-
5-Jun-05	10:15	-	49.9	-	-	-
10-Jul-05	16:28	-	21.7	-	-	-
12-Jul-05	15:40	-	34.3	-	-	-
17-Aug-05	9:45	-	19.0	-	-	-
17-Sep-05	10:12	-	102.6	-	-	-
10-Feb-06	13:45	-	18.5	-	-	-
20-May-06	9:55	-	97.1	-	-	-
20-Jun-06	16:00	-	47.2	-	-	-
24-Jul-06	11:25	-	20.6	-	-	-
18-Aug-06	8:30	-	58.8	-	-	-
12-Sep-06	17:00	-	39.7	-	-	-
12-Dec-06	11:05	-	20.0	-	-	-
21-Feb-07	11:15	-	15.0	-	-	-
1-Apr-07	12:03	-	7.6	-	-	-
14-May-07	15:00	-	47.3	-	-	-
19-Jun-07	15:08	93.42	26.7	-	-	-
15-Jul-07	15:25	93.82	20.4	-	-	Aquatic veg.
17-Aug-07	13:45	94.17	19.8	-	-	Aquatic veg slowing flow through the site.
19-Sep-07	13:06	95.97	103.1	-	-	Veg influence on channel bottom. Logger reading, staff gage submerged.
17-Oct-76	13:20	94.94	62.2	-	-	Tall aquatic veg throughout stream.
12-Nov-07	14:15	-	59.1	-	-	-
12-Dec-07	14:05	-	35.7	-	-	-
26-Jan-08	13:10	-	19.2	-	-	-
23-Feb-08	16:20	-	18.9	-	-	-
16-Mar-08	10:50	-	13.9	-	-	-
28-Mar-08	11:00	-	13.7	-	-	-
20-Apr-08	16:15	-	11.4	-	-	-
16-May-08	16:06	95.20	135.1	-	-	Overflowing banks.
13-Jun-08	15:15	94.38	80.5	-	-	-
17-Jul-08	13:15	93.78	46.8	-	-	Bank sloughed upstream of SG/DL along left bank.
20-Aug-08	13:55	93.52	22.2	-	-	Deep and slow, mucky bottom, vegetation mats.
21-Sep-08	10:15	94.84	84.7	-	-	-
19-Oct-08	16:42	-	63.0	-	-	Ice conditions, staff gage frozen.
19-Dec-08	15:40	-	35.3	-	-	-

Note:
a. Rating curve not defined due to a poor stage-discharge relationship.

TABLE 58
UT135A Monthly Discharge Summary

	Monthly Discharge (cfs)						Monthly Unit Runoff (cfs/mi^2)					
Month	**2003-04**	**2004-05**	**2005-06**	**2006-07**	**2007-08**	**Mean**	**2003-04**	**2004-05**	**2005-06**	**2006-07**	**2007-08**	**Mean**
Oct				82.1	65.2	73.6				4.02	3.20	3.61
Nov				34.6	73.6	54.1				1.70	3.61	2.65
Dec				23.1	47.4	35.3				1.13	2.32	1.73
Jan				17.1	26.9	22.0				0.84	1.32	1.08
Feb				21.0	17.9	19.5				1.03	0.88	0.95
Mar				11.1	10.5	10.8				0.54	0.52	0.53
Apr				47.5	19.8	33.7				2.33	0.97	1.65
May				40.8	116.0	78.4				2.00	5.69	3.84
Jun				28.0	73.9	51.0				1.37	3.62	2.50
Jul				22.1	38.3	30.2				1.08	1.88	1.48
Aug				23.5	29.0	26.3				1.15	1.42	1.29
Sep				64.5	54.7	59.6				3.16	2.68	2.92
Mean				34.6	48.0	41.3				1.70	2.35	2.02

Note:

a. All flows estimated by regression analysis due to rating curve problems.

TABLE 59
KC100A Discharge Measurement Record

Date	Time	Stage (ft)	Measured Discharge (cfs) [a]	Rating Curve Discharge (cfs)	Rating Curve Error	Notes
20-May-04	17:26	-	*45.7*	-	-	-
15-Jun-04	16:16	-	*26.9*	-	-	-
13-Jul-04	11:40	96.00	20.6	20.8	1.1%	-
23-Aug-04	9:05	95.96	19.4	18.9	2.2%	-
15-Sep-04	16:30	95.91	16.3	16.7	2.3%	-
17-Oct-04	14:48	96.15	*20.8*	-	-	No staff gage or survey to verify stage value.
28-Jan-05	13:00	-	*35.4*	-	-	-
19-Mar-05	12:00	-	*28.5*	-	-	-
7-May-05	9:45	96.45	54.1	48.8	10.3%	-
7-Jun-05	10:00	96.07	24.4	24.4	0.1%	-
12-Jul-05	13:45	96.52	54.0	54.3	0.5%	-
17-Aug-05	15:45	96.31	37.0	38.8	4.7%	Approximate bankfull stage.
15-Sep-05	14:15	97.00	92.8	100.1	7.6%	-
30-Oct-05	13:40	96.68	*33.0*	-	-	Ice shelves on both banks.
11-Feb-06	11:50	-	*21.9*	-	-	-
14-Mar-06	13:00	-	*21.4*	-	-	-
20-May-06	13:40	96.50	70.5	65.5	7.3%	-
19-Jun-06	16:55	96.04	32.2	33.8	4.6%	-
25-Jul-06	12:17	96.05	28.1	34.4	20.1%	-
16-Aug-06	9:15	96.42	59.2	59.2	0.1%	-
15-Sep-06	11:35	96.73	80.4	85.5	6.1%	-
14-Dec-06	10:20	-	*27.6*	-	-	-
14-Dec-06	10:54	-	*27.1*	-	-	-
21-Feb-07	13:45	-	*24.8*	-	-	-
17-Mar-07	14:11	-	*15.8*	-	-	-
22-Apr-07	10:05	-	*62.3*	-	-	-
15-May-07	11:10	95.88	36.5	25.3	36.5%	-
18-Jun-07	17:20	95.75	25.3	19.3	27.0%	-
14-Jul-07	14:40	95.92	33.0	27.3	18.9%	-
14-Aug-07	15:07	95.84	23.1	23.3	0.9%	-
17-Sep-07	16:09	96.03	32.8	33.2	1.1%	-
12-Oct-07	16:32	96.06	32.3	34.9	7.8%	-
11-Nov-07	10:30	96.11	*38.6*	-	-	-
12-Dec-07	12:40	96.45	*33.8*	-	-	-
24-Feb-08	11:00	-	*21.2*	-	-	-
17-Mar-08	13:20	96.15	*24.2*	-	-	-
20-Apr-08	12:30	96.11	*31.5*	-	-	-
18-May-08	14:20	96.28	61.7	49.0	23.1%	-
15-Jun-08	14:05	95.90	30.1	26.3	13.6%	-
19-Jul-08	14:22	95.92	24.3	27.0	10.6%	RB sloughing D/S of DL/SG.
20-Aug-08	15:23	95.84	20.1	23.3	15.1%	Beaver dam upstream.
21-Sep-08	10:30	96.04	33.9	33.8	0.2%	-
16-Oct-08	14:15	96.23	*52.3*	-	-	Stage changing as ice and slush floating downstream through cross-section.
10-Dec-08	12:05	-	*26.2*	-	-	-
				Average	9.2%	

Note:

a. Italicized values were not used in rating curve development.

TABLE 60
KC100A Monthly Discharge Summary

	Monthly Discharge (cfs)						Monthly Unit Runoff (cfs/mi^2)					
Month	**2003-04**	**2004-05**	**2005-06**	**2006-07**	**2007-08**	**Mean**	**2003-04**	**2004-05**	**2005-06**	**2006-07**	**2007-08**	**Mean**
Oct		44.5	45.4	74.4	43.6	52.0		1.73	1.77	2.90	1.70	2.03
Nov		46.6	30.7	38.8	45.5	40.4		1.82	1.20	1.51	1.77	1.58
Dec		37.9	40.2	25.5	30.0	33.4		1.48	1.57	0.99	1.17	1.30
Jan		26.2	28.2	25.1	30.4	27.5		1.02	1.10	0.98	1.18	1.07
Feb		26.1	26.5	27.2	25.5	26.3		1.02	1.03	1.06	1.00	1.03
Mar		27.0	25.8	21.8	21.3	24.0		1.05	1.01	0.85	0.83	0.94
Apr		49.4	27.6	47.7	19.6	36.1		1.93	1.08	1.86	0.76	1.41
May		38.4	75.4	32.4	50.8	49.3		1.50	2.94	1.26	1.98	1.92
Jun		27.8	37.5	22.1	27.8	28.8		1.08	1.46	0.86	1.08	1.12
Jul		26.9	33.6	24.2	27.8	28.1		1.05	1.31	0.94	1.08	1.10
Aug	20.1	32.4	55.0	25.0	23.5	31.2	0.78	1.26	2.15	0.97	0.92	1.22
Sep	37.9	63.9	57.1	54.8	36.4	50.0	1.48	2.49	2.23	2.14	1.42	1.95
Mean		37.2	40.4	34.9	31.9	36.1		1.45	1.57	1.36	1.24	1.41

TABLE 61
NH100-APC2 Discharge Measurement Record

Date	Time	Stage (ft)	Measured Discharge (cfs)	Rating Curve Discharge (cfs) [a]	Rating Curve Error	Notes
16-May-08	10:40	95.12	5545	-	-	-
25-Jun-08	15:11	98.59	17358	-	-	- Mobile riverbed; measurement site 7.2 miles upstream of gage.
25-Sep-08	15:04	97.88	15012	-	-	-

Note:

a. Rating curve not determined at this time.

TABLE 62
NH100-APC3 Discharge Measurement Record

Date	Time	Stage (ft)	Measured Discharge (cfs)	Rating Curve Discharge (cfs) [a,b]	Rating Curve Error	Notes
24-Sep-08	13:43	96.21	14536.0	13510.6	7.3%	-

Notes:

a. Rating curve discharge and error refers to the historic rating curve at USGS station 15300000.

b. A site-specific rating curve is not defined at this time, nor has the USGS rating curve been confirmed as applicable.

TABLE 63
Cominco Station 13 Discharge Measurement Record

Date	Stage (ft)	Measured Discharge (cfs) [a]	Rating Curve Discharge (cfs)	Rating Curve Error	Notes
20-Aug-91	738.09	23.8	23.5	1.5%	-
27-Aug-91	738.04	19.8	20.7	4.3%	-
19-Sep-91	738.17	27.7	28.4	2.3%	-
24-Oct-91	738.13	25.9	25.8	0.2%	-
6-Jun-92	738.12	31.9	29.7	7.4%	-
23-Jul-92	737.98	21.2	21.2	0.0%	-
18-Aug-92	738.12	31.7	29.7	6.5%	-
16-Sep-92	738.26	37.5	39.7	5.7%	-
28-May-93	738.29	40.7	42.1	3.4%	-
30-Jun-93	737.91	16.6	17.6	5.6%	-
30-Jul-93	737.80	13.9	12.6	9.9%	-
9-Sep-93	738.36	50.2	47.9	4.7%	-
6-Oct-93	738.37	47.6	48.8	2.5%	-
13-Nov-93	738.65	74.8	76.6	2.4%	-
			Average	4.0%	

Note:

a. All values were used in rating curve development.

TABLE 64
Cominco Station 16 Discharge Measurement Record

Date	Stage (ft)	Measured Discharge (cfs) [a]	Rating Curve Discharge (cfs)	Rating Curve Error	Notes
21-Aug-91	844.50	19.2	19.4	0.9%	-
28-May-93	846.18	124.1	123.7	0.3%	-
30-Jun-93	844.40	16.6	16.0	3.7%	-
30-Jul-93	843.40	0.0	0.0	0.0%	-
9-Sep-93	845.22	53.4	53.0	0.7%	-
8-Oct-93	845.83	94.3	94.5	0.1%	-
			Average	1.0%	

Note:
a. All values were used in rating curve development.

TABLE 65
Cominco Station 17 Discharge Measurement Record

Date	Stage (ft)	Measured Discharge (cfs) [a]	Rating Curve Discharge (cfs)	Rating Curve Error	Notes
29-Aug-91	918.01	17.4	17.7	1.8%	-
19-Sep-91	918.25	37.8	38.4	1.8%	-
24-Oct-91	918.23	30.9	36.3	16.2%	-
6-Jun-92	918.31	42.4	45.1	6.2%	-
23-Jul-92	918.05	19.3	20.5	6.2%	-
18-Aug-92	918.19	34.4	32.3	6.3%	-
16-Sep-92	918.14	27.4	27.7	1.4%	-
25-May-93	918.54	77.5	77.2	0.3%	-
30-Jun-93	918.08	24.1	22.8	5.8%	-
30-Jul-93	918.00	18.9	17.0	10.6%	-
9-Sep-93	918.25	44.7	38.4	15.1%	-
6-Oct-93	918.37	56.8	52.5	7.7%	-
13-Nov-93	918.58	81.0	83.9	3.6%	-
			Average	6.4%	

Note:
a. All values were used in rating curve development.

TABLE 66
Cominco Station 19 Discharge Measurement Record

Date	Stage (ft)	Measured Discharge (cfs) [a]	Rating Curve Discharge (cfs)	Rating Curve Error	Notes
26-May-93	673.25	81.3	79.4	2.3%	-
30-Jun-93	672.51	26.2	28.5	8.4%	-
1-Aug-93	672.28	19.5	17.8	8.8%	-
9-Sep-93	673.03	61.8	61.6	0.2%	-
13-Nov-93	673.41	94.0	93.7	0.3%	-
			Average	4.0%	

Note:
a. All values were used in rating curve development.

TABLE 67
Historical Cominco Stations, Monthly Discharge Summary

	Station 13			Station 16			Station 17			Station 19		
	Discharge	Unit Runoff (cfs/mi^2) [a]		Discharge	Unit Runoff (cfs/mi^2) [a]		Discharge	Unit Runoff (cfs/mi^2) [a]		Discharge	Unit Runoff (cfs/mi^2) [a]	
Date	(cfs)	Stn 13	UT100D	(cfs)	Stn 16	SK100C	(cfs)	Stn 17	SK100F	(cfs)	Stn 19	UT135A
Jul-92	27.9	2.3	1.8				19.7	1.4	1.5			
Aug-92	102.6	8.6	1.9				62.8	4.5	2.1			
Sep-92	45.9	3.9	3.4				41.5	2.9	4.2			
Jul-93				7.1	0.2	0.7						
Aug-93				1.6	0.0	0.7				37.6	2.0	1.3
Sep-93				61.5	1.6	2.2				88.1	4.7	2.9
Oct-93										122.4	6.6	3.6
May-94										53.3	2.9	3.8
Jun-94										20.2	1.1	2.5
Jul-94										21.0	1.1	1.5
Aug-94										9.5	0.5	1.3

Notes:

a. Monthly unit runoff values for SK100C, SK100F, UT100D, and UT135A are mean values for the periods of record, which are not concurrent with the historical periods of record at the Cominco stations.

TABLE 68
Discharge Regression Analysis (Winter)

Pebble Partnership Station	USGS Station	Drainage Area Ratio	Regression Results [a, b]		
			Slope	Intercept	R^2
SK100A	SK100B	1.54	1.59	27.04	0.70
SK100B1	SK100B	0.78	0.54	0.00	0.94
SK100C	SK100B	0.54	0.39	-20.00	0.93
SK100F	SK100B	0.17	0.13	0.00	0.73
SK100G	SK100B	0.08	0.10	0.00	0.79
SK119A	SK100B	0.15	0.14	-2.39	0.94
SK124A	SK100B	0.12	0.10	-4.80	0.82
NK100A1	NK100A	0.81	0.77	11.33	0.73
NK100B	NK100A	0.35	0.28	8.55	0.68
NK100C	NK100A	0.23	0.19	4.00	0.71
NK119A	NK100A	0.07	0.04	1.26	0.96
NK119B	NK100A	0.04	0.01	-0.48	0.86
UT100-APC3	UT100B	1.56	1.55	0.00	0.54
UT100-APC2	UT100B	1.28	1.28	0.00	0.85
UT100-APC1	UT100B	1.18	1.19	0.00	0.91
UT100C	UT100B	0.81	0.64	2.85	0.92
UT100C1	UT100B	0.70	0.62	-17.85	0.97
UT100C2	UT100B	0.56	0.54	-24.80	0.95
UT100D	UT100B	0.14	0.15	-6.51	0.87
UT100E	UT100B	0.04	0.06	-1.93	0.78
UT106-APC1	-	-	-	-	-
UT119A	UT100B	0.05	0.02	22.47	0.08
UT135A	UT100B	0.24	0.30	-17.01	0.90
KC100A	UT100B	0.30	0.16	6.72	0.72
NH100-APC3	-	-	-	-	-
NH100-APC2	-	-	-	-	-

Notes:

a. This analysis compares instantaneous discharge at Pebble Partnership stations versus corresponding daily discharge at USGS stations, with USGS discharge as the independent variable.

b. Regression analysis has not yet been peformed for stations UT106-APC1, NH100-APC2, or NH100-APC3 due to the small number of winter IQ measurements collected to the end of 2008.

TABLE 69

Discharge Regression Analysis (May to October)

Pebble Partnership Station	USGS Station	Drainage Area Ratio	Regression Results [a, d] May - June Slope	May - June Intercept	May - June R^2	July - August Slope	July - August Intercept	July - August R^2	September - October Slope	September - October Intercept	September - October R^2
SK100A	SK100B	1.54	1.09	80.42	0.93	1.19	48.18	0.98	1.11	52.79	0.95
SK100B1	SK100B	0.78	0.97	-58.85	0.99	0.72	-8.12	0.99	0.77	-29.27	0.99
SK100C	SK100B	0.54	0.39	-21.55	0.99	0.33	-18.27	0.94	0.35	-17.28	0.93
SK100F	SK100B	0.17	0.15	3.90	0.96	0.15	3.02	0.96	0.15	3.64	0.91
SK100G	SK100B	0.08	0.05	3.24	0.77	0.07	2.25	0.91	0.08	-2.86	0.80
SK119A	SK100B	0.15	0.28	-15.45	0.94	0.25	-4.84	0.81	0.24	-11.61	0.64
SK124A	SK100B	0.12	0.17	-11.59	0.92	0.17	-11.75	0.86	0.18	-24.03	0.73
NK100A	SK100B	1.53	1.24	129.51	0.81	1.18	52.39	0.91	1.15	24.85	0.80
NK100A1	NK100A	0.81	0.67	57.92	0.94	0.78	4.94	0.98	0.79	10.80	0.99
NK100B	NK100A	0.35	0.36	-15.19	0.98	0.36	-2.95	0.97	0.30	19.78	0.96
NK100C	NK100A	0.23	0.17	-1.63	0.96	0.14	10.61	0.91	0.15	16.74	0.86
NK119A	NK100A	0.07	0.13	-12.62	0.85	0.11	-4.70	0.79	0.15	-17.51	0.68
NK119B	NK100A	0.04	0.04	-11.00	0.88	0.03	-4.00	0.64	0.04	-8.16	0.85
UT100-APC3	UT100B	1.56	0.86	96.31	1.00	0.85	114.07	0.86	1.39	36.10	0.95
UT100-APC2	UT100B	1.28	1.61	-155.08	1.00	0.99	20.61	0.87	1.85	-134.63	0.95
UT100-APC1	UT100B	1.18	1.24	-50.46	0.99	1.11	4.87	0.94	1.35	-42.24	0.97
UT100B	SK100B	1.24	0.60	100.00	0.25	0.69	86.19	0.94	0.72	94.06	0.80
UT100C	UT100B	0.81	0.78	5.85	0.99	0.74	0.33	0.95	0.76	9.19	0.97
UT100C1	UT100B	0.70	0.59	3.14	0.96	0.75	-29.73	0.98	0.58	7.88	0.90
Ut100C2	UT100B	0.56	0.49	17.91	0.95	0.62	-25.39	0.81	0.62	-12.35	0.93
UT100D	UT100B	0.14	0.17	-7.29	0.95	0.17	-7.94	0.87	0.18	-13.98	0.83
UT100E	UT100B	0.04	0.04	-0.46	0.68	0.03	2.05	0.87	0.03	2.97	0.69
UT119A	UT100B	0.05	0.01	24.06	0.37	0.01	24.98	0.11	0.01	25.47	0.27
KC100A	UT100B	0.30	0.07	11.2	0.72	0.14	5.5	0.78	0.18	-8.0	0.63
NH100-APC3	-	-	-	-	-	-	-	-	-	-	-
NH100-APC2	-	-	-	-	-	-	-	-	-	-	-

Pebble Partnership Station	Pebble Partnership Station	Drainage Area Ratio	Regression Results [b, c] May - June Slope	May - June Intercept	May - June R^2	July - August Slope	July - August Intercept	July - August R^2	September - October Slope	September - October Intercept	September - October R^2
SK124A	SK119A	0.79	0.65	-3.7	0.95	0.62	-6.0	0.84	0.64	-5.1	0.83
NK119A	SK119A	0.72	0.59	5.5	0.92	0.56	3.5	0.92	0.74	-5.8	0.90
NK119B	SK119A	0.37	0.18	-3.54	0.96	0.15	-3.00	0.62	0.24	-5.46	0.78
UT135A	UT100B	0.24	0.30	-45.60	0.93	0.21	-12.41	0.49	0.28	-2.34	0.63

Notes:

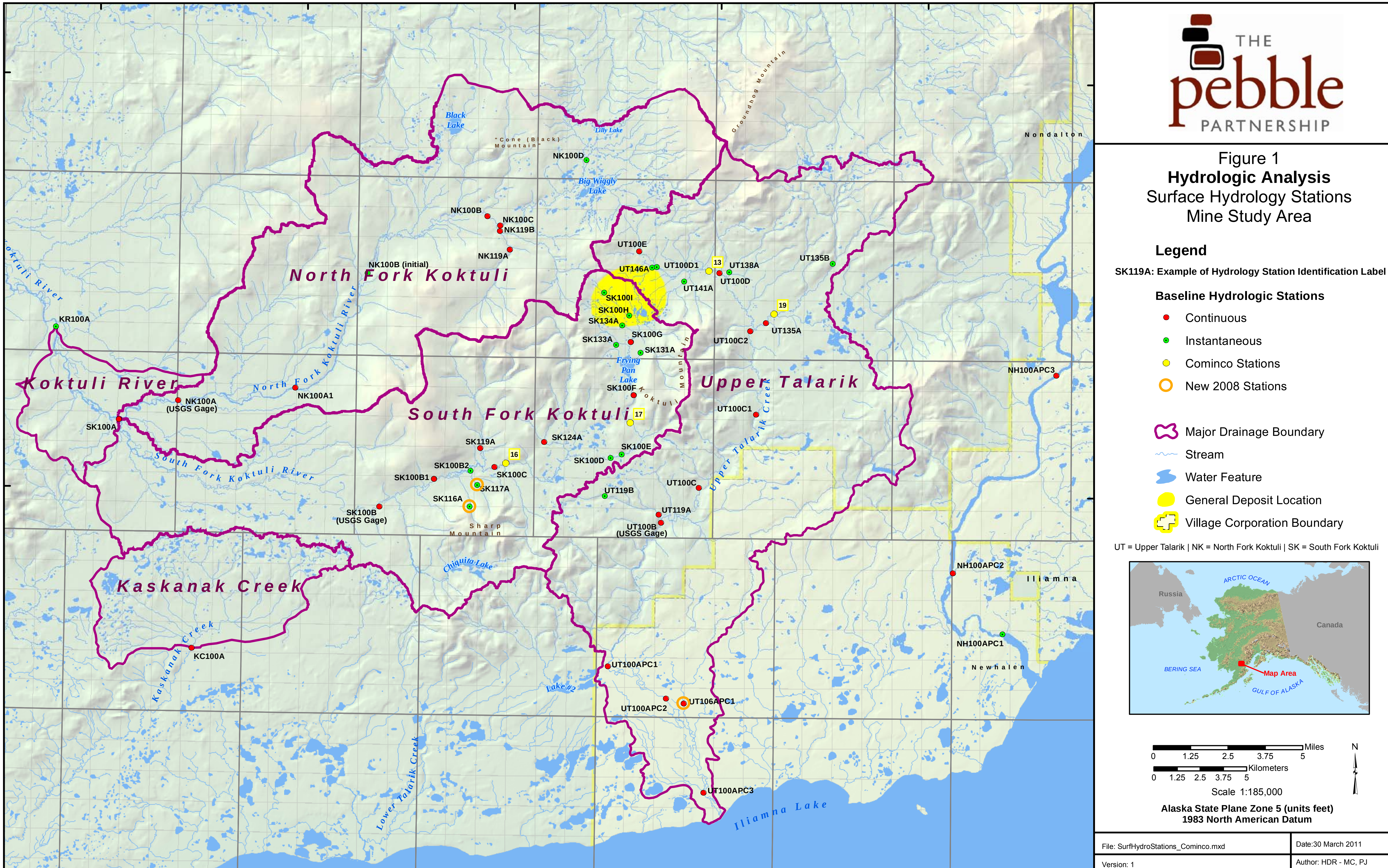
a. This analysis compares concurrent daily discharge at Pebble Partnership stations versus USGS stations, with USGS discharge as the independent variable.

b. This analysis compares concurrent daily discharge at Pebble Partnership stations on upland tributaries, with SK119A discharge as the independent variable.

c. This analysis compares instantaneous discharge at UT135A versus concurrent daily discharge at UT100B.

d. Regression analysis has not yet been performed for stations UT106-APC1, NH100-APC2, or NH100-APC3 due to incomplete stage-discharge rating curves and the small number of instantaneous discharge measurements collected to the end of 2008.

FIGURES


THE pebble PARTNERSHIP
Figure 1
Hydrologic Analysis
Surface Hydrology Stations
Mine Study Area
Legend
SK119A: Example of Hydrology Station Identification Label
Baseline Hydrologic Stations
Continuous
Instantaneous
Cominco Stations
New 2008 Stations
Major Drainage Boundary
Stream
Water Feature
General Deposit Location
Village Corporation Boundary
UT = Upper Talarik | NK = North Fork Koktuli | SK = South Fork Koktuli
Russia
ARCTIC OCEAN
Canada
BERING SEA
Map Area
GULF OF ALASKA
Miles
0 1.25 2.5 3.75 5
Kilometers
0 1.25 2.5 3.75 5
N
Scale 1:185,000
Alaska State Plane Zone 5 (units feet)
1983 North American Datum
File: SurfHydroStations_Cominco.mxd
Date:30 March 2011
Version: 1
Author: HDR - MC, PJ
155:48'0"W
155:36'0"W
155:24'0"W
155:12'0"W
155:0'0"W
60:0'0"N
59:48'0"N
North Fork Koktuli
Koktuli River
South Fork Koktuli
Upper Talarik
Kaskanak Creek
Black Lake
"Cone (Black) Mountain"
Lilly Lake
Big Wiggly Lake
Groundhog Mountain
Nondalton
Frying Pan Lake
Koktuli Mountain
North Fork Koktuli River
South Fork Koktuli River
Upper Talarik Creek
Sharp Mountain
Chiquita Lake
Kaskanak Creek
Lake #2
Lower Talarik Creek
Iliamna Lake
Iliamna
Newhalen
NK100D
NK100B
NK100C
NK119B
NK119A
NK100B (initial)
UT100E
UT146A
UT100D1
13
UT138A
UT100D
UT141A
UT135B
SK100I
SK100H
SK134A
19
UT135A
UT100C2
SK133A
SK100G
SK131A
KR100A
NH100APC3
SK100F
NK100A (USGS Gage)
NK100A1
SK100A
UT100C1
17
SK124A
SK119A
SK100E
16
SK100B2
SK100D
SK100C
SK100B1
SK117A
UT100C
UT119B
SK116A
SK100B (USGS Gage)
UT119A
UT100B (USGS Gage)
NH100APC2
NH100APC1
KC100A
UT100APC1
UT100APC2
UT106APC1
UT100APC3

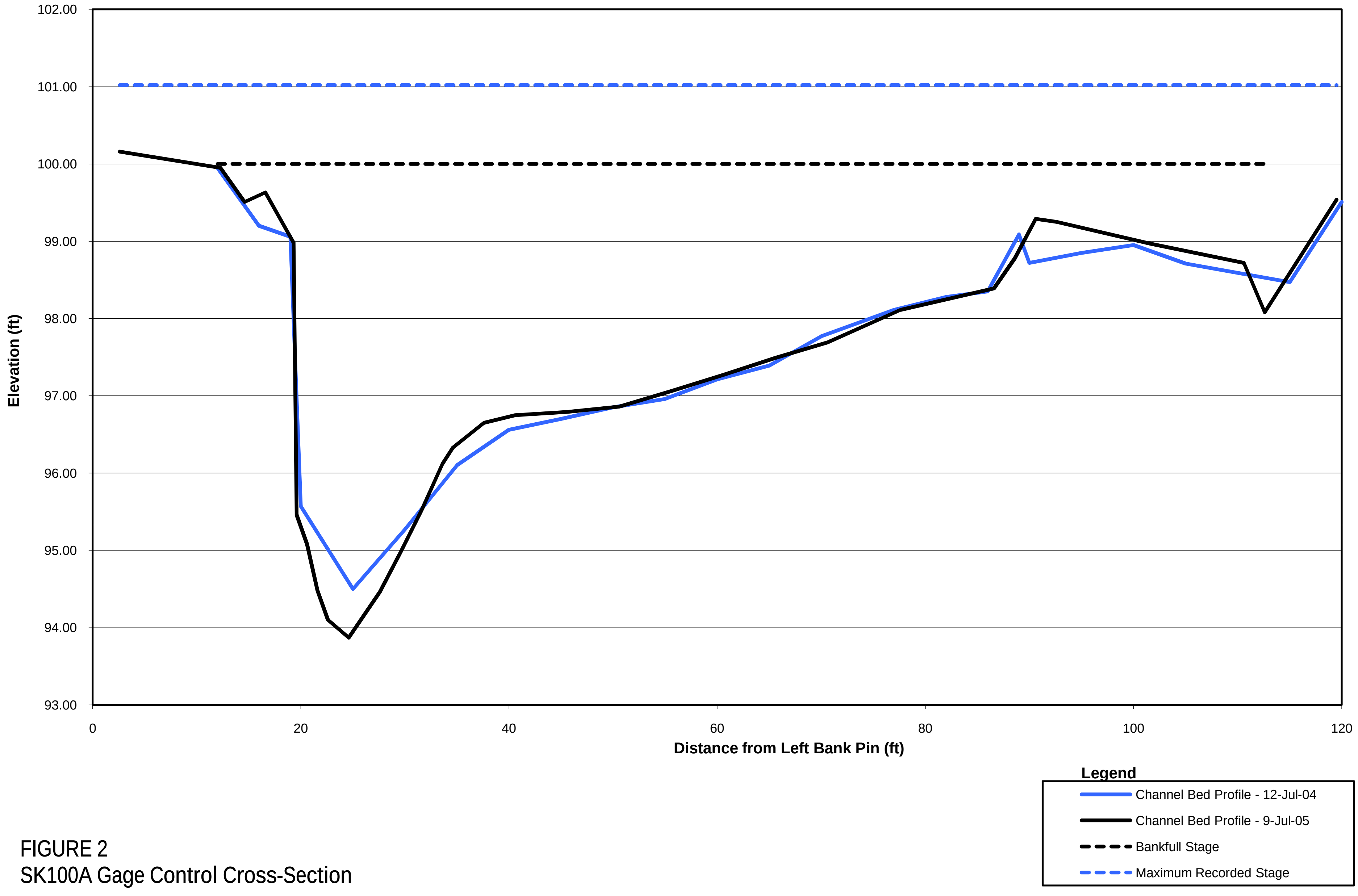


FIGURE 2
SK100A Gage Control Cross-Section

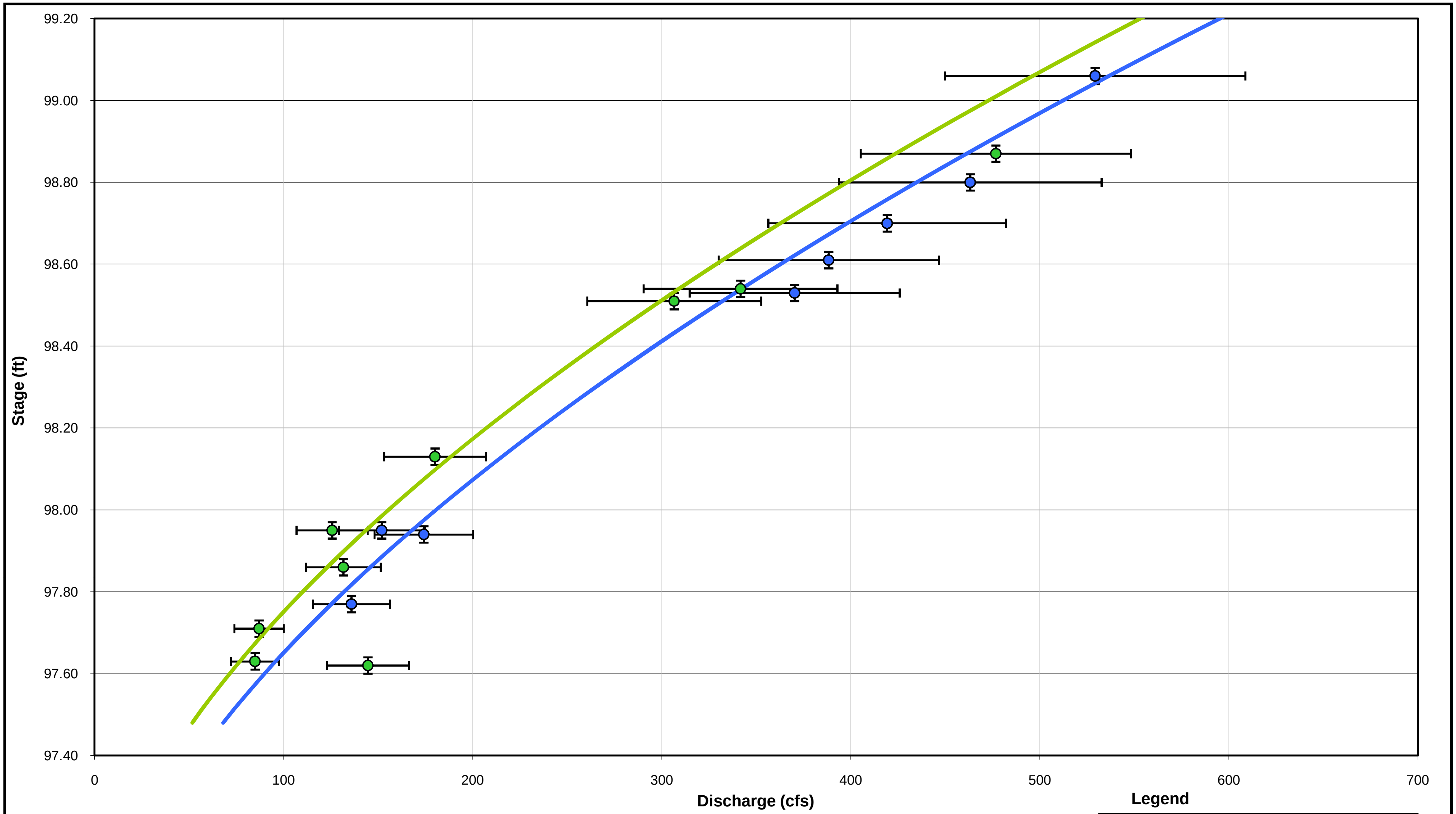


FIGURE 3

SK100A Rating Curves over the Range of Manual Discharge Measurements

Notes: a. Rating Curve for 2004-05 Main Channel: $Q = 132 (h - 96.90)^{1.72}$

b. Rating Curve for 2006-07 Main Channel: $Q = 132 (h - 96.80)^{1.72}$

c. Rating Curve for Side Channel: $Q = 26.0 (h - 99.00)^{3.00}$

d. Q = Discharge (cfs), h = Stage (ft)

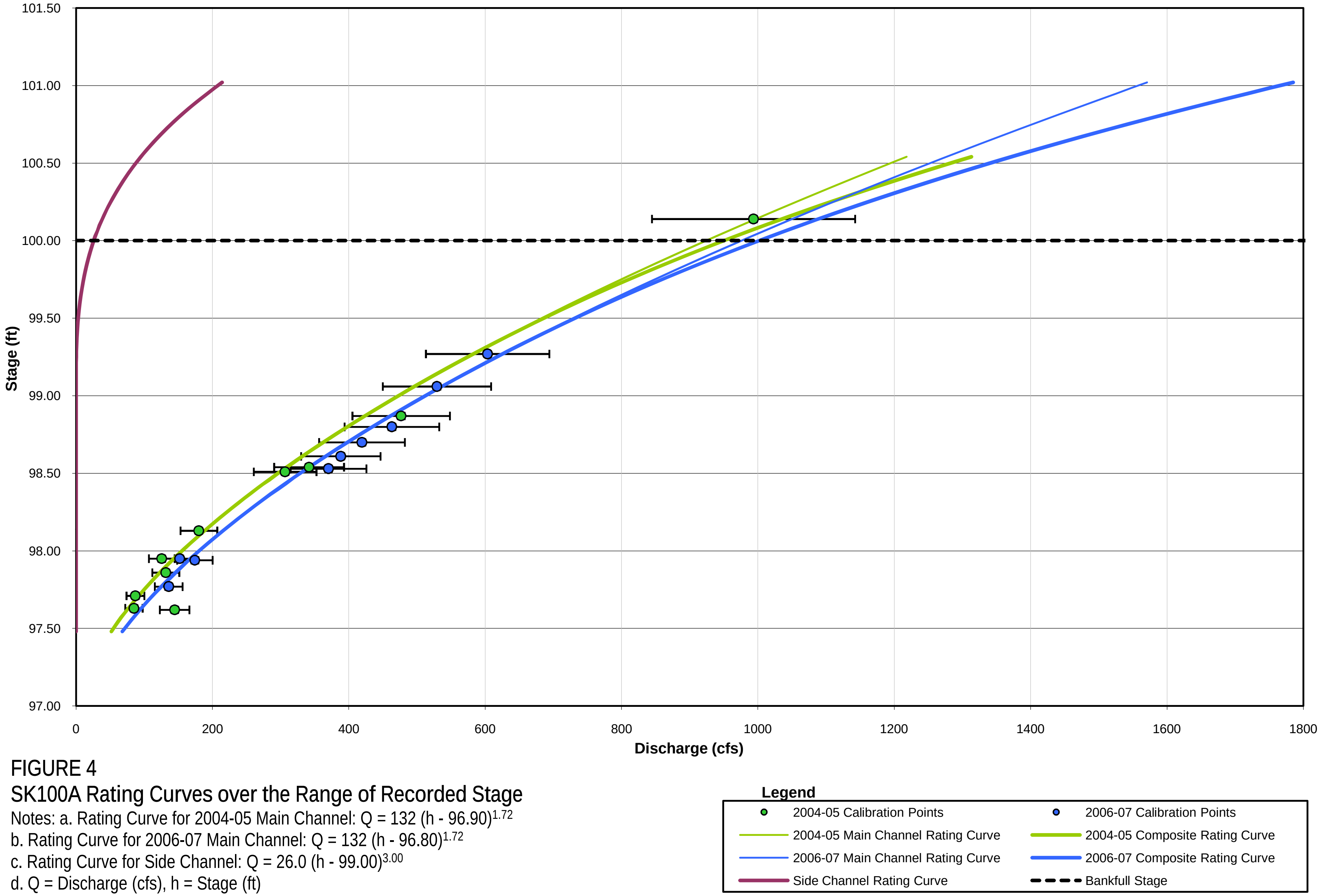


FIGURE 4

SK100A Rating Curves over the Range of Recorded Stage

Notes: a. Rating Curve for 2004-05 Main Channel: $Q = 132\ (h - 96.90)^{1.72}$

b. Rating Curve for 2006-07 Main Channel: $Q = 132\ (h - 96.80)^{1.72}$

c. Rating Curve for Side Channel: $Q = 26.0\ (h - 99.00)^{3.00}$

d. Q = Discharge (cfs), h = Stage (ft)

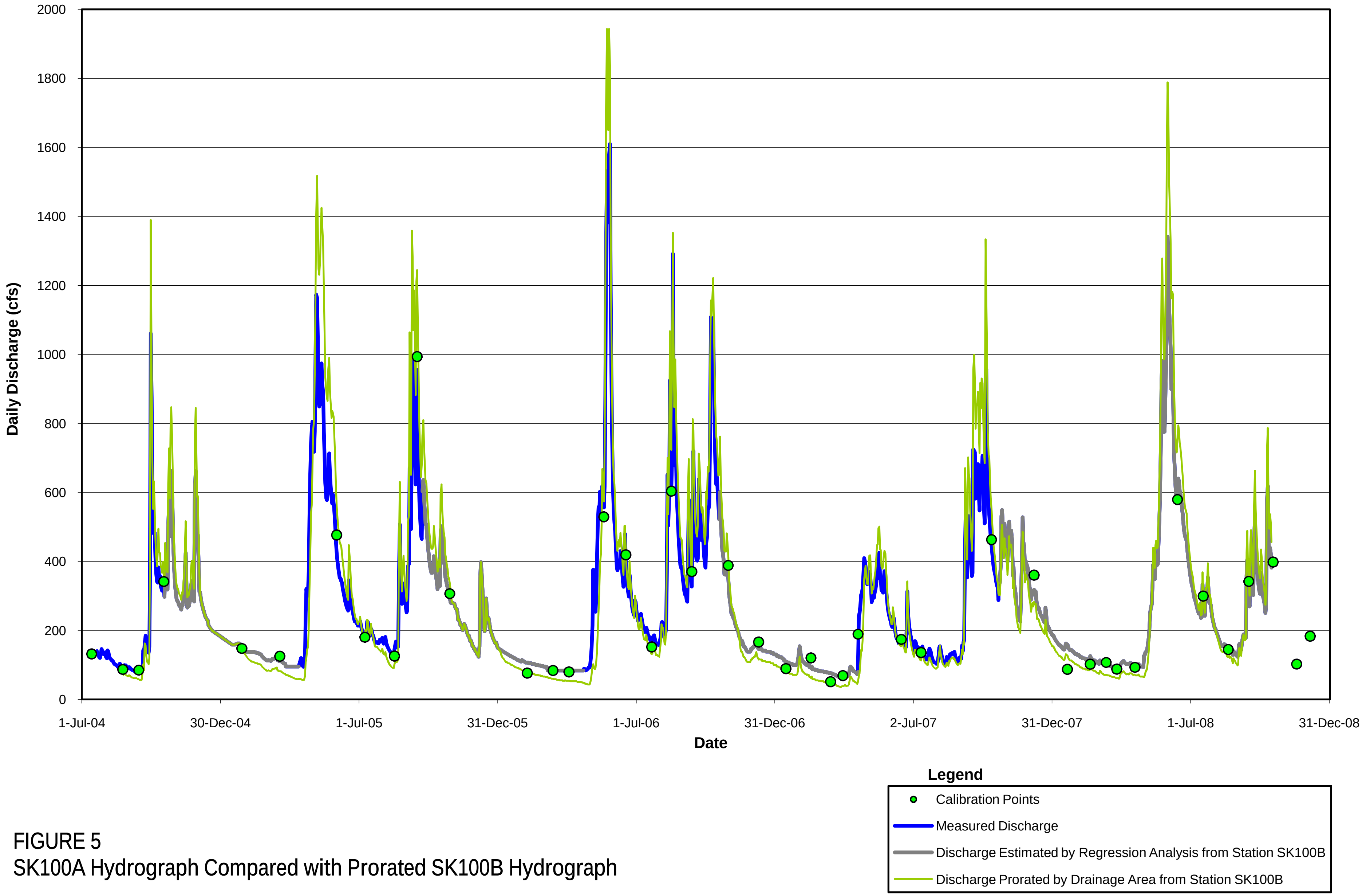


FIGURE 5
SK100A Hydrograph Compared with Prorated SK100B Hydrograph

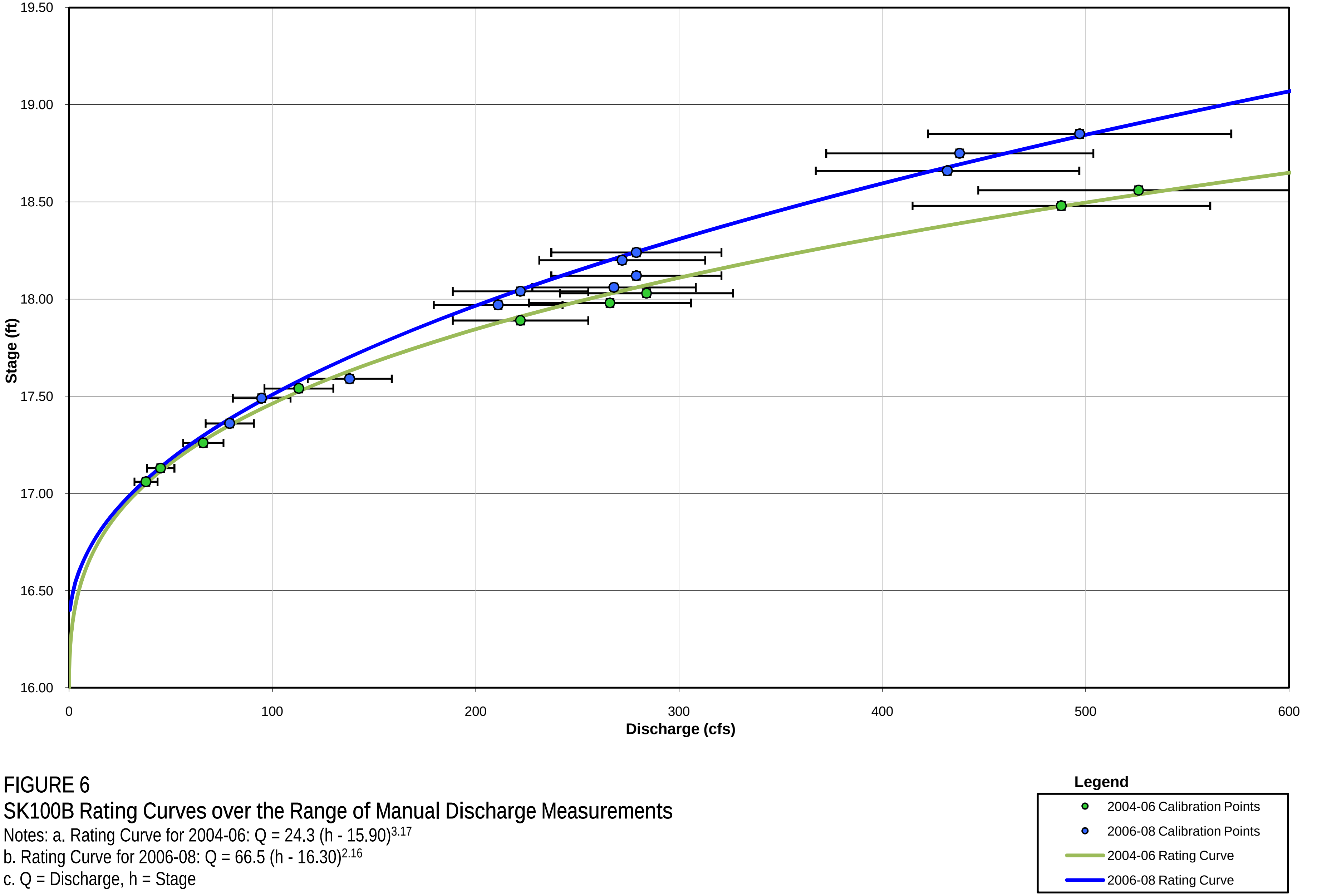


FIGURE 6

SK100B Rating Curves over the Range of Manual Discharge Measurements

Notes: a. Rating Curve for 2004-06: $Q = 24.3 (h - 15.90)^{3.17}$

b. Rating Curve for 2006-08: $Q = 66.5 (h - 16.30)^{2.16}$

c. Q = Discharge, h = Stage

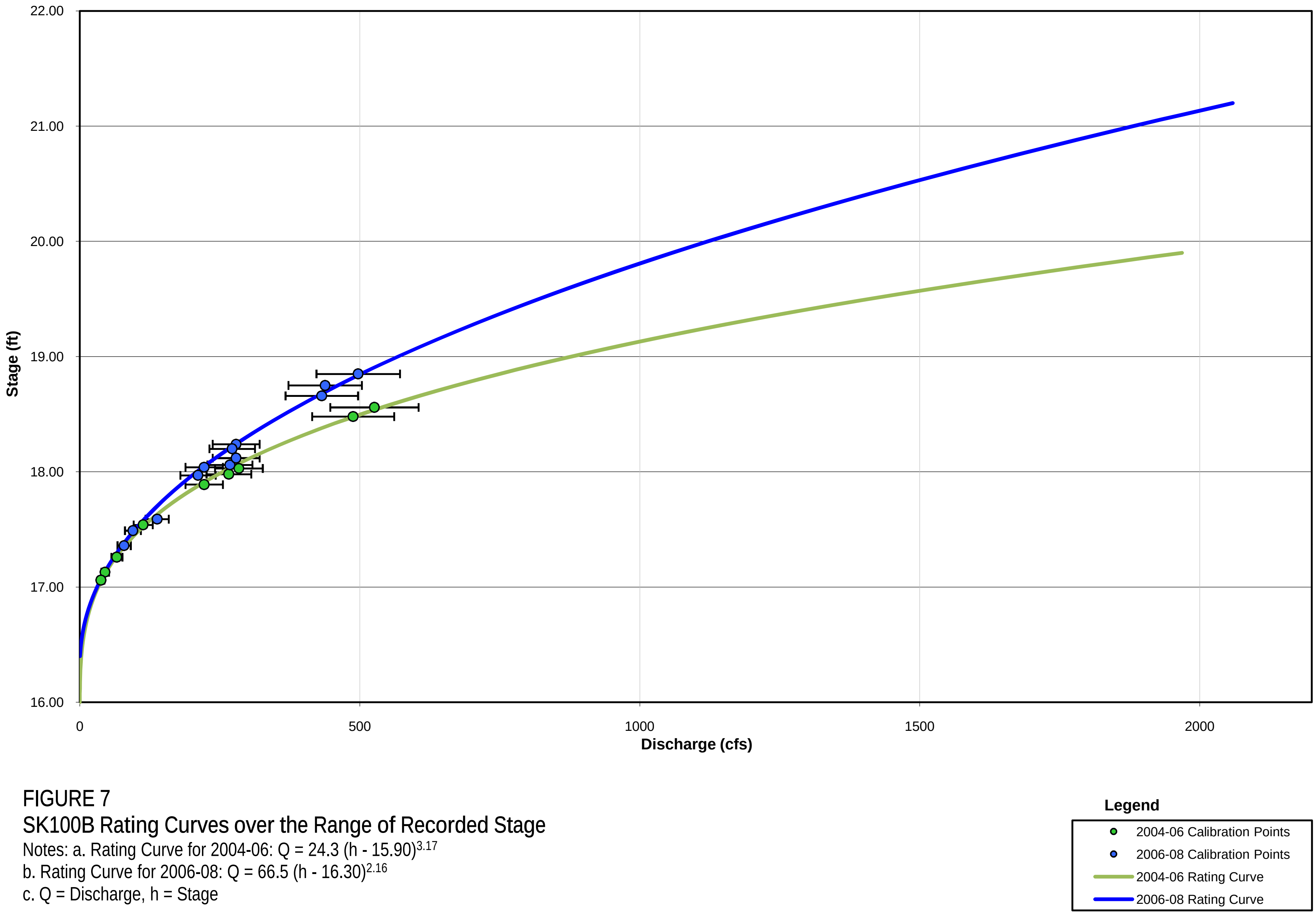


FIGURE 7

SK100B Rating Curves over the Range of Recorded Stage

Notes: a. Rating Curve for 2004-06: $Q = 24.3 (h - 15.90)^{3.17}$

b. Rating Curve for 2006-08: $Q = 66.5 (h - 16.30)^{2.16}$

c. Q = Discharge, h = Stage

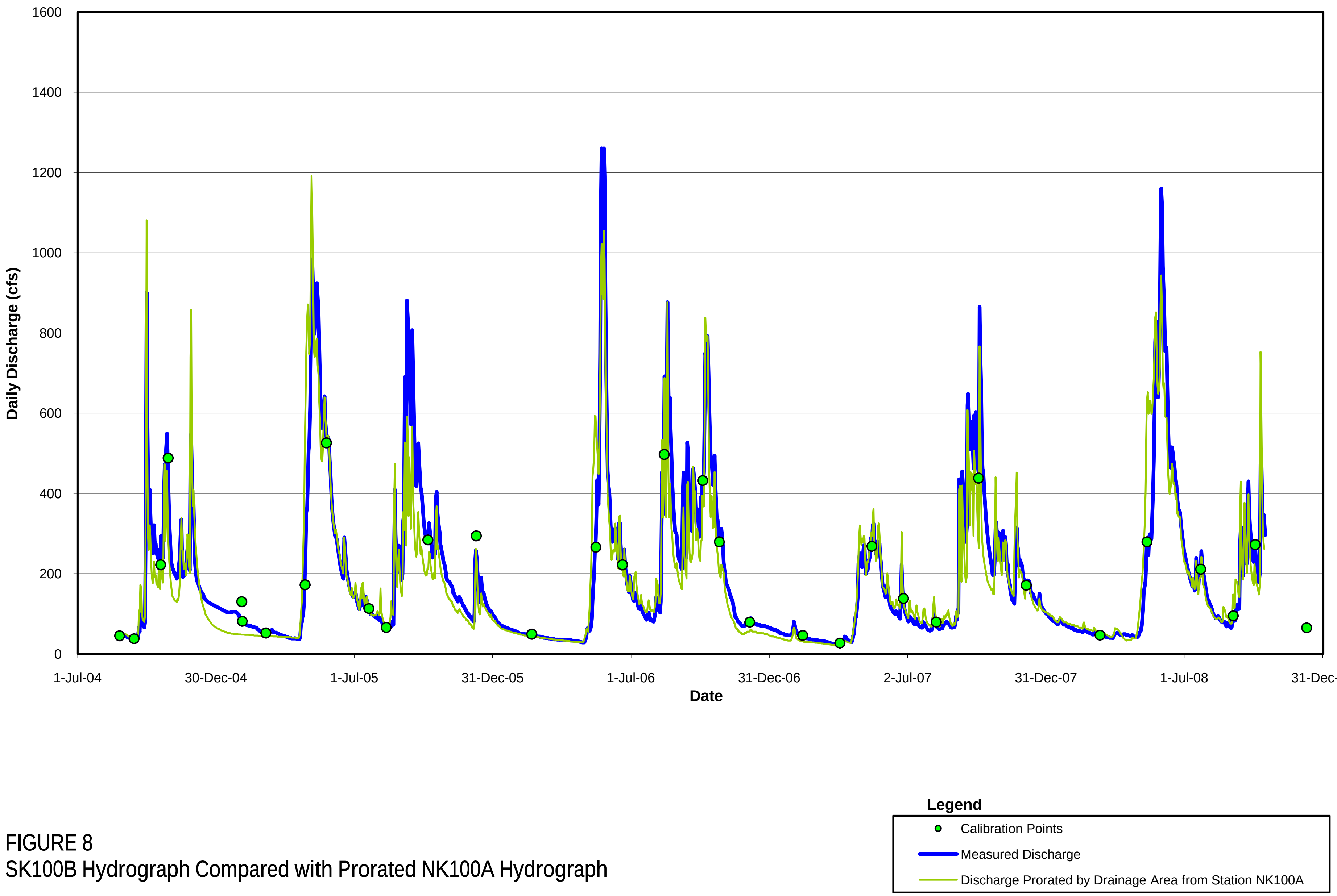


FIGURE 8
SK100B Hydrograph Compared with Prorated NK100A Hydrograph

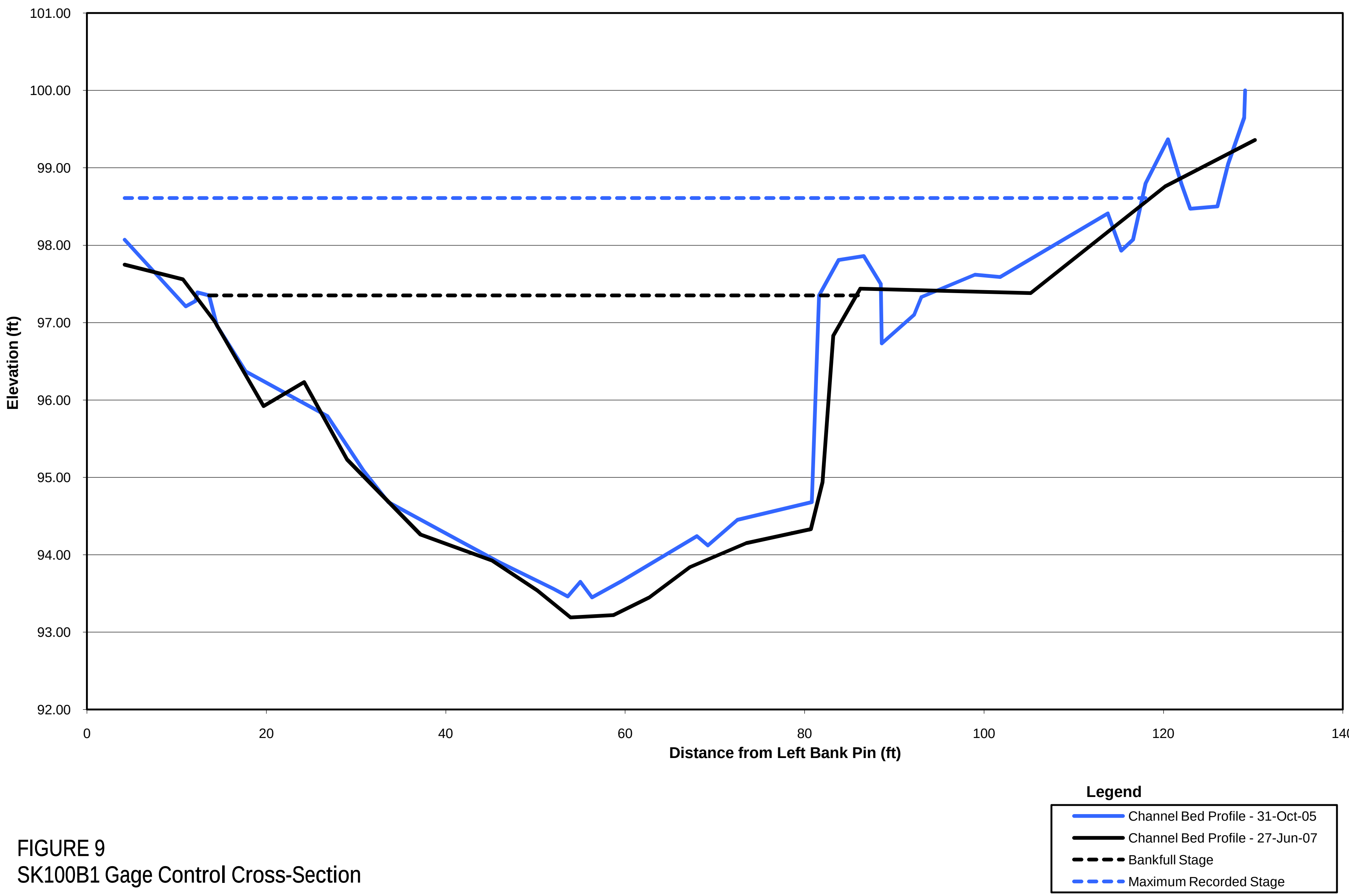


FIGURE 9
SK100B1 Gage Control Cross-Section

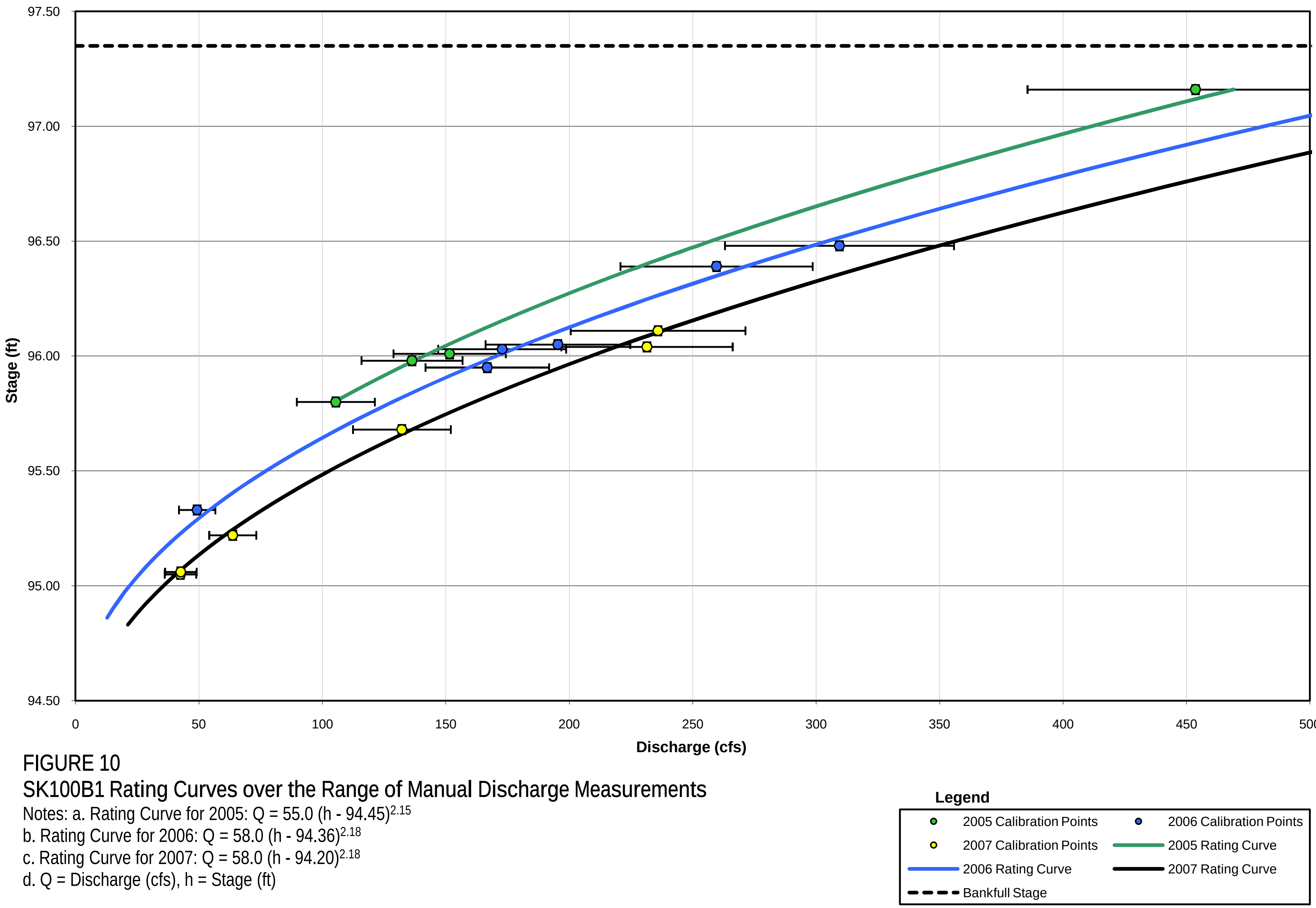


FIGURE 10

SK100B1 Rating Curves over the Range of Manual Discharge Measurements

Notes: a. Rating Curve for 2005: $Q = 55.0 (h - 94.45)^{2.15}$

b. Rating Curve for 2006: $Q = 58.0 (h - 94.36)^{2.18}$

c. Rating Curve for 2007: $Q = 58.0 (h - 94.20)^{2.18}$

d. Q = Discharge (cfs), h = Stage (ft)

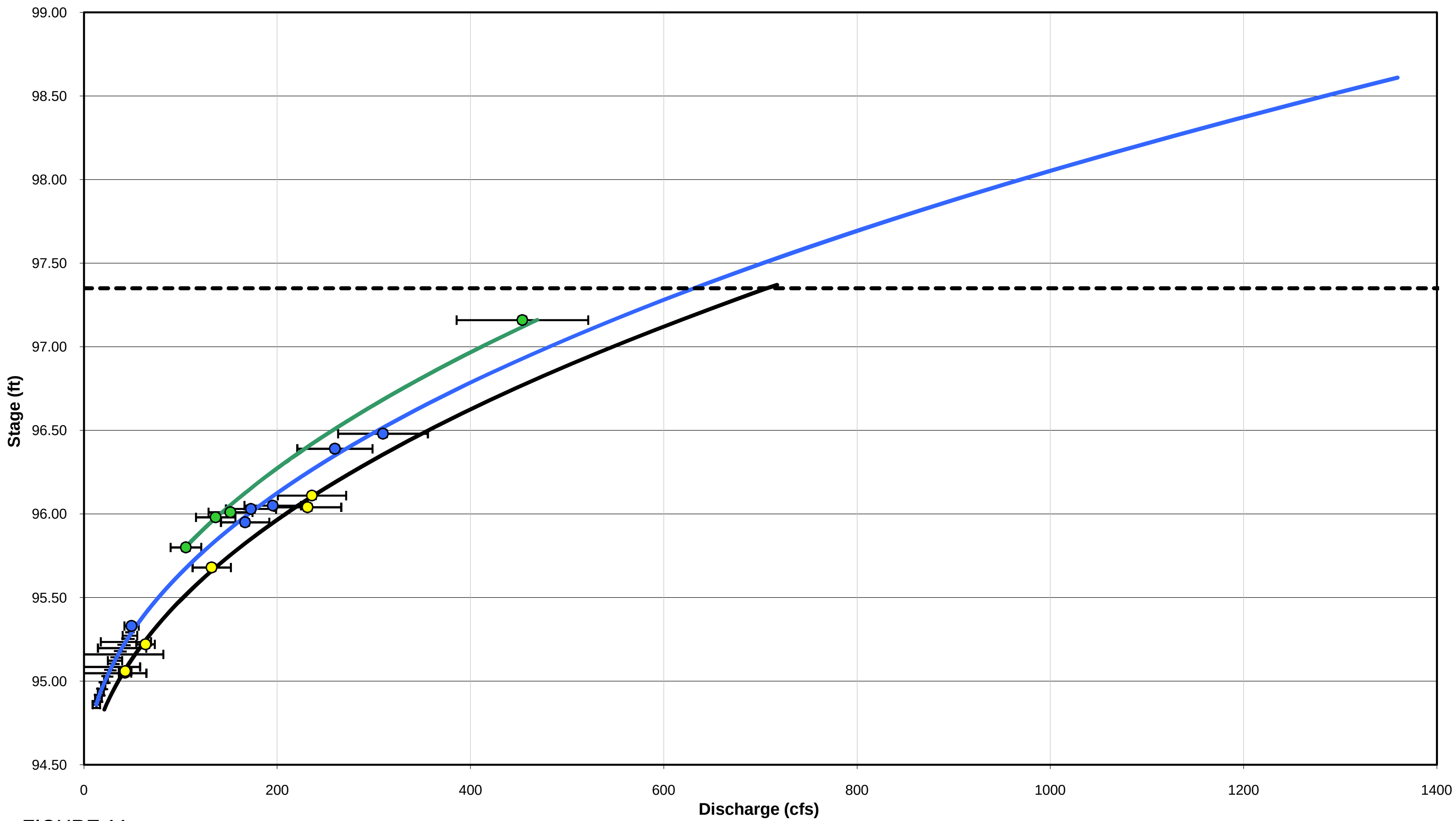


FIGURE 11

SK100B1 Rating Curves over the Range of Recorded Stage

Notes: a. Rating Curve for 2005: $Q = 55.0\ (h - 94.45)^{2.15}$

b. Rating Curve for 2006: $Q = 58.0\ (h - 94.36)^{2.18}$

c. Rating Curve for 2007: $Q = 58.0\ (h - 94.20)^{2.18}$

d. Q = Discharge (cfs), h = Stage (ft)

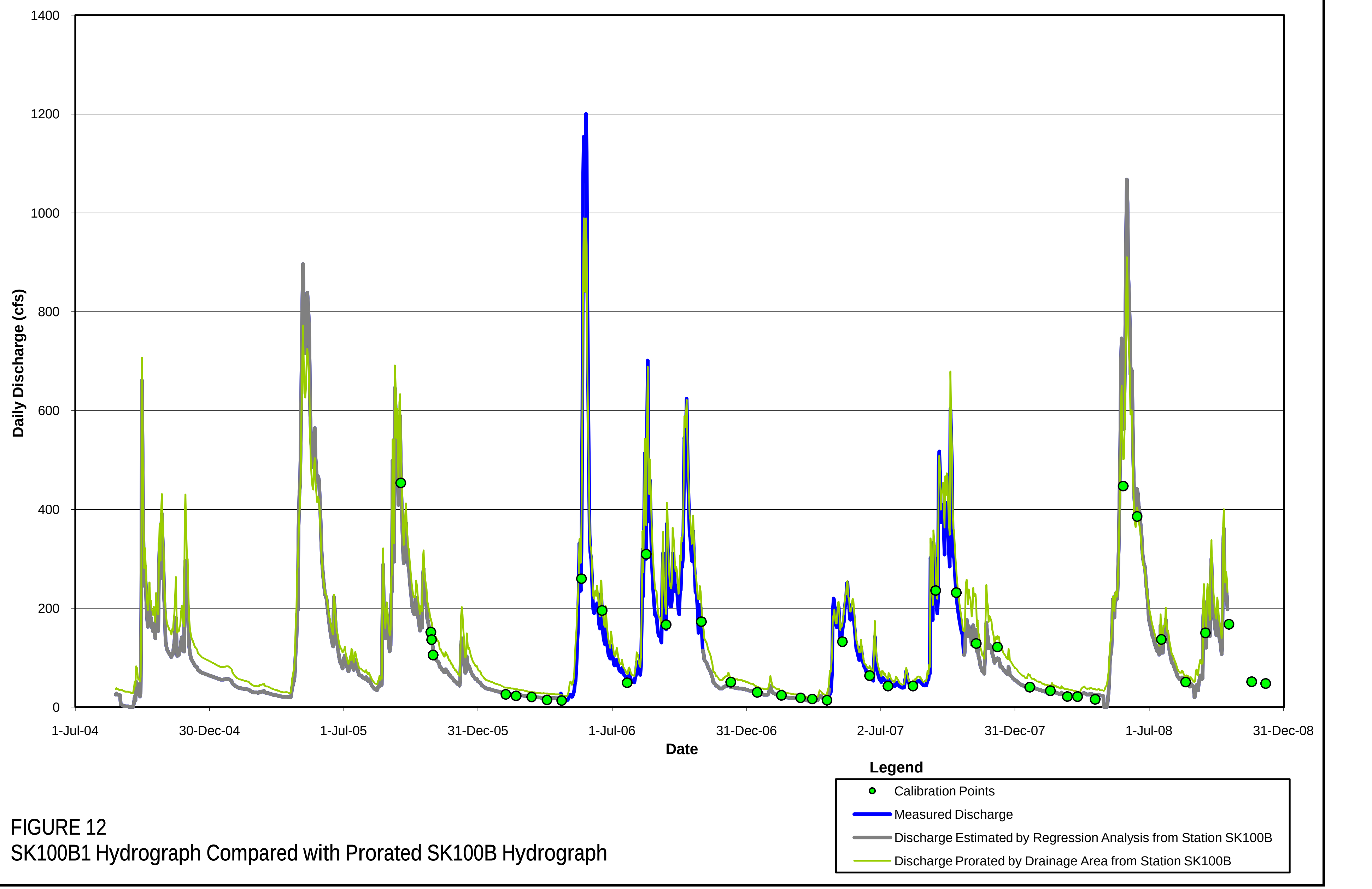


FIGURE 12
SK100B1 Hydrograph Compared with Prorated SK100B Hydrograph

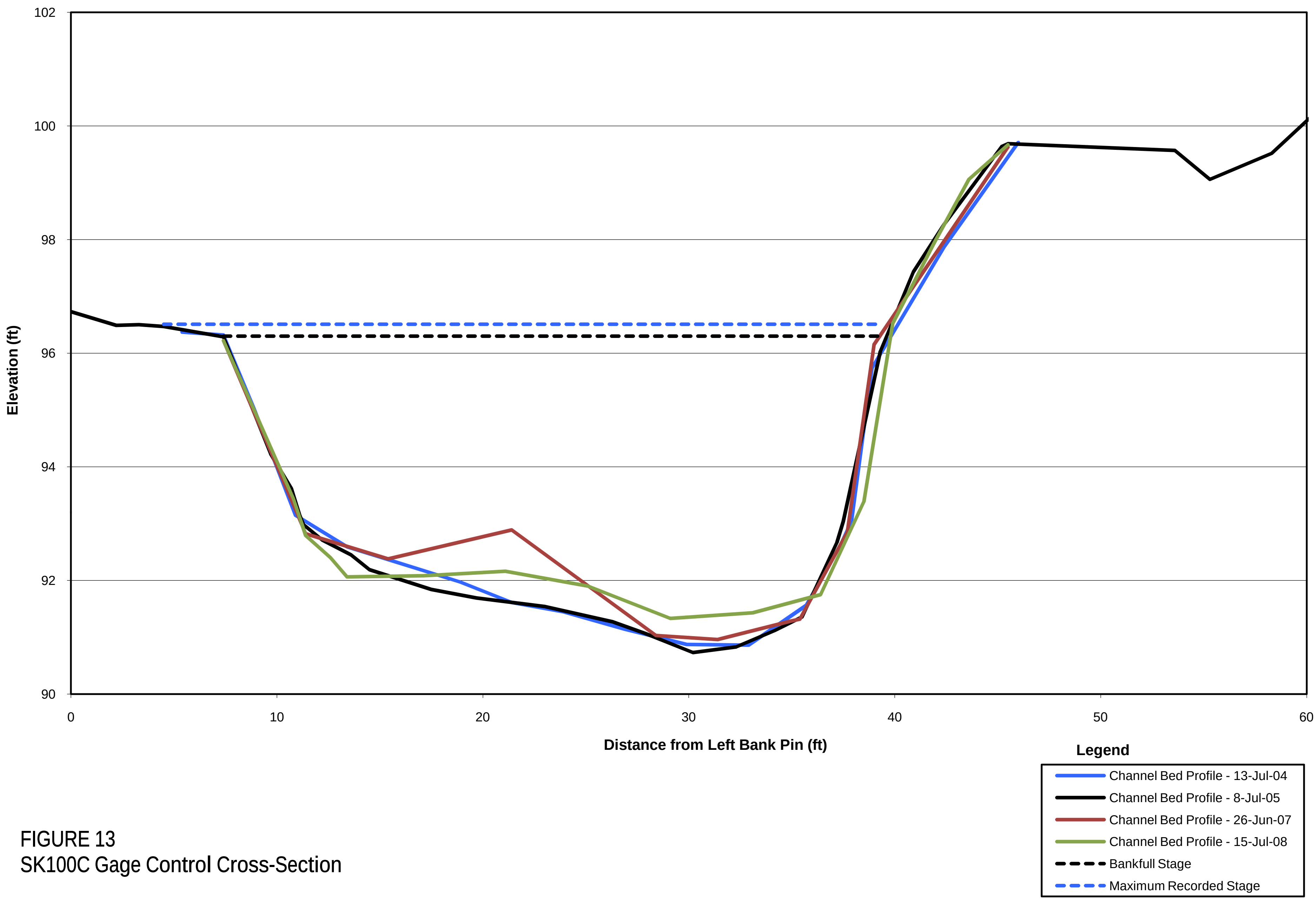


FIGURE 13
SK100C Gage Control Cross-Section

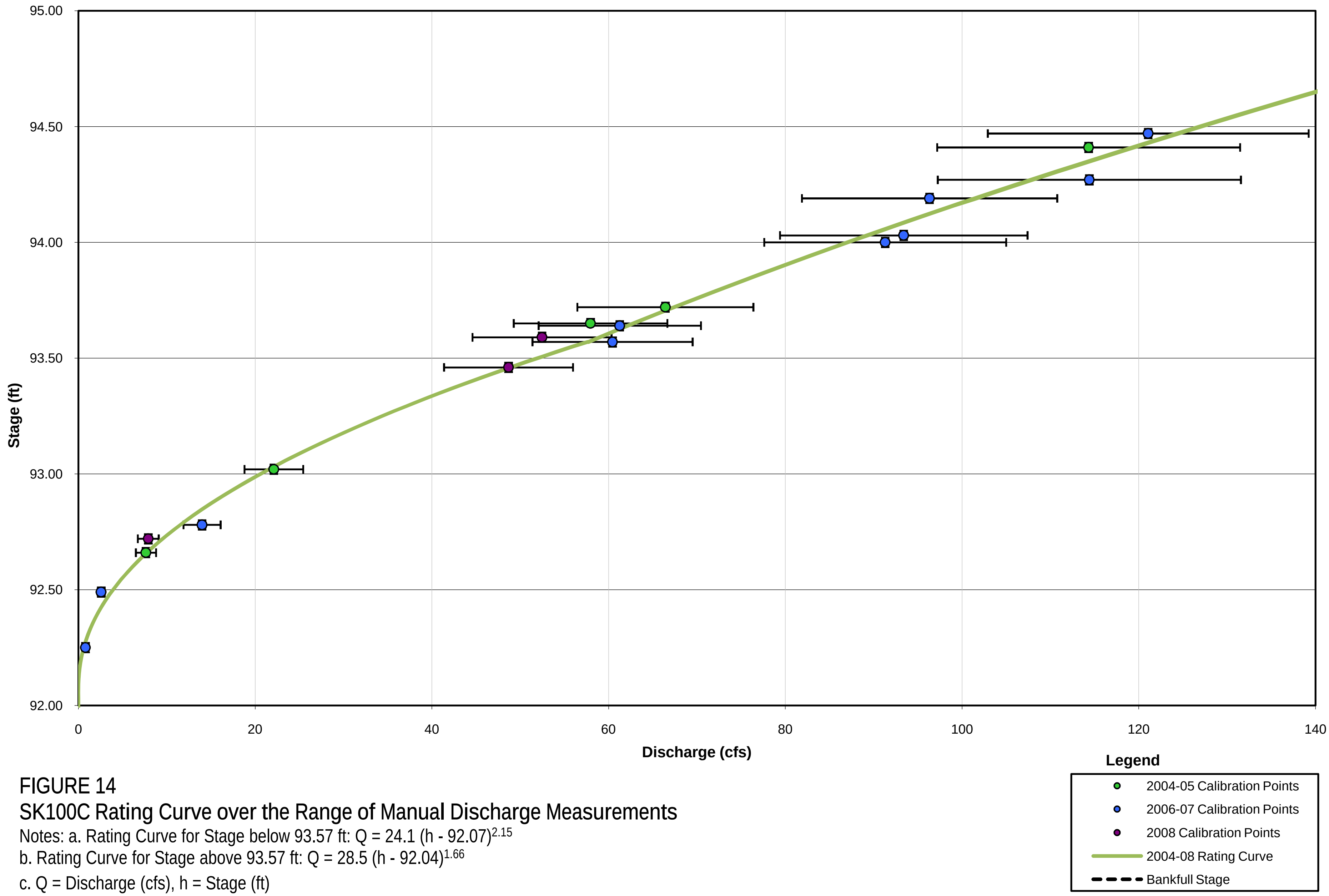


FIGURE 14
SK100C Rating Curve over the Range of Manual Discharge Measurements
Notes: a. Rating Curve for Stage below 93.57 ft: $Q = 24.1\,(h - 92.07)^{2.15}$
b. Rating Curve for Stage above 93.57 ft: $Q = 28.5\,(h - 92.04)^{1.66}$
c. Q = Discharge (cfs), h = Stage (ft)

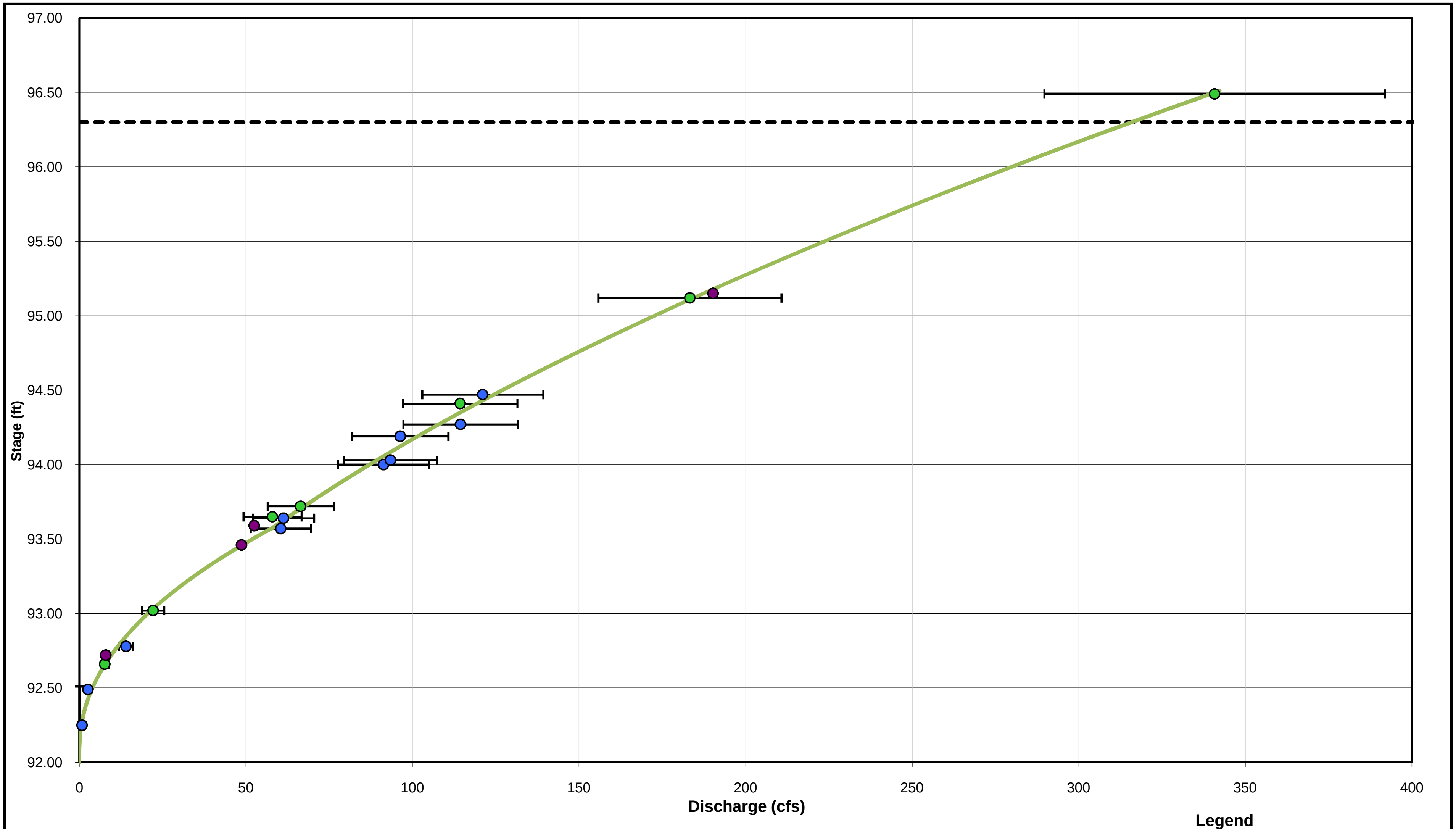


FIGURE 15

SK100C Rating Curve over the Range of Recorded Stage

Notes: a. Rating Curve for Stage below 93.57 ft: $Q = 24.1 (h - 92.07)^{2.15}$

b. Rating Curve for Stage above 93.57 ft: $Q = 28.5 (h - 92.04)^{1.66}$

c. Q = Discharge (cfs), h = Stage (ft)

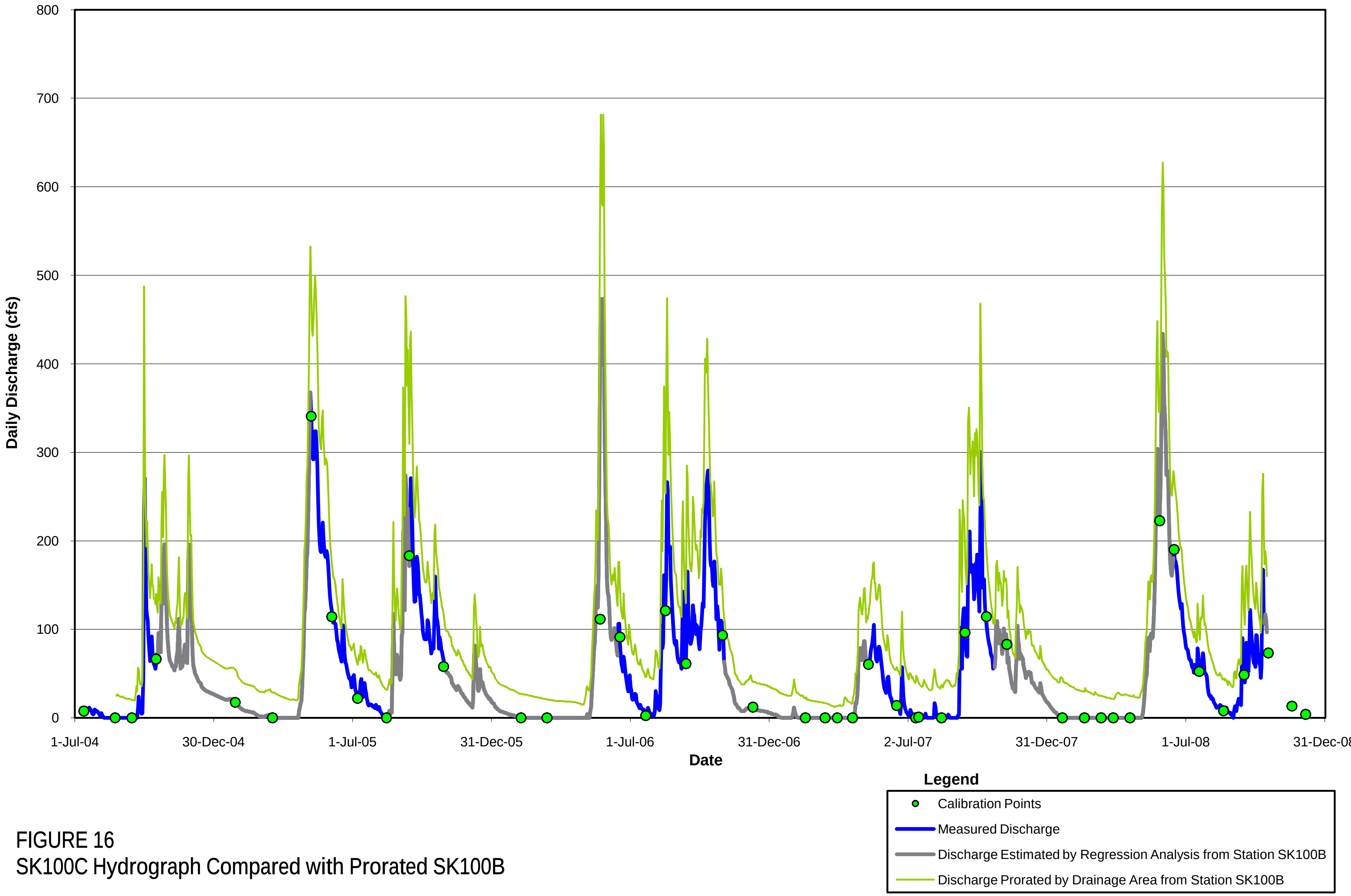


FIGURE 16
SK100C Hydrograph Compared with Prorated SK100B

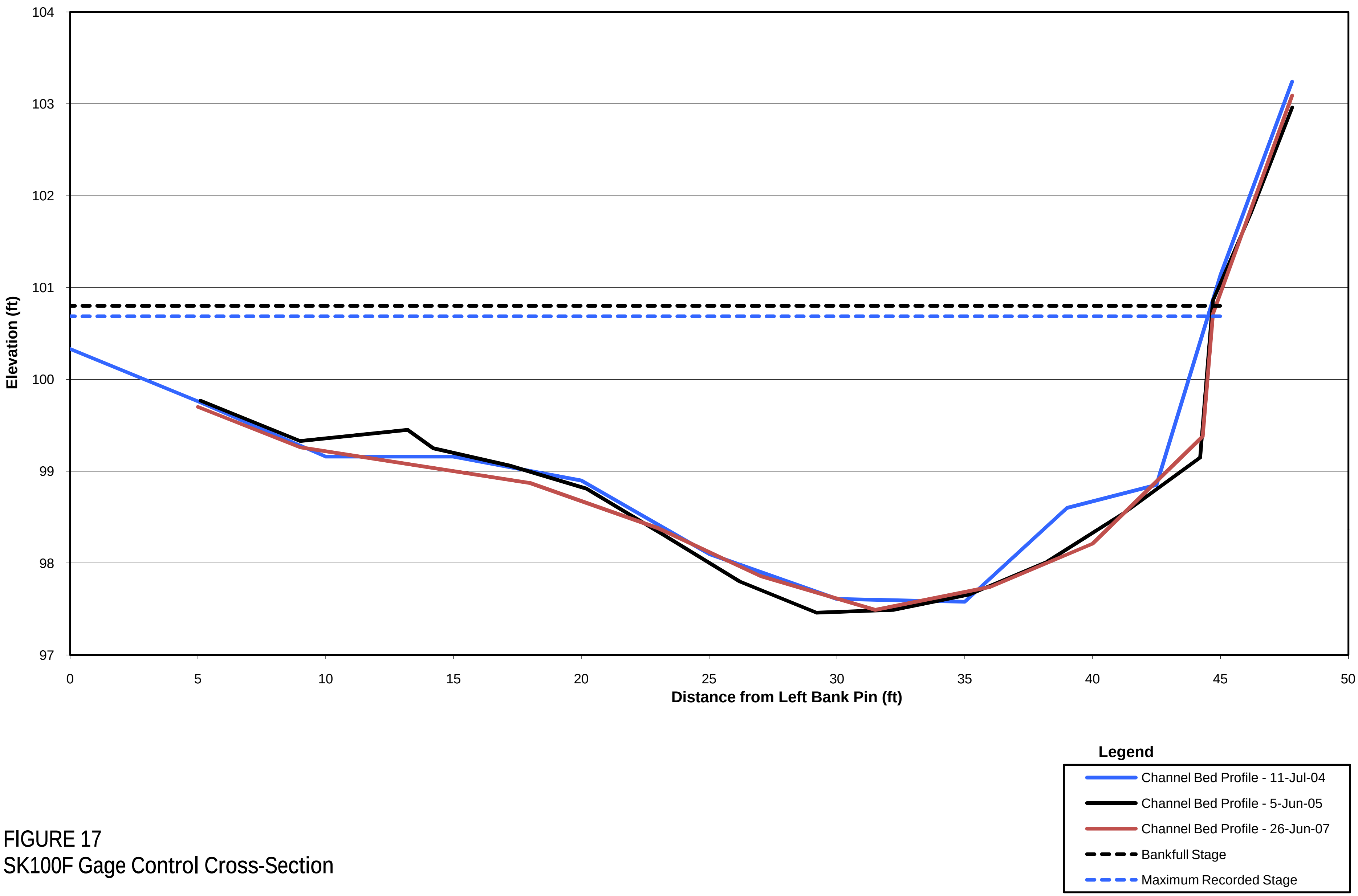


FIGURE 17
SK100F Gage Control Cross-Section

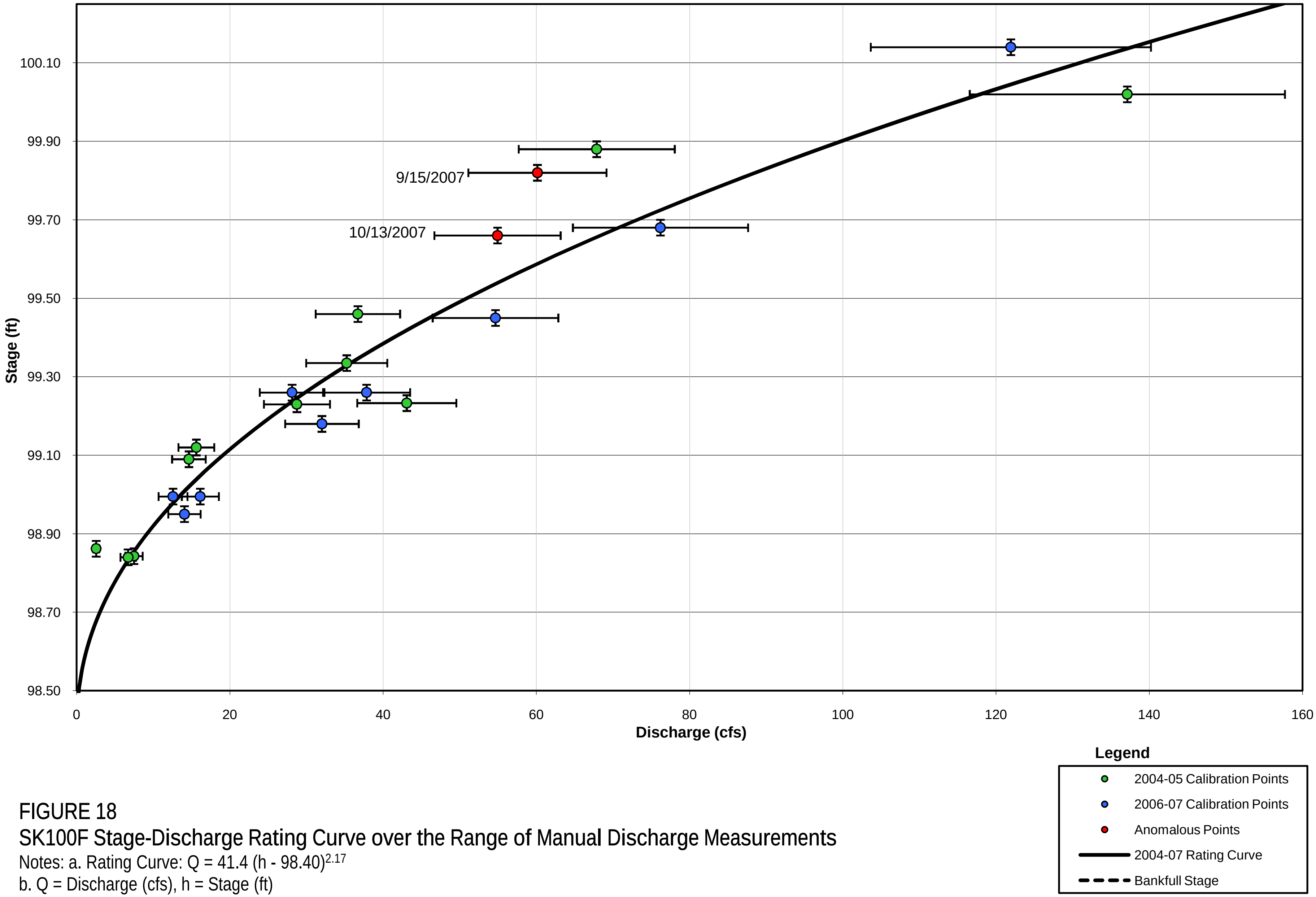


FIGURE 18

SK100F Stage-Discharge Rating Curve over the Range of Manual Discharge Measurements

Notes: a. Rating Curve: $Q = 41.4 (h - 98.40)^{2.17}$

b. Q = Discharge (cfs), h = Stage (ft)

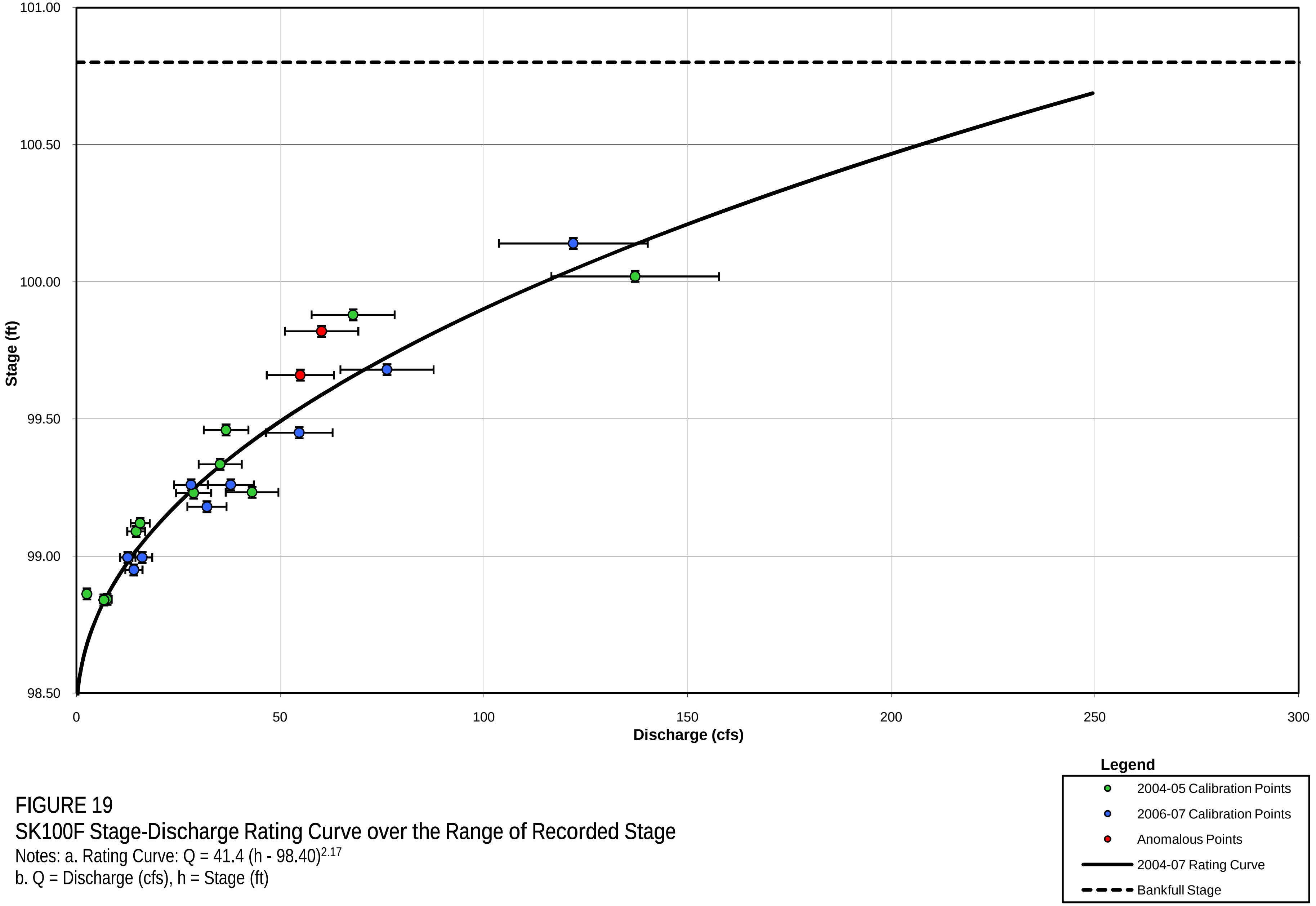


FIGURE 19
SK100F Stage-Discharge Rating Curve over the Range of Recorded Stage
Notes: a. Rating Curve: $Q = 41.4\ (h - 98.40)^{2.17}$
b. Q = Discharge (cfs), h = Stage (ft)

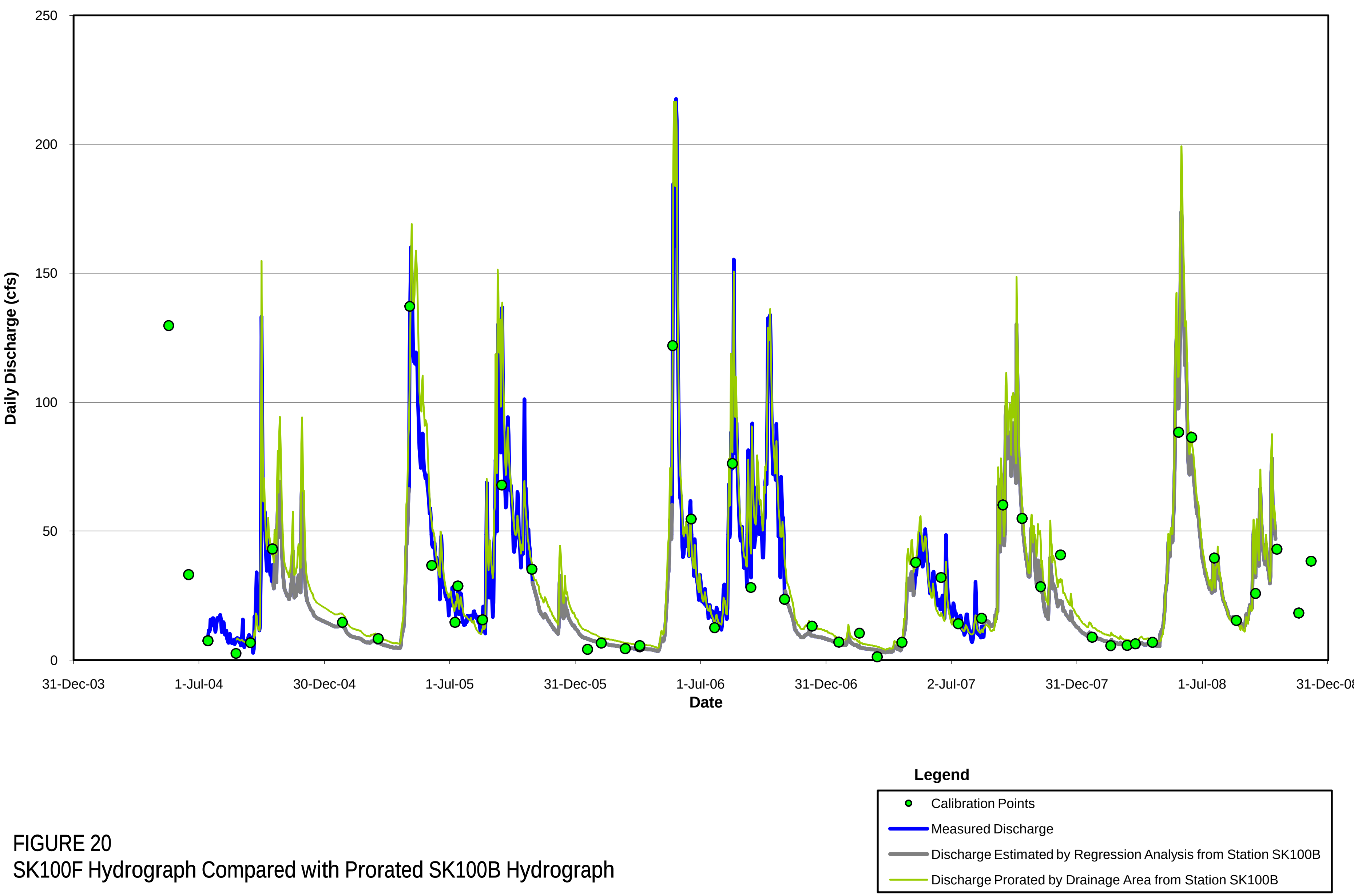


FIGURE 20
SK100F Hydrograph Compared with Prorated SK100B Hydrograph

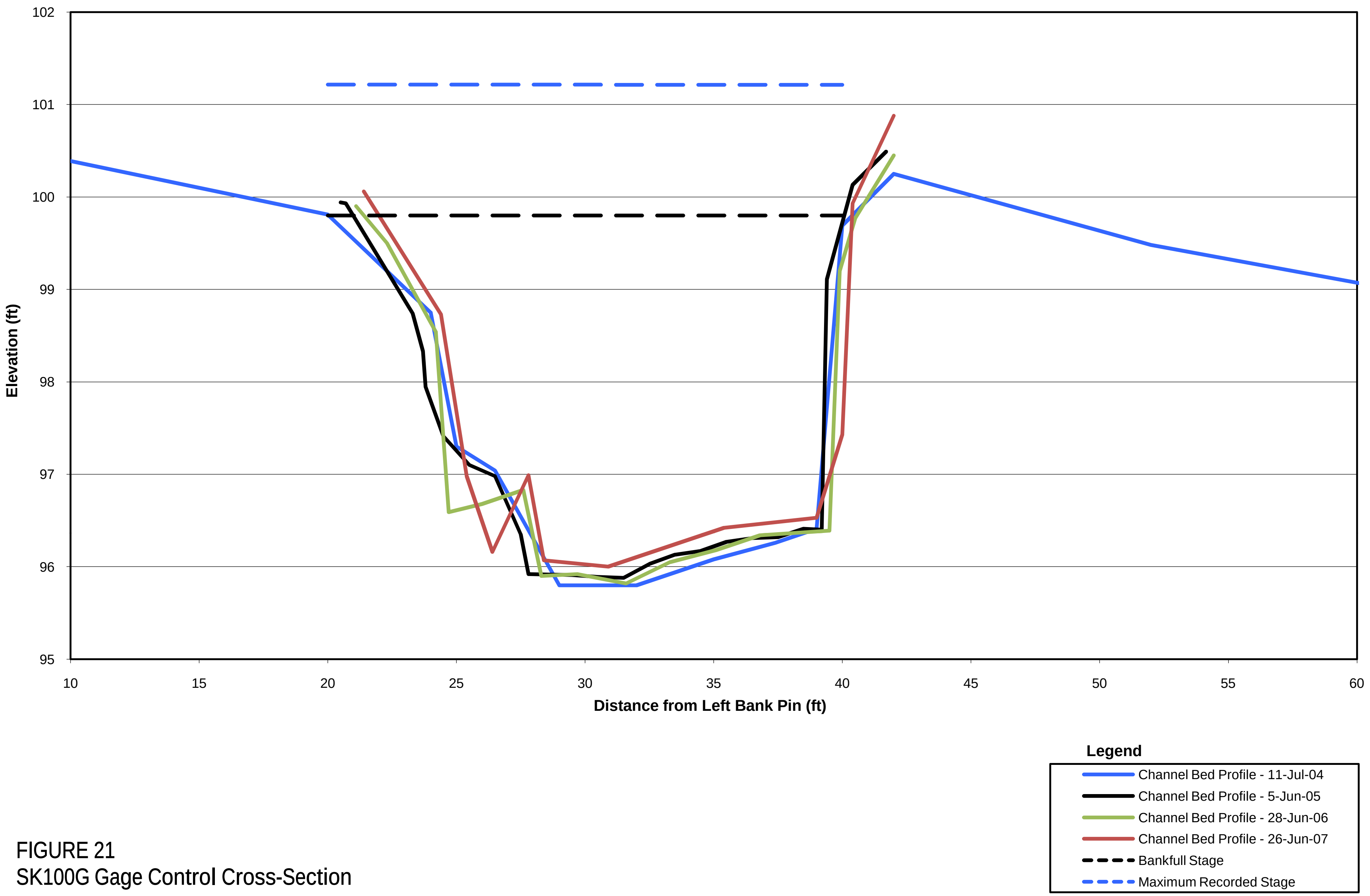


FIGURE 21
SK100G Gage Control Cross-Section

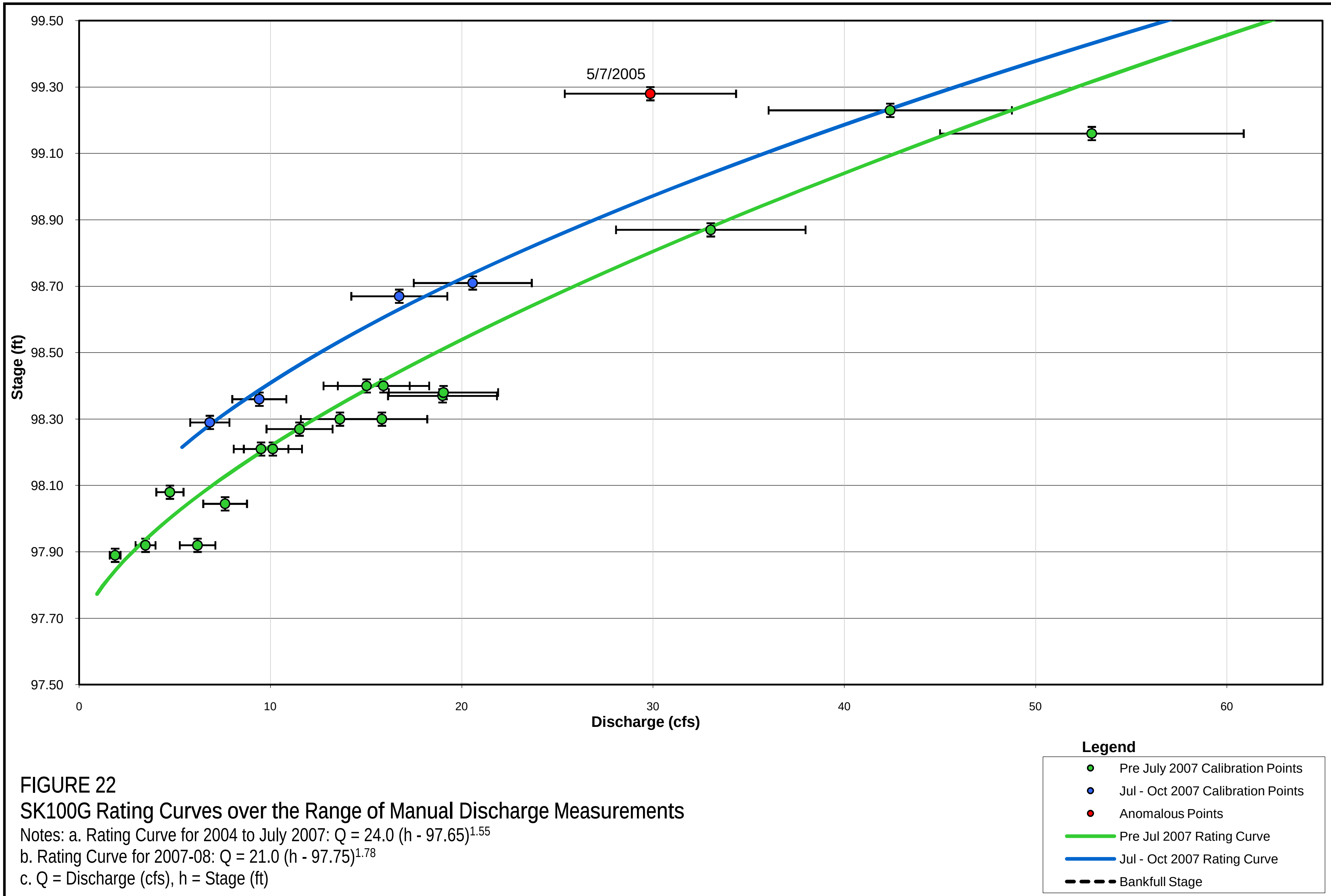


FIGURE 22

SK100G Rating Curves over the Range of Manual Discharge Measurements

Notes: a. Rating Curve for 2004 to July 2007: $Q = 24.0 (h - 97.65)^{1.55}$

b. Rating Curve for 2007-08: $Q = 21.0 (h - 97.75)^{1.78}$

c. Q = Discharge (cfs), h = Stage (ft)

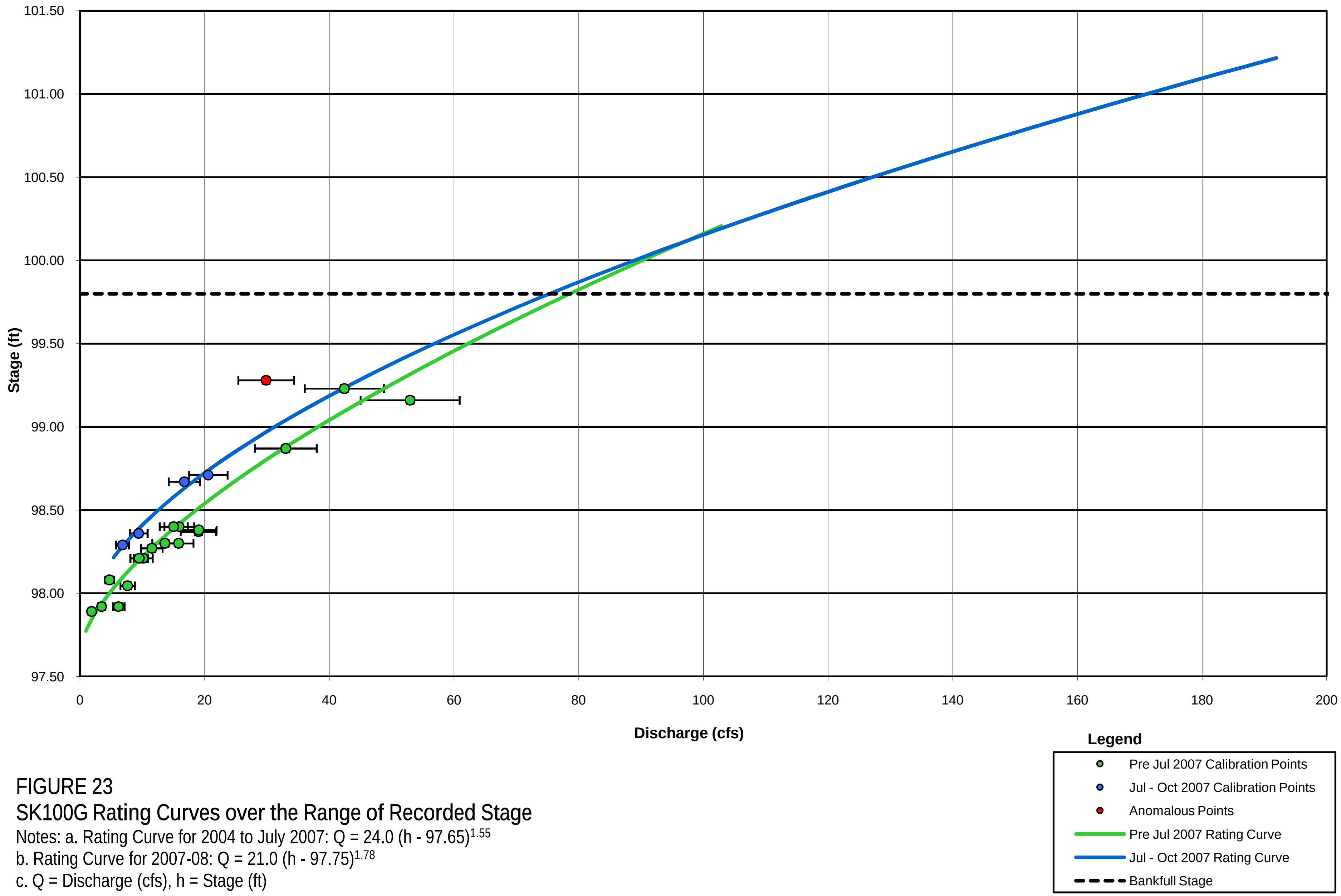


FIGURE 23

SK100G Rating Curves over the Range of Recorded Stage

Notes: a. Rating Curve for 2004 to July 2007: $Q = 24.0 (h - 97.65)^{1.55}$

b. Rating Curve for 2007-08: $Q = 21.0 (h - 97.75)^{1.78}$

c. Q = Discharge (cfs), h = Stage (ft)

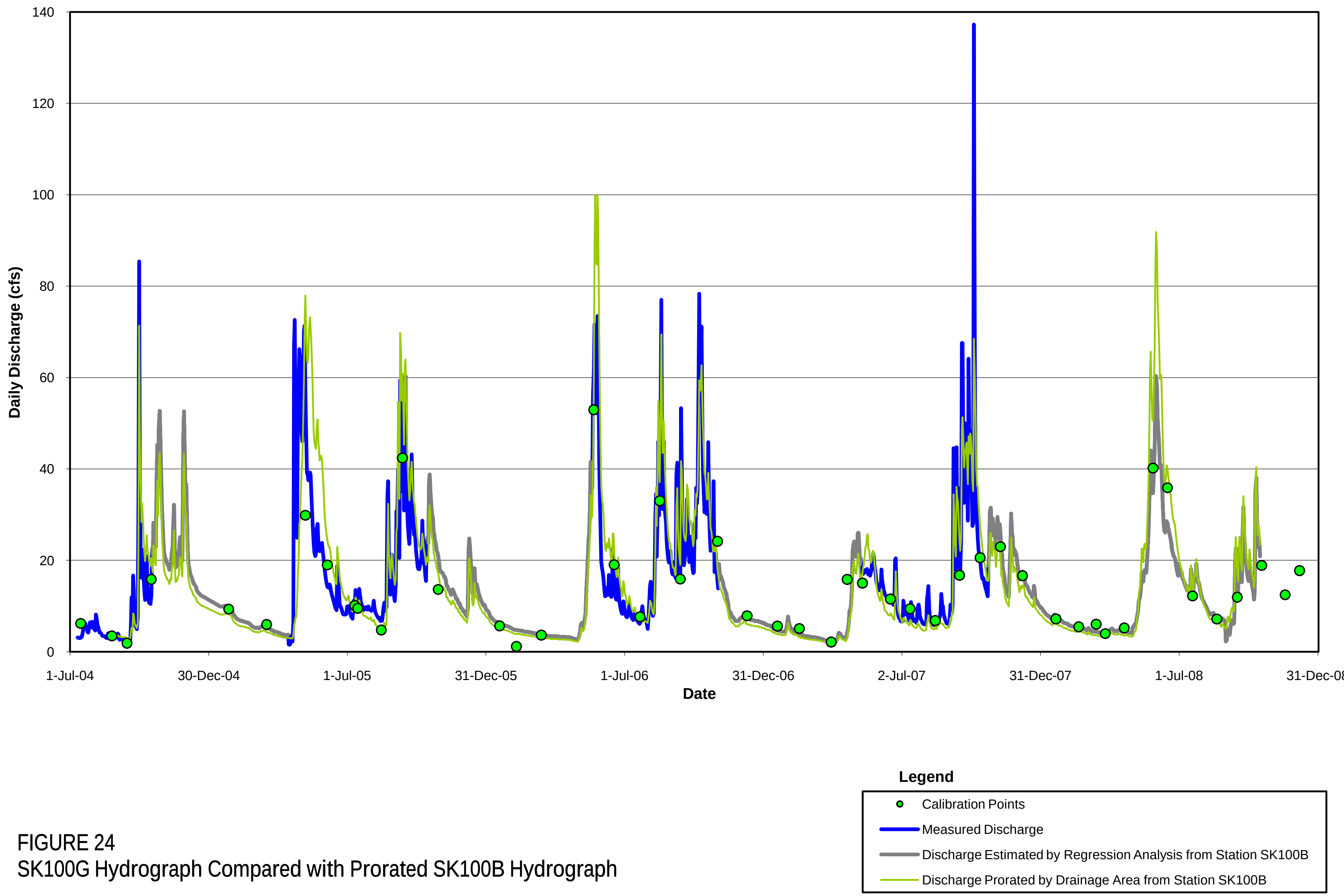


FIGURE 24
SK100G Hydrograph Compared with Prorated SK100B Hydrograph

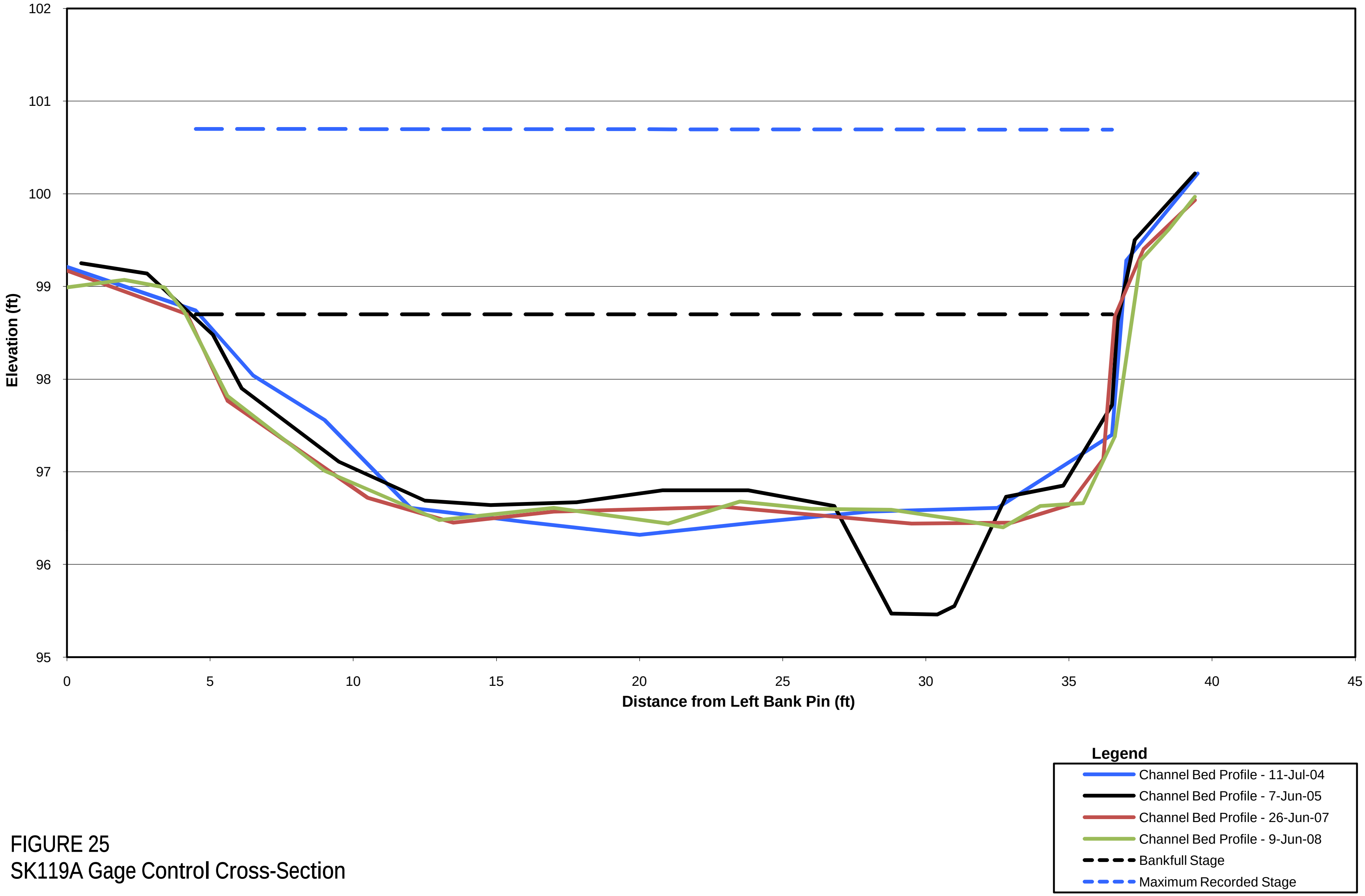


FIGURE 25
SK119A Gage Control Cross-Section

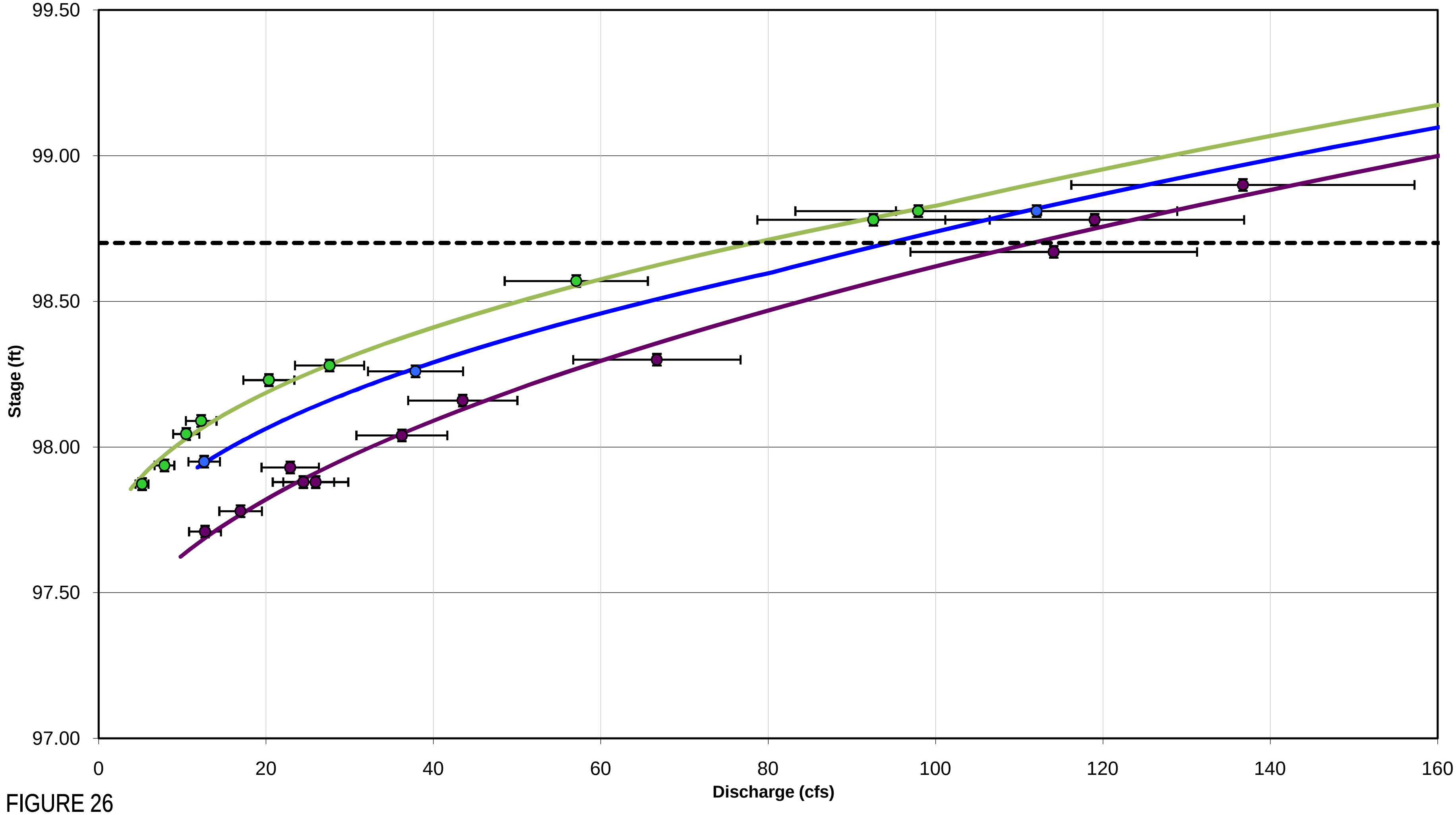


FIGURE 26

SK119A Rating Curves over the Range of Manual Discharge Measurements

Notes: a. Rating Curve for 2004-05 for Stage below 98.83 ft: $Q = 54.0 (h - 97.53)^{2.36}$

b. Rating Curve for 2004-05 for Stage above 98.83 ft: $Q = 51.0 (h - 97.45)^{2.10}$

c. Rating Curve for 2006 for Stage below 98.60 ft: $Q = 52.5 (h - 97.40)^{2.35}$

d. Rating Curve for 2006 for Stage above 98.60 ft: $Q = 51.0 (h - 97.35)^{2.05}$

e. Rating Curve for 2007-08: $Q = 45.4 (h - 97.15)^{2.05}$

f. Q = Discharge (cfs), h = Stage (ft)

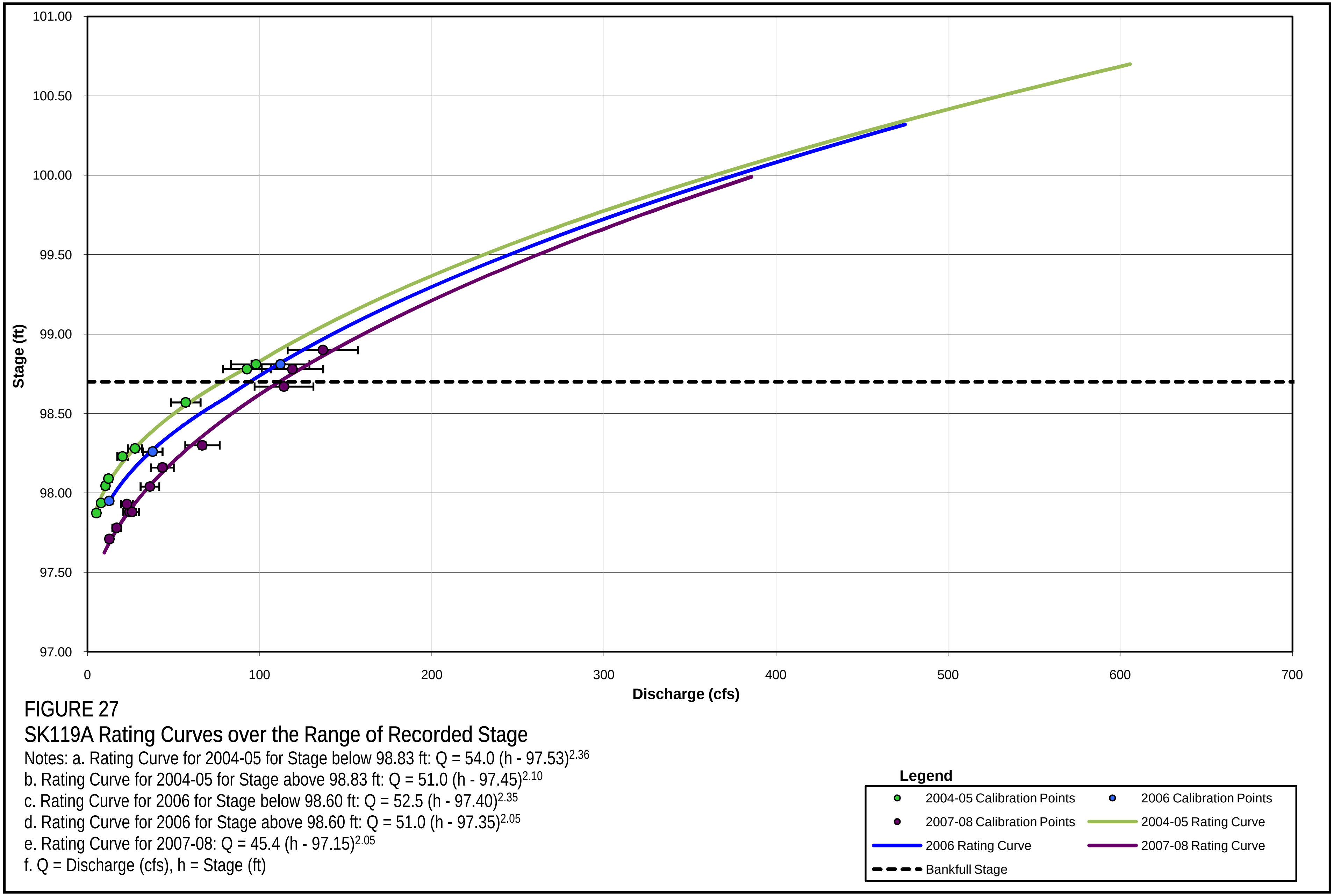


FIGURE 27

SK119A Rating Curves over the Range of Recorded Stage

Notes: a. Rating Curve for 2004-05 for Stage below 98.83 ft: $Q = 54.0\ (h - 97.53)^{2.36}$

b. Rating Curve for 2004-05 for Stage above 98.83 ft: $Q = 51.0\ (h - 97.45)^{2.10}$

c. Rating Curve for 2006 for Stage below 98.60 ft: $Q = 52.5\ (h - 97.40)^{2.35}$

d. Rating Curve for 2006 for Stage above 98.60 ft: $Q = 51.0\ (h - 97.35)^{2.05}$

e. Rating Curve for 2007-08: $Q = 45.4\ (h - 97.15)^{2.05}$

f. Q = Discharge (cfs), h = Stage (ft)

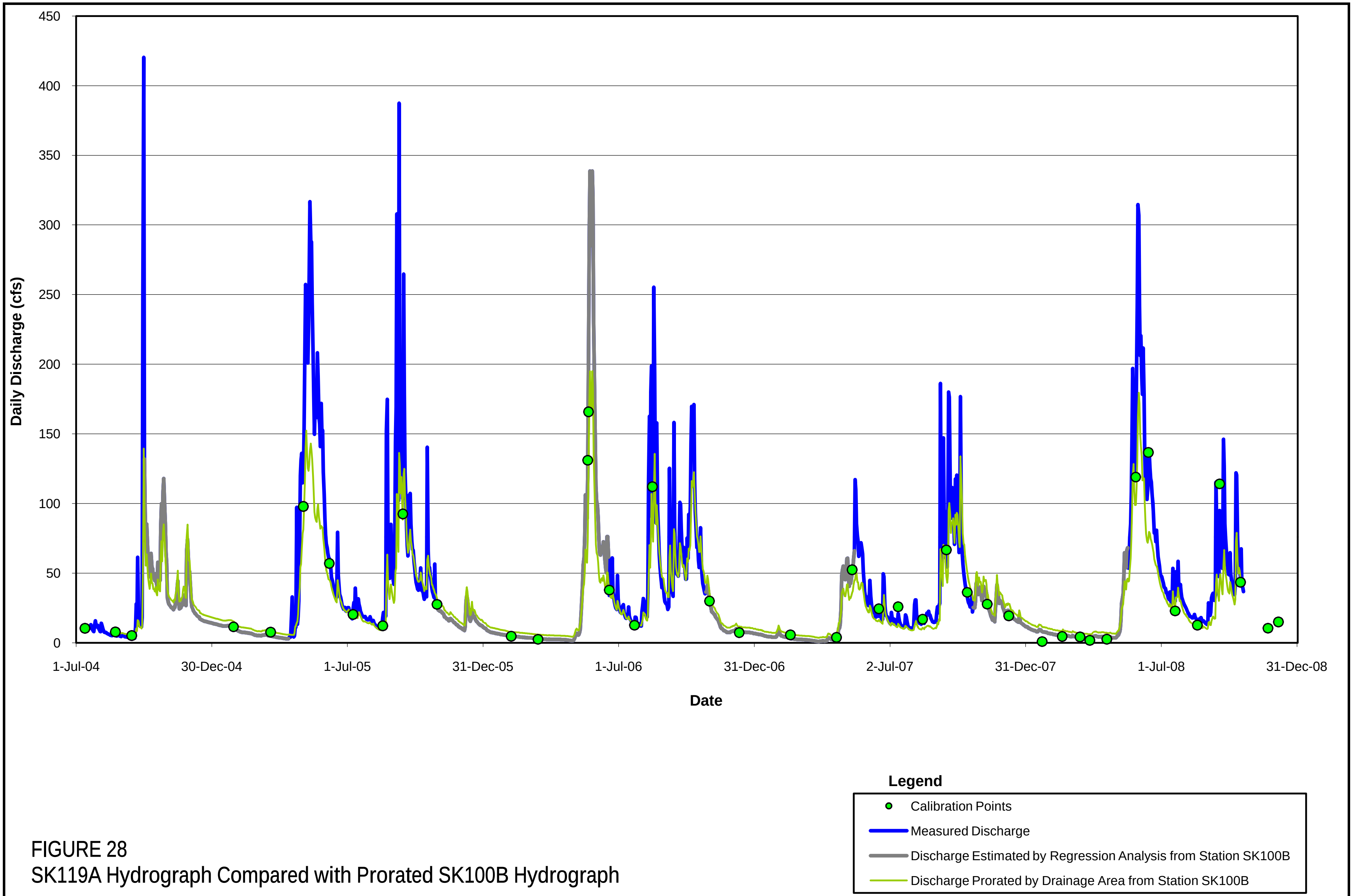


FIGURE 28
SK119A Hydrograph Compared with Prorated SK100B Hydrograph

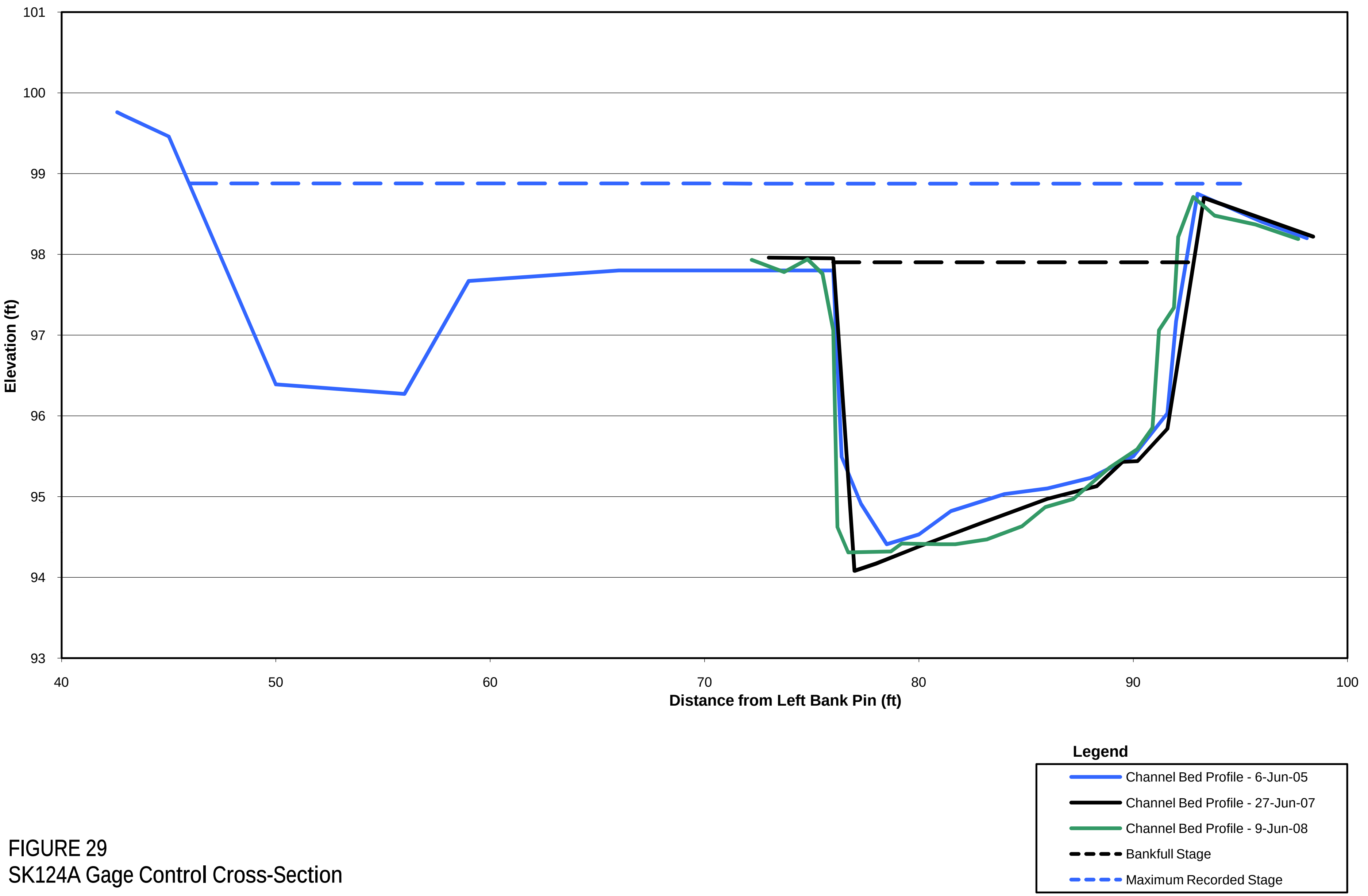


FIGURE 29
SK124A Gage Control Cross-Section

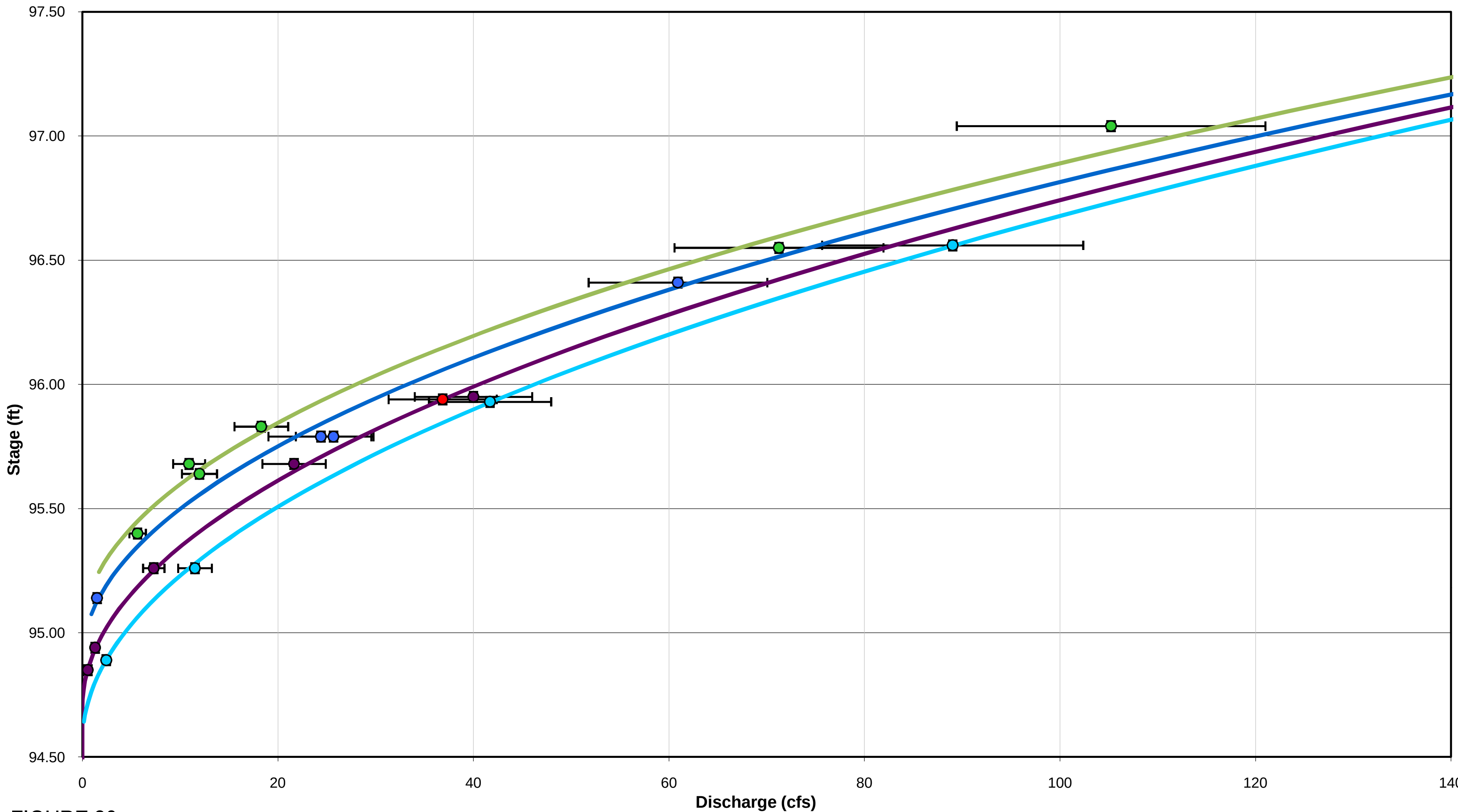


FIGURE 30

SK124A Rating Curves over the Range of Manual Discharge Measurements

Notes: a. Rating Curve for 2005: $Q = 28.0 (h - 95.00)^{2.00}$

b. Rating Curve for 2006: $Q = 27.0 (h - 94.89)^{2.00}$

c. Rating Curve for 2007: $Q = 24.0 (h - 94.70)^{2.00}$

d. Rating Curve for 2008: $Q = 22.3 (h - 94.56)^{2.00}$

e. Q = Discharge (cfs), h = Stage (ft)

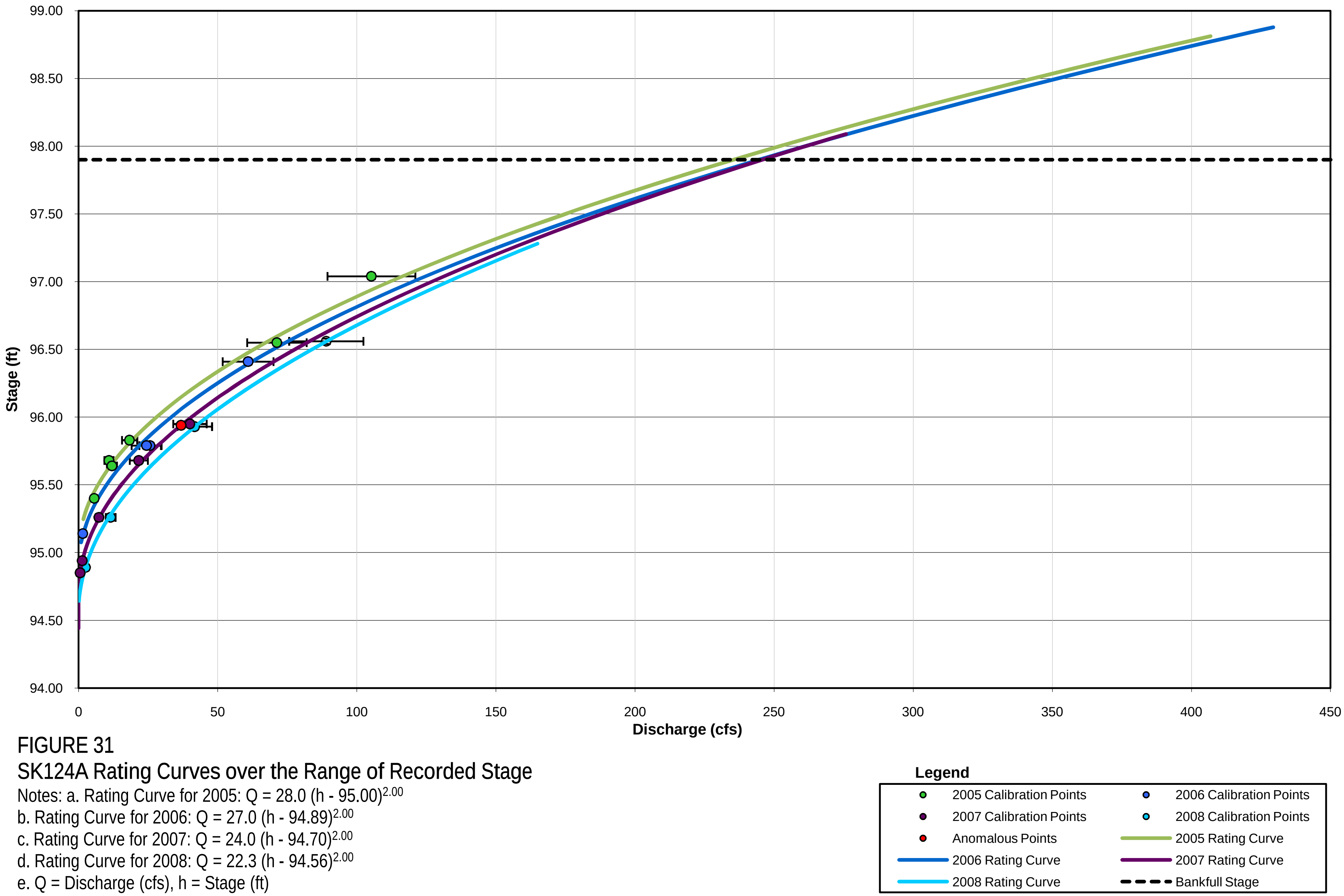


FIGURE 31

SK124A Rating Curves over the Range of Recorded Stage

Notes: a. Rating Curve for 2005: $Q = 28.0 (h - 95.00)^{2.00}$

b. Rating Curve for 2006: $Q = 27.0 (h - 94.89)^{2.00}$

c. Rating Curve for 2007: $Q = 24.0 (h - 94.70)^{2.00}$

d. Rating Curve for 2008: $Q = 22.3 (h - 94.56)^{2.00}$

e. Q = Discharge (cfs), h = Stage (ft)

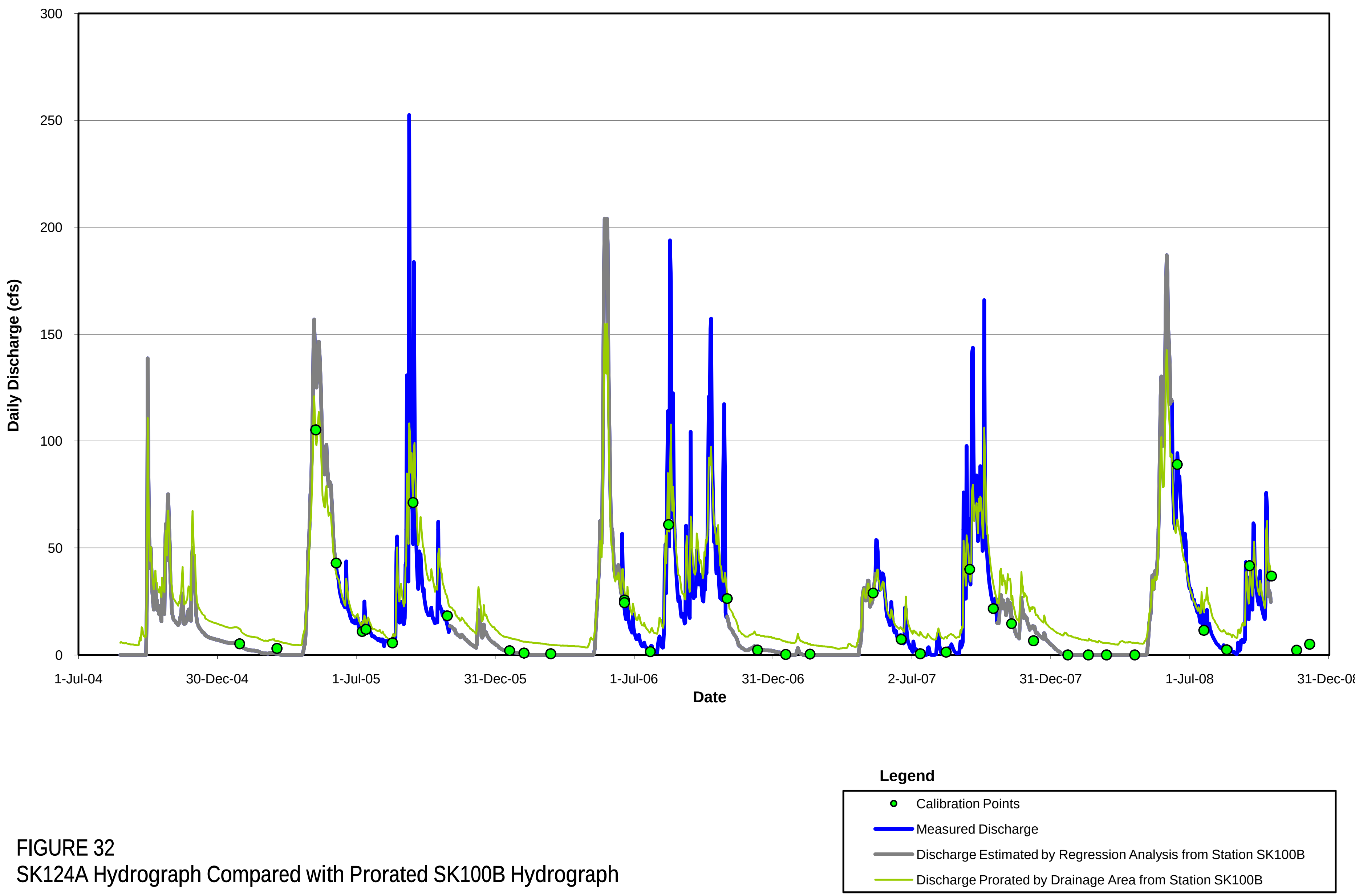


FIGURE 32
SK124A Hydrograph Compared with Prorated SK100B Hydrograph

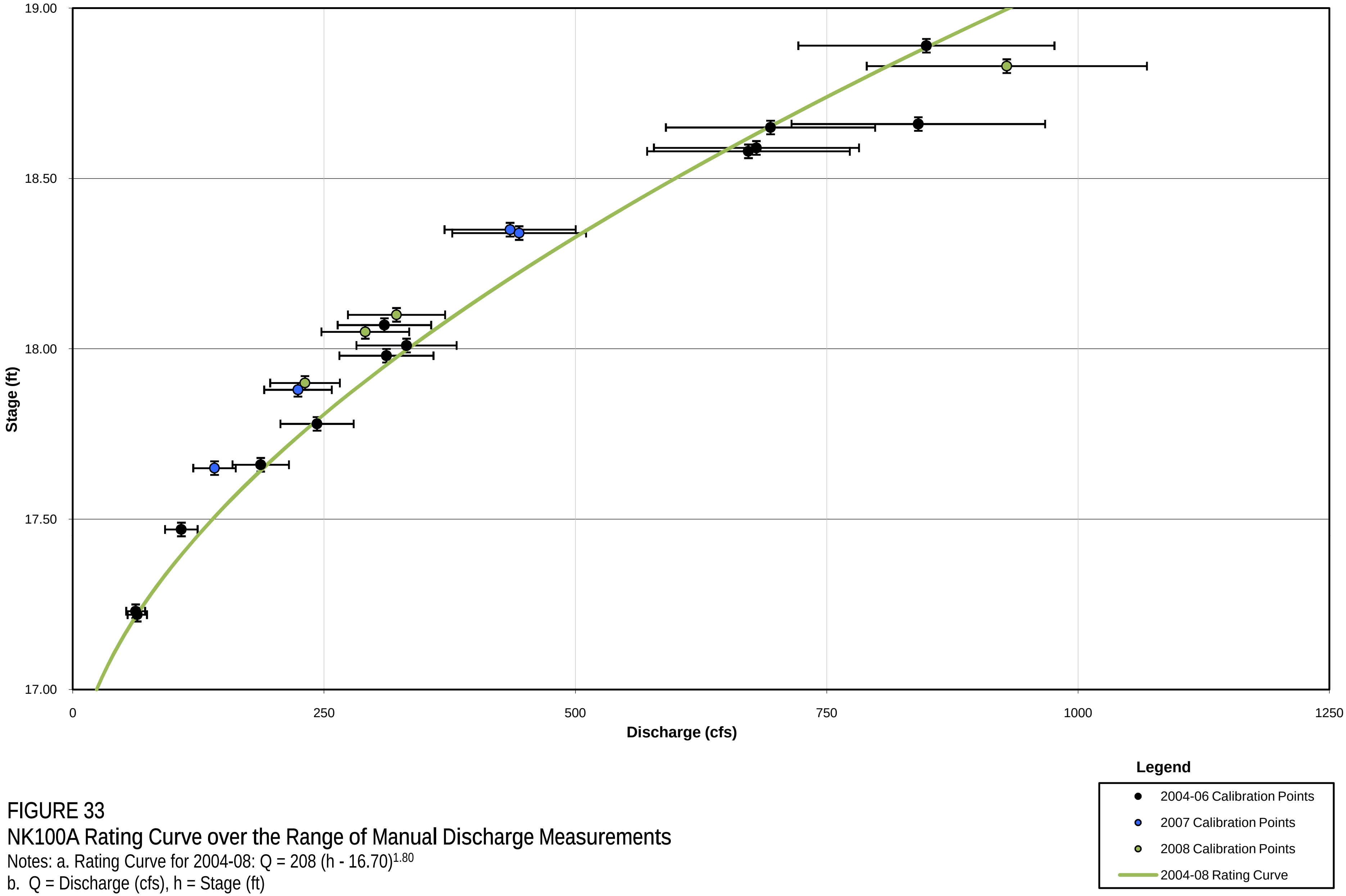


FIGURE 33
NK100A Rating Curve over the Range of Manual Discharge Measurements
Notes: a. Rating Curve for 2004-08: $Q = 208\ (h - 16.70)^{1.80}$
b. Q = Discharge (cfs), h = Stage (ft)

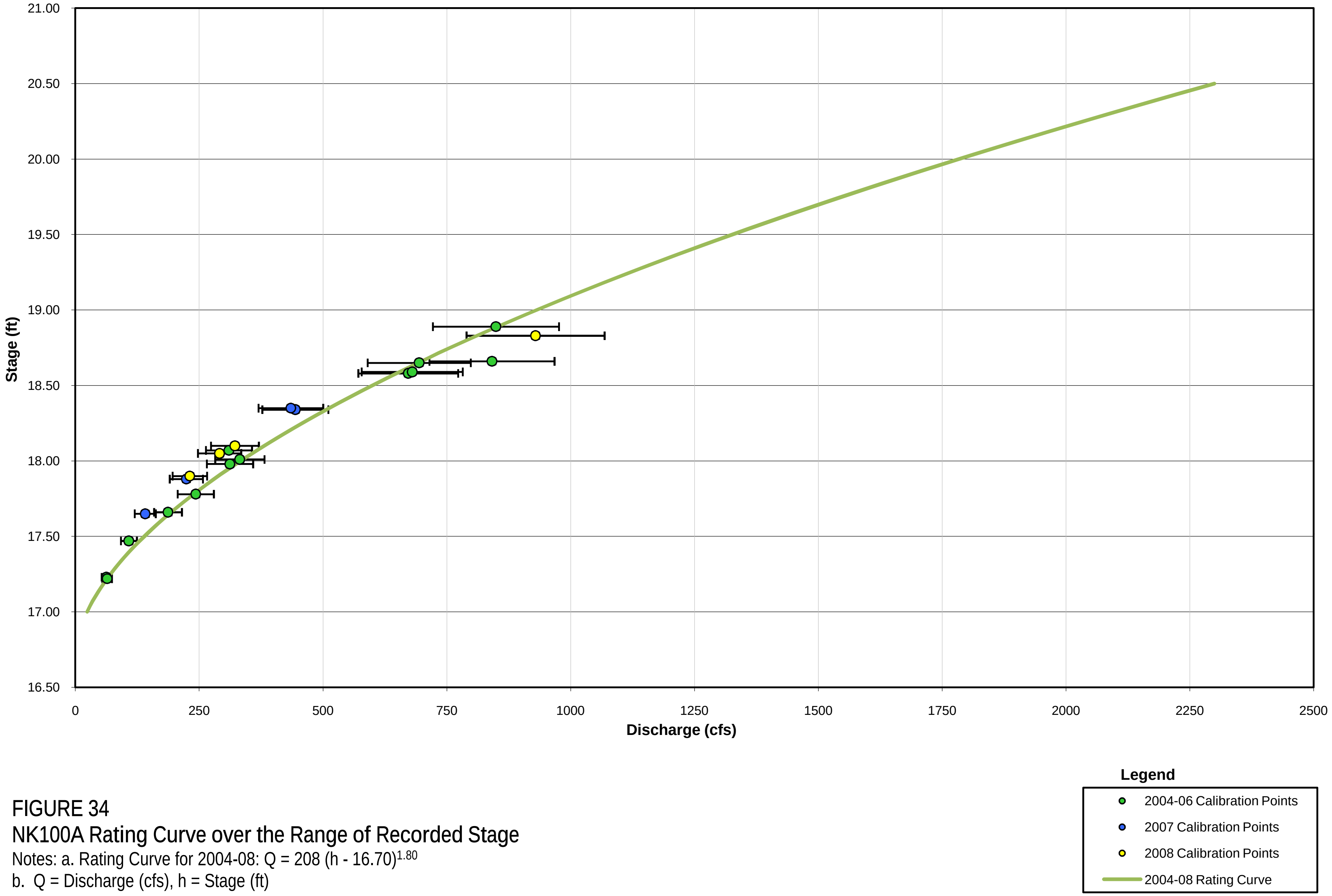


FIGURE 34

NK100A Rating Curve over the Range of Recorded Stage

Notes: a. Rating Curve for 2004-08: $Q = 208 (h - 16.70)^{1.80}$

b. Q = Discharge (cfs), h = Stage (ft)

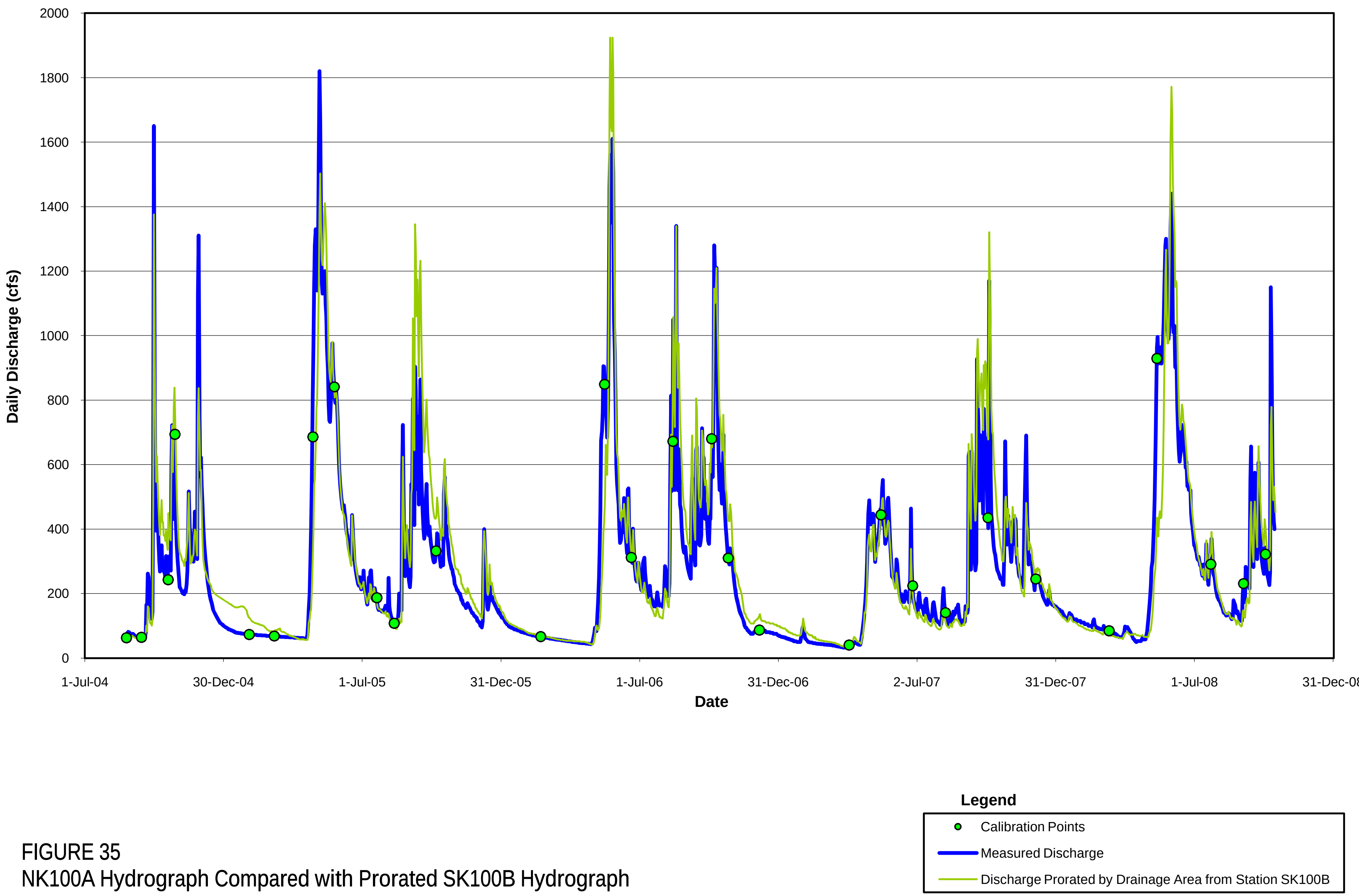


FIGURE 35
NK100A Hydrograph Compared with Prorated SK100B Hydrograph

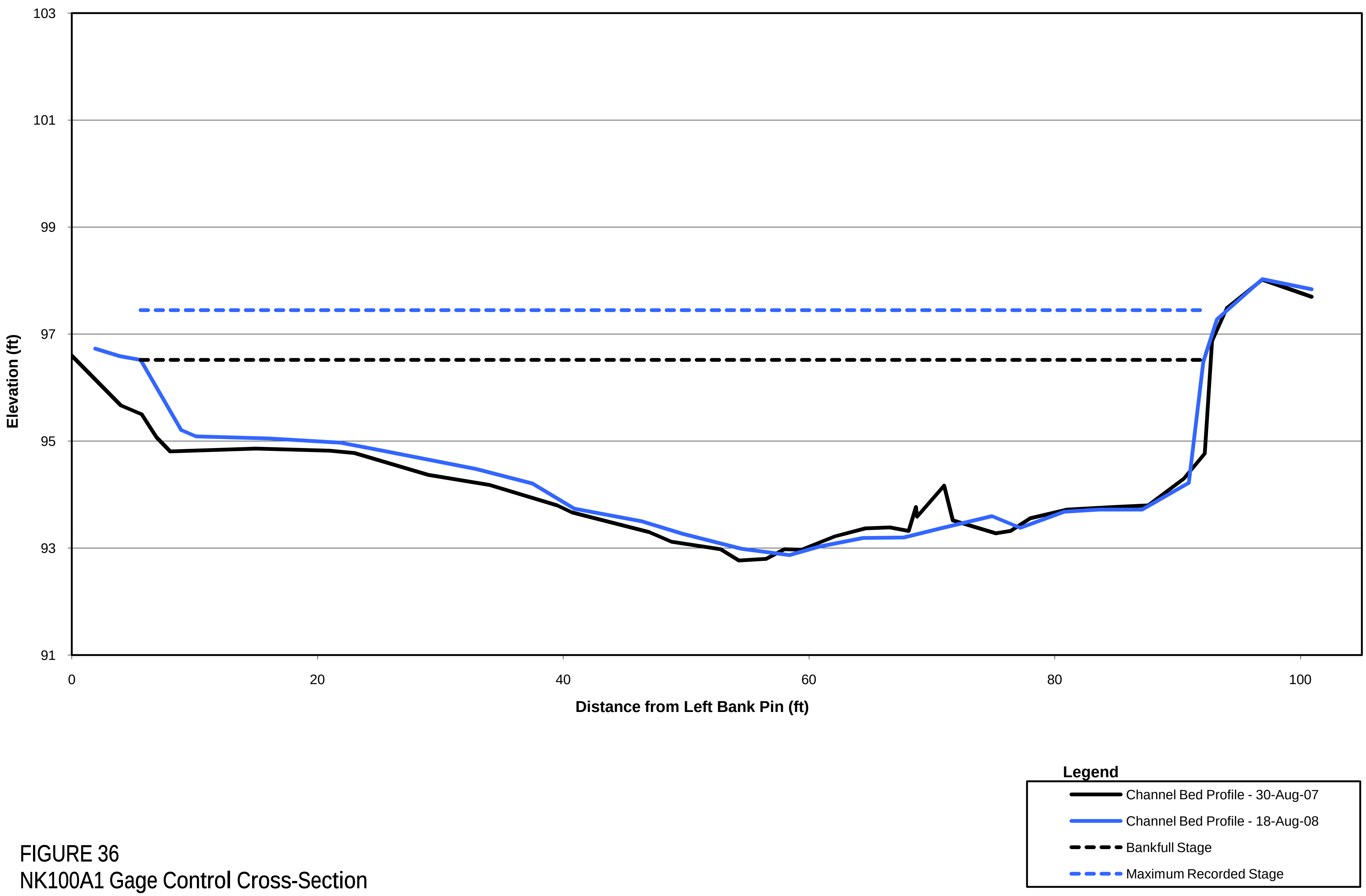


FIGURE 36
NK100A1 Gage Control Cross-Section

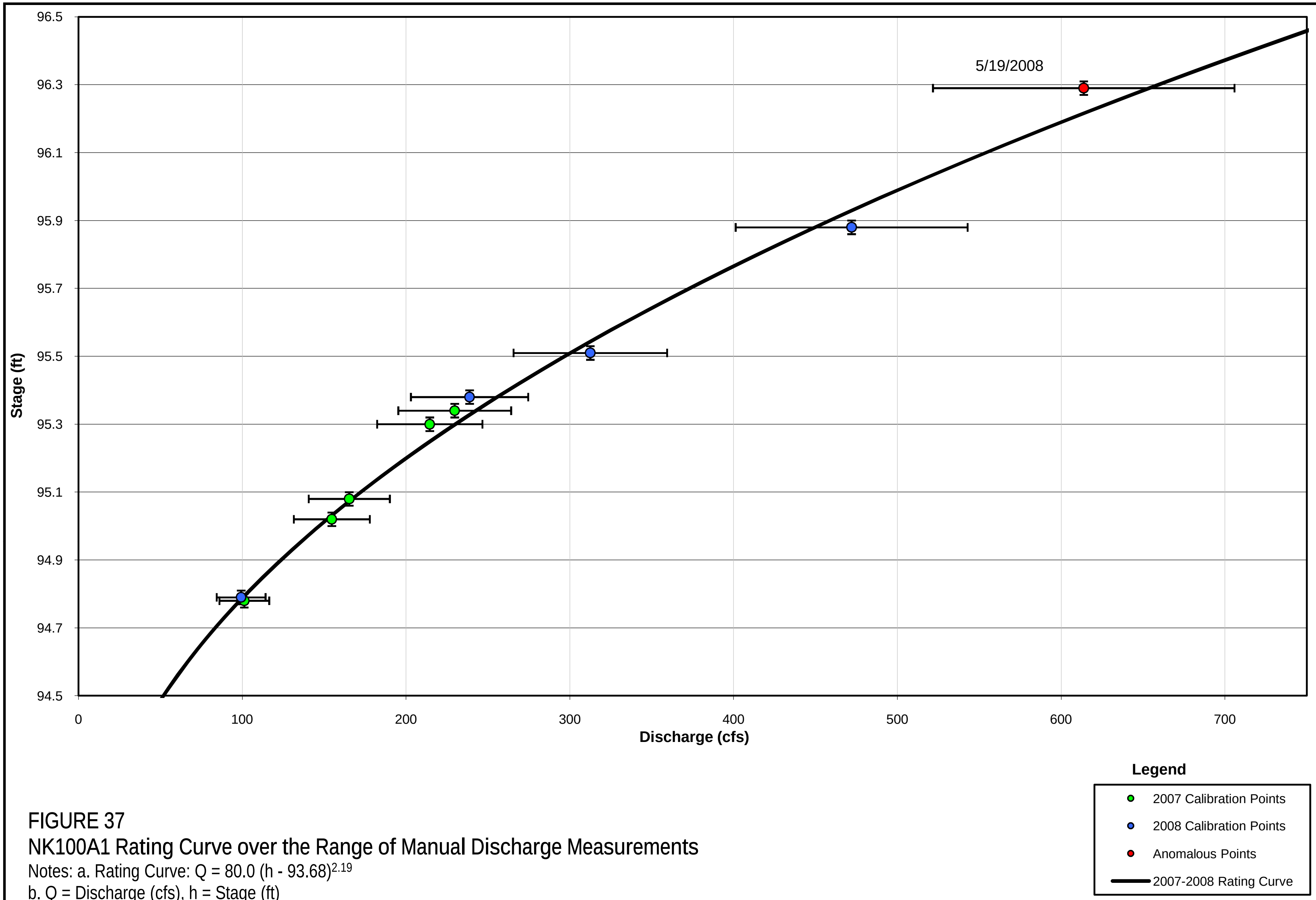


FIGURE 37

NK100A1 Rating Curve over the Range of Manual Discharge Measurements

Notes: a. Rating Curve: $Q = 80.0 (h - 93.68)^{2.19}$

b. Q = Discharge (cfs), h = Stage (ft)

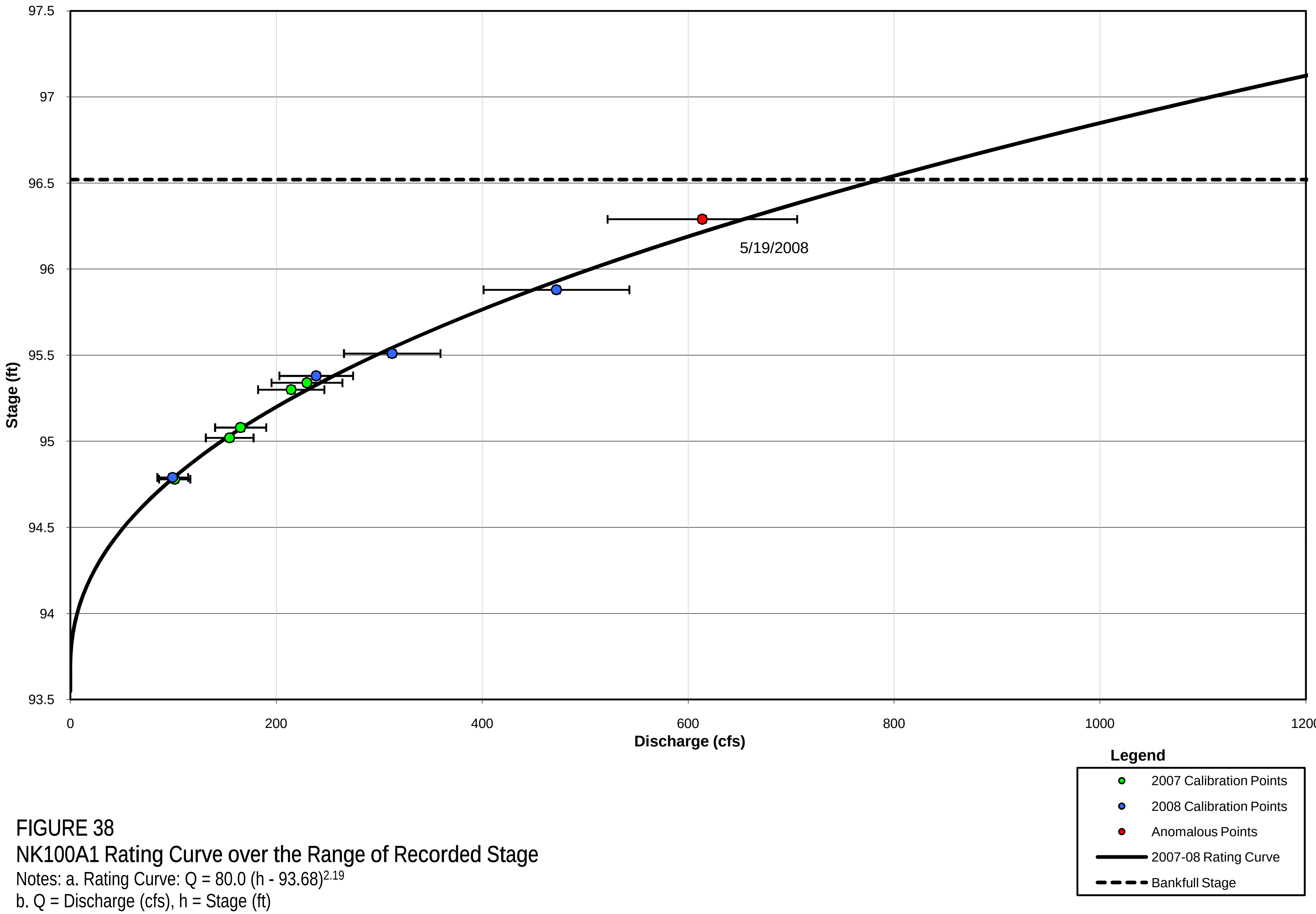


FIGURE 38
NK100A1 Rating Curve over the Range of Recorded Stage
Notes: a. Rating Curve: $Q = 80.0 (h - 93.68)^{2.19}$
b. Q = Discharge (cfs), h = Stage (ft)

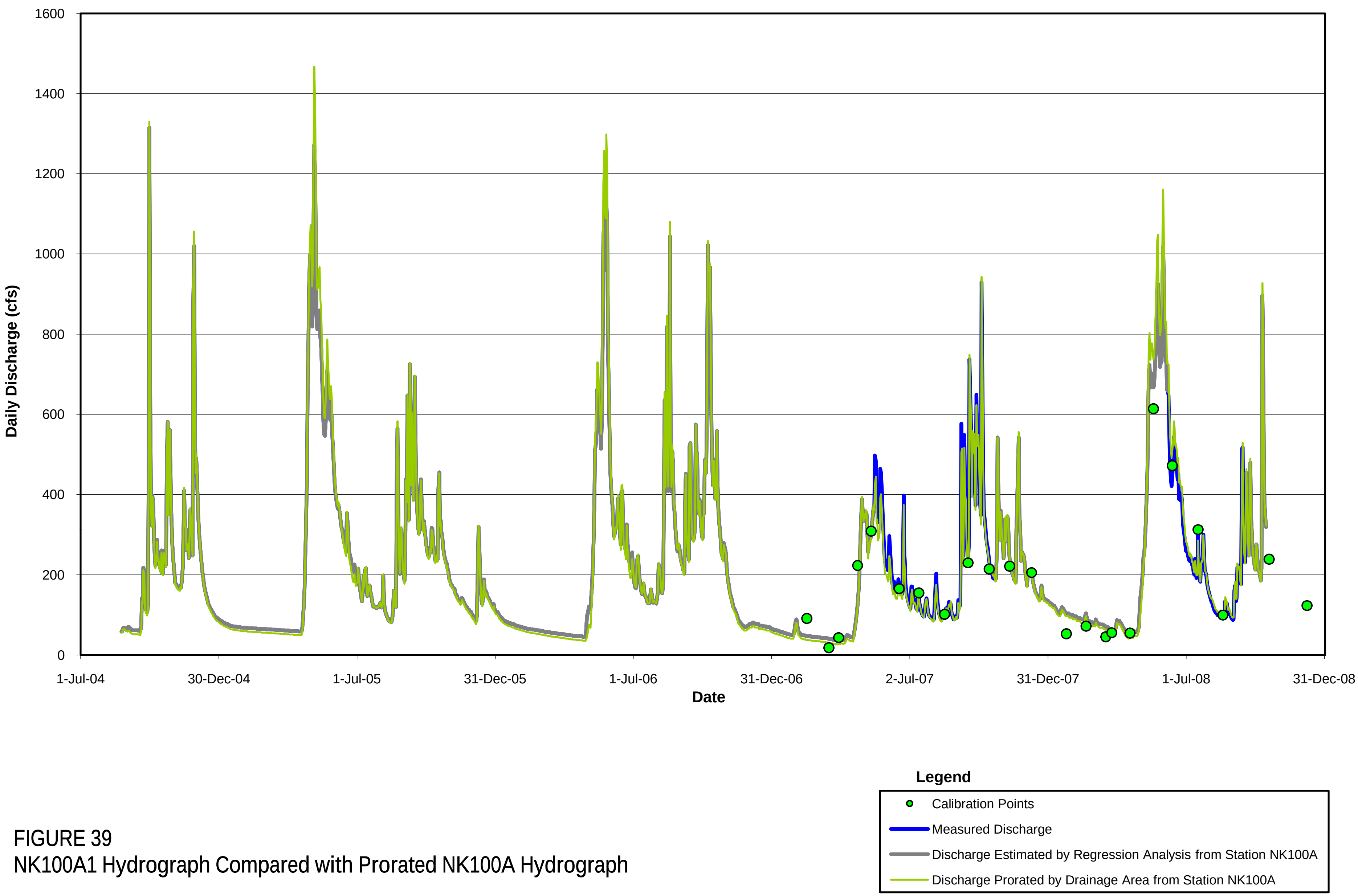


FIGURE 39
NK100A1 Hydrograph Compared with Prorated NK100A Hydrograph

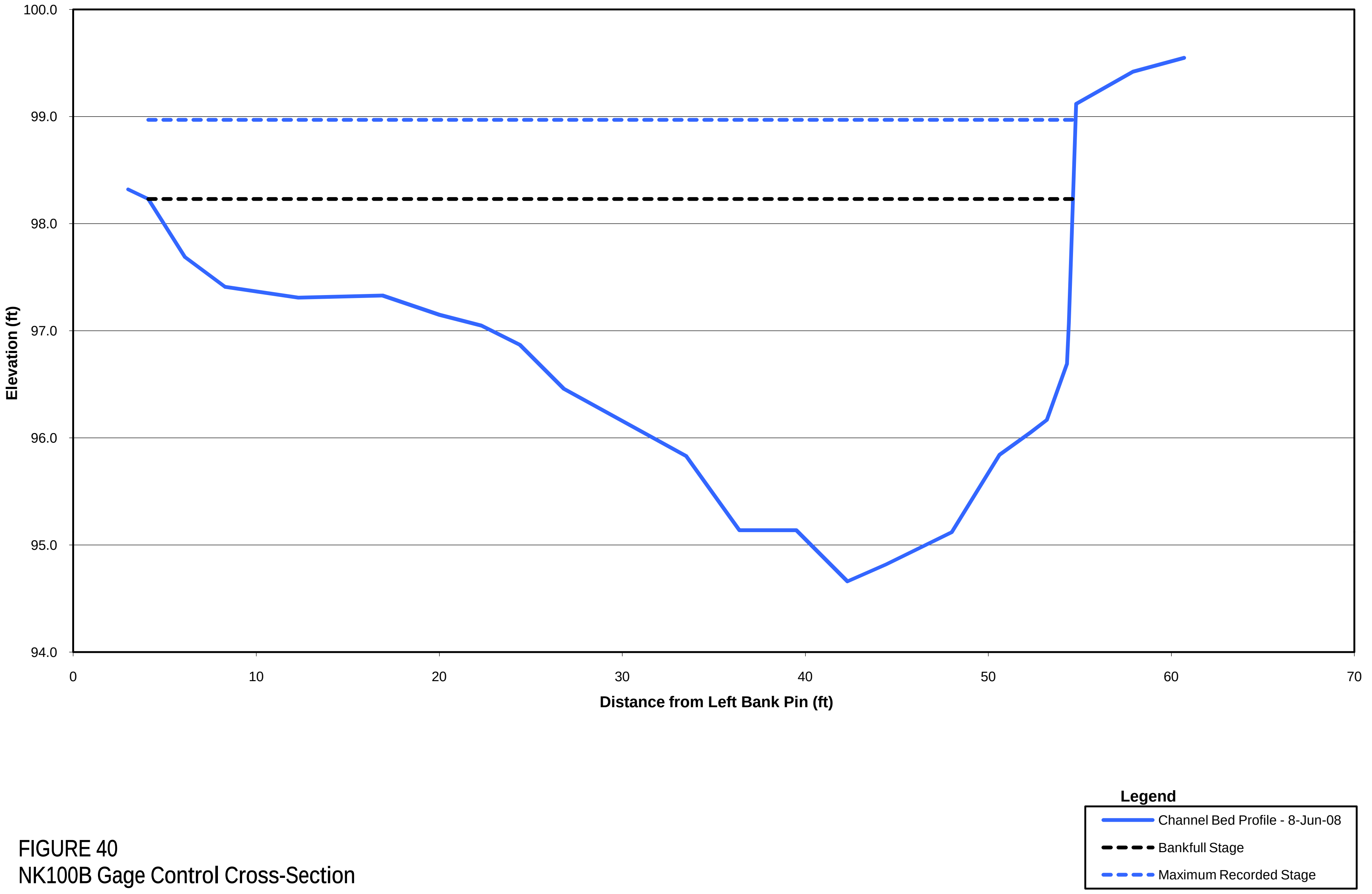


FIGURE 40
NK100B Gage Control Cross-Section

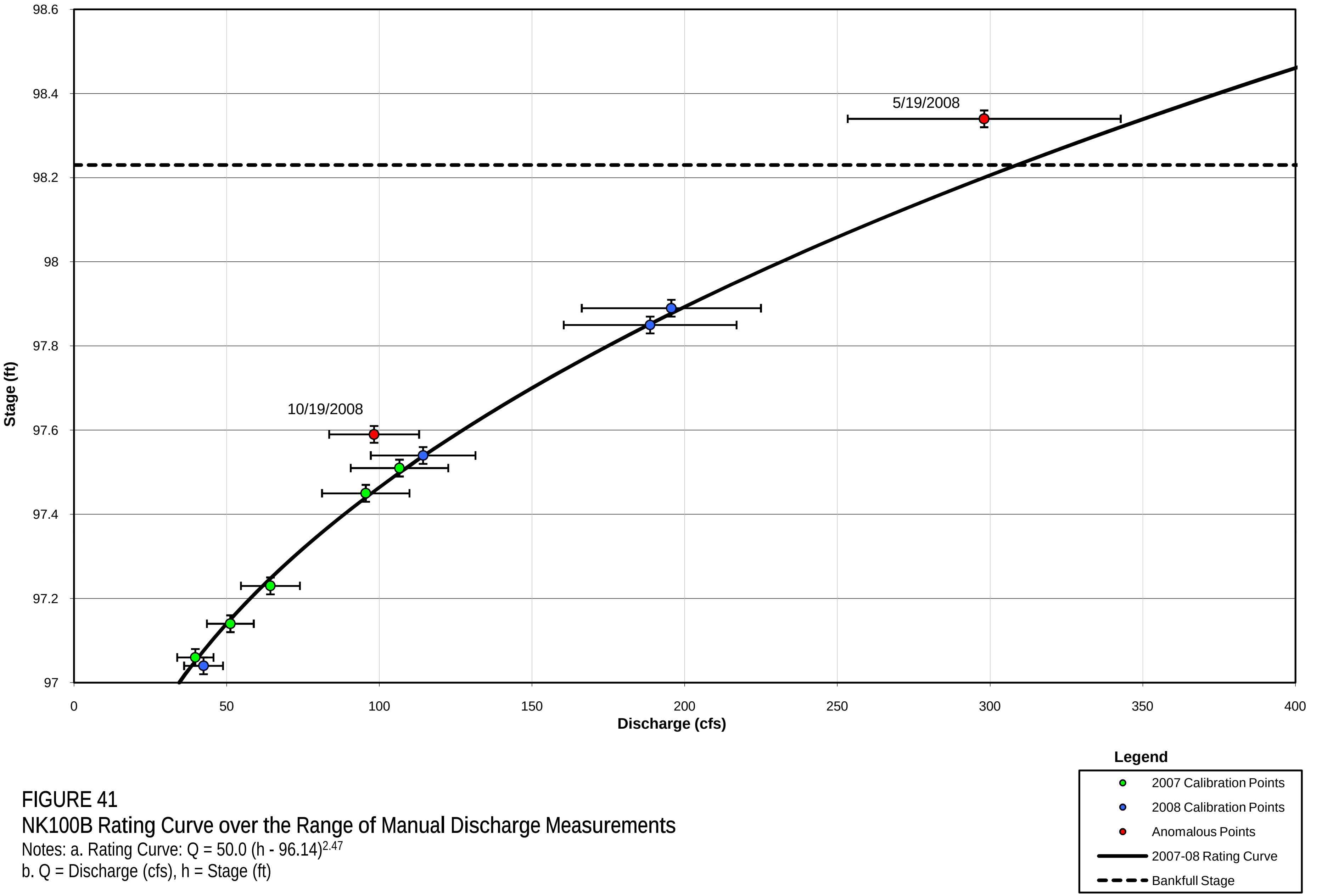


FIGURE 41

NK100B Rating Curve over the Range of Manual Discharge Measurements

Notes: a. Rating Curve: $Q = 50.0 (h - 96.14)^{2.47}$

b. Q = Discharge (cfs), h = Stage (ft)

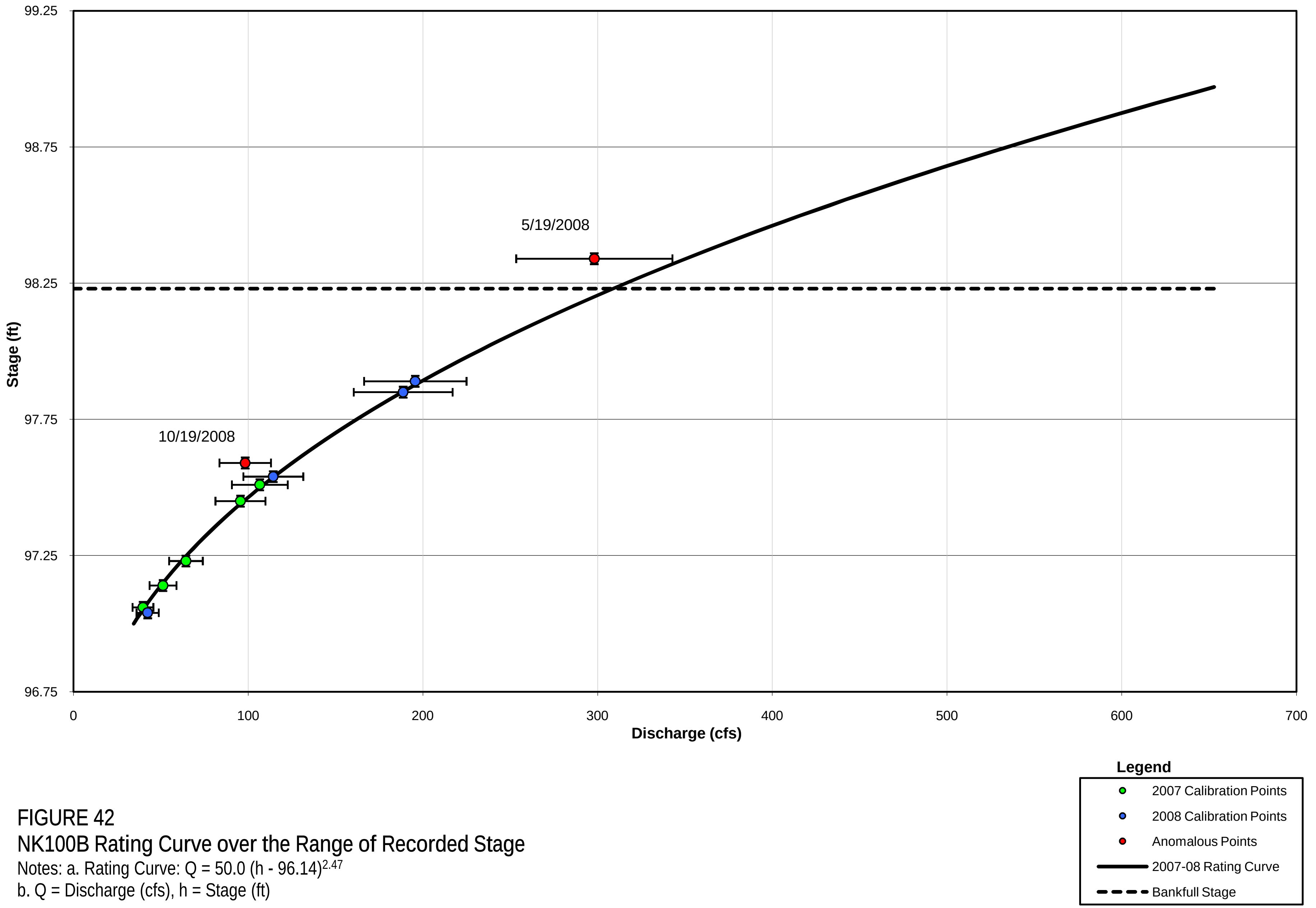


FIGURE 42

NK100B Rating Curve over the Range of Recorded Stage

Notes: a. Rating Curve: $Q = 50.0 (h - 96.14)^{2.47}$

b. Q = Discharge (cfs), h = Stage (ft)

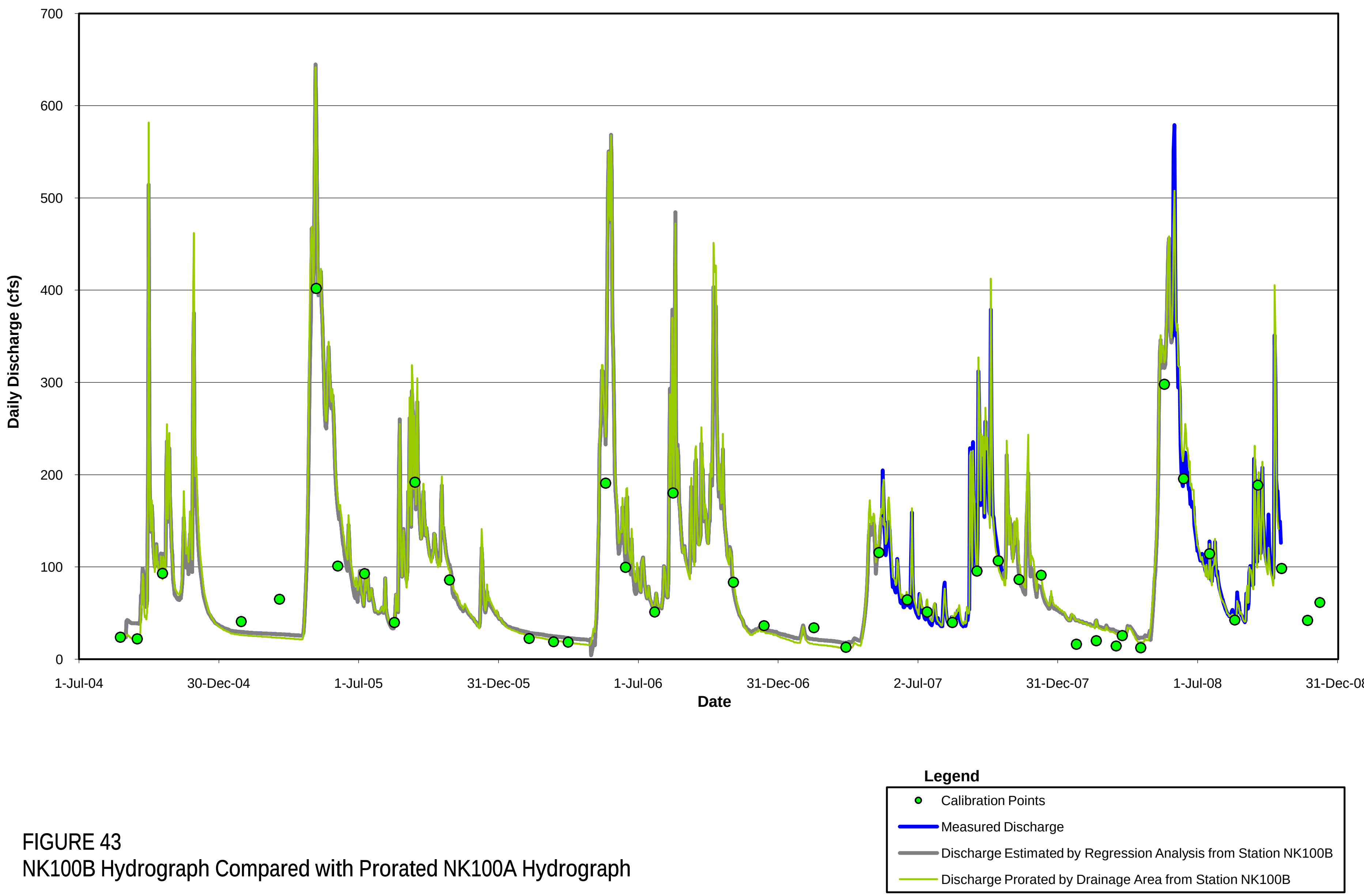


FIGURE 43
NK100B Hydrograph Compared with Prorated NK100A Hydrograph

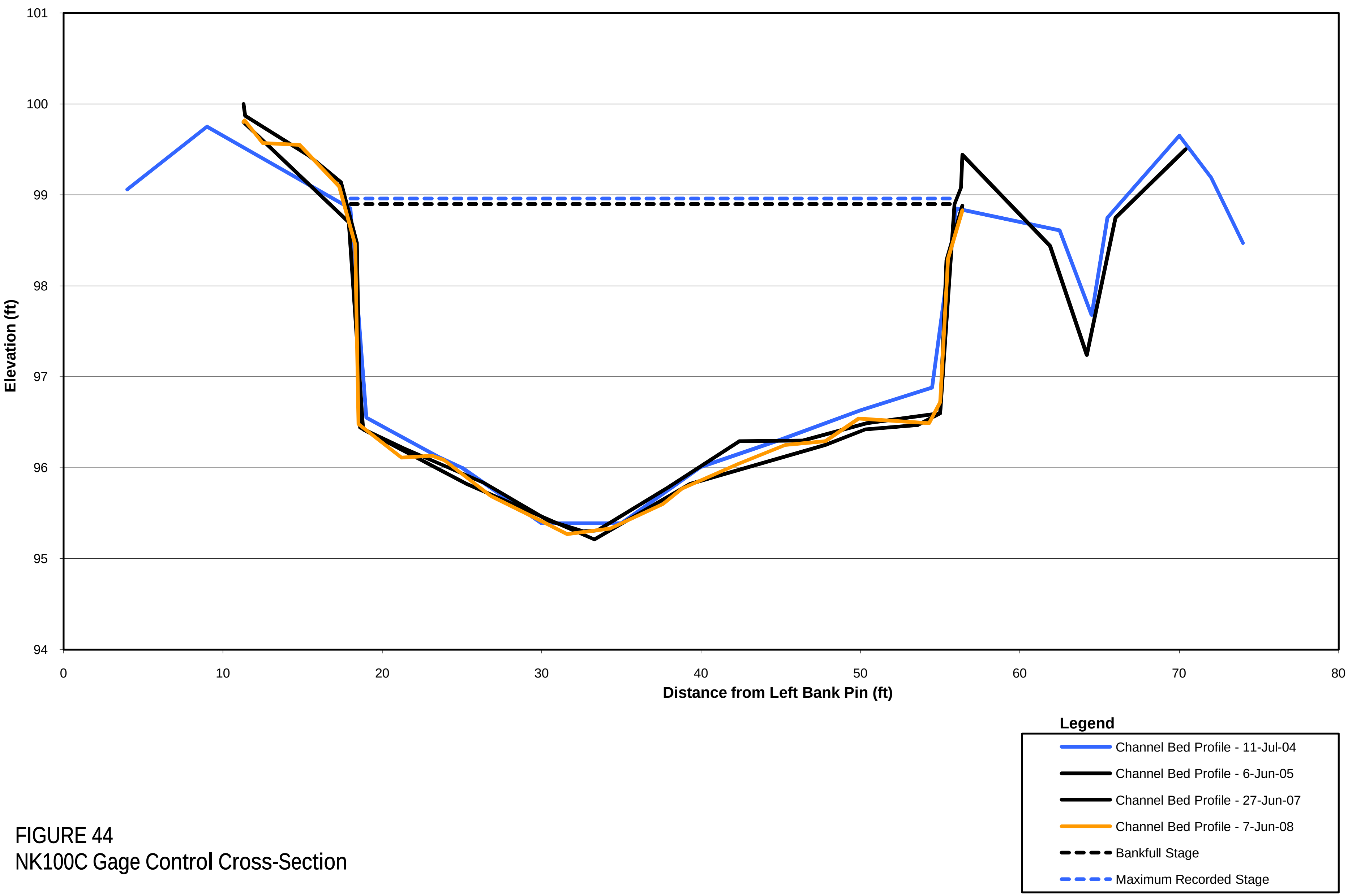


FIGURE 44
NK100C Gage Control Cross-Section

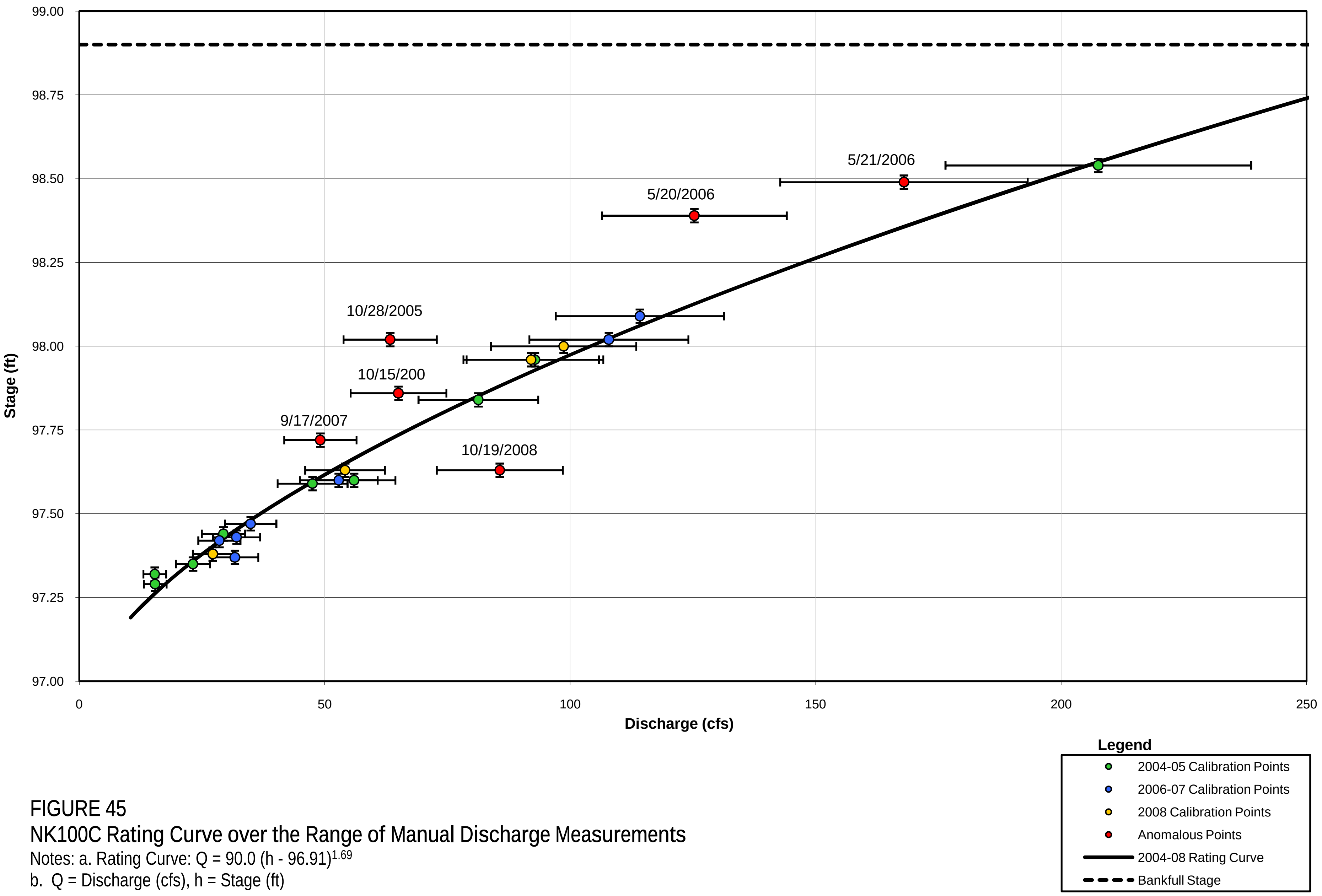


FIGURE 45

NK100C Rating Curve over the Range of Manual Discharge Measurements

Notes: a. Rating Curve: $Q = 90.0 (h - 96.91)^{1.69}$

b. Q = Discharge (cfs), h = Stage (ft)

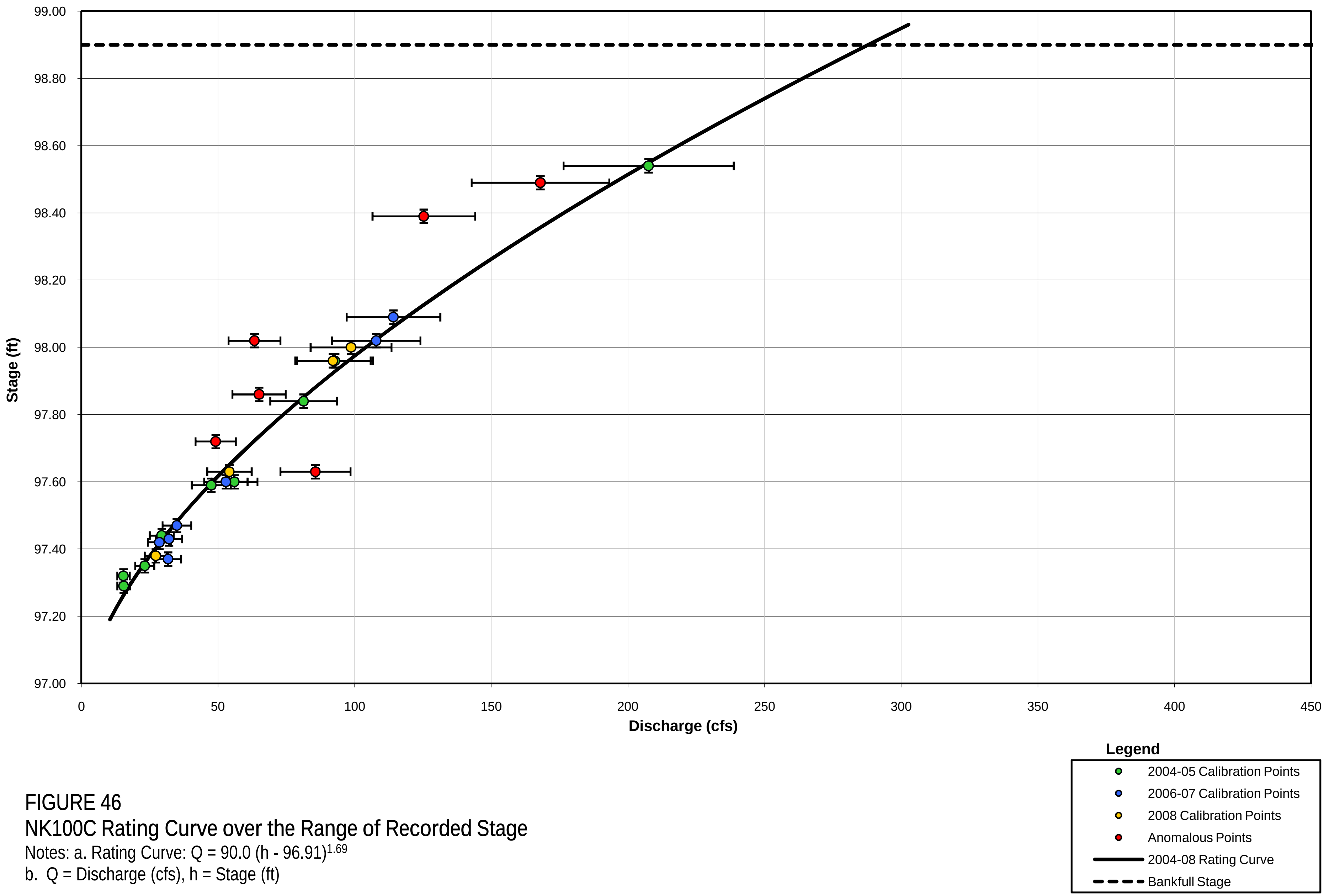


FIGURE 46

NK100C Rating Curve over the Range of Recorded Stage

Notes: a. Rating Curve: $Q = 90.0 (h - 96.91)^{1.69}$

b. Q = Discharge (cfs), h = Stage (ft)

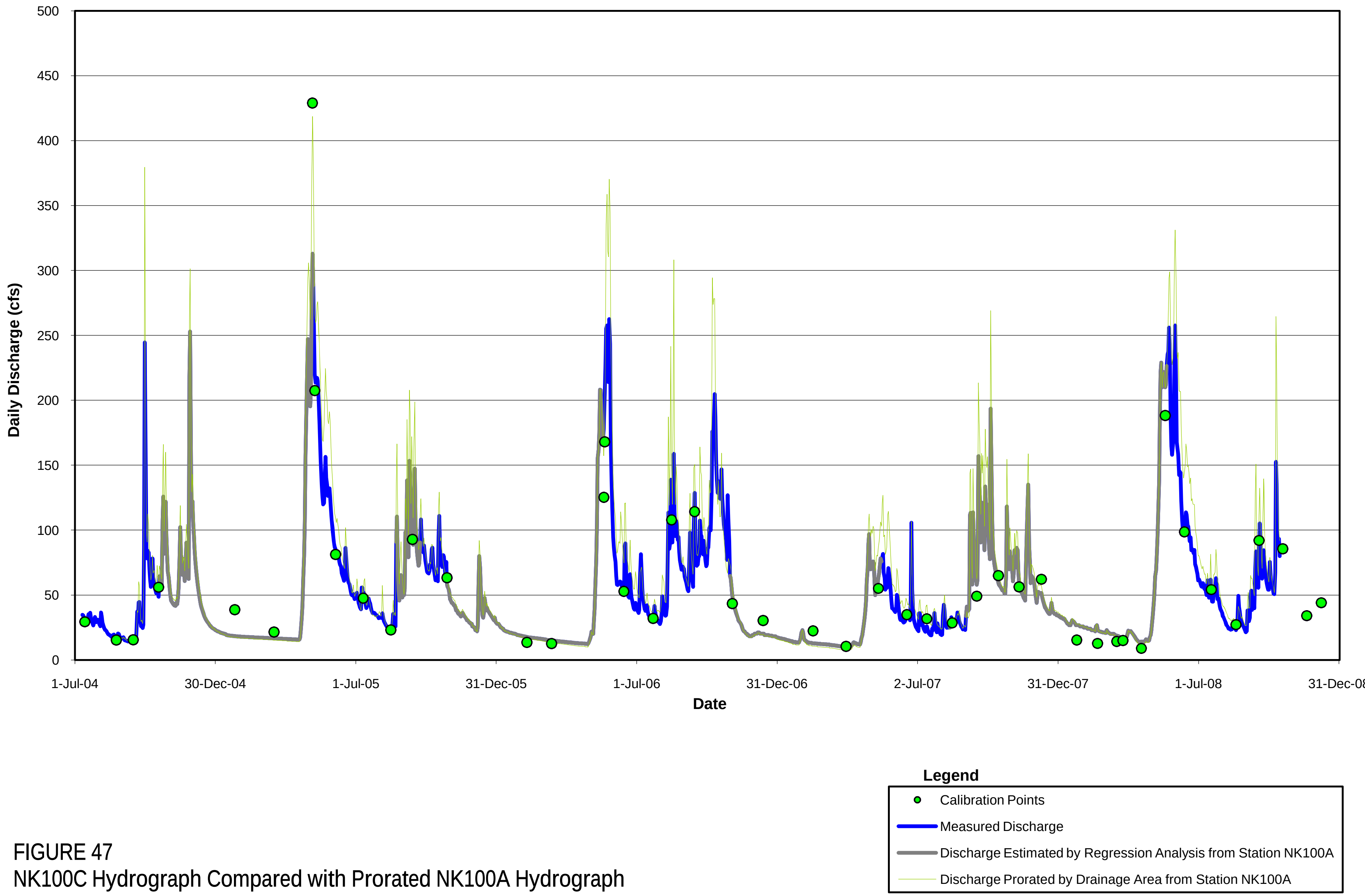


FIGURE 47
NK100C Hydrograph Compared with Prorated NK100A Hydrograph

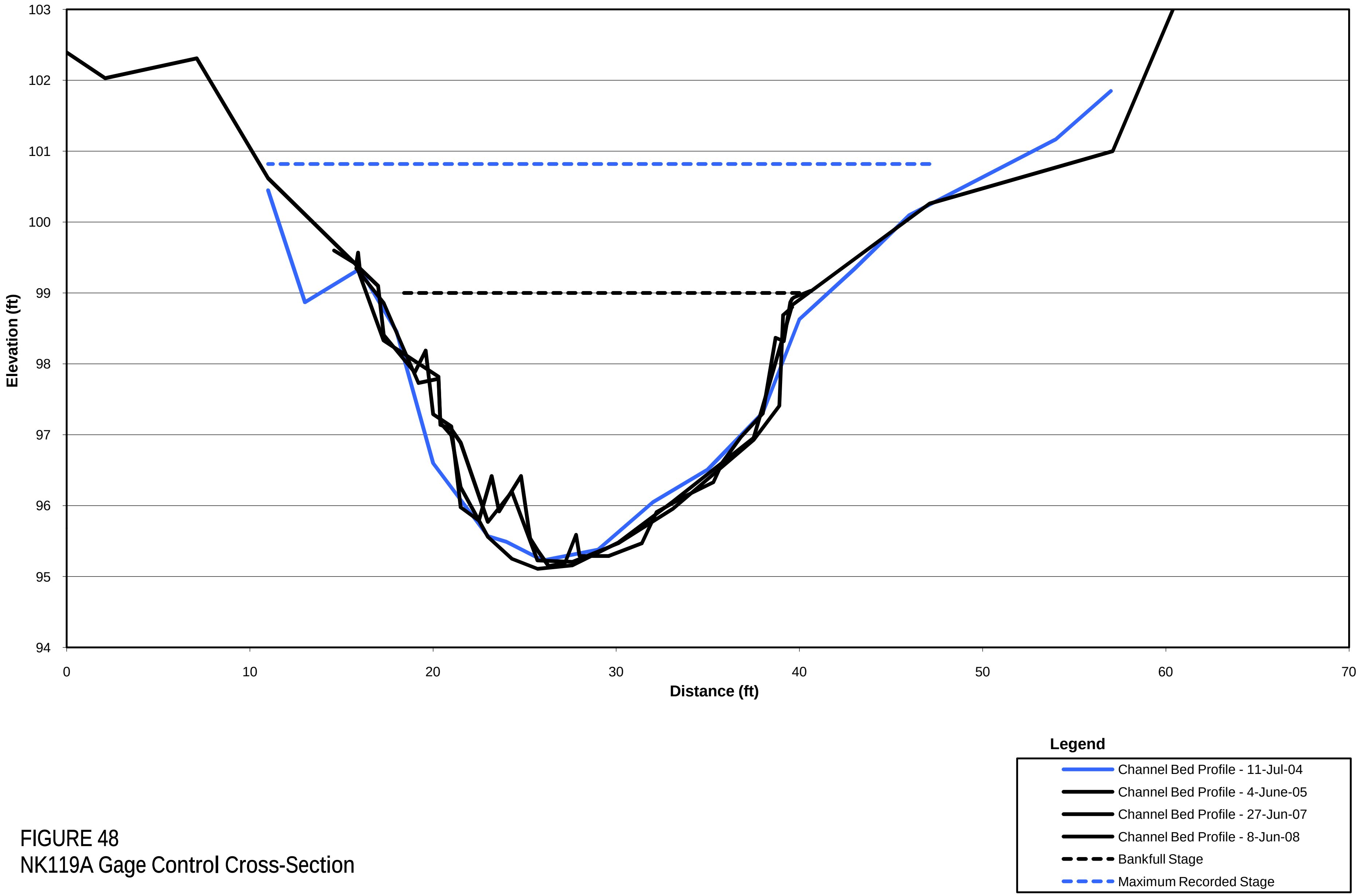


FIGURE 48
NK119A Gage Control Cross-Section

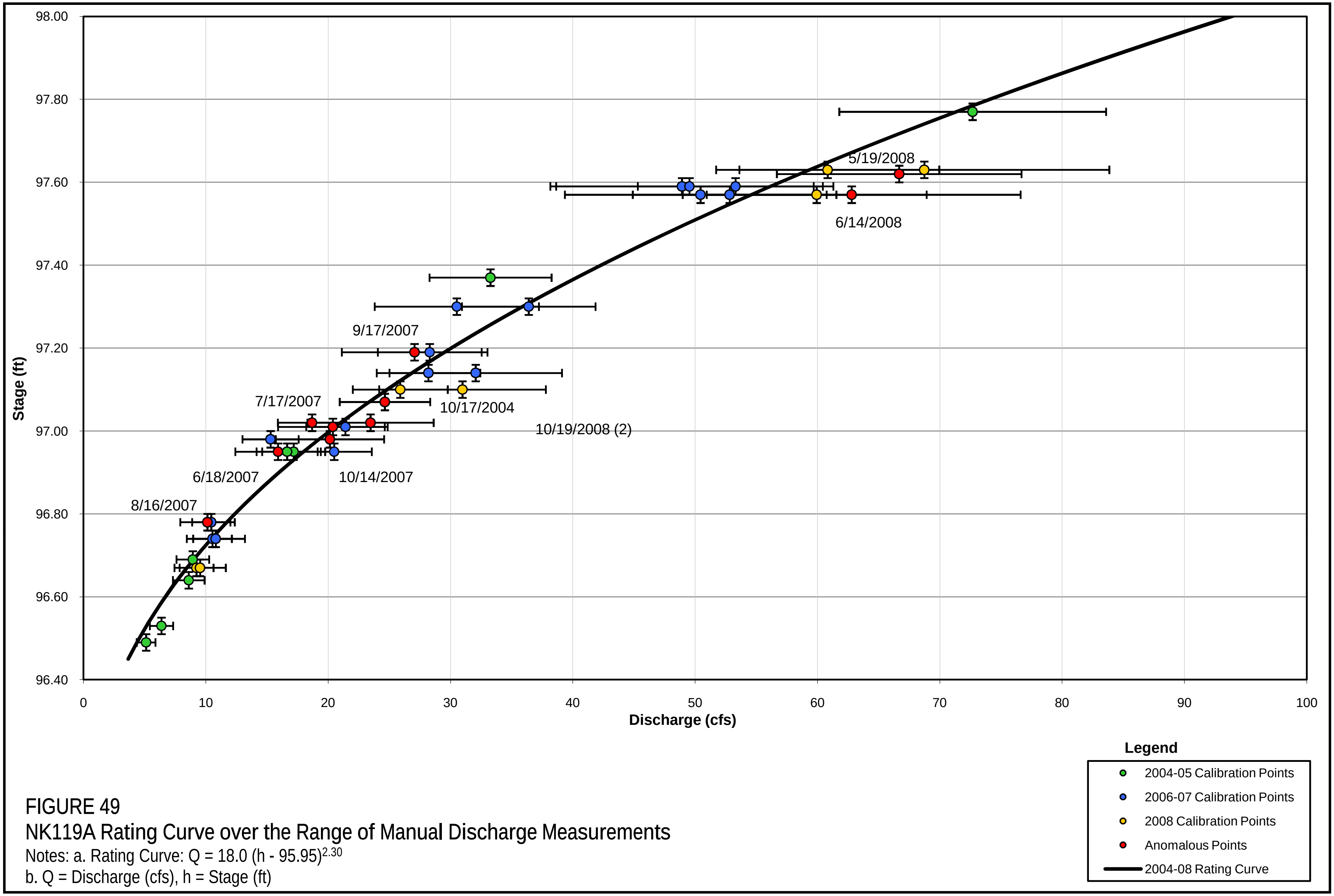


FIGURE 49

NK119A Rating Curve over the Range of Manual Discharge Measurements

Notes: a. Rating Curve: $Q = 18.0 (h - 95.95)^{2.30}$

b. Q = Discharge (cfs), h = Stage (ft)

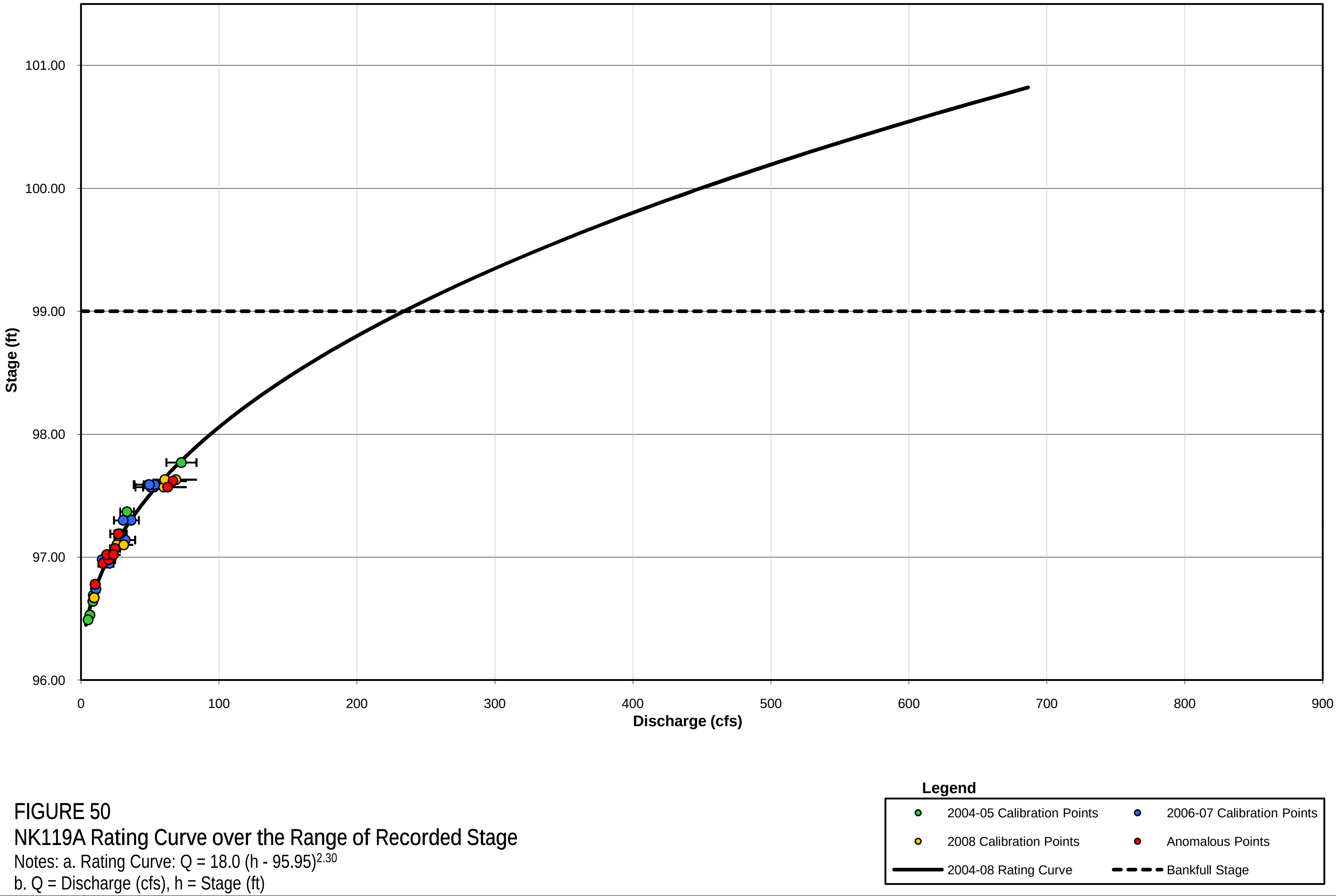


FIGURE 50
NK119A Rating Curve over the Range of Recorded Stage
Notes: a. Rating Curve: $Q = 18.0 (h - 95.95)^{2.30}$
b. Q = Discharge (cfs), h = Stage (ft)

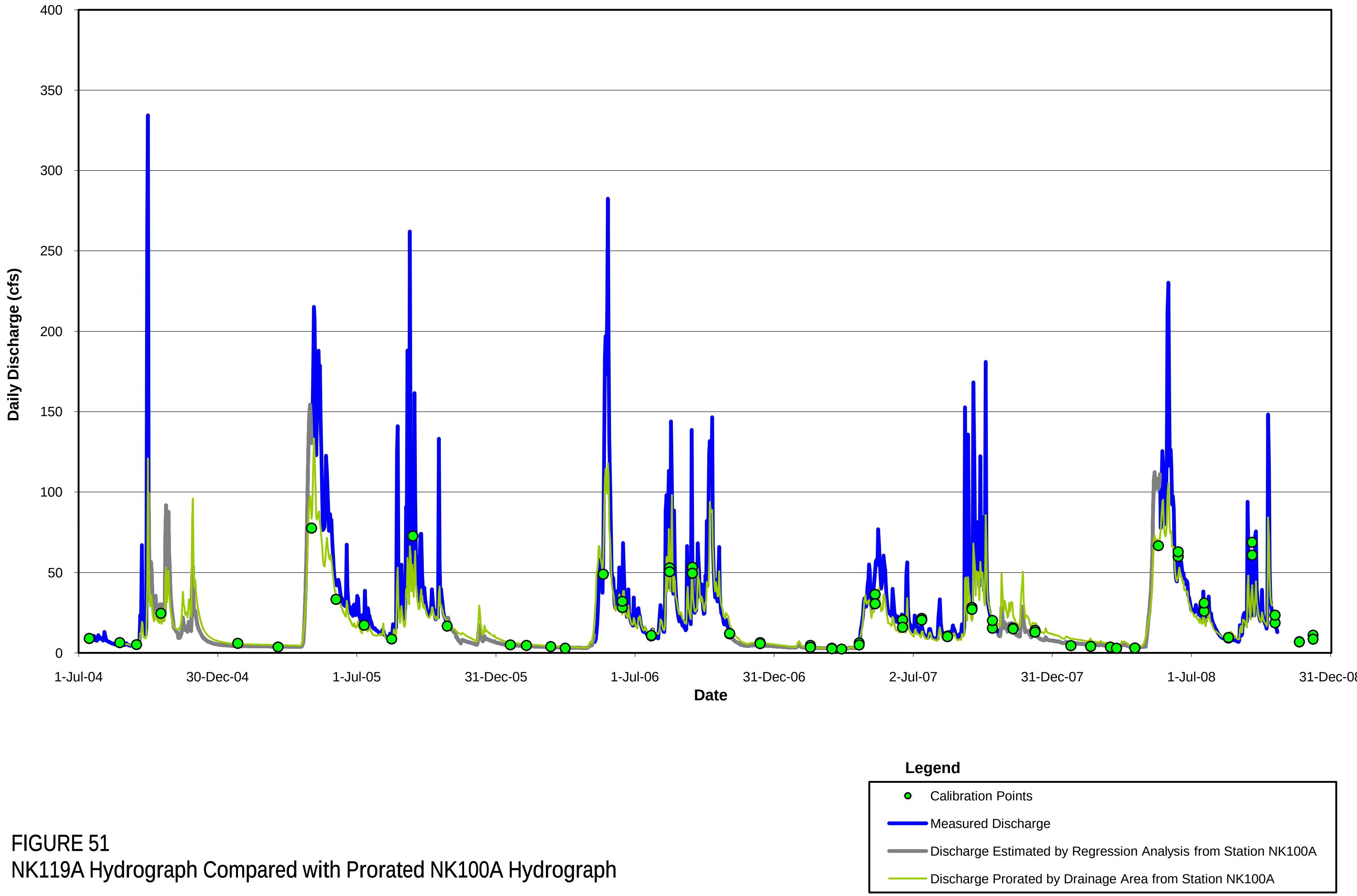


FIGURE 51
NK119A Hydrograph Compared with Prorated NK100A Hydrograph

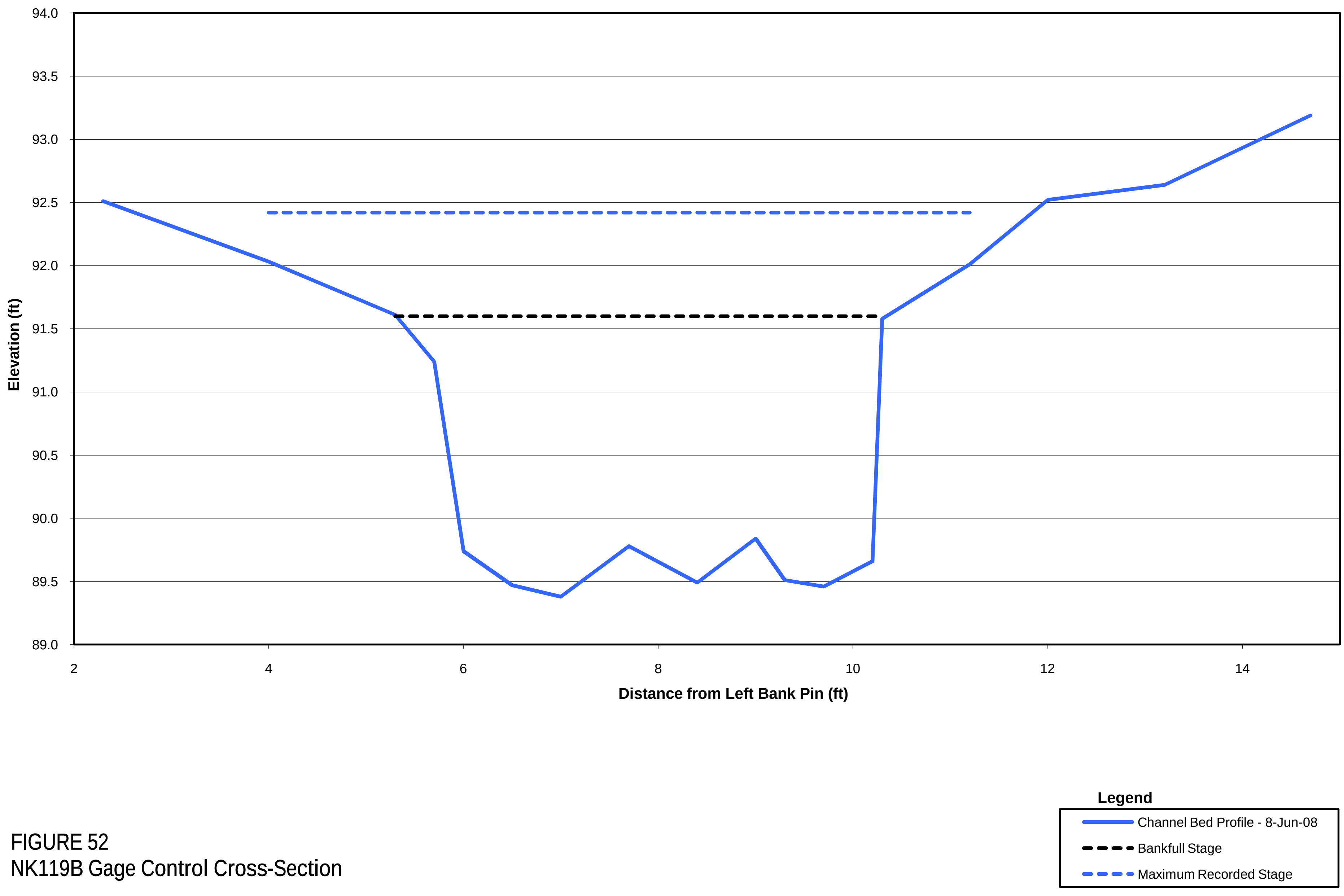


FIGURE 52
NK119B Gage Control Cross-Section

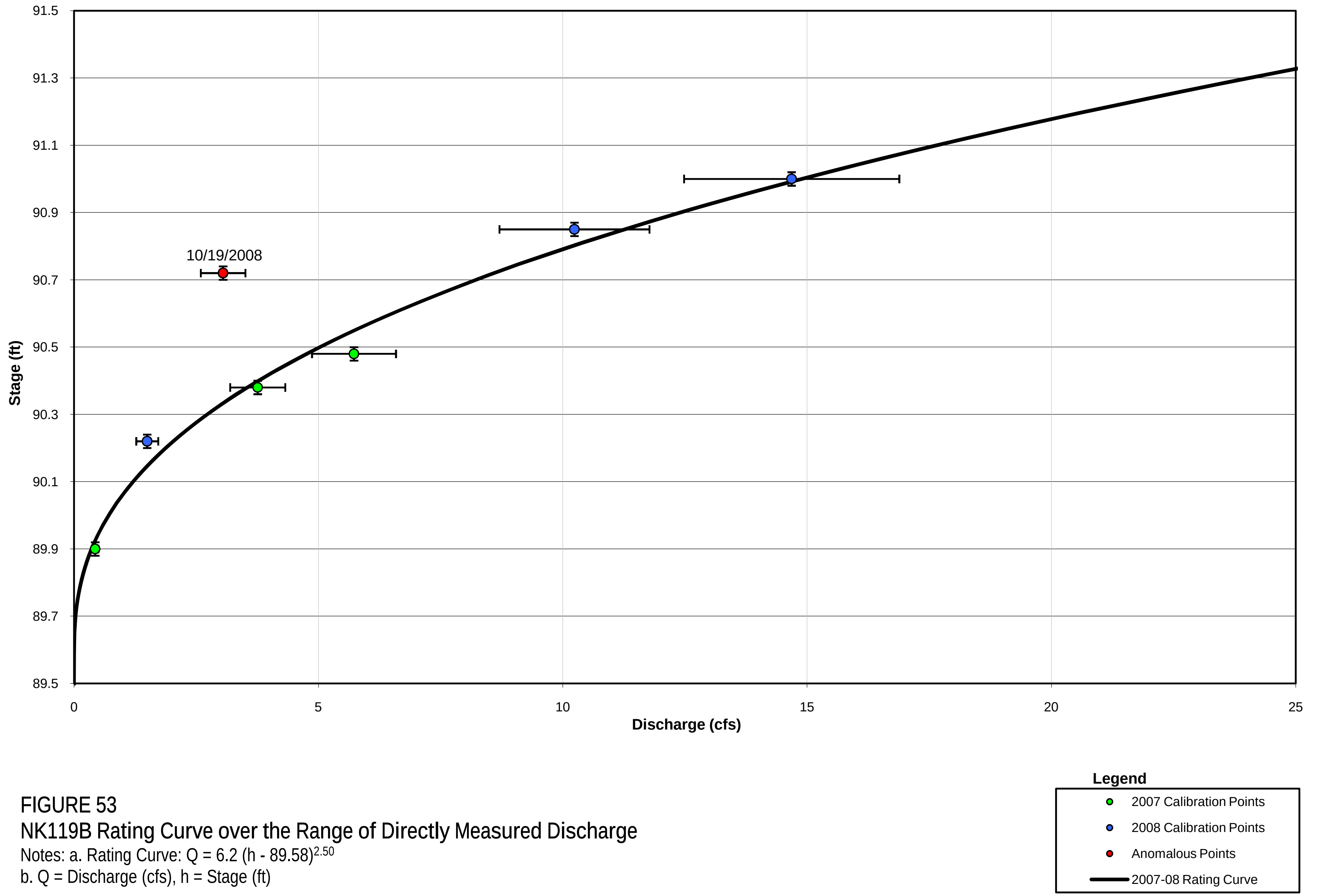


FIGURE 53
NK119B Rating Curve over the Range of Directly Measured Discharge
Notes: a. Rating Curve: $Q = 6.2\,(h - 89.58)^{2.50}$
b. Q = Discharge (cfs), h = Stage (ft)

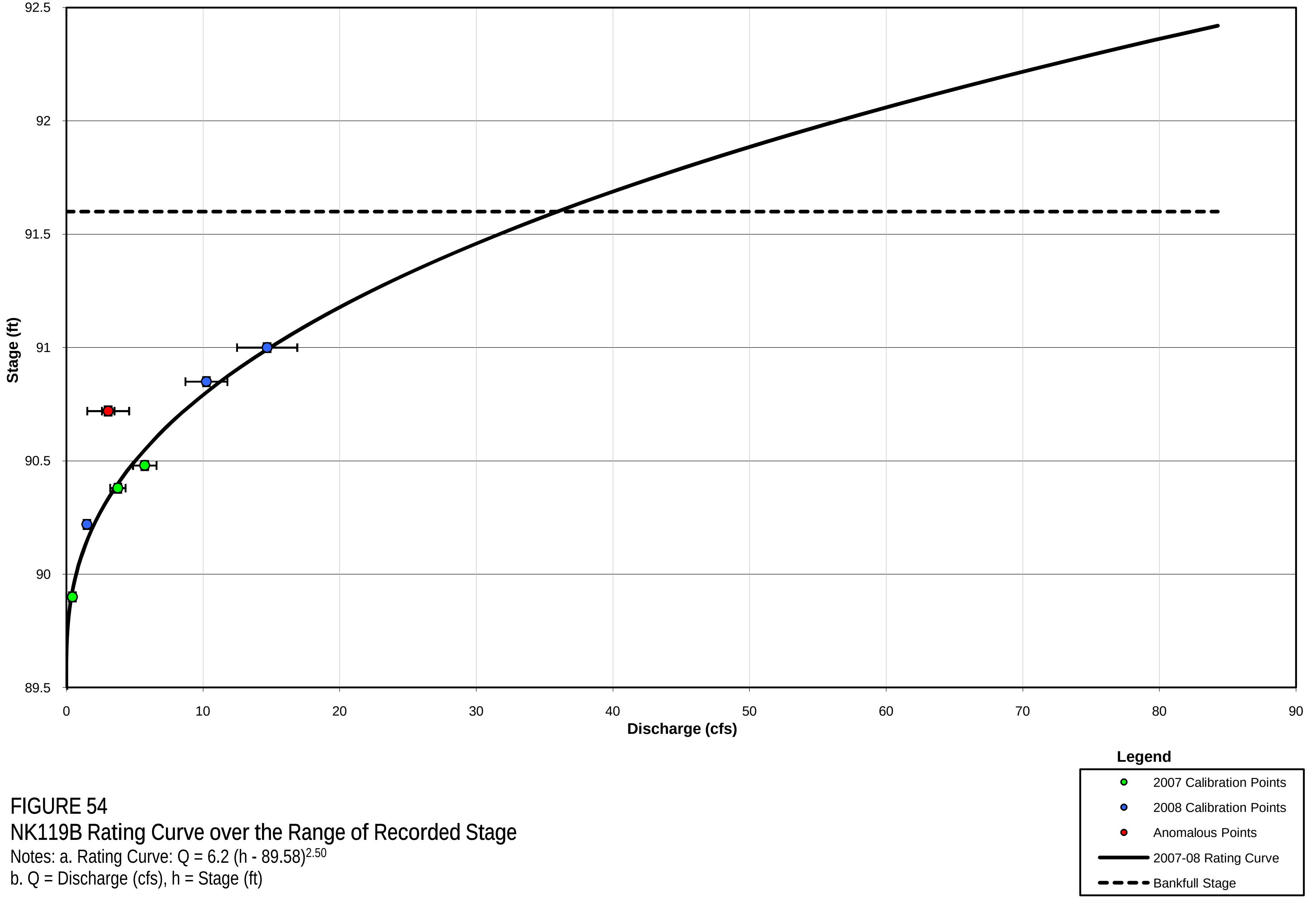


FIGURE 54
NK119B Rating Curve over the Range of Recorded Stage
Notes: a. Rating Curve: $Q = 6.2\ (h - 89.58)^{2.50}$
b. Q = Discharge (cfs), h = Stage (ft)

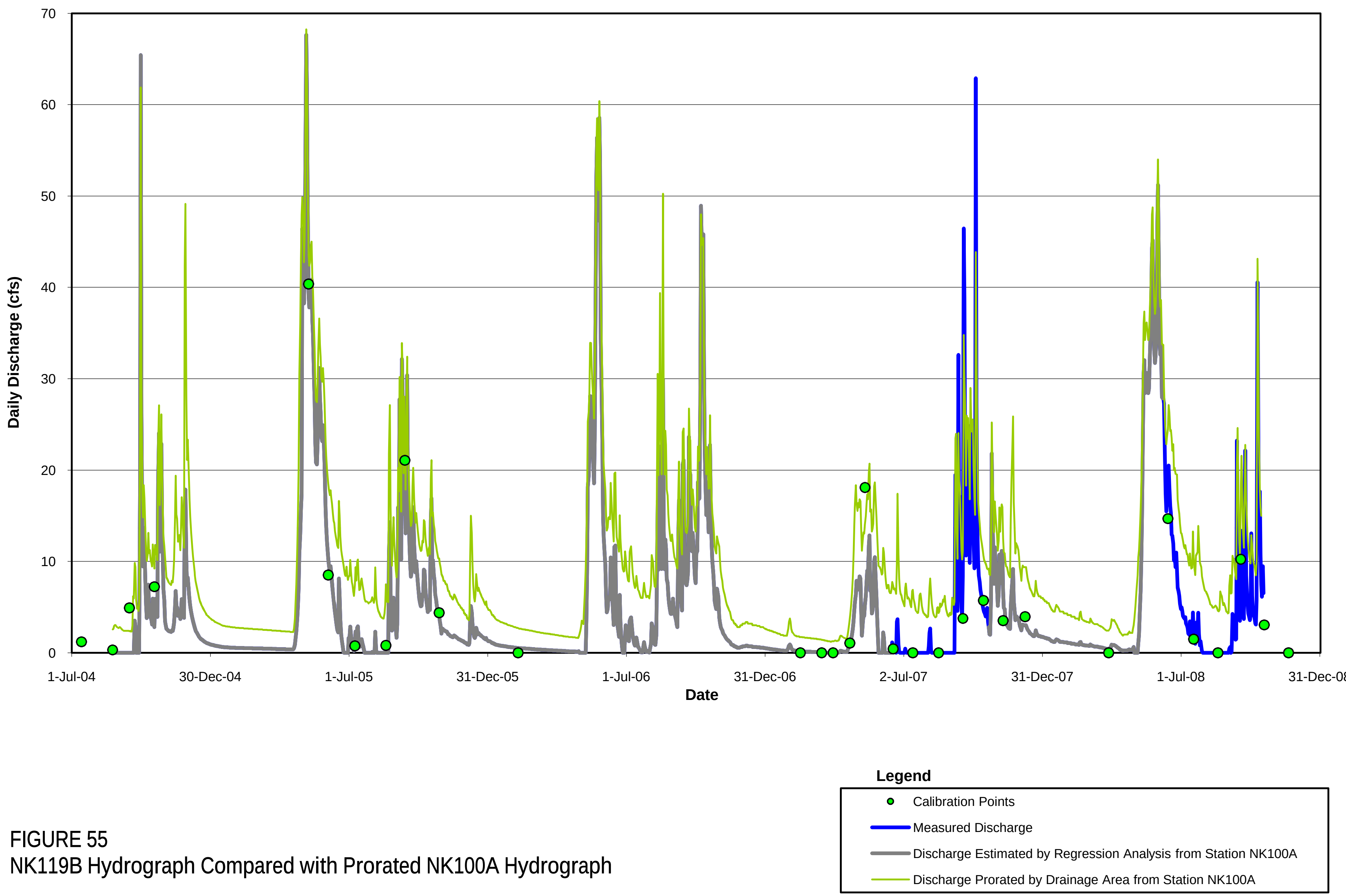


FIGURE 55
NK119B Hydrograph Compared with Prorated NK100A Hydrograph

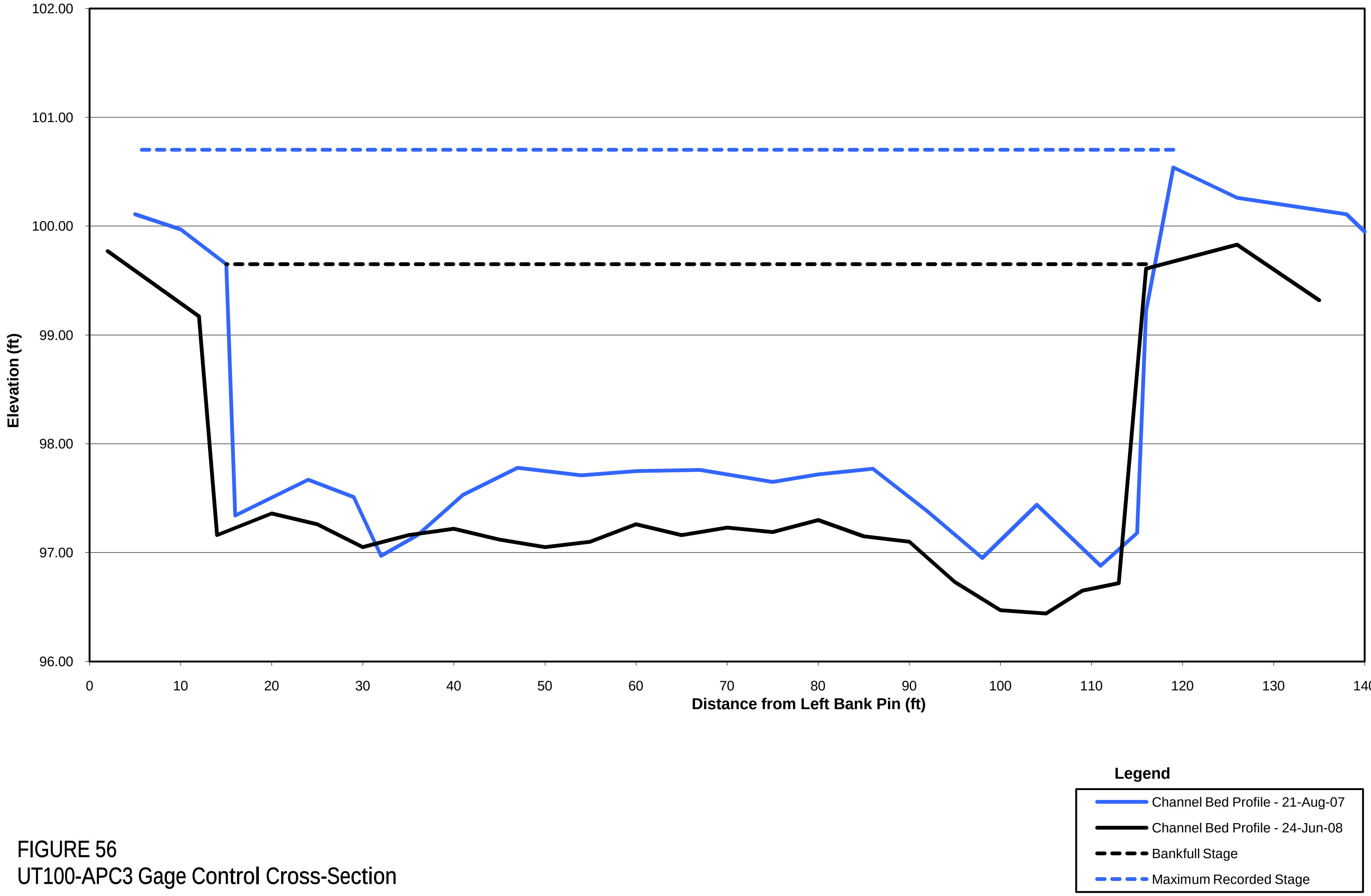


FIGURE 56
UT100-APC3 Gage Control Cross-Section

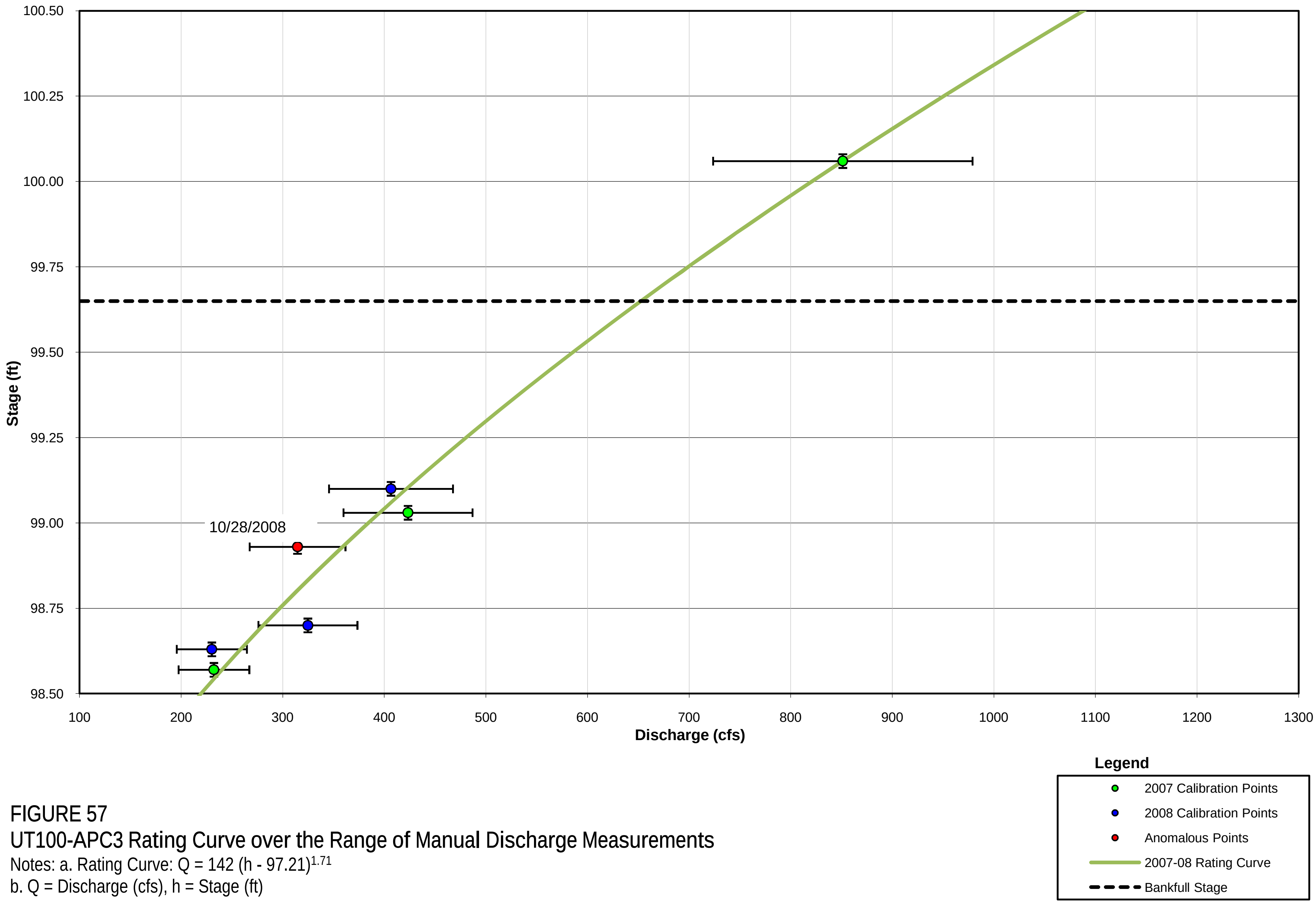


FIGURE 57

UT100-APC3 Rating Curve over the Range of Manual Discharge Measurements

Notes: a. Rating Curve: $Q = 142 (h - 97.21)^{1.71}$

b. Q = Discharge (cfs), h = Stage (ft)

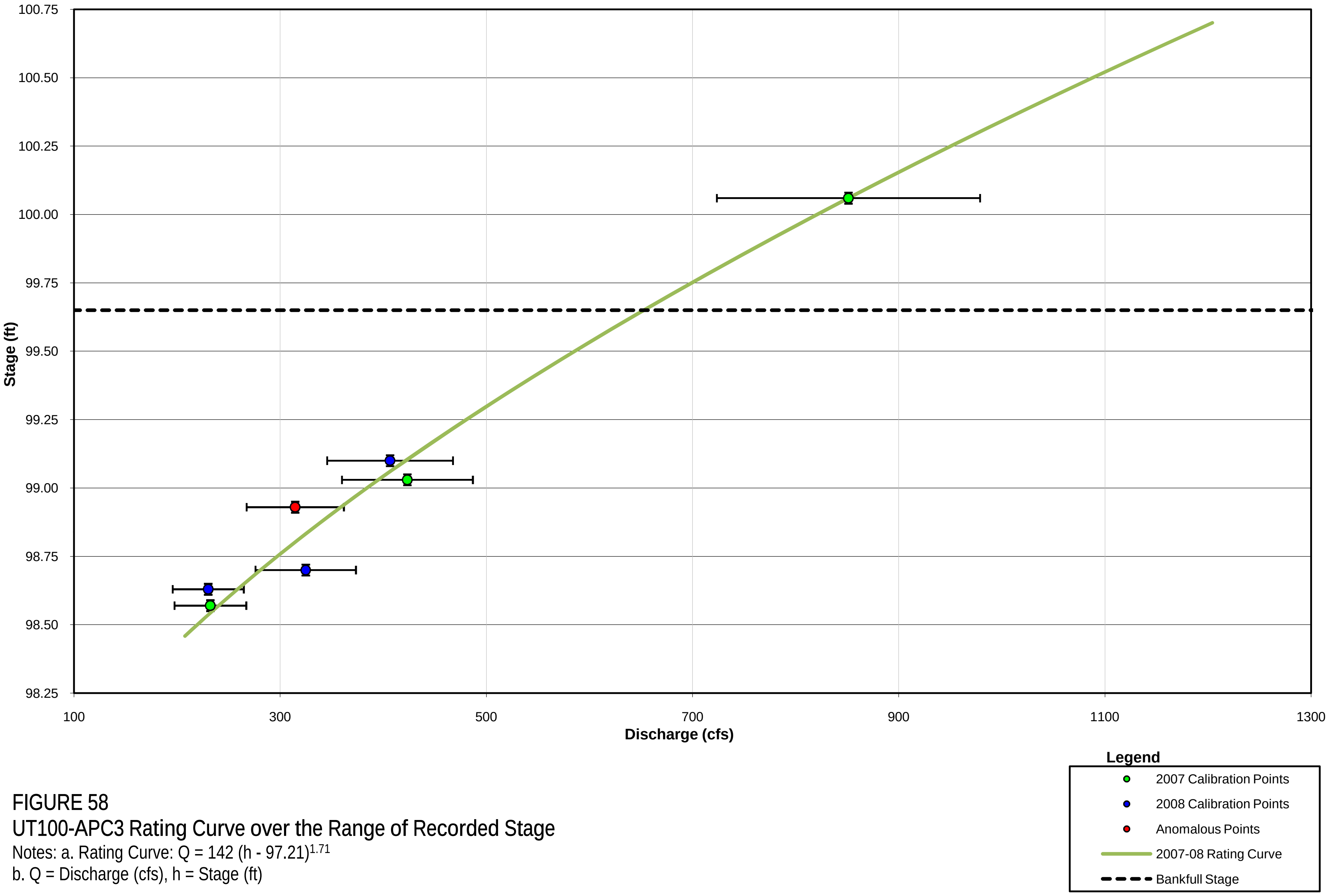


FIGURE 58

UT100-APC3 Rating Curve over the Range of Recorded Stage

Notes: a. Rating Curve: $Q = 142 (h - 97.21)^{1.71}$

b. Q = Discharge (cfs), h = Stage (ft)

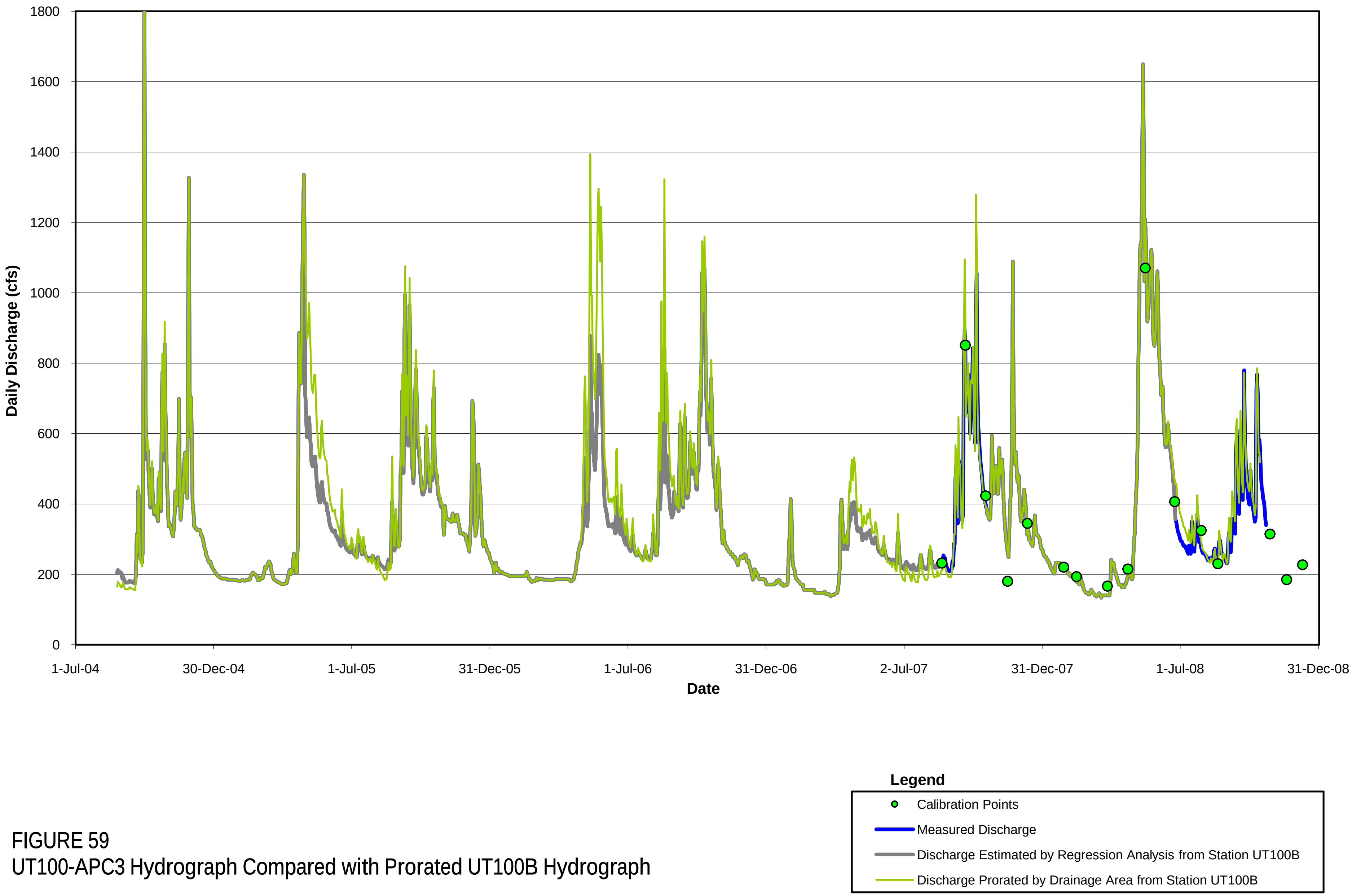


FIGURE 59
UT100-APC3 Hydrograph Compared with Prorated UT100B Hydrograph

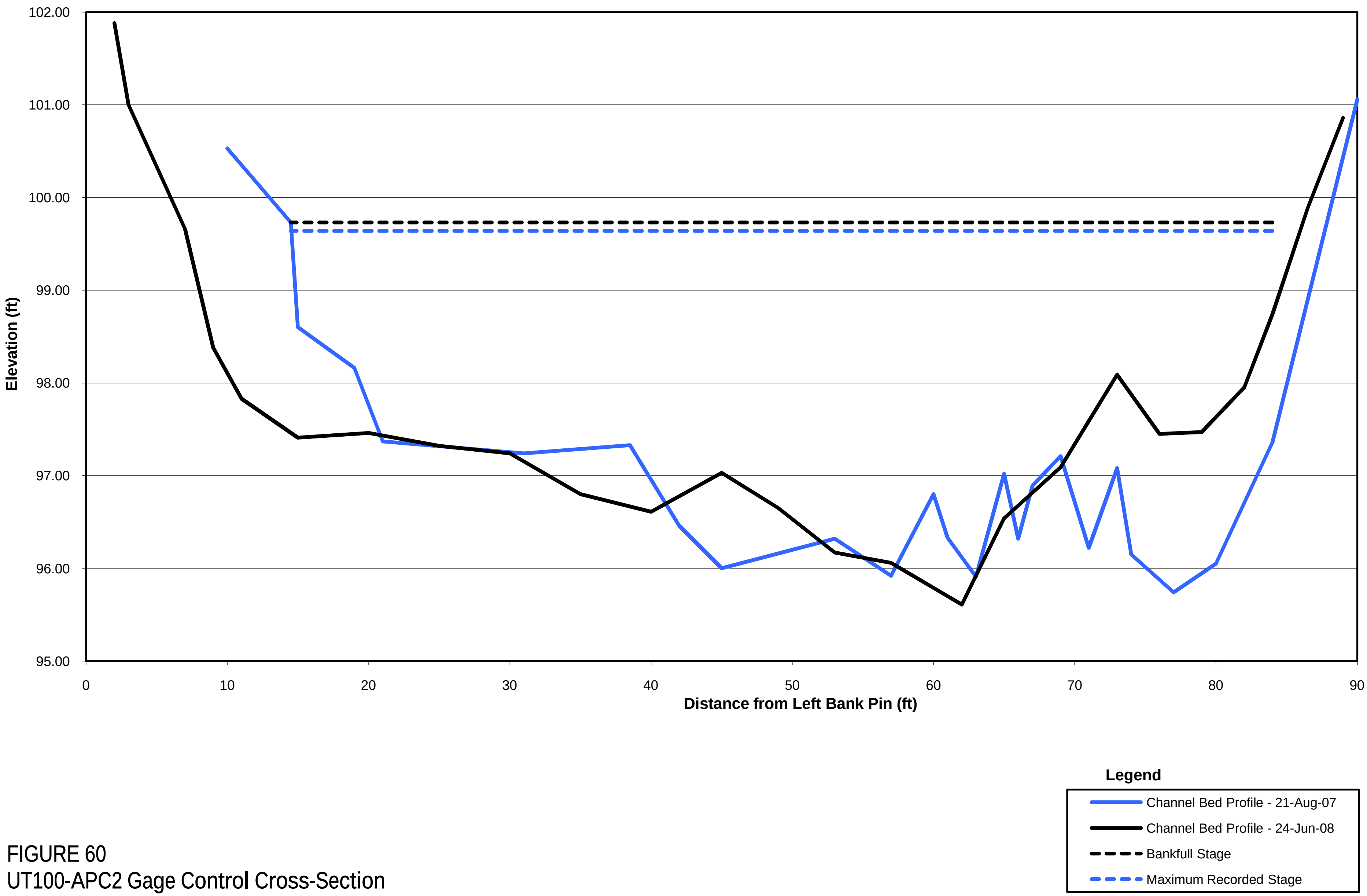


FIGURE 60
UT100-APC2 Gage Control Cross-Section

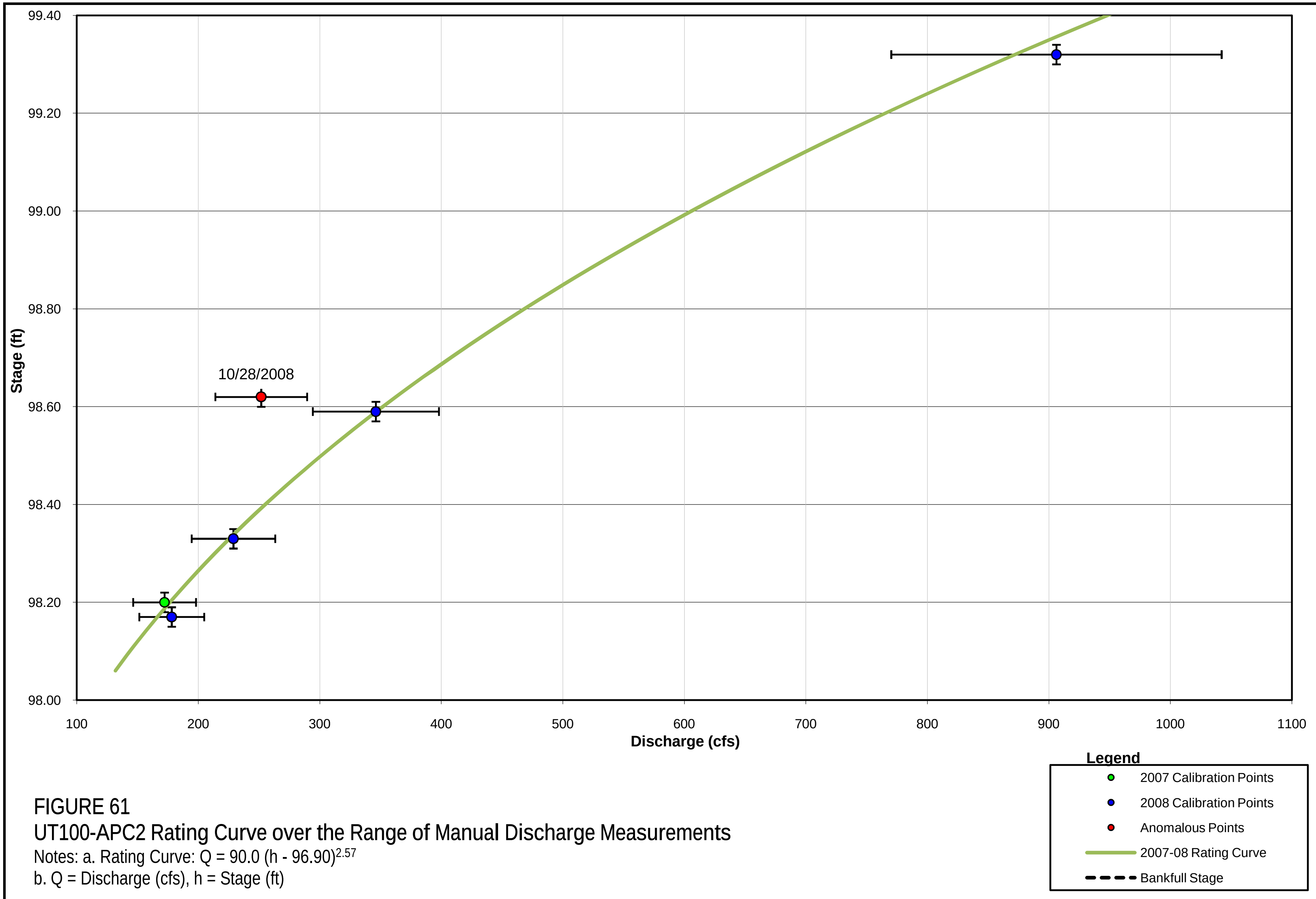


FIGURE 61
UT100-APC2 Rating Curve over the Range of Manual Discharge Measurements
Notes: a. Rating Curve: $Q = 90.0 (h - 96.90)^{2.57}$
b. Q = Discharge (cfs), h = Stage (ft)

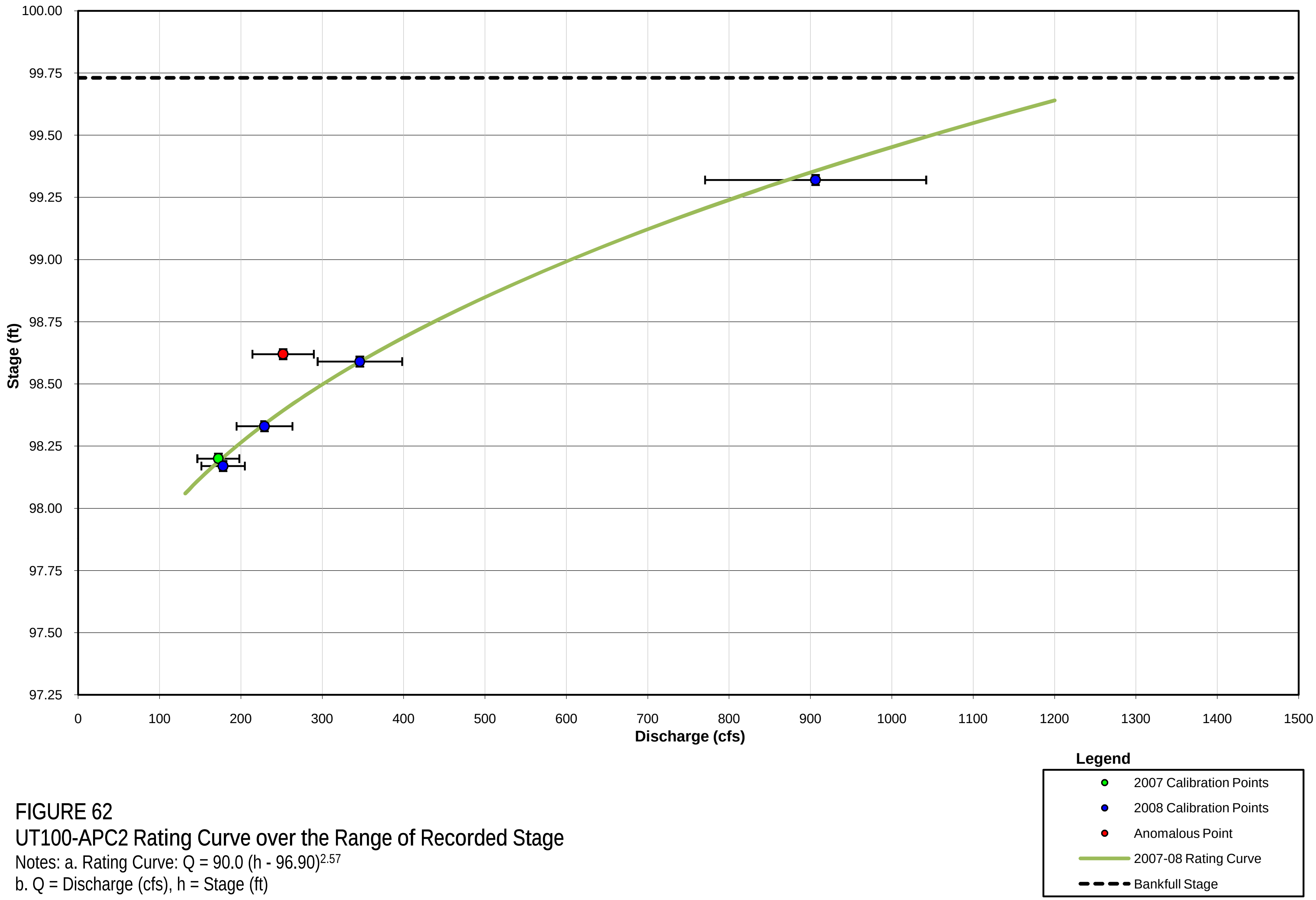


FIGURE 62

UT100-APC2 Rating Curve over the Range of Recorded Stage

Notes: a. Rating Curve: $Q = 90.0 (h - 96.90)^{2.57}$

b. Q = Discharge (cfs), h = Stage (ft)

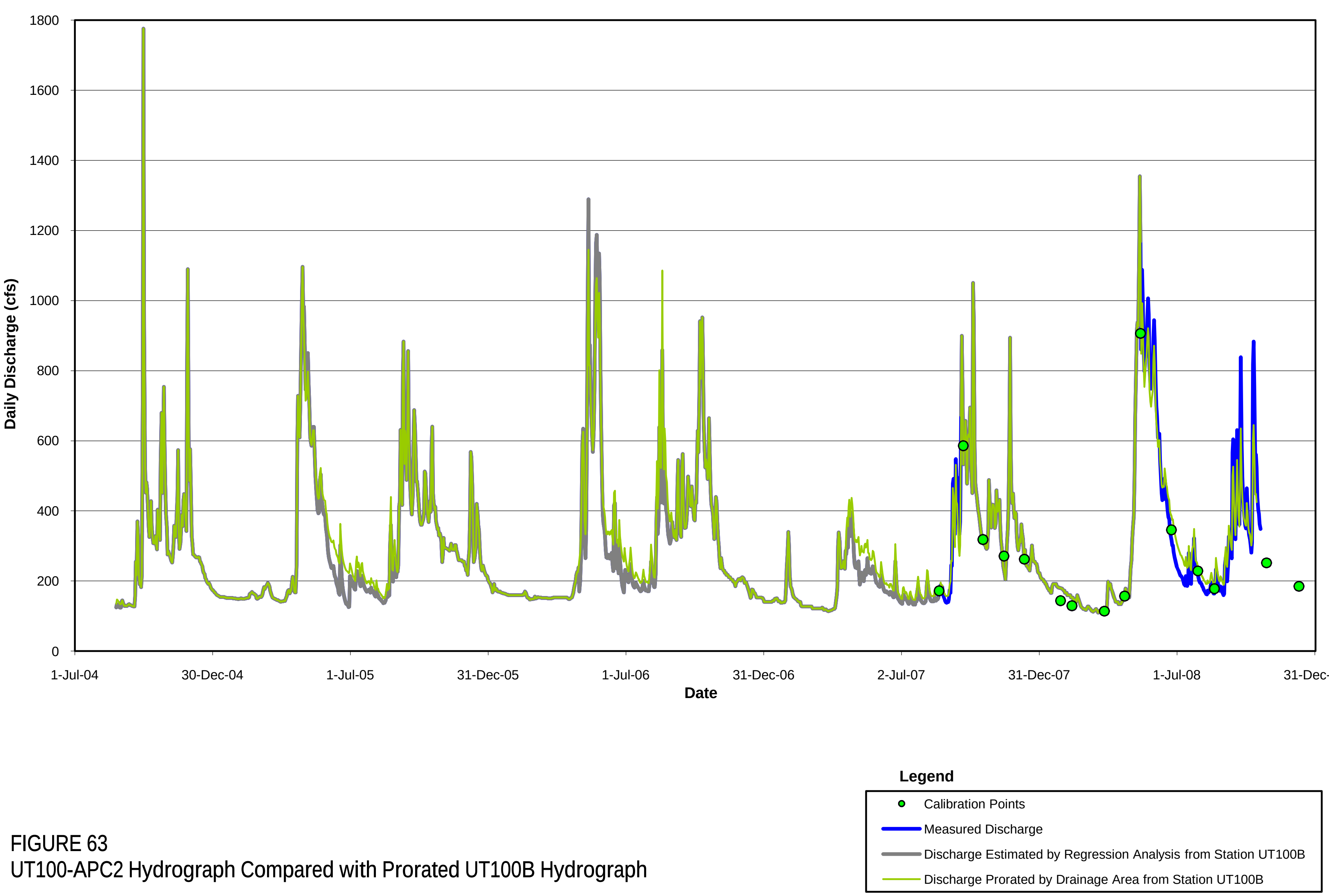


FIGURE 63
UT100-APC2 Hydrograph Compared with Prorated UT100B Hydrograph

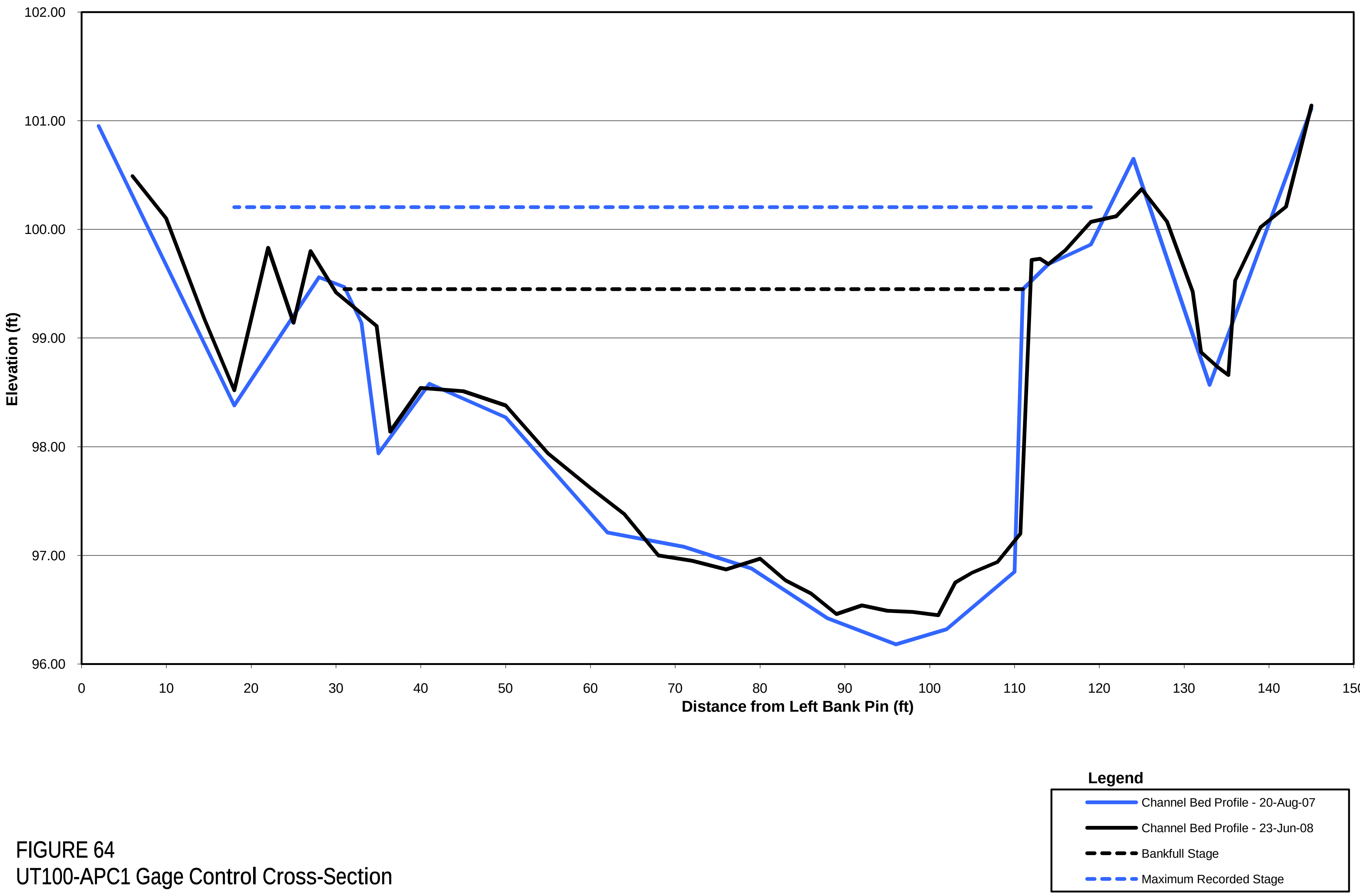


FIGURE 64
UT100-APC1 Gage Control Cross-Section

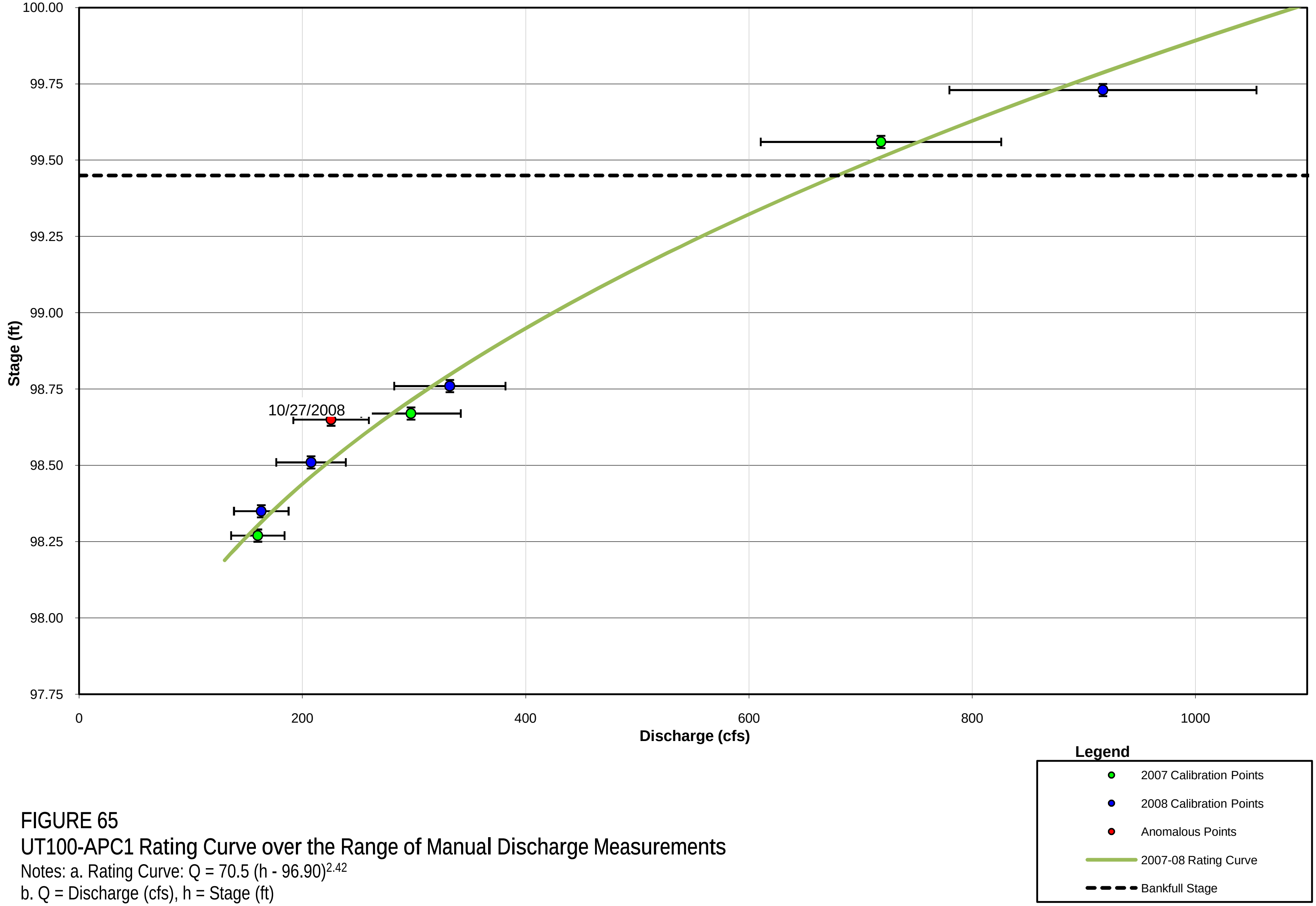


FIGURE 65

UT100-APC1 Rating Curve over the Range of Manual Discharge Measurements

Notes: a. Rating Curve: $Q = 70.5\,(h - 96.90)^{2.42}$

b. Q = Discharge (cfs), h = Stage (ft)

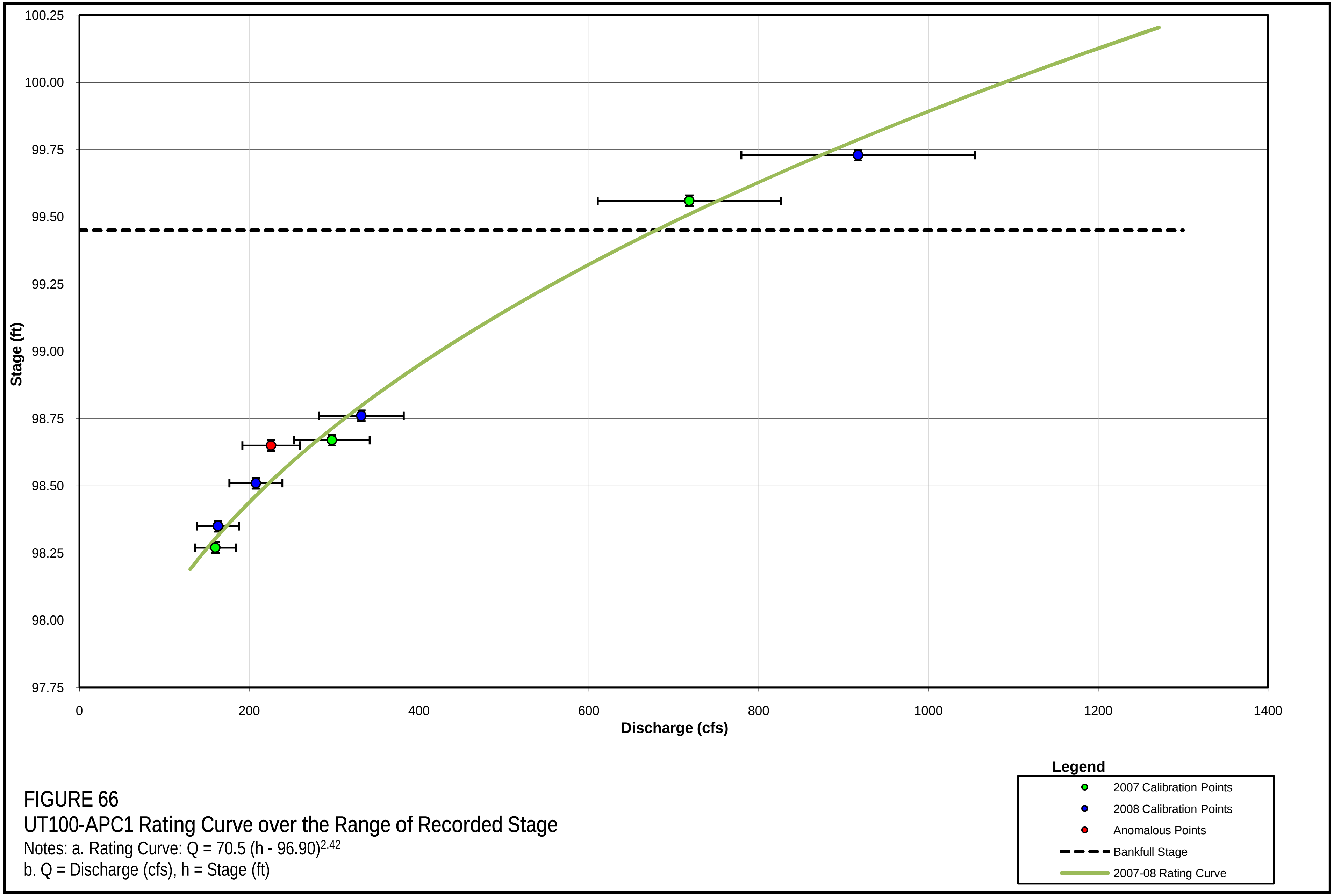


FIGURE 66

UT100-APC1 Rating Curve over the Range of Recorded Stage

Notes: a. Rating Curve: $Q = 70.5\ (h - 96.90)^{2.42}$

b. Q = Discharge (cfs), h = Stage (ft)

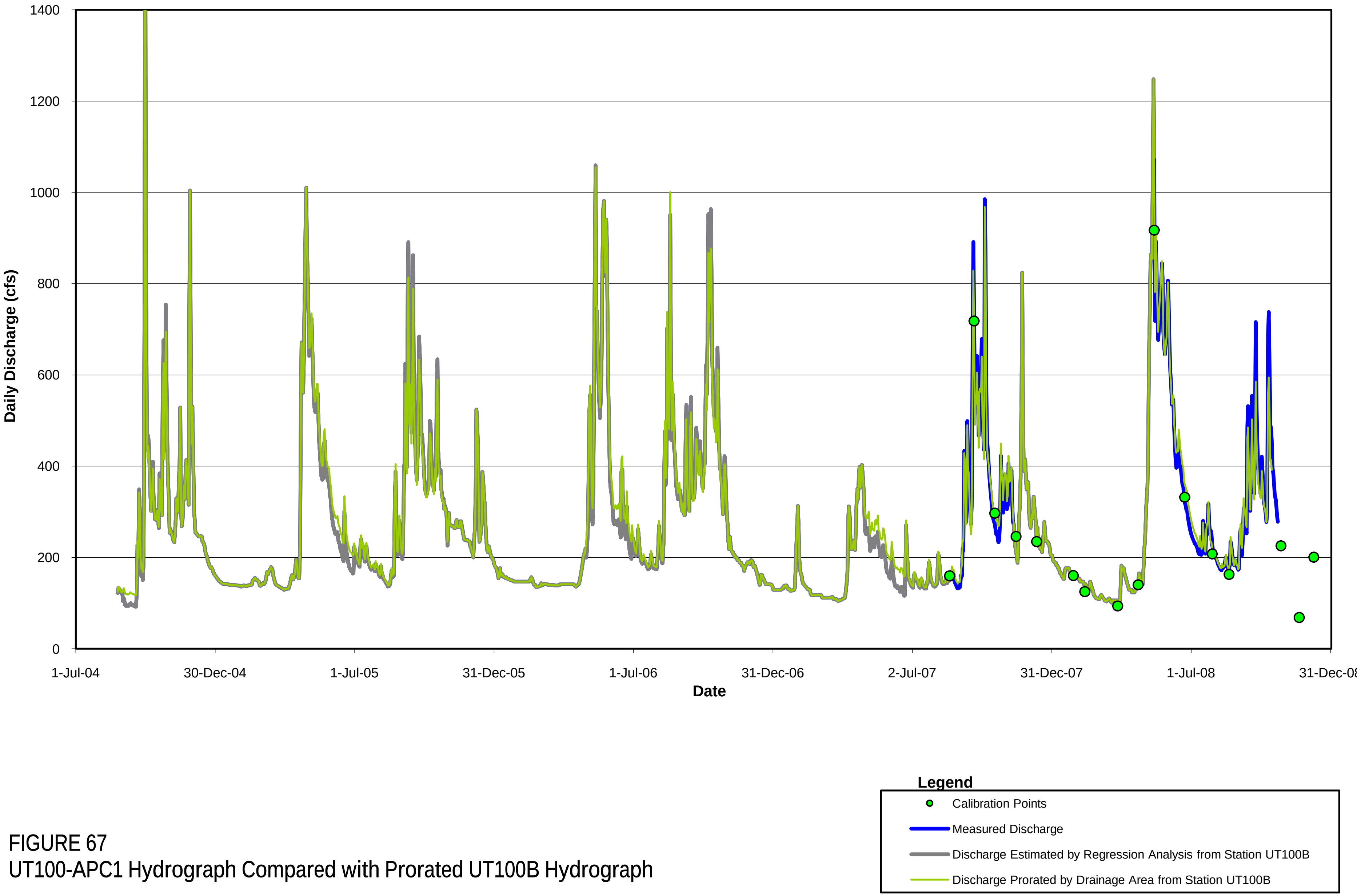


FIGURE 67
UT100-APC1 Hydrograph Compared with Prorated UT100B Hydrograph

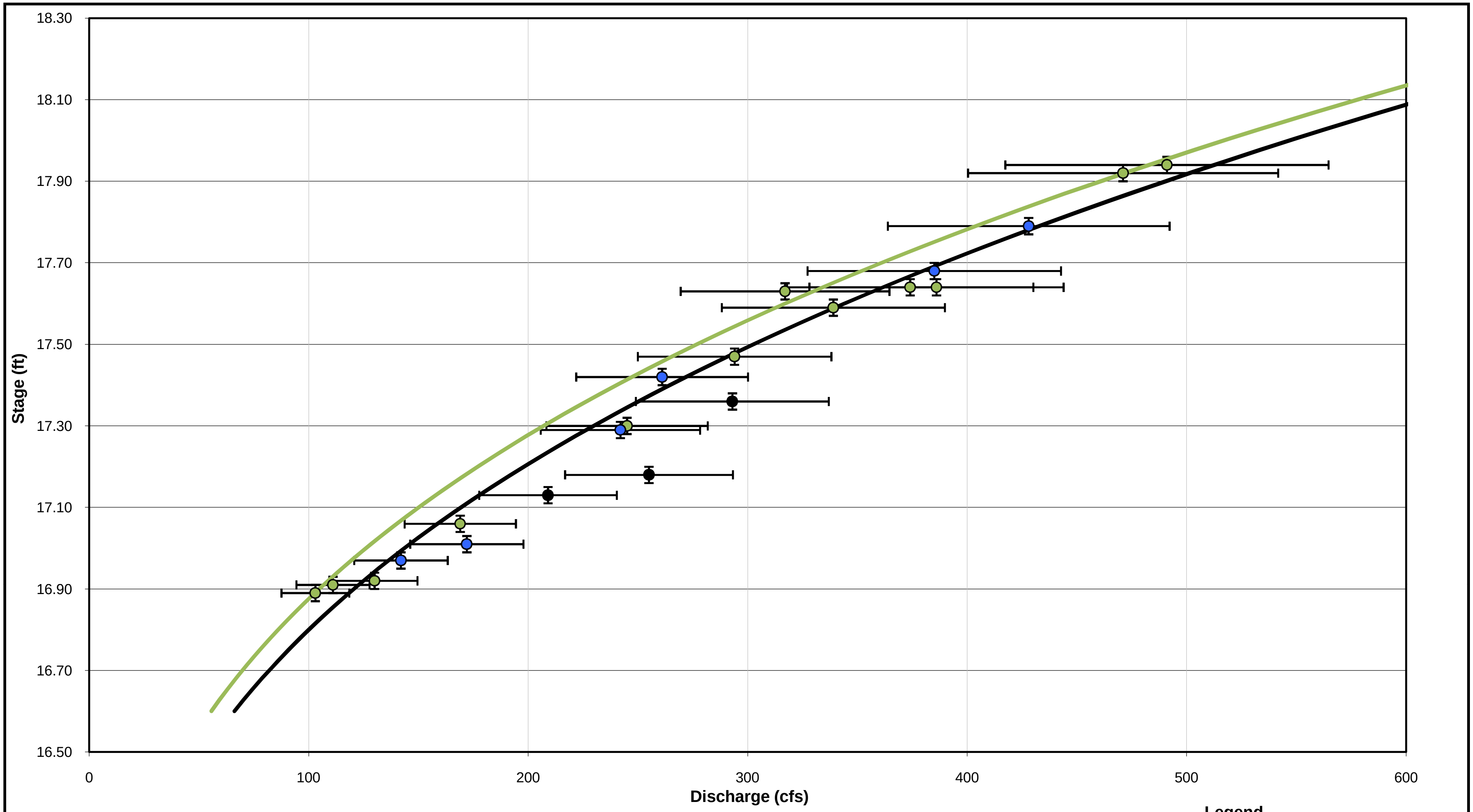


FIGURE 68

UT100B Rating Curves over the Range of Manual Discharge Measurements

Notes: a. Rating Curve for 2004-06: $Q = 25.0\ (h - 15.30)^{3.05}$

b. Rating Curve for 2006-07: $Q = 31.0\ (h - 15.30)^{2.89}$

c. Q = Discharge (cfs), h = Stage (ft)

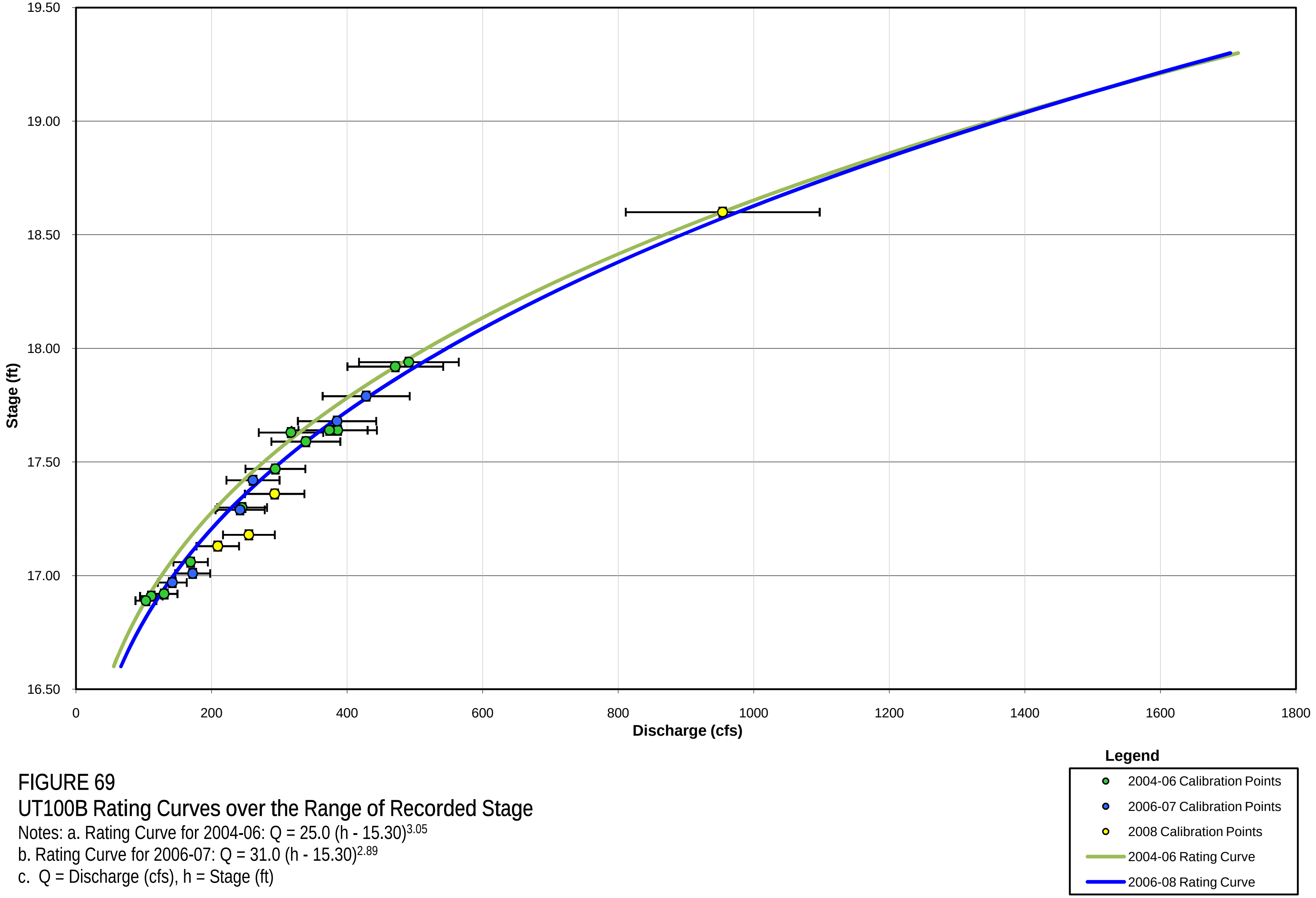


FIGURE 69

UT100B Rating Curves over the Range of Recorded Stage

Notes: a. Rating Curve for 2004-06: $Q = 25.0 (h - 15.30)^{3.05}$

b. Rating Curve for 2006-07: $Q = 31.0 (h - 15.30)^{2.89}$

c. Q = Discharge (cfs), h = Stage (ft)

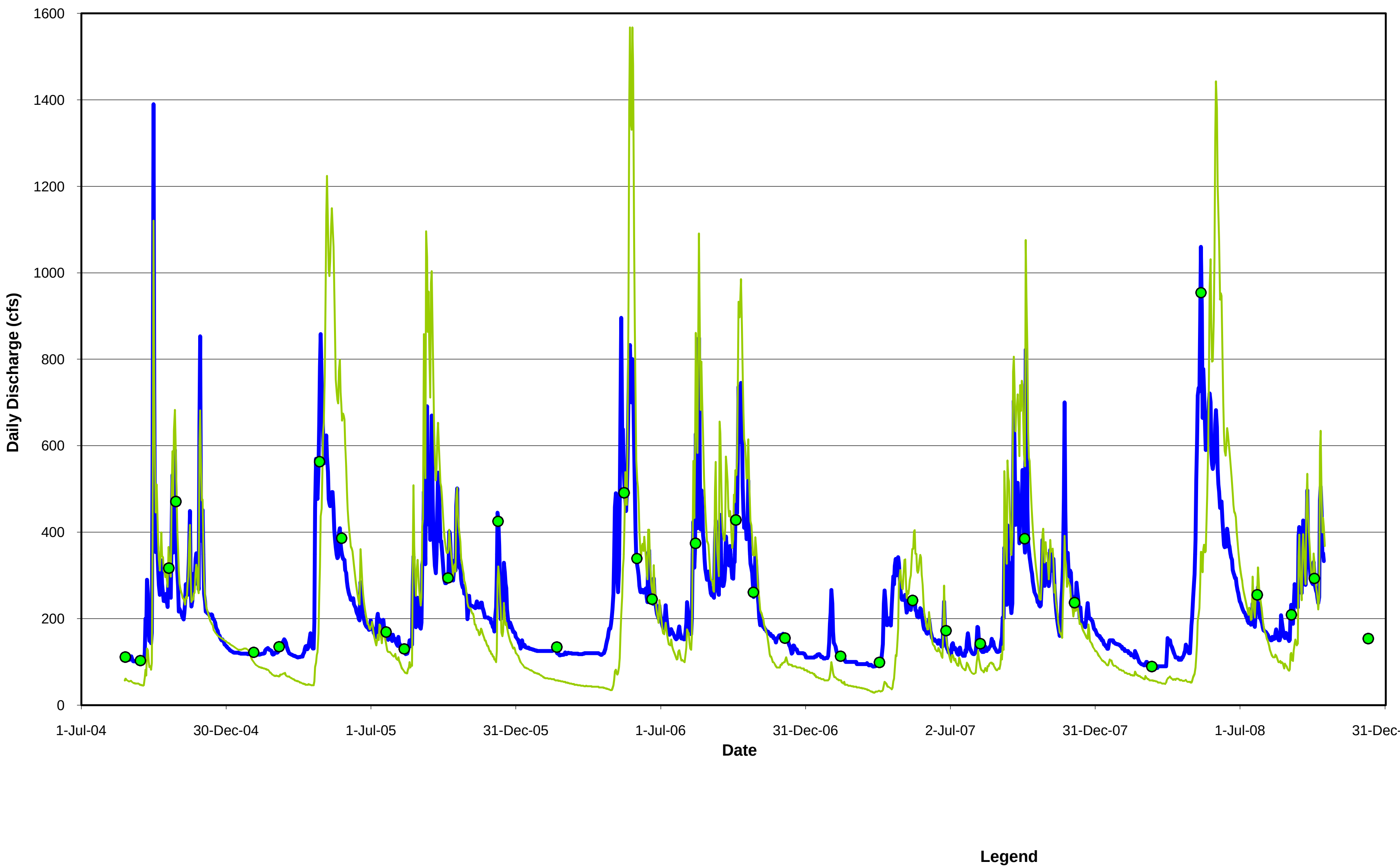


FIGURE 70
UT100B Hydrograph Compared with Prorated SK100B Hydrograph

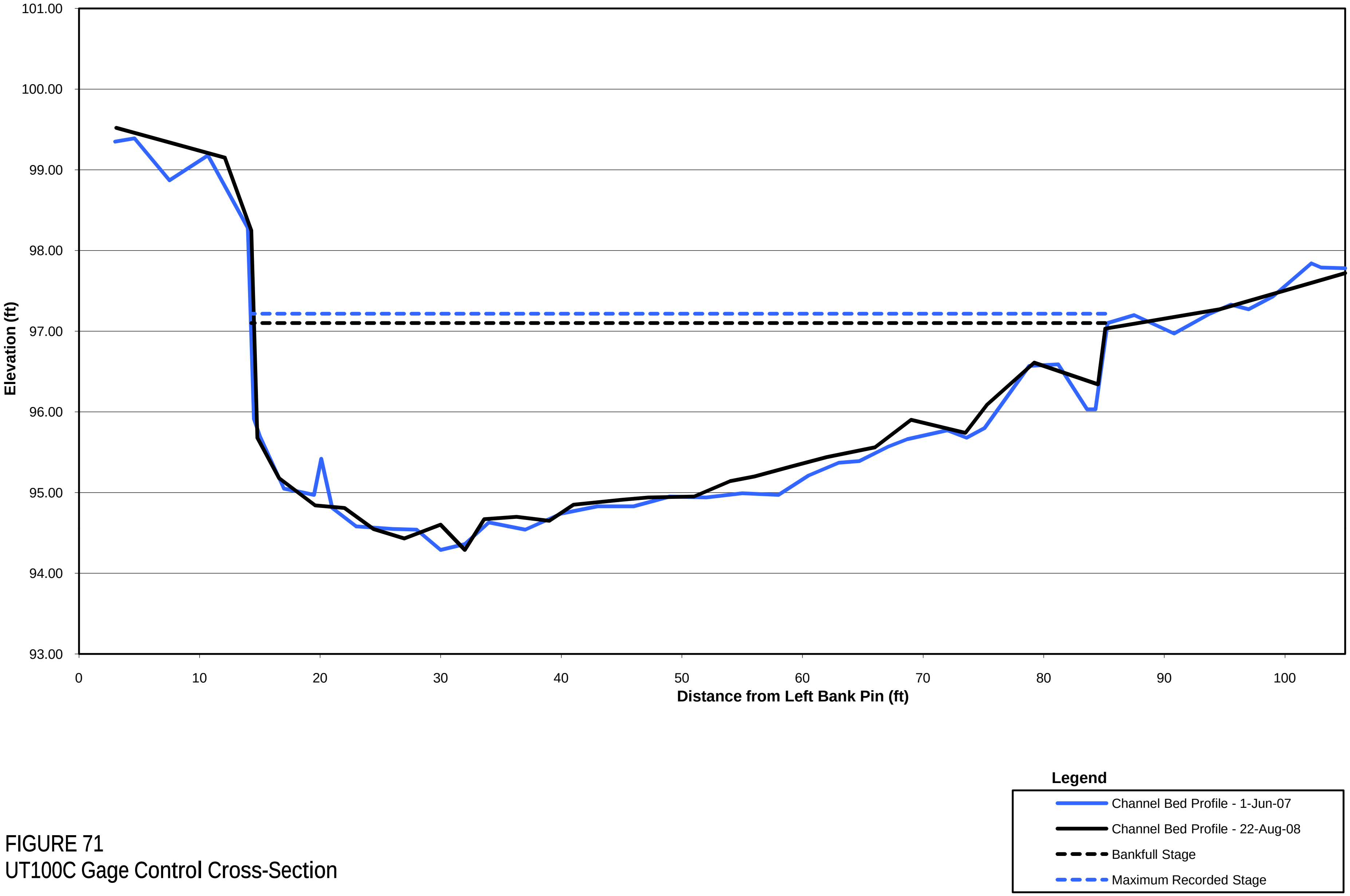


FIGURE 71
UT100C Gage Control Cross-Section

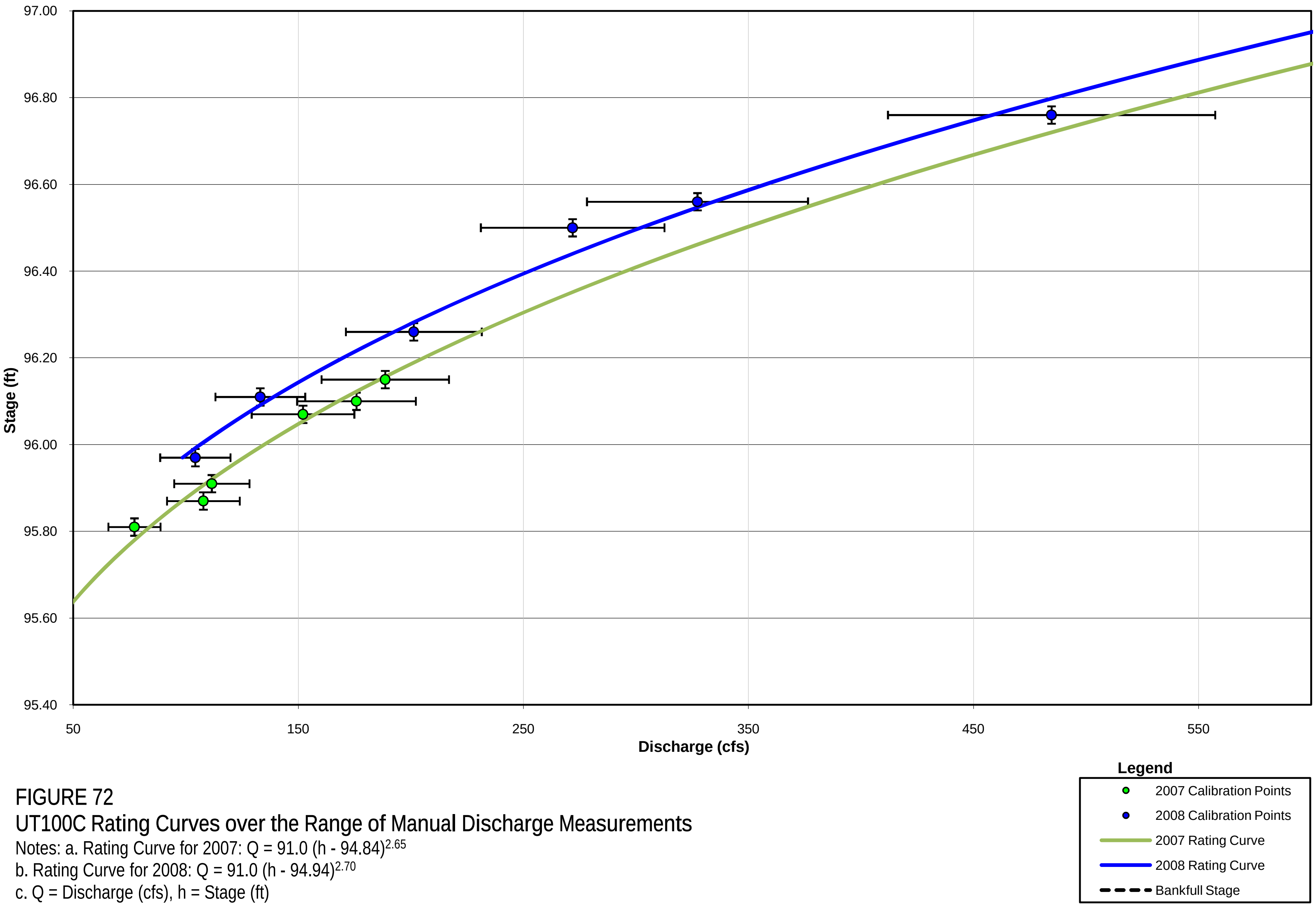


FIGURE 72

UT100C Rating Curves over the Range of Manual Discharge Measurements

Notes: a. Rating Curve for 2007: $Q = 91.0 (h - 94.84)^{2.65}$

b. Rating Curve for 2008: $Q = 91.0 (h - 94.94)^{2.70}$

c. Q = Discharge (cfs), h = Stage (ft)

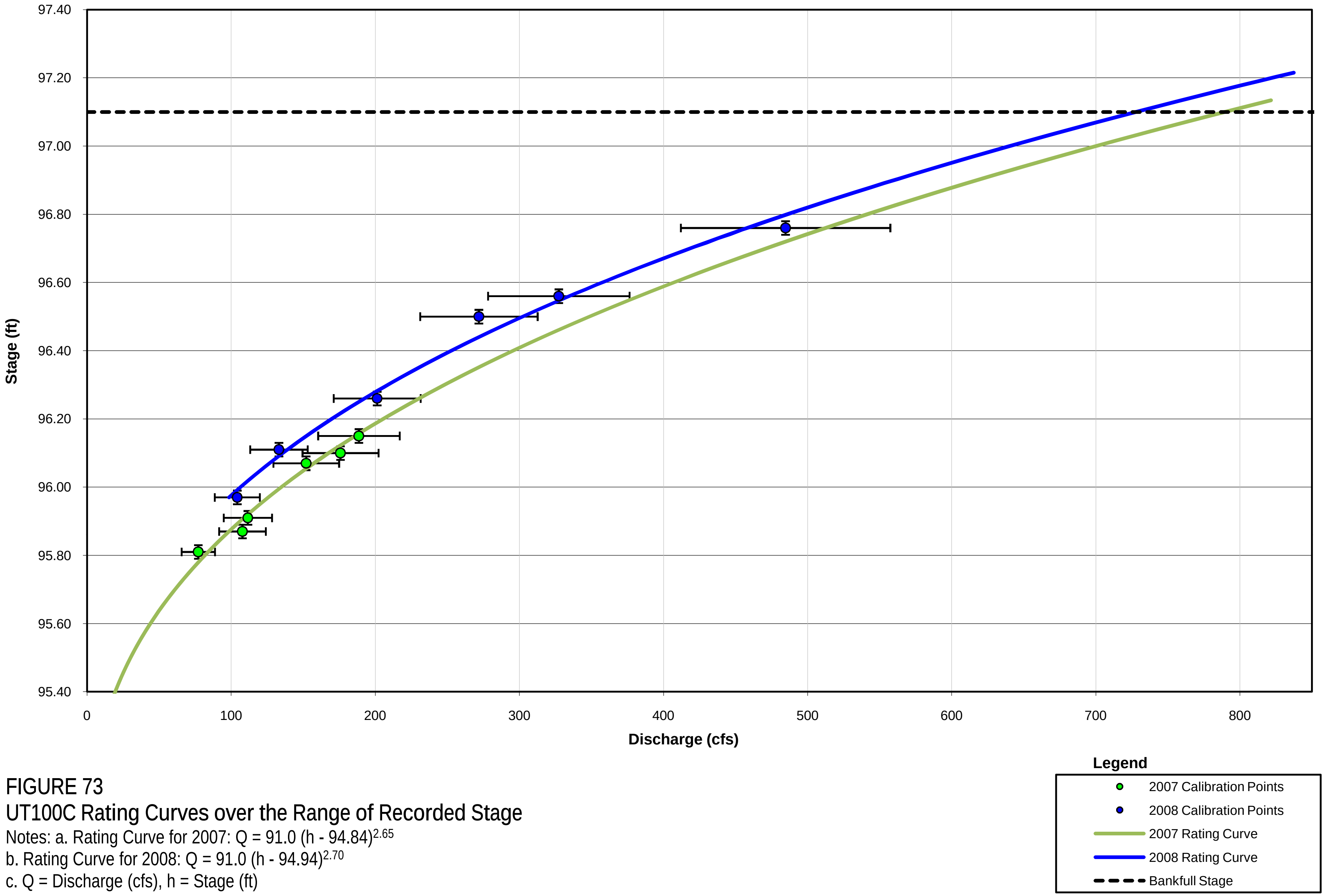


FIGURE 73

UT100C Rating Curves over the Range of Recorded Stage

Notes: a. Rating Curve for 2007: $Q = 91.0 (h - 94.84)^{2.65}$

b. Rating Curve for 2008: $Q = 91.0 (h - 94.94)^{2.70}$

c. Q = Discharge (cfs), h = Stage (ft)

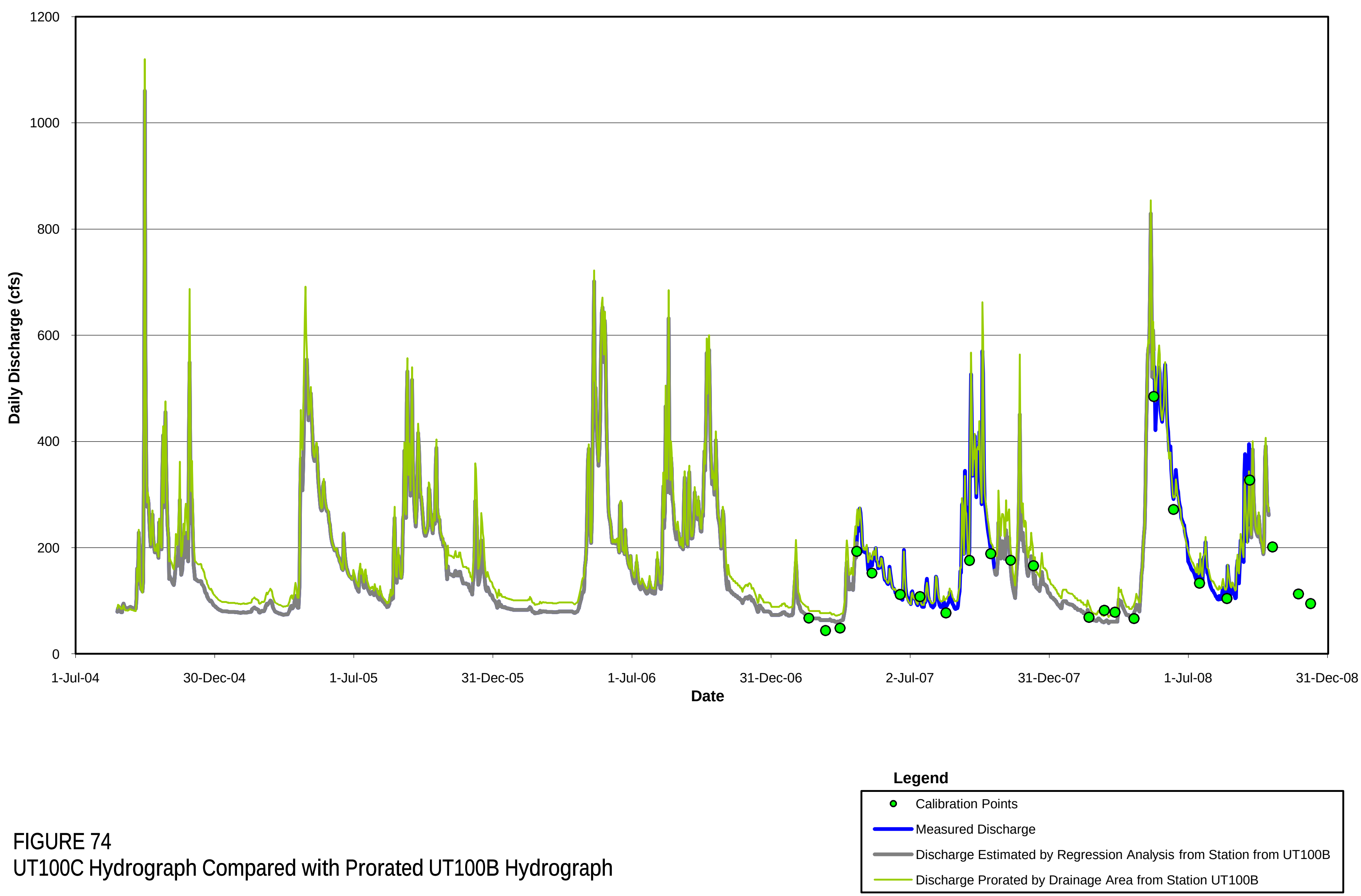


FIGURE 74
UT100C Hydrograph Compared with Prorated UT100B Hydrograph

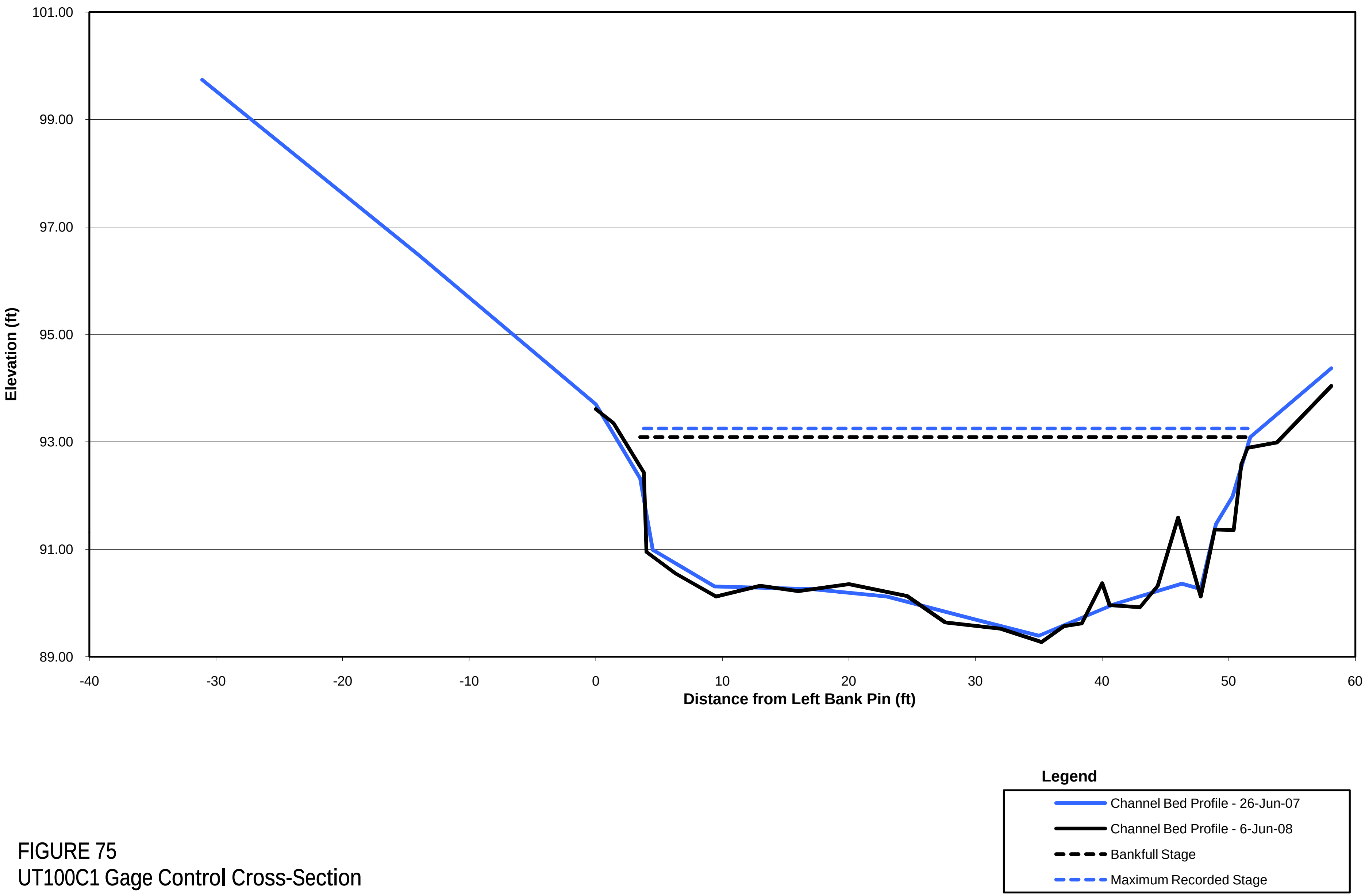


FIGURE 75
UT100C1 Gage Control Cross-Section

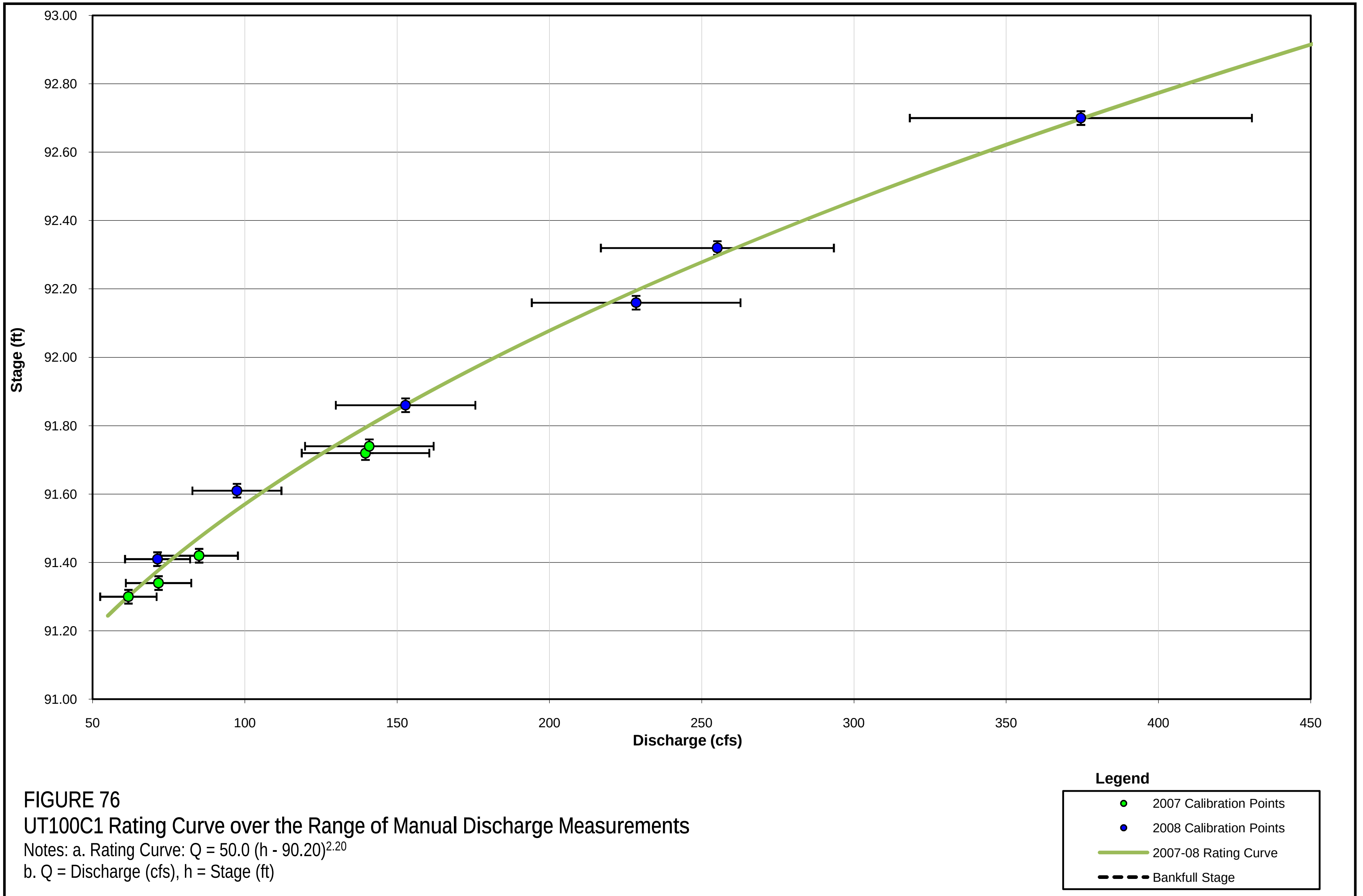


FIGURE 76

UT100C1 Rating Curve over the Range of Manual Discharge Measurements

Notes: a. Rating Curve: $Q = 50.0\ (h - 90.20)^{2.20}$

b. Q = Discharge (cfs), h = Stage (ft)

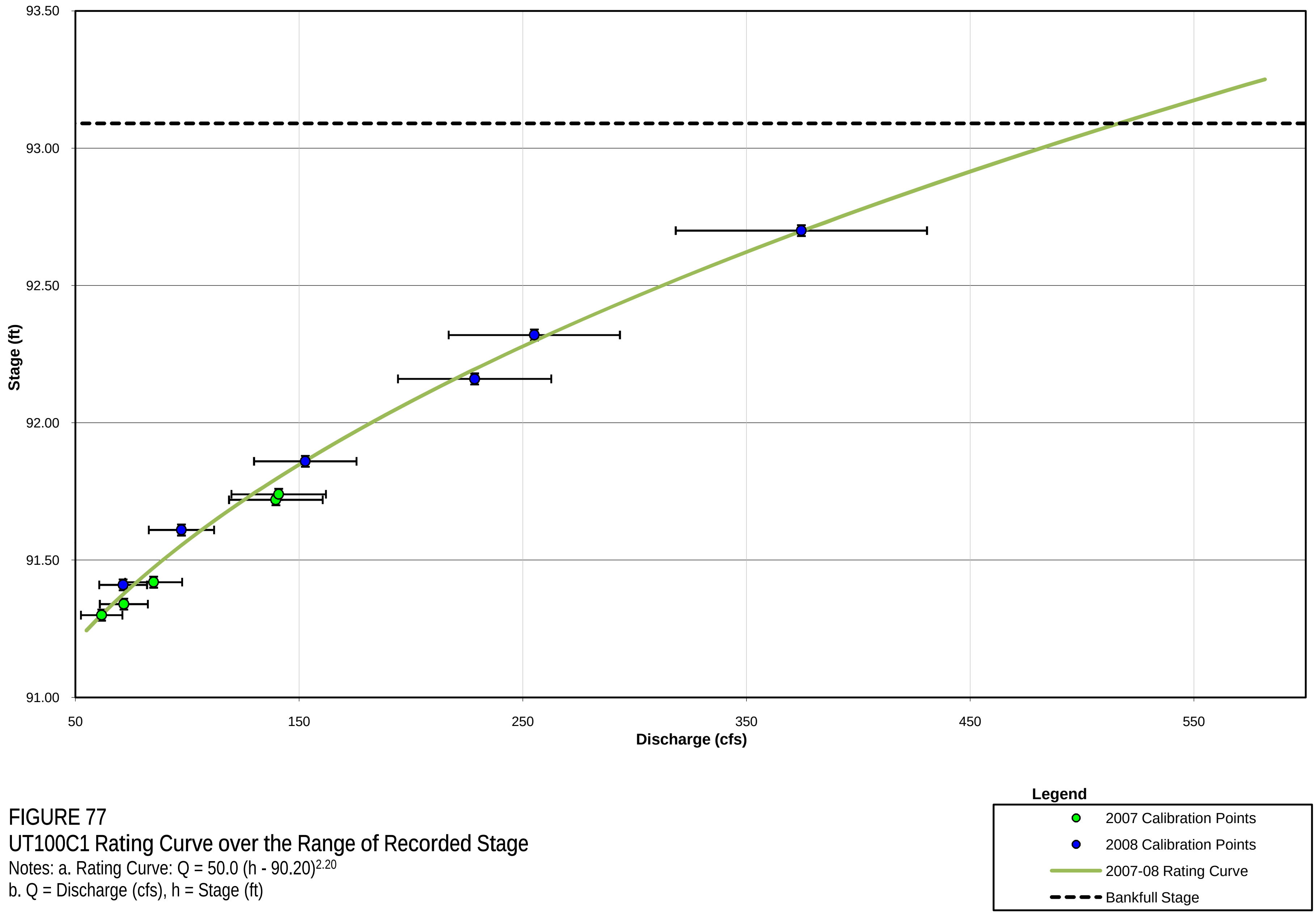


FIGURE 77
UT100C1 Rating Curve over the Range of Recorded Stage
Notes: a. Rating Curve: $Q = 50.0\ (h - 90.20)^{2.20}$
b. Q = Discharge (cfs), h = Stage (ft)

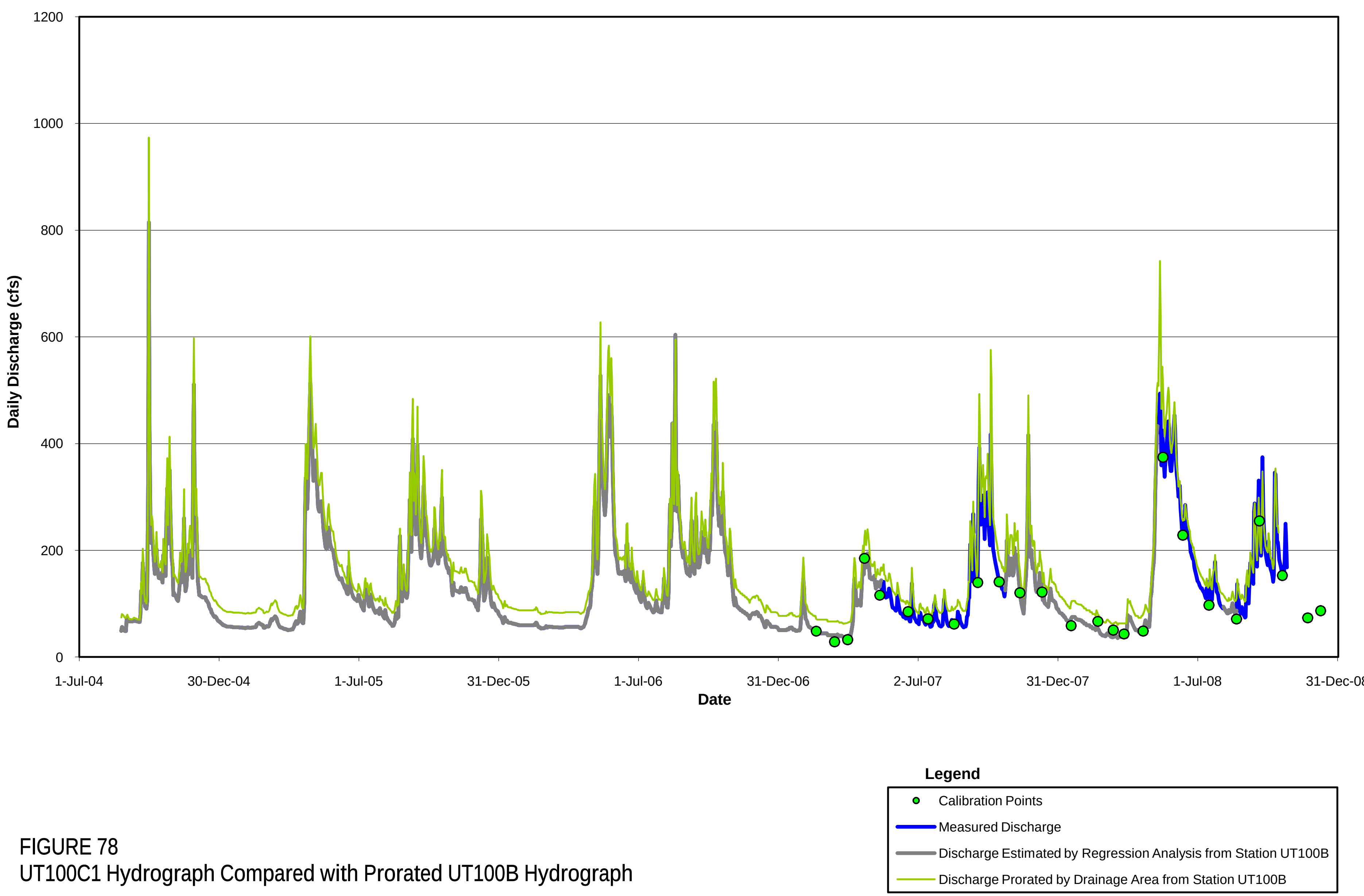


FIGURE 78
UT100C1 Hydrograph Compared with Prorated UT100B Hydrograph

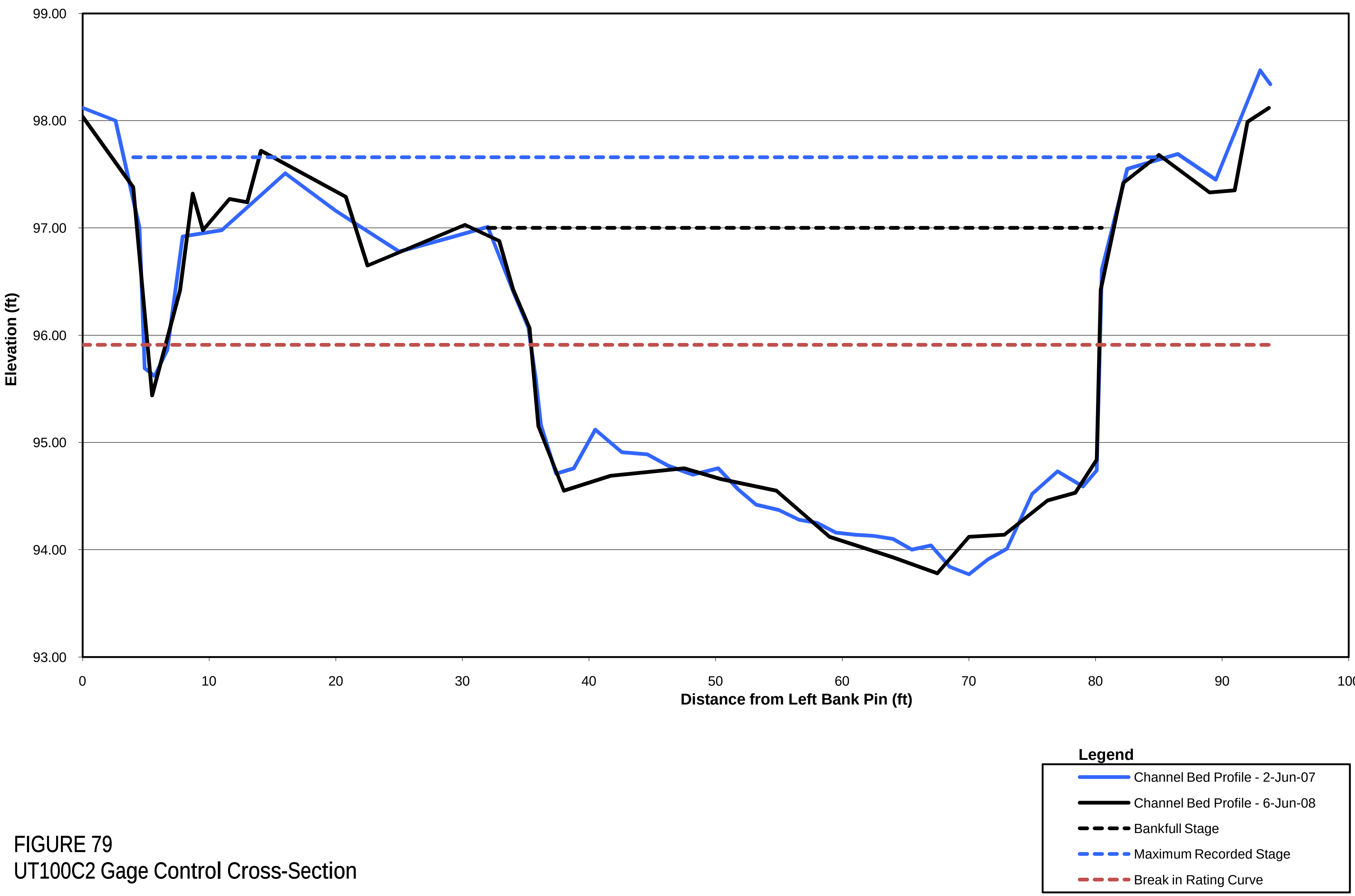


FIGURE 79
UT100C2 Gage Control Cross-Section

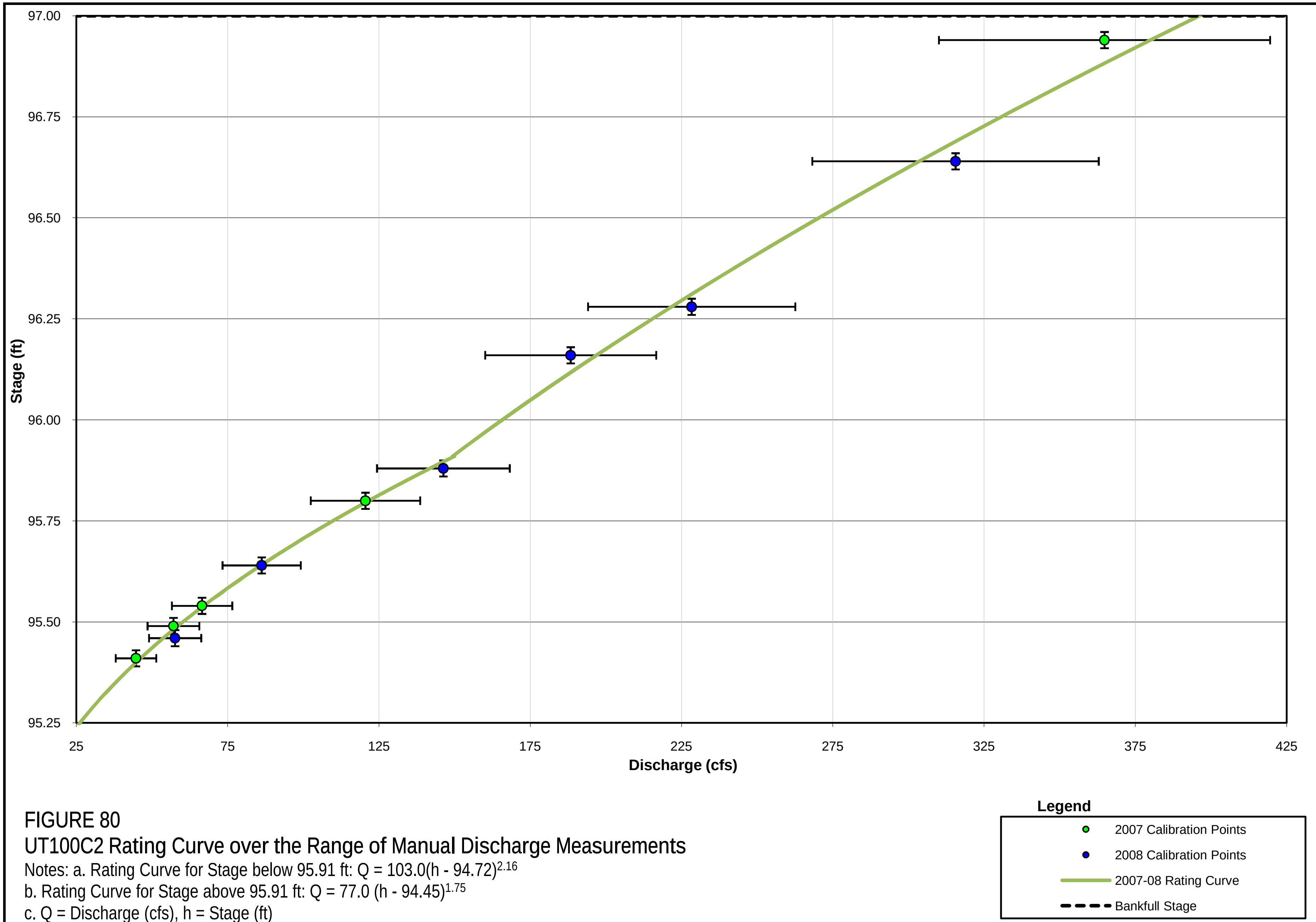


FIGURE 80

UT100C2 Rating Curve over the Range of Manual Discharge Measurements

Notes: a. Rating Curve for Stage below 95.91 ft: $Q = 103.0(h - 94.72)^{2.16}$

b. Rating Curve for Stage above 95.91 ft: $Q = 77.0\ (h - 94.45)^{1.75}$

c. Q = Discharge (cfs), h = Stage (ft)

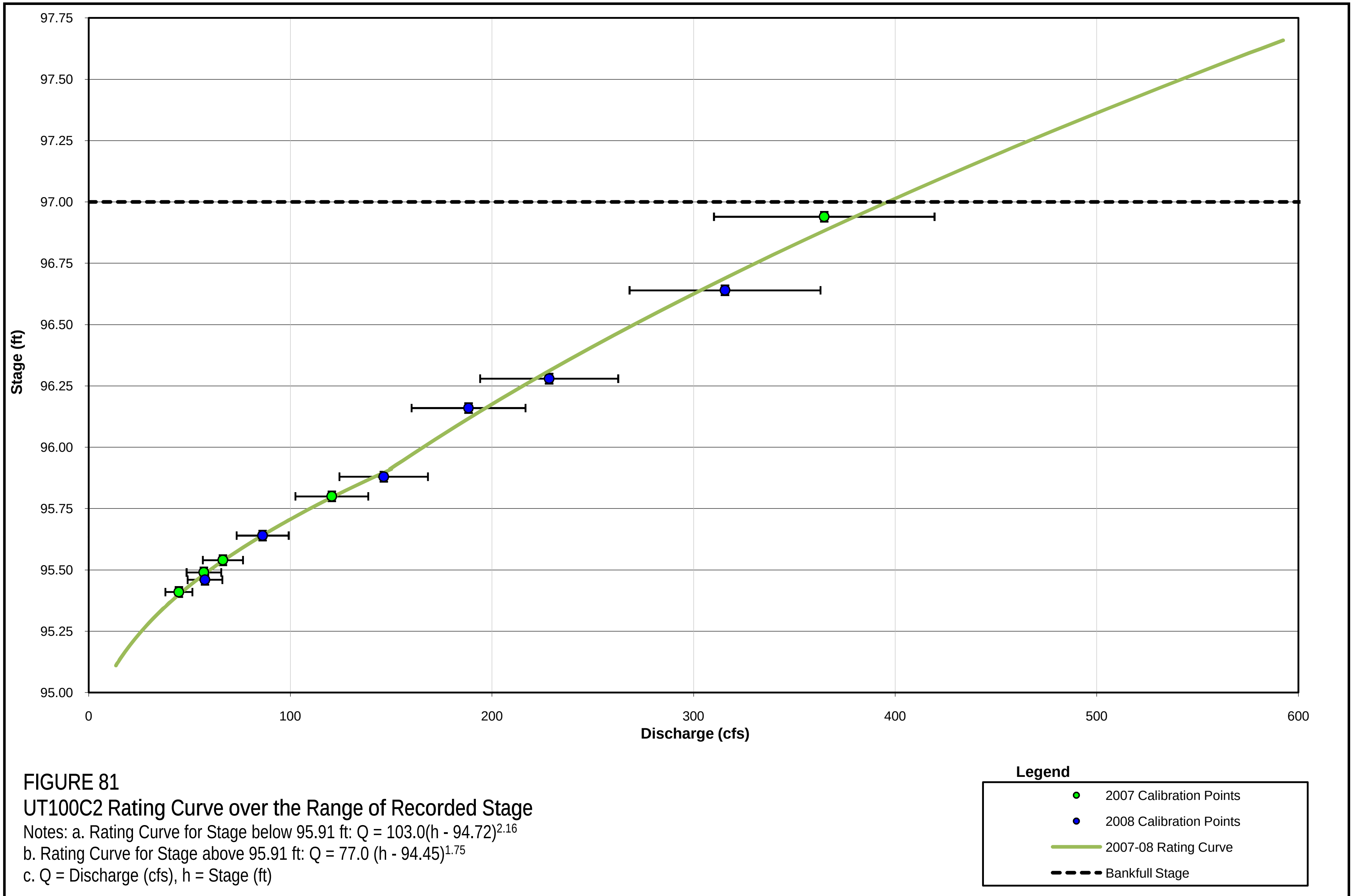


FIGURE 81

UT100C2 Rating Curve over the Range of Recorded Stage

Notes: a. Rating Curve for Stage below 95.91 ft: $Q = 103.0(h - 94.72)^{2.16}$

b. Rating Curve for Stage above 95.91 ft: $Q = 77.0\ (h - 94.45)^{1.75}$

c. Q = Discharge (cfs), h = Stage (ft)

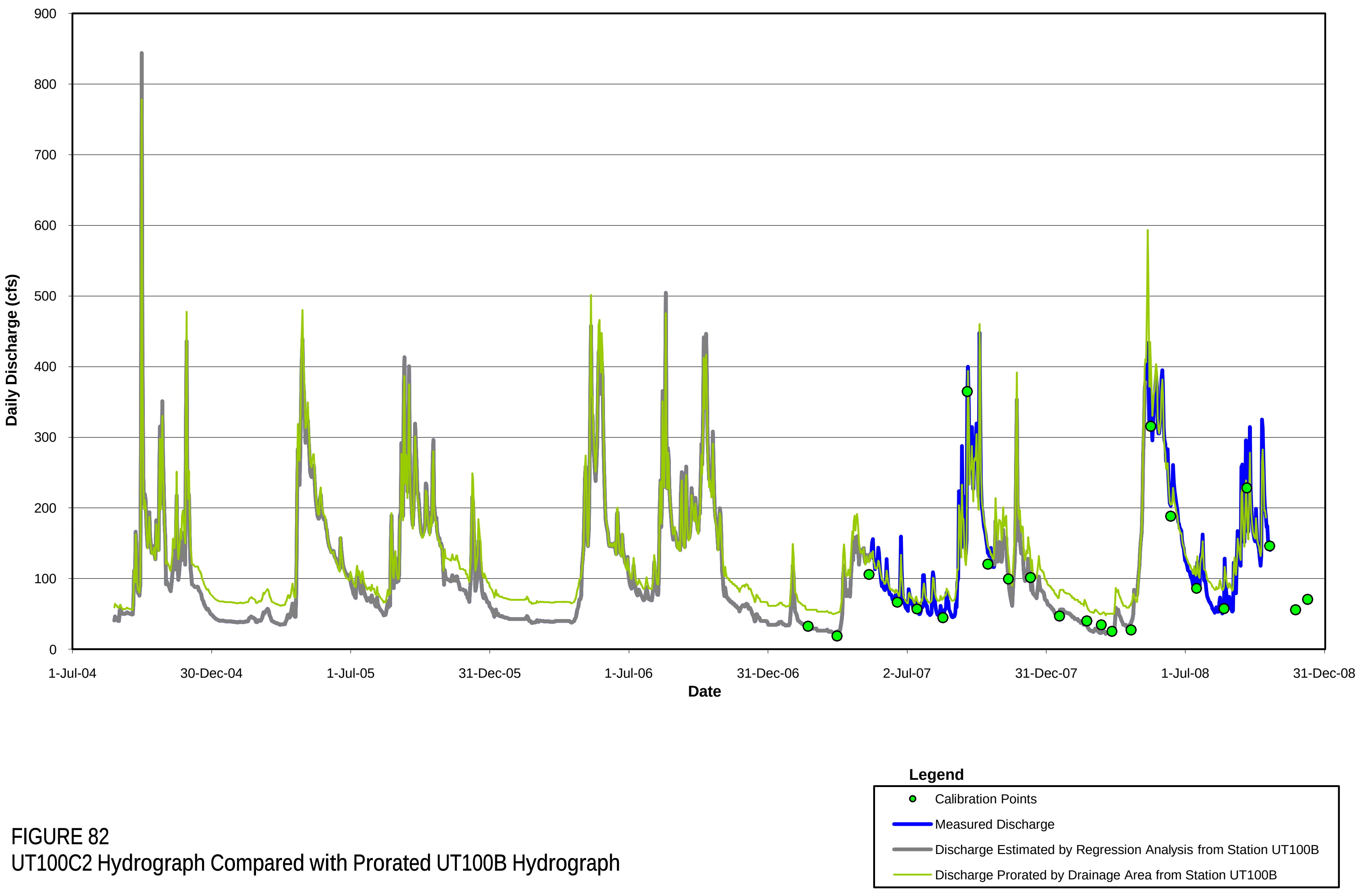


FIGURE 82
UT100C2 Hydrograph Compared with Prorated UT100B Hydrograph

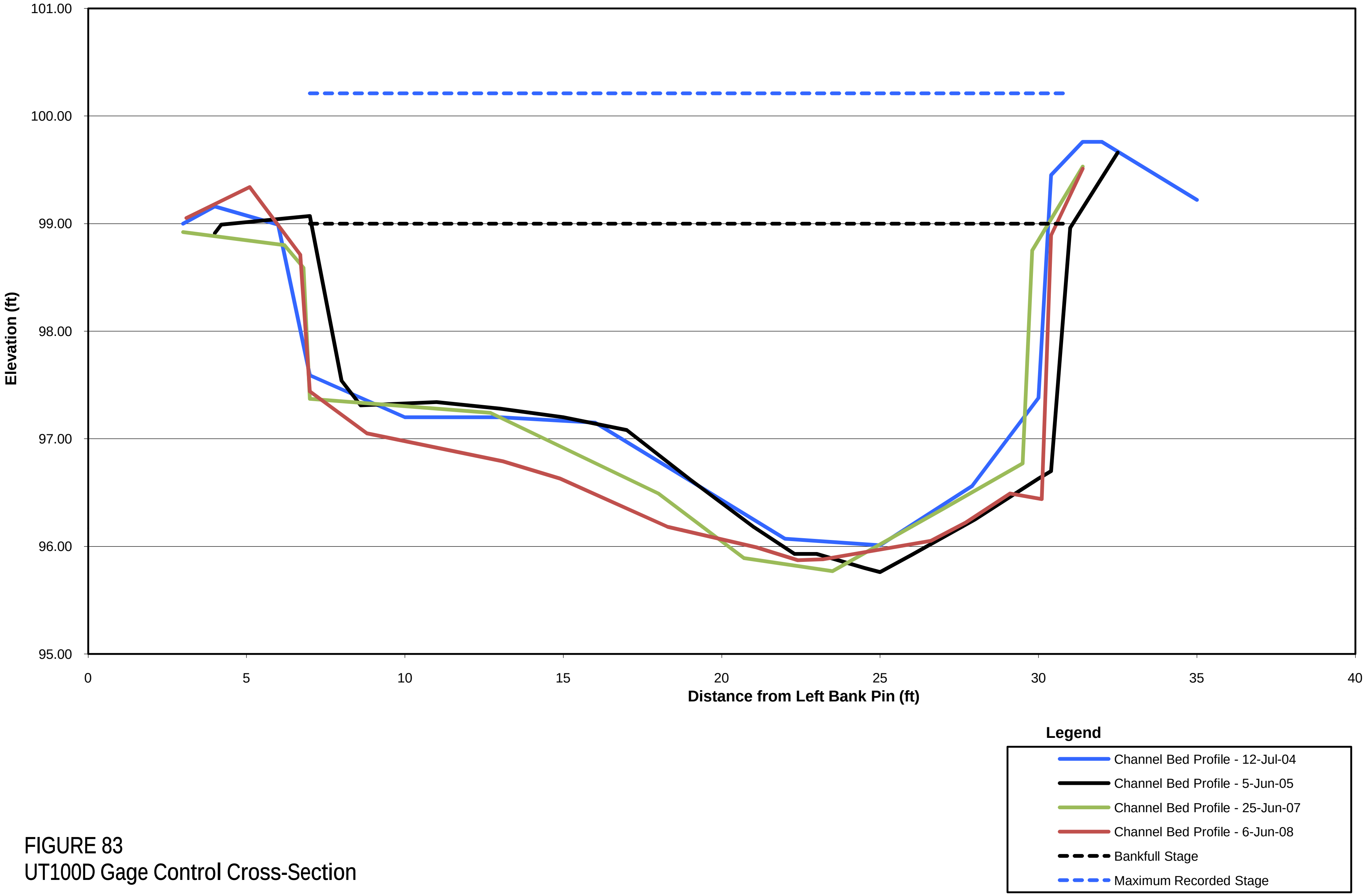


FIGURE 83
UT100D Gage Control Cross-Section

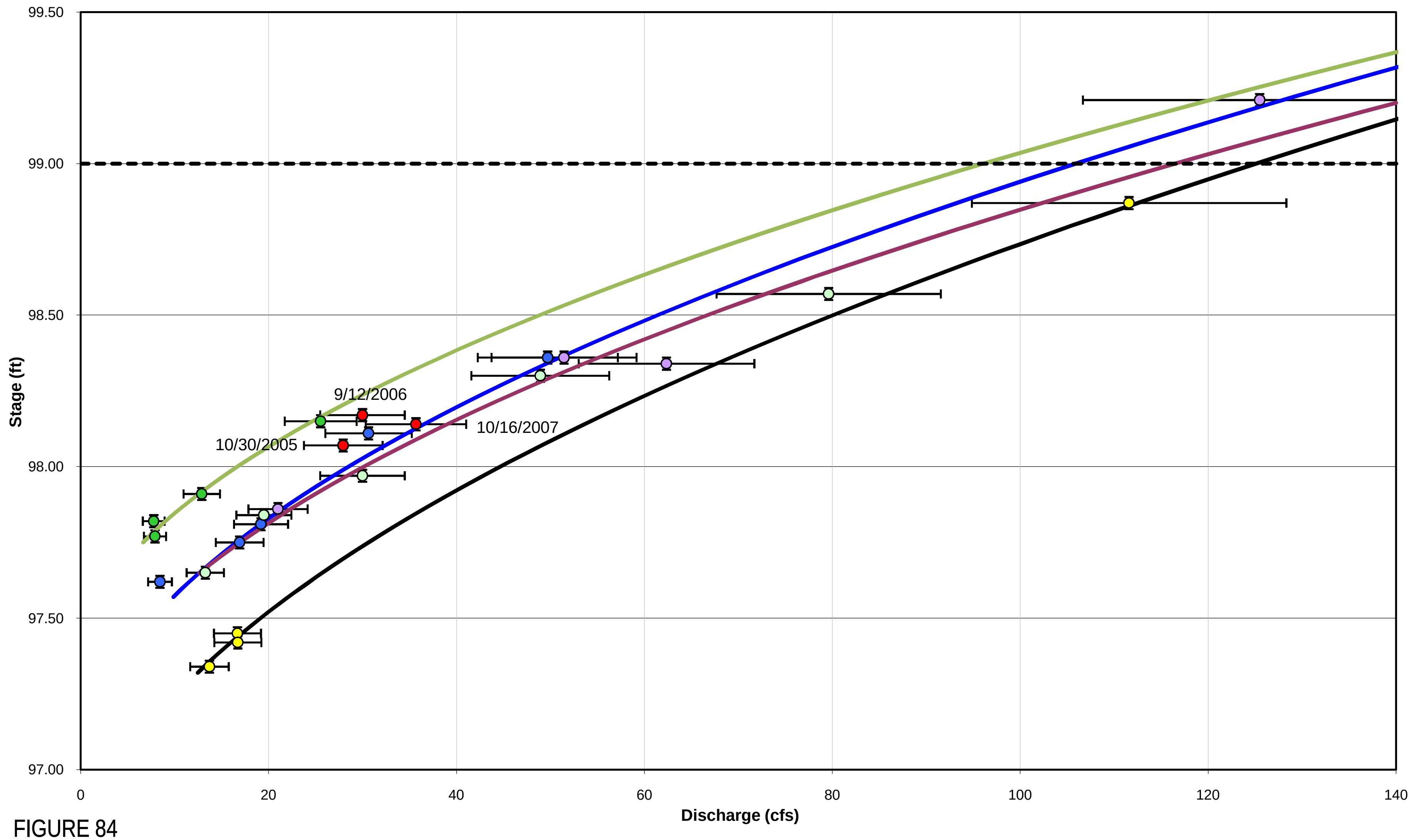


FIGURE 84

UT100D Rating Curves over the Range of Manual Discharge Measurements

Notes: a. Rating Curve for 2004: $Q = 38.3 (h - 97.36)^{1.86}$

b. Rating Curve for 2005-06: $Q = 28.3 (h - 97.00)^{1.90}$

c. Rating Curve for 2007: $Q = 23.9 (h - 96.61)^{1.90}$

d. Rating Curve for 2008: $Q = 33.2 (h - 97.05)^{1.88}$

e. Q = Discharge (cfs), h = Stage (ft)

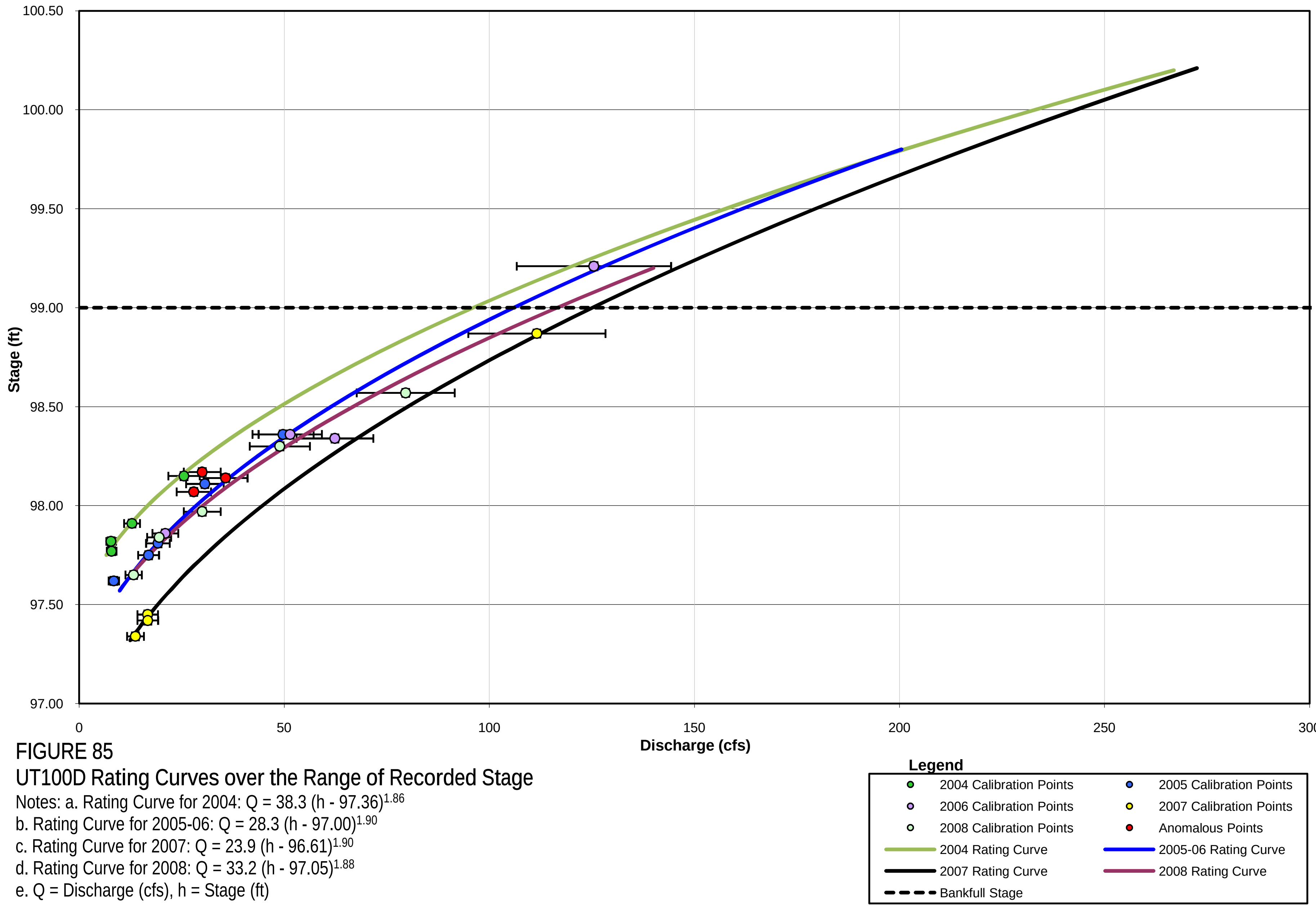


FIGURE 85

UT100D Rating Curves over the Range of Recorded Stage

Notes: a. Rating Curve for 2004: $Q = 38.3\ (h - 97.36)^{1.86}$

b. Rating Curve for 2005-06: $Q = 28.3\ (h - 97.00)^{1.90}$

c. Rating Curve for 2007: $Q = 23.9\ (h - 96.61)^{1.90}$

d. Rating Curve for 2008: $Q = 33.2\ (h - 97.05)^{1.88}$

e. Q = Discharge (cfs), h = Stage (ft)

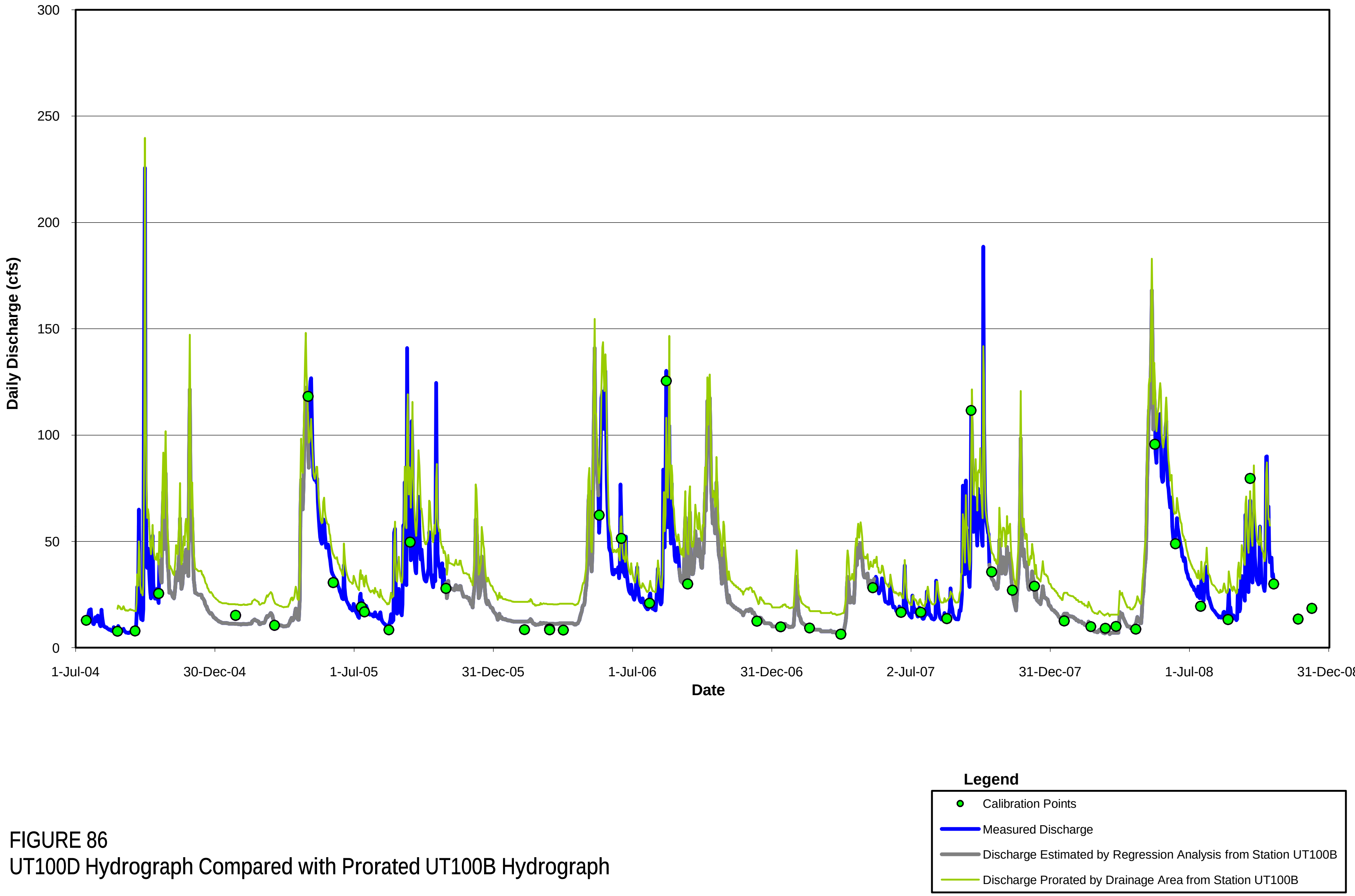


FIGURE 86
UT100D Hydrograph Compared with Prorated UT100B Hydrograph

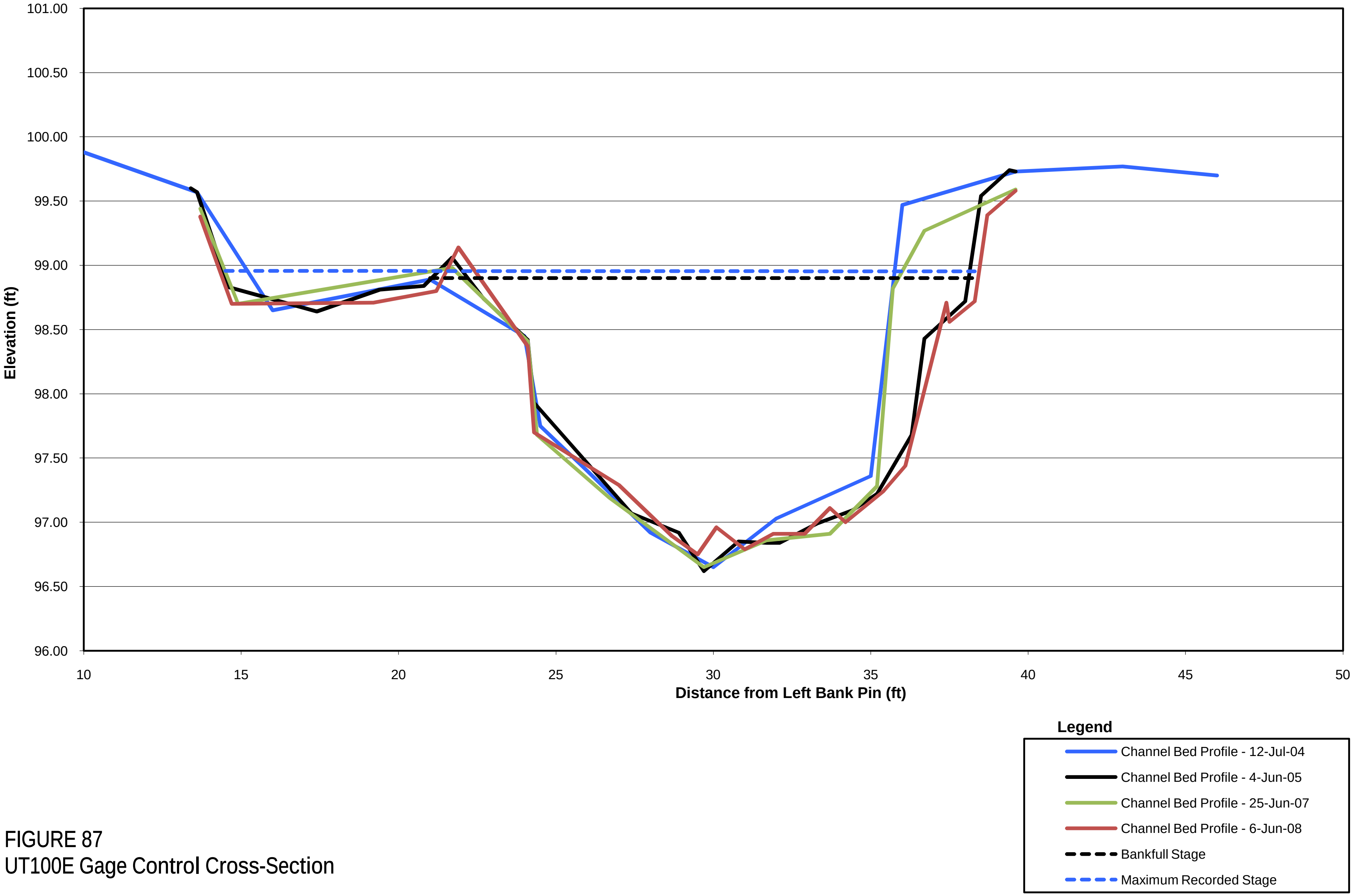


FIGURE 87
UT100E Gage Control Cross-Section

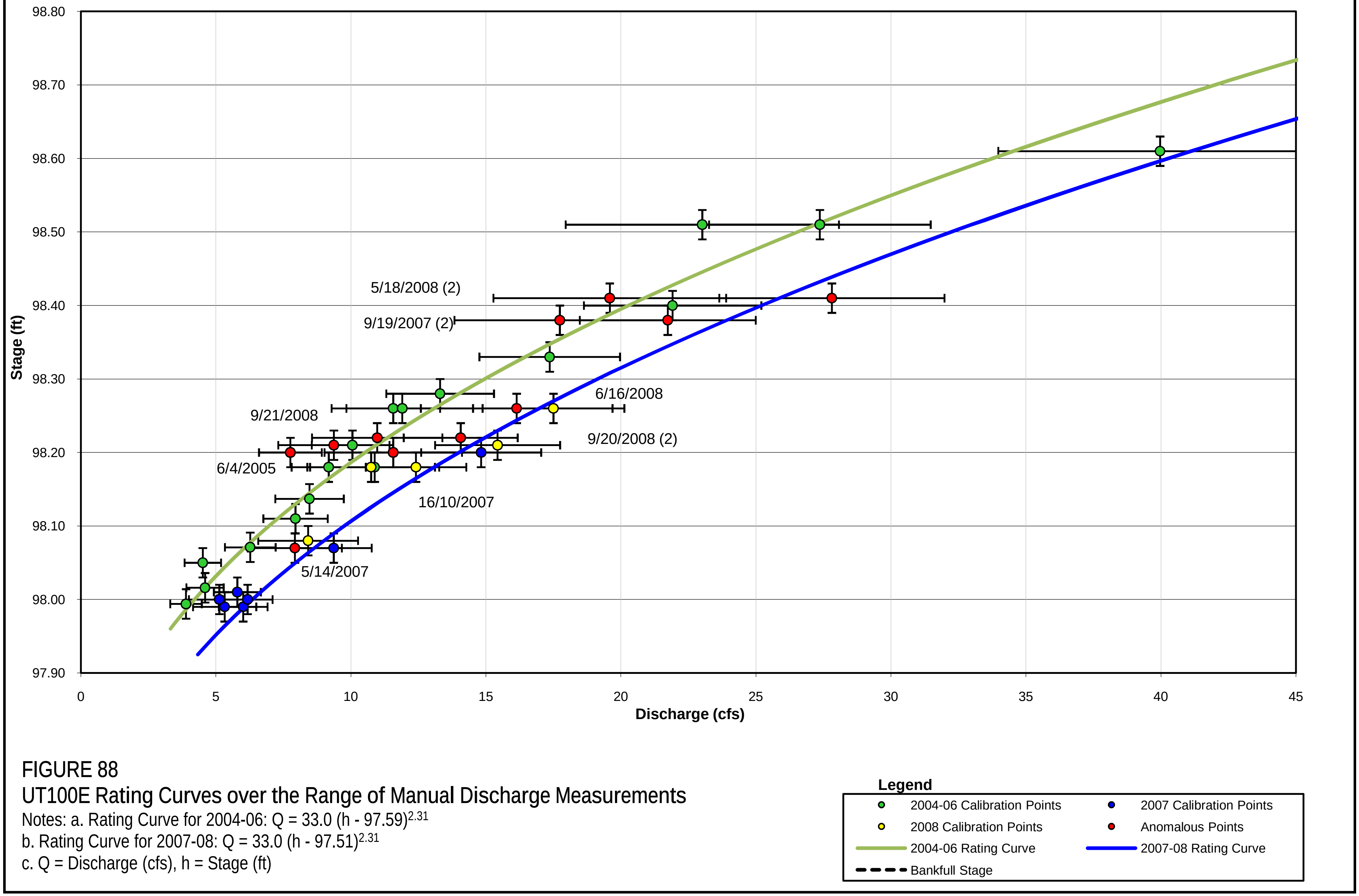


FIGURE 88

UT100E Rating Curves over the Range of Manual Discharge Measurements

Notes: a. Rating Curve for 2004-06: $Q = 33.0\ (h - 97.59)^{2.31}$

b. Rating Curve for 2007-08: $Q = 33.0\ (h - 97.51)^{2.31}$

c. Q = Discharge (cfs), h = Stage (ft)

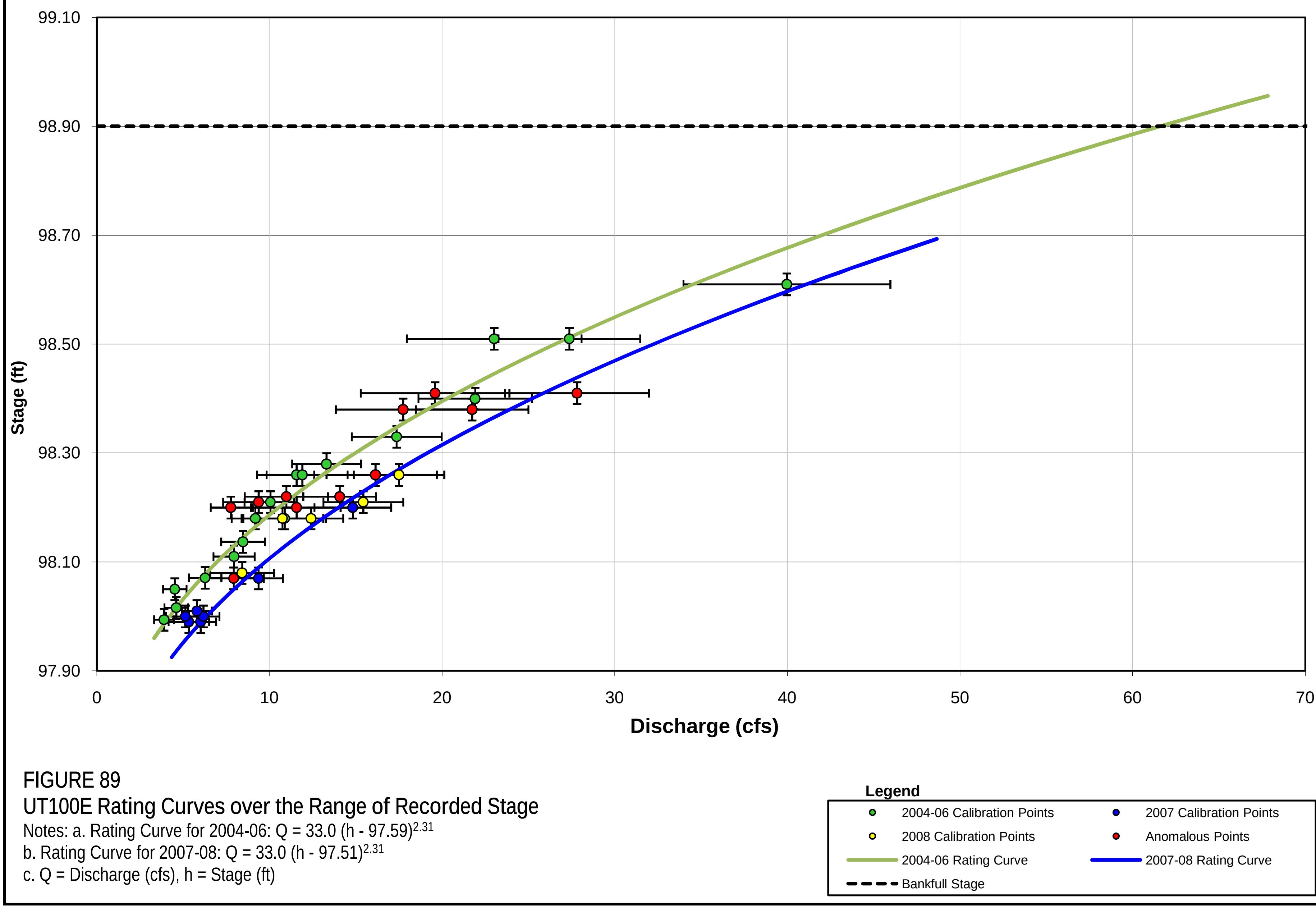


FIGURE 89

UT100E Rating Curves over the Range of Recorded Stage

Notes: a. Rating Curve for 2004-06: $Q = 33.0 (h - 97.59)^{2.31}$

b. Rating Curve for 2007-08: $Q = 33.0 (h - 97.51)^{2.31}$

c. Q = Discharge (cfs), h = Stage (ft)

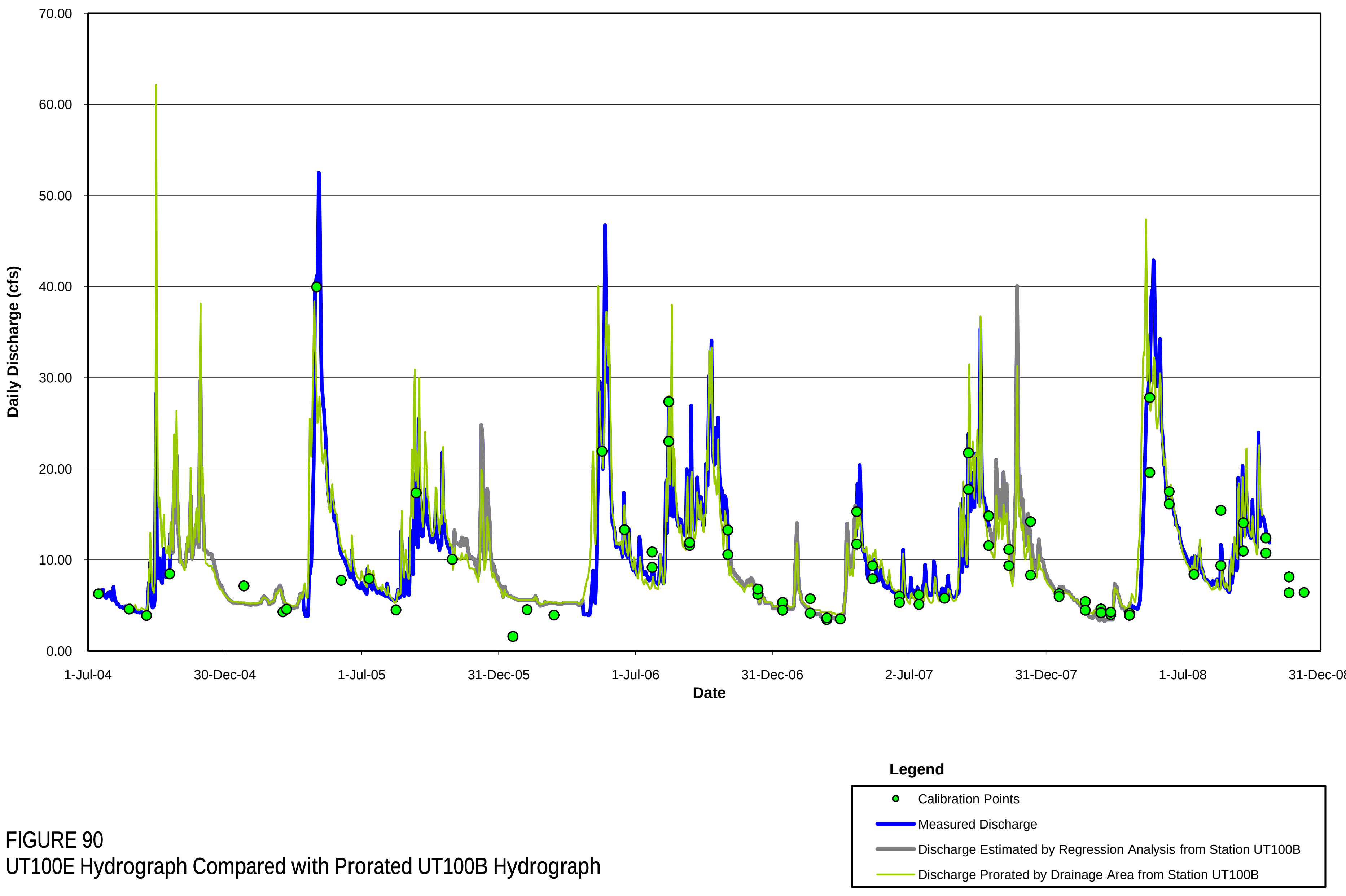


FIGURE 90
UT100E Hydrograph Compared with Prorated UT100B Hydrograph

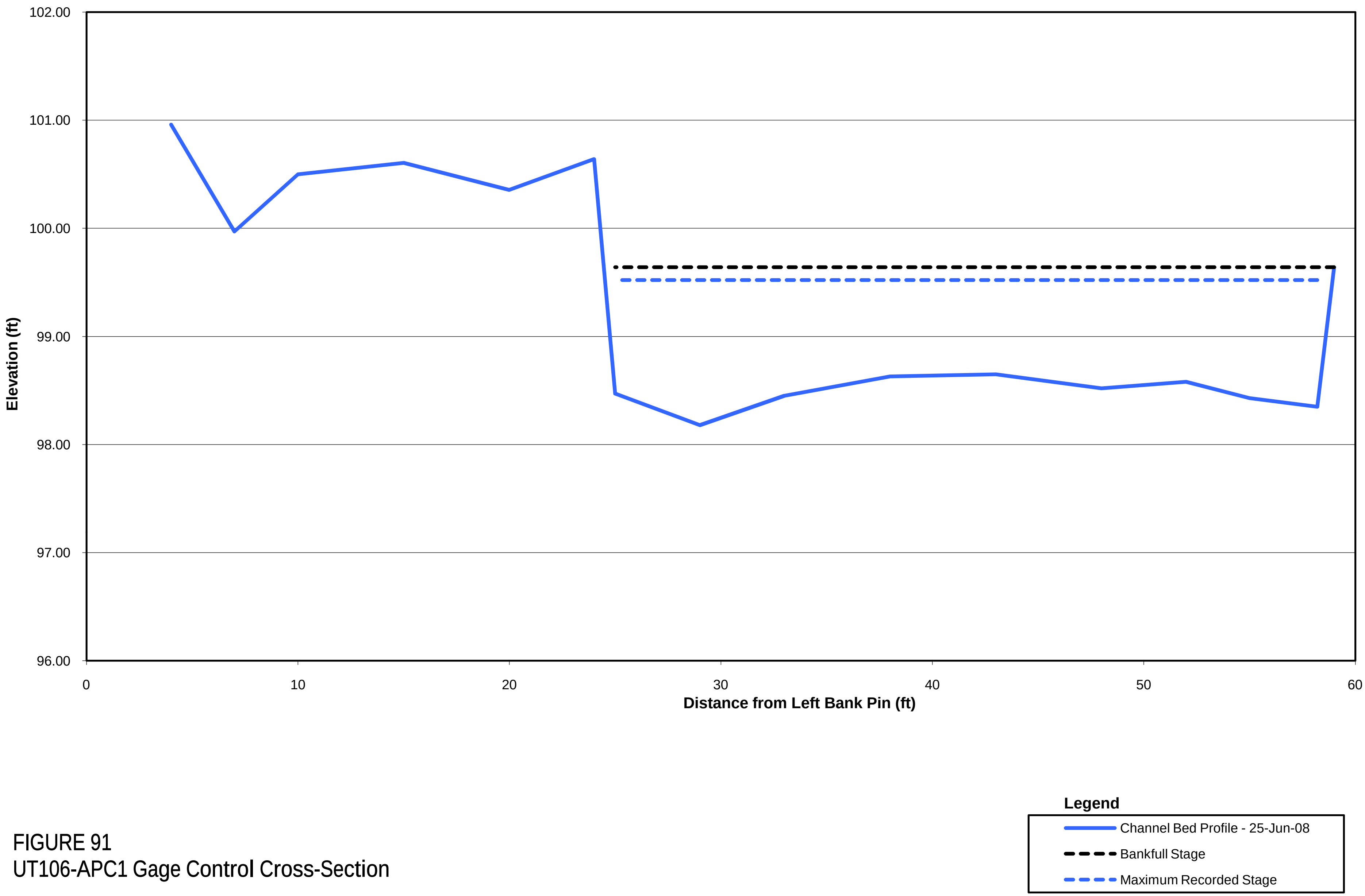


FIGURE 91
UT106-APC1 Gage Control Cross-Section

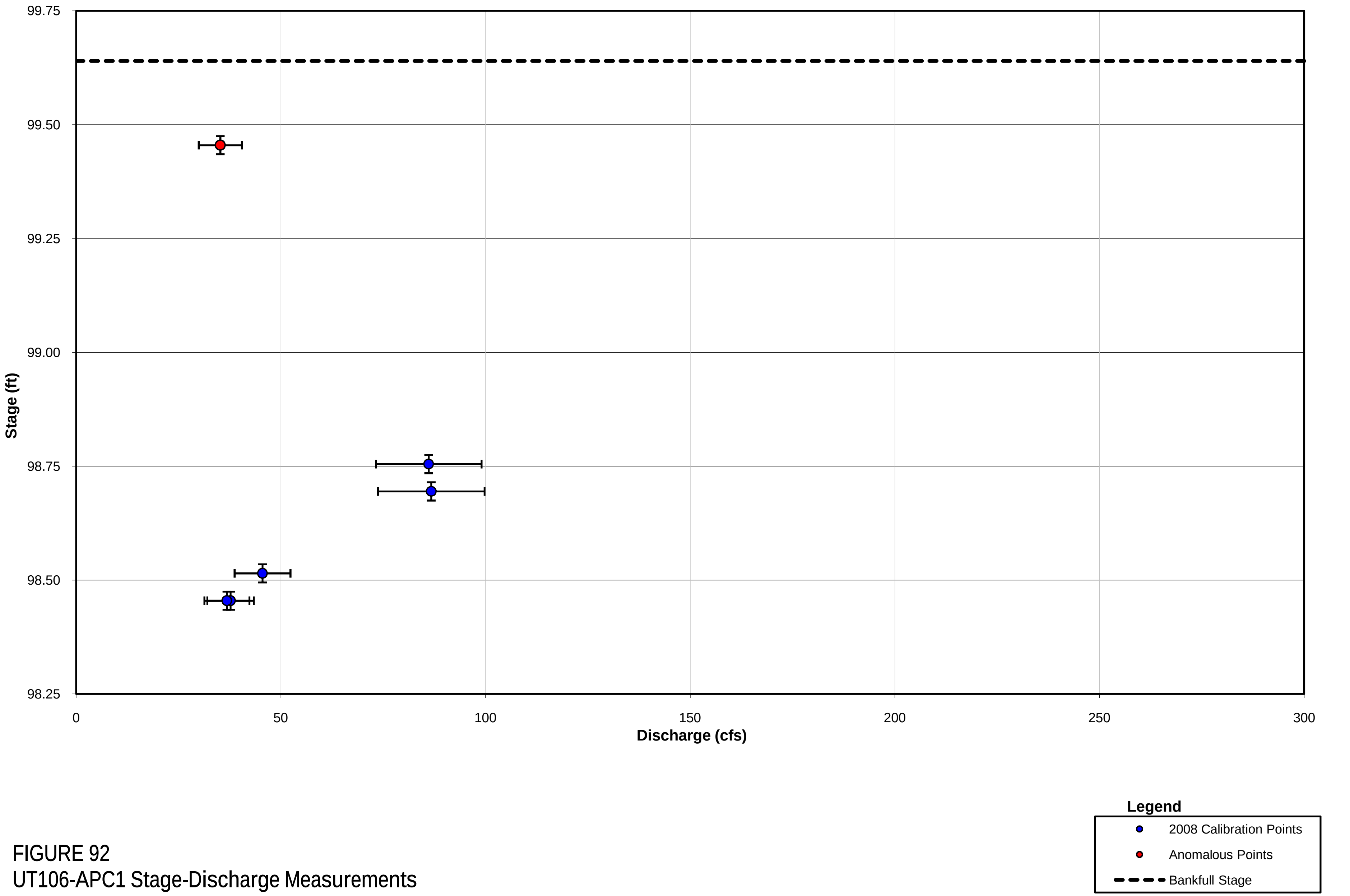


FIGURE 92
UT106-APC1 Stage-Discharge Measurements

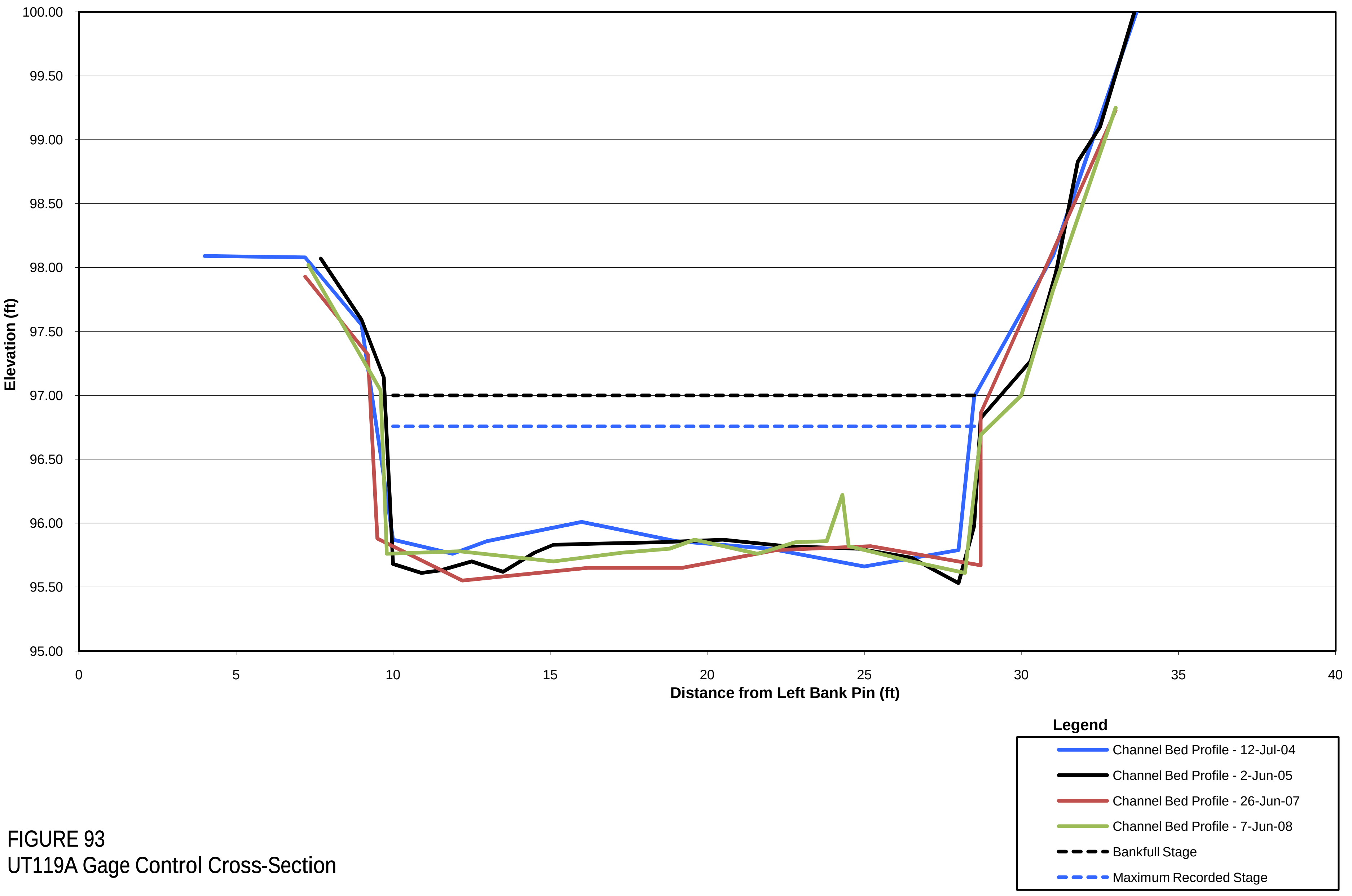


FIGURE 93
UT119A Gage Control Cross-Section

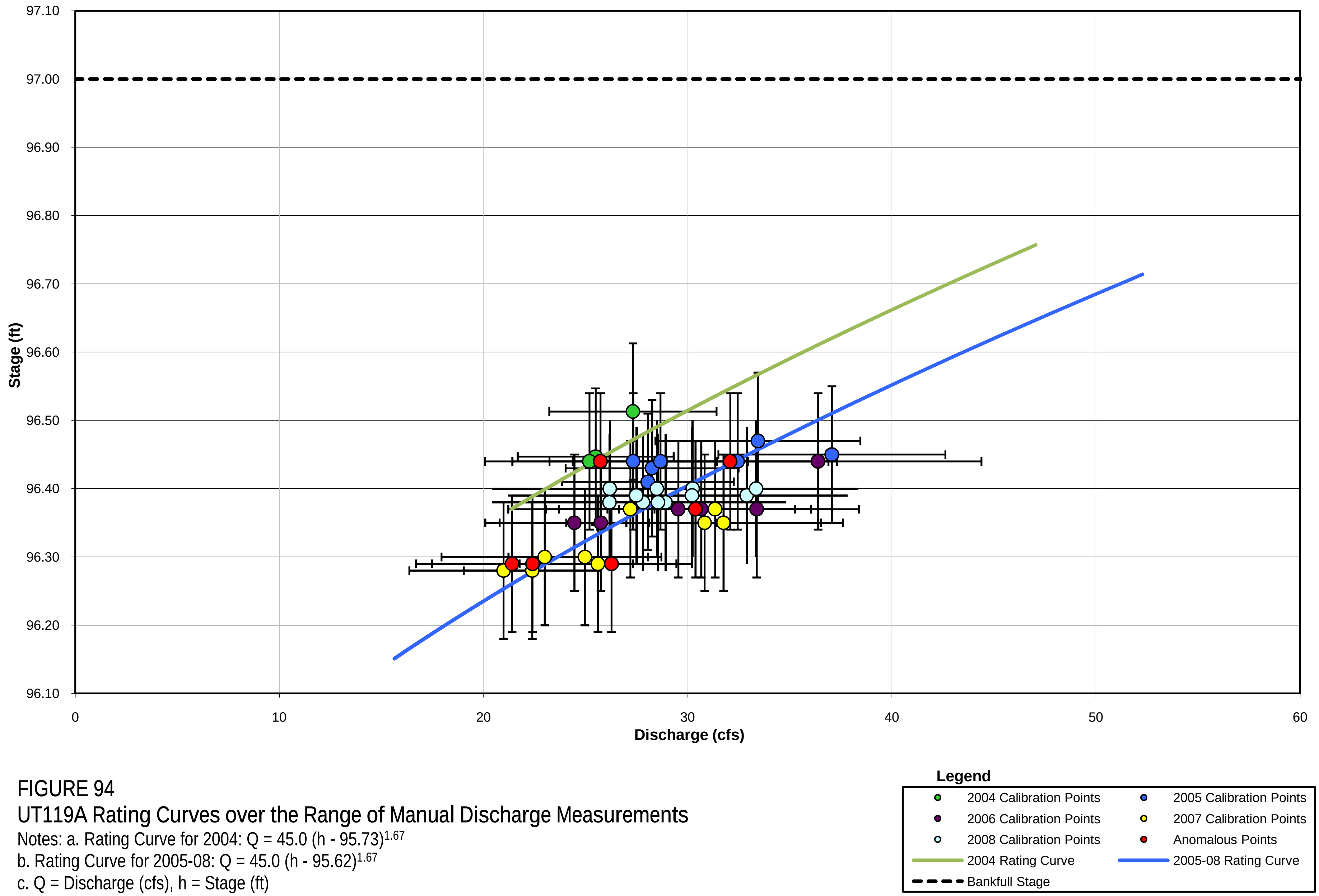


FIGURE 94

UT119A Rating Curves over the Range of Manual Discharge Measurements

Notes: a. Rating Curve for 2004: $Q = 45.0\ (h - 95.73)^{1.67}$

b. Rating Curve for 2005-08: $Q = 45.0\ (h - 95.62)^{1.67}$

c. Q = Discharge (cfs), h = Stage (ft)

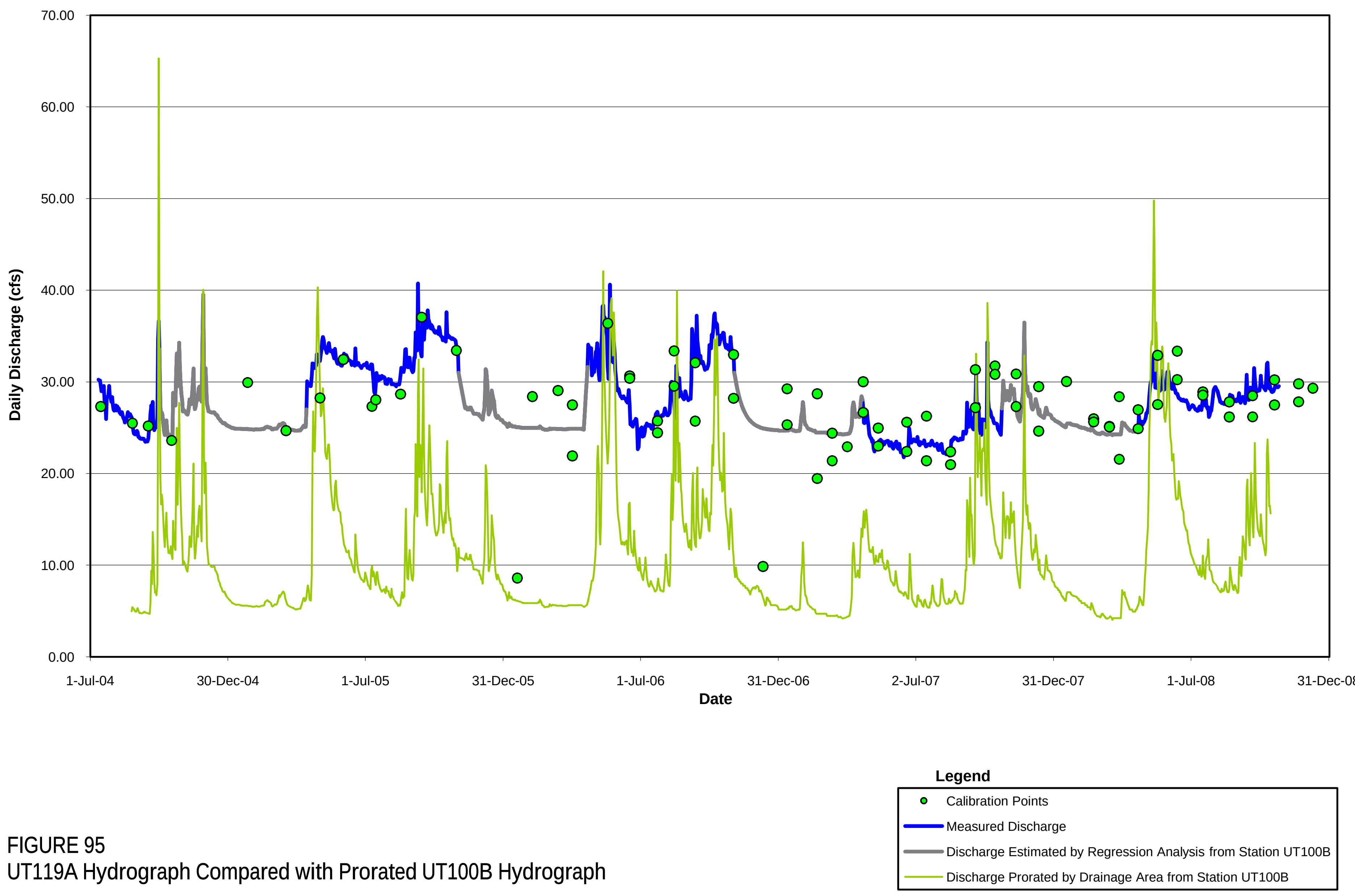


FIGURE 95
UT119A Hydrograph Compared with Prorated UT100B Hydrograph

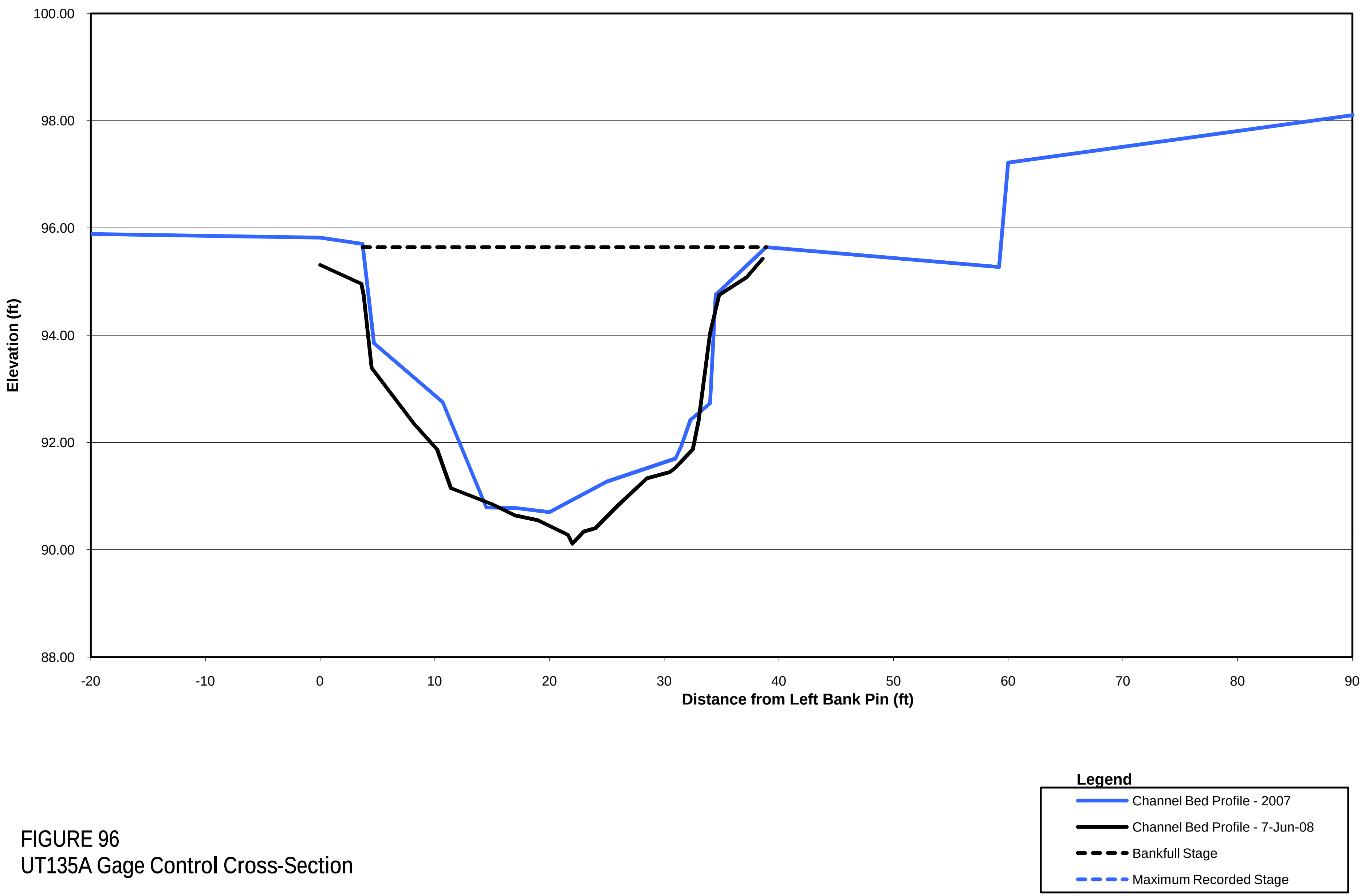


FIGURE 96
UT135A Gage Control Cross-Section

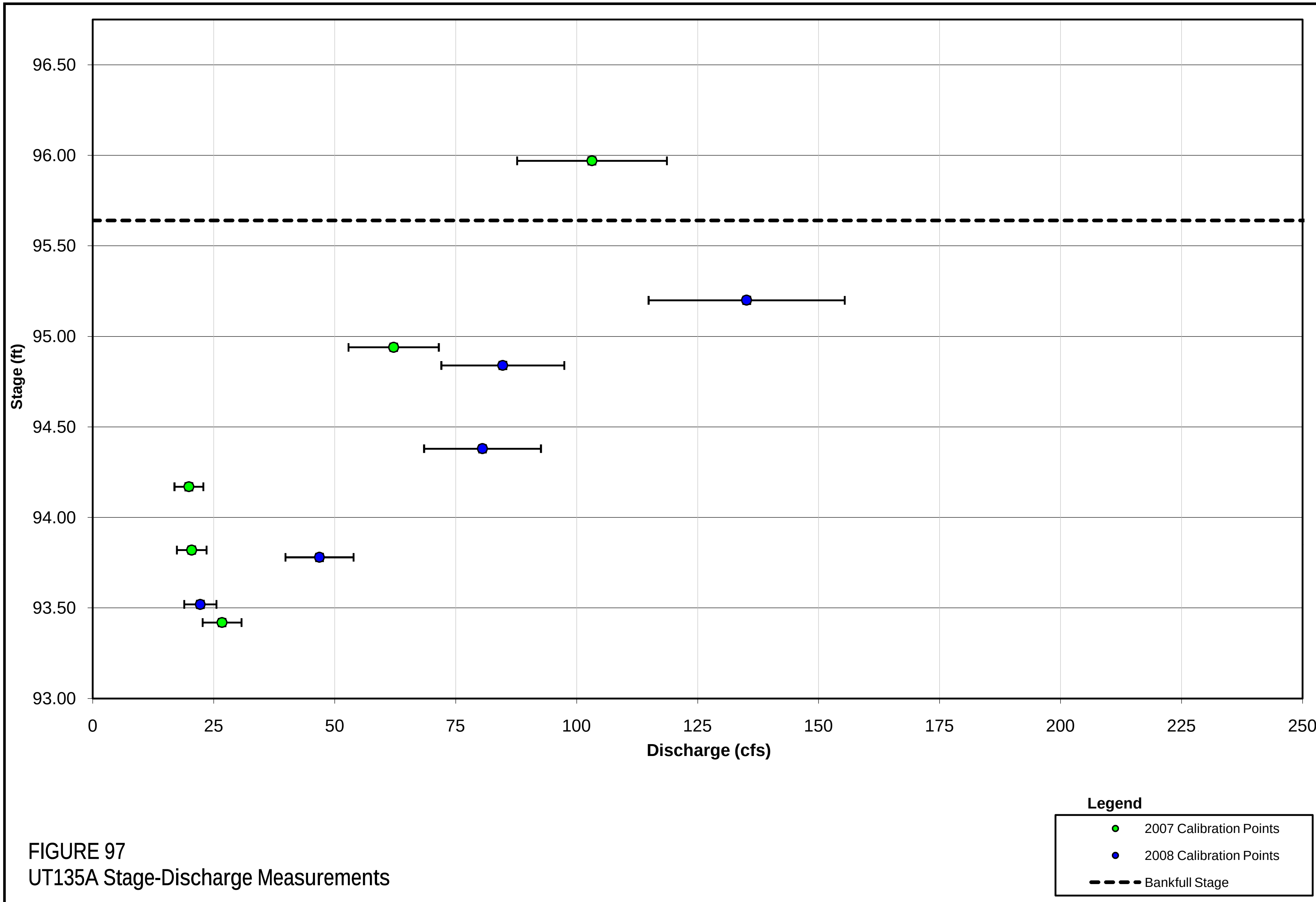


FIGURE 97
UT135A Stage-Discharge Measurements

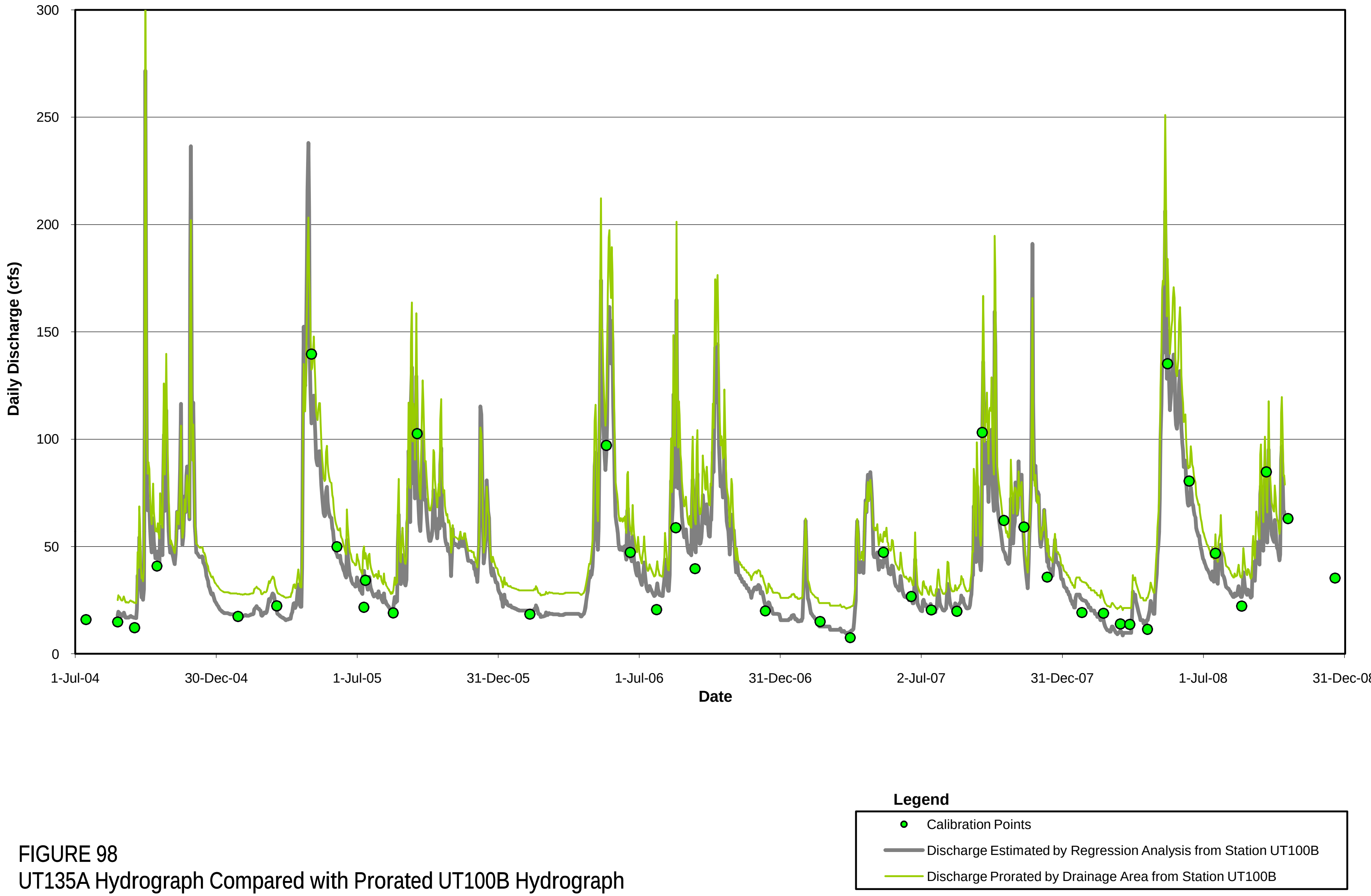


FIGURE 98
UT135A Hydrograph Compared with Prorated UT100B Hydrograph

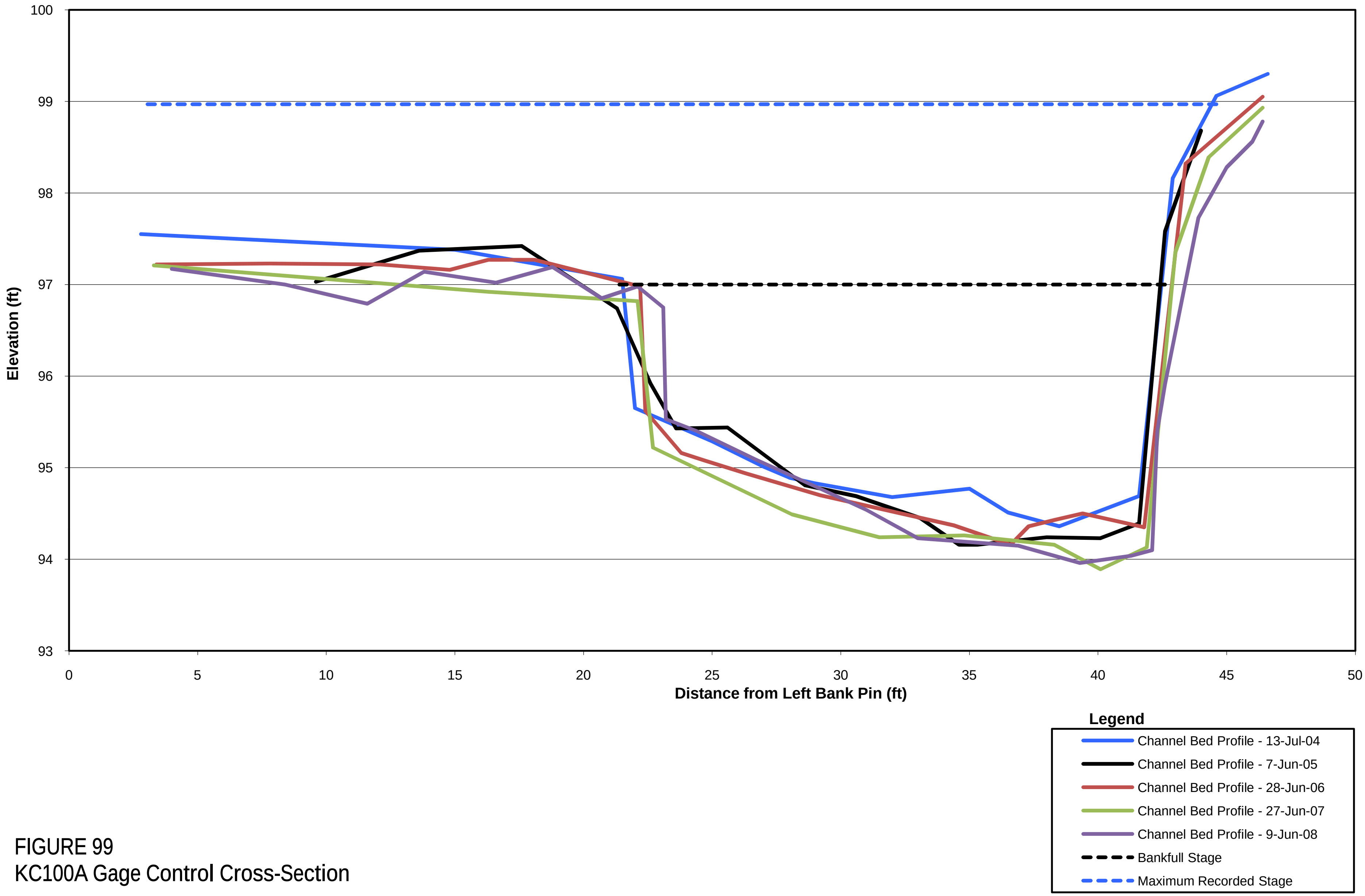


FIGURE 99
KC100A Gage Control Cross-Section

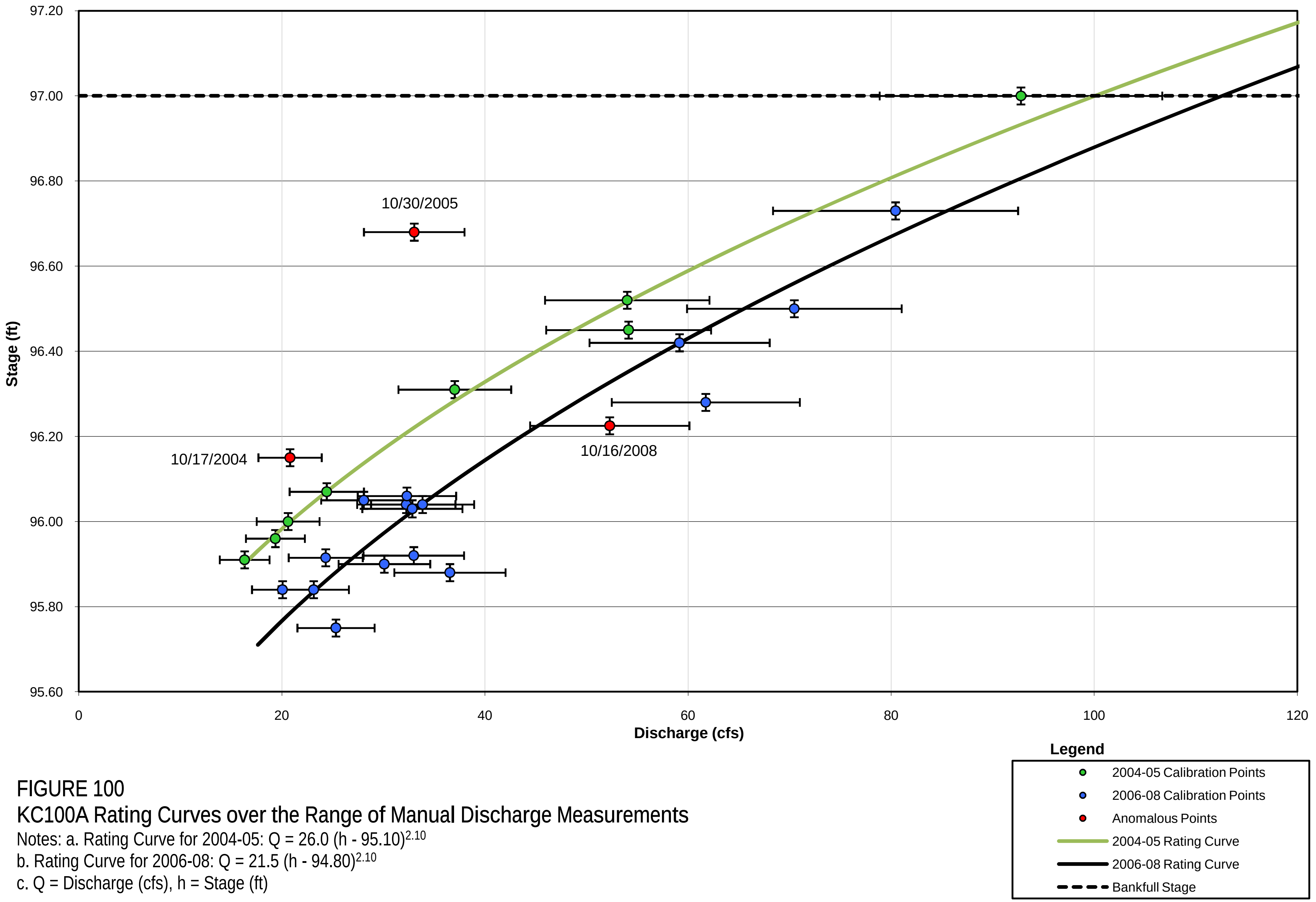


FIGURE 100

KC100A Rating Curves over the Range of Manual Discharge Measurements

Notes: a. Rating Curve for 2004-05: $Q = 26.0 (h - 95.10)^{2.10}$

b. Rating Curve for 2006-08: $Q = 21.5 (h - 94.80)^{2.10}$

c. Q = Discharge (cfs), h = Stage (ft)

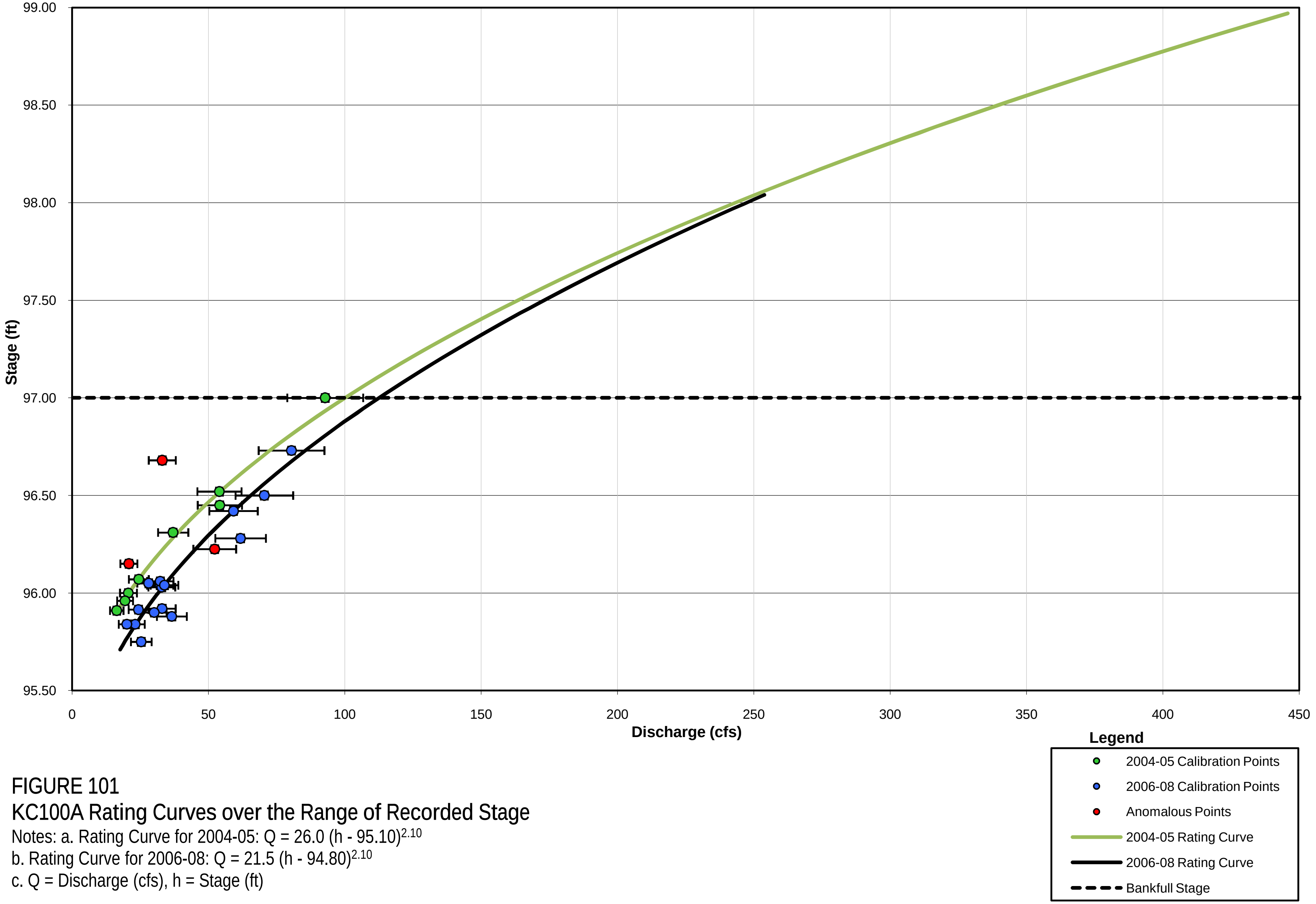


FIGURE 101
KC100A Rating Curves over the Range of Recorded Stage

Notes: a. Rating Curve for 2004-05: $Q = 26.0 (h - 95.10)^{2.10}$

b. Rating Curve for 2006-08: $Q = 21.5 (h - 94.80)^{2.10}$

c. Q = Discharge (cfs), h = Stage (ft)

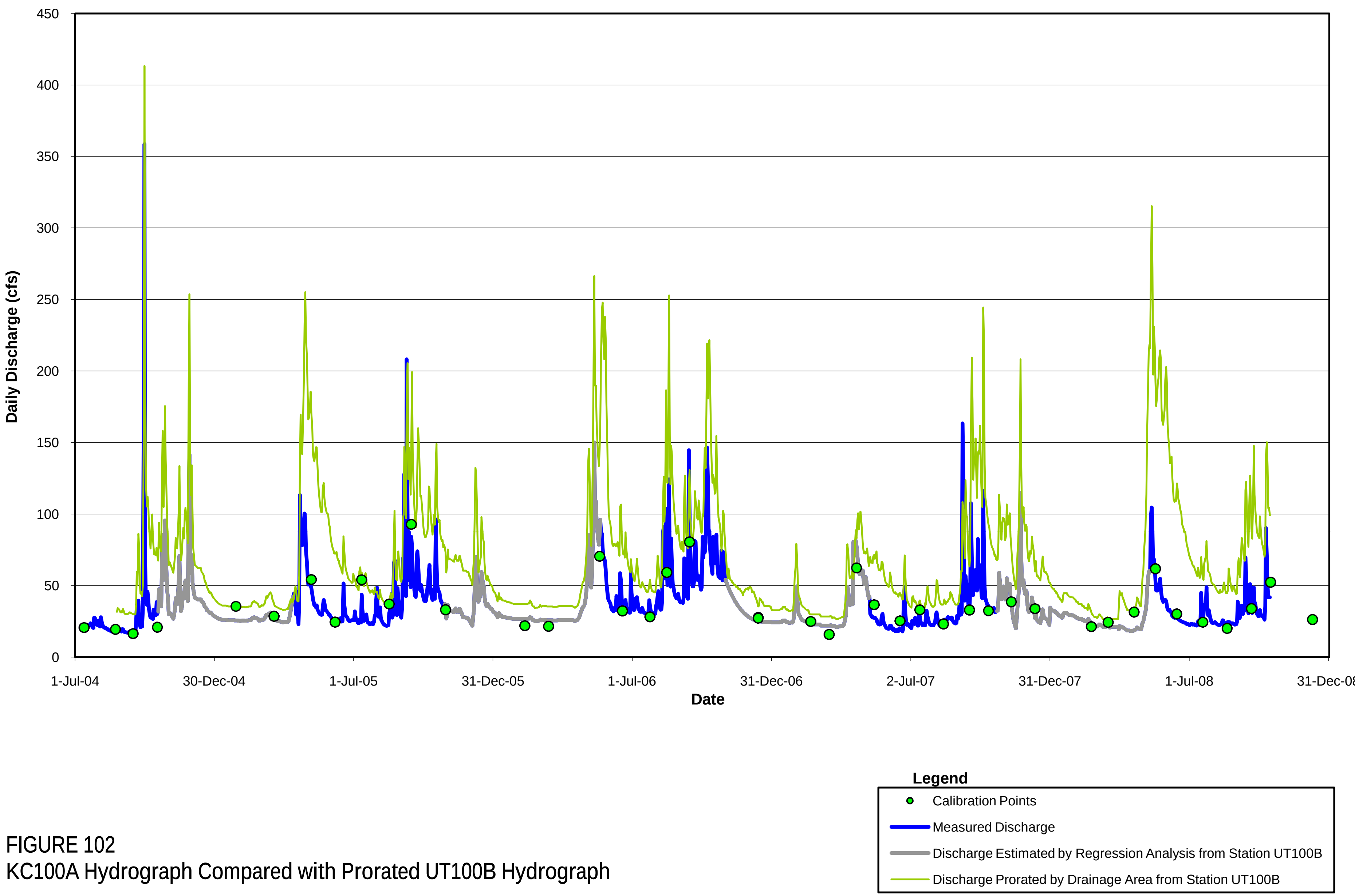


FIGURE 102
KC100A Hydrograph Compared with Prorated UT100B Hydrograph

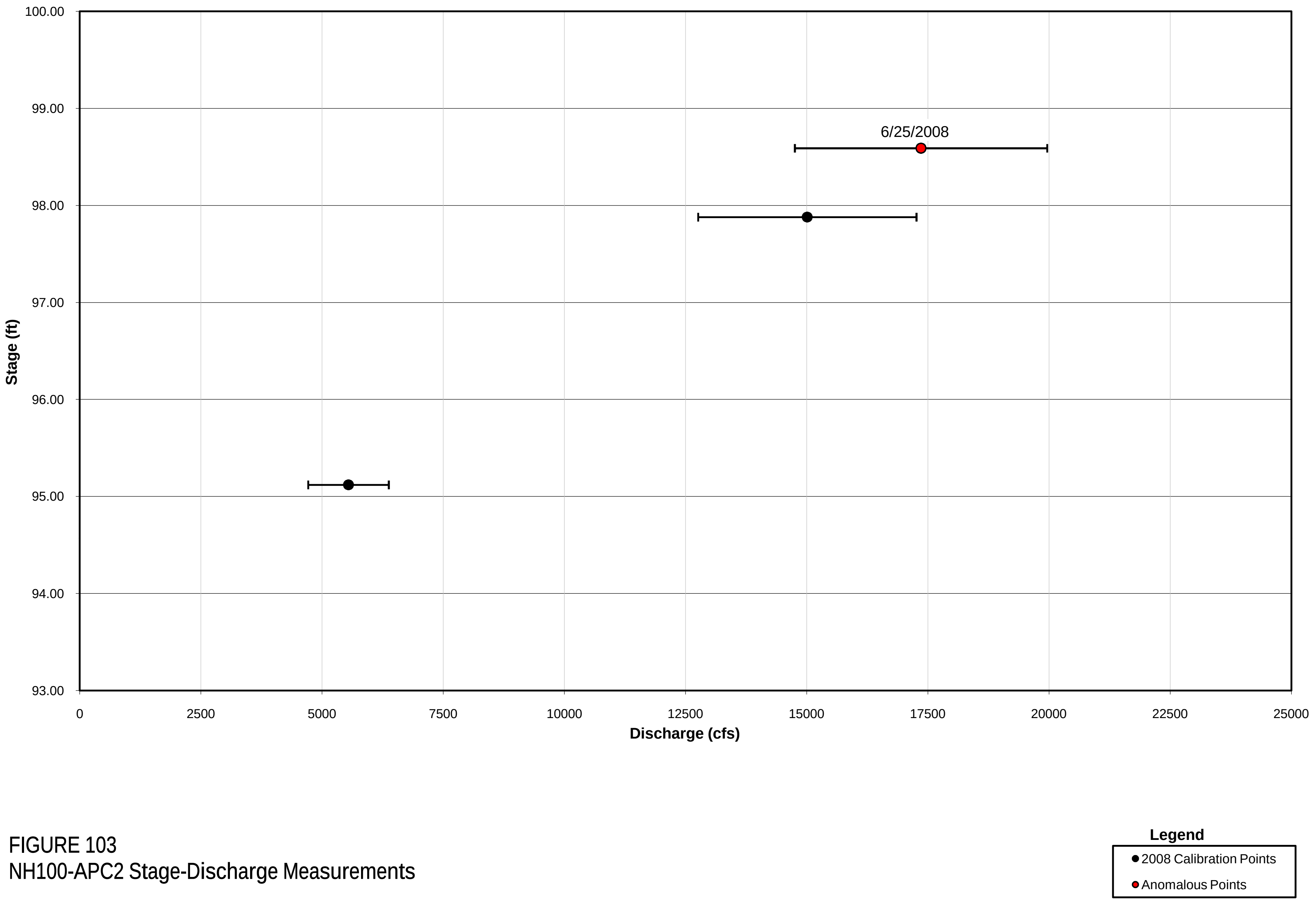


FIGURE 103
NH100-APC2 Stage-Discharge Measurements

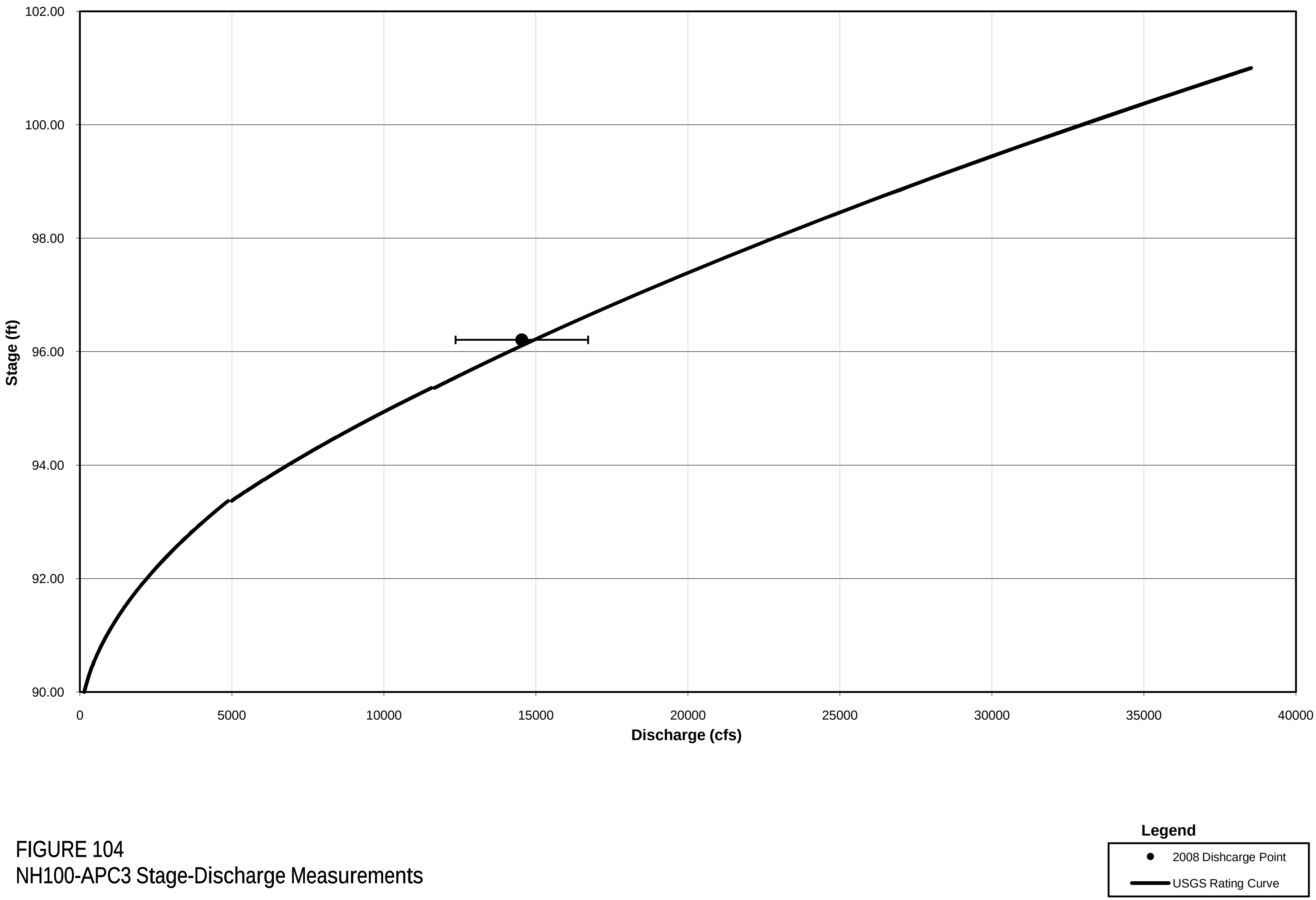


FIGURE 104
NH100-APC3 Stage-Discharge Measurements

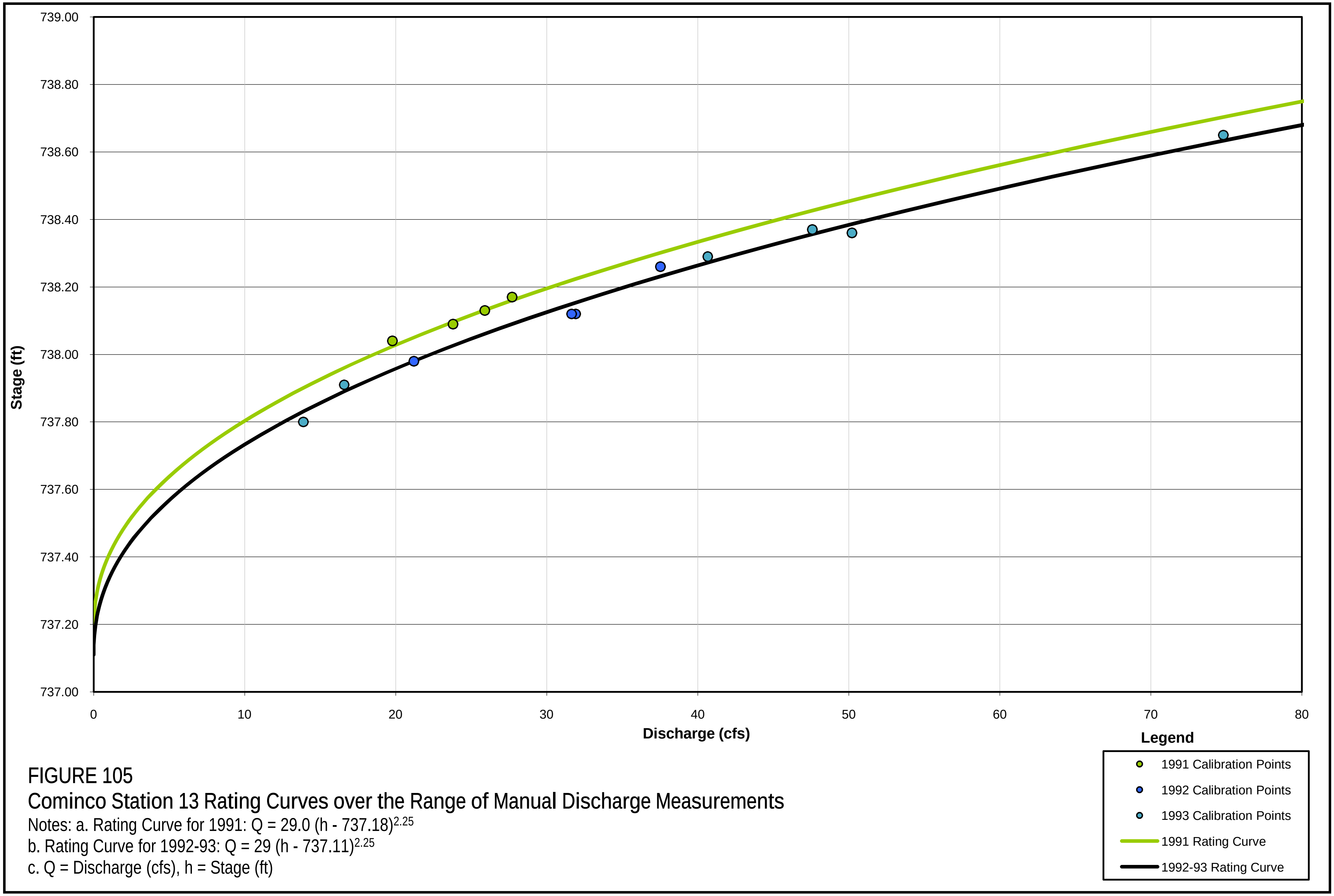


FIGURE 105

Cominco Station 13 Rating Curves over the Range of Manual Discharge Measurements

Notes: a. Rating Curve for 1991: $Q = 29.0 (h - 737.18)^{2.25}$

b. Rating Curve for 1992-93: $Q = 29 (h - 737.11)^{2.25}$

c. Q = Discharge (cfs), h = Stage (ft)

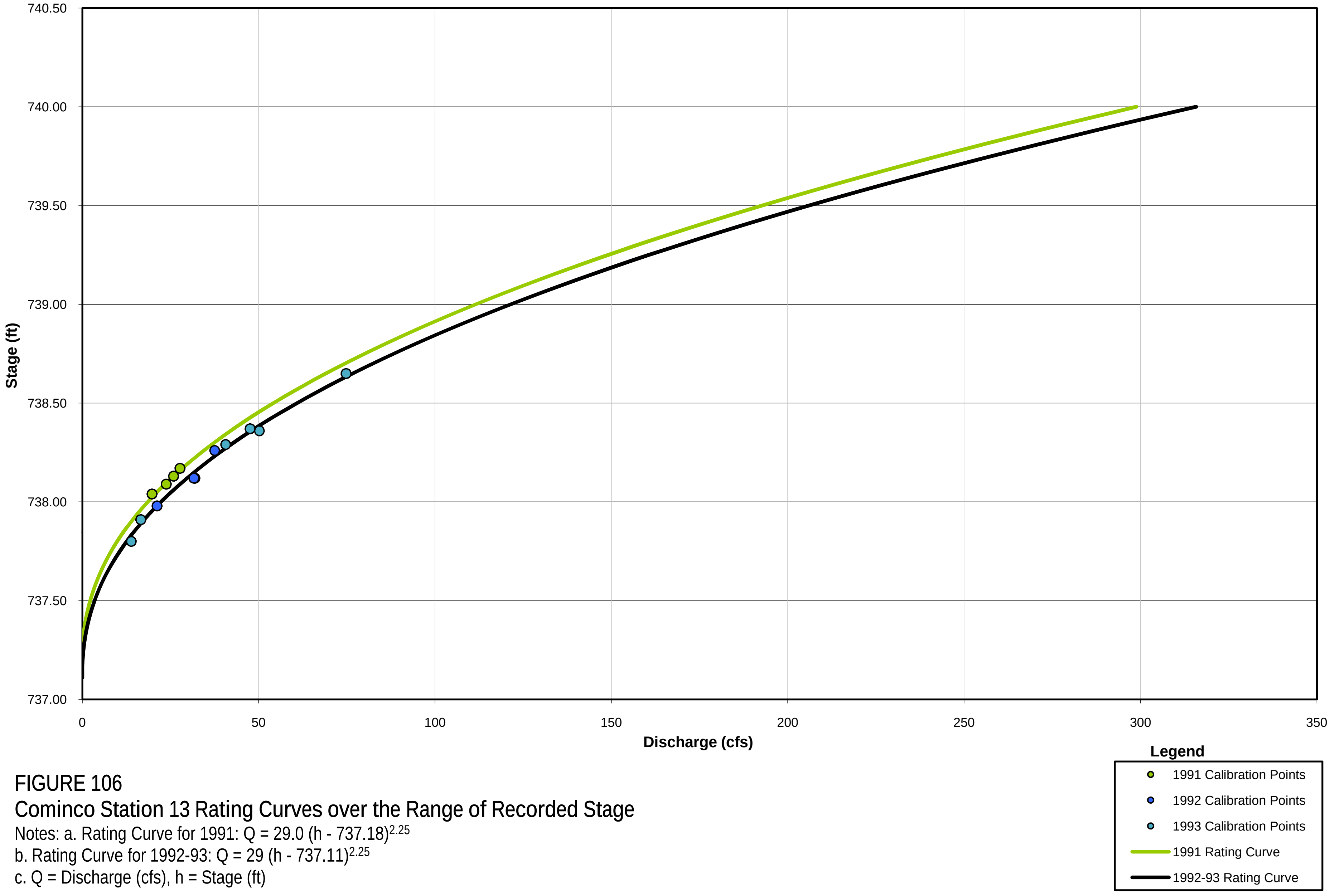


FIGURE 106
Cominco Station 13 Rating Curves over the Range of Recorded Stage
Notes: a. Rating Curve for 1991: $Q = 29.0 (h - 737.18)^{2.25}$
b. Rating Curve for 1992-93: $Q = 29 (h - 737.11)^{2.25}$
c. Q = Discharge (cfs), h = Stage (ft)

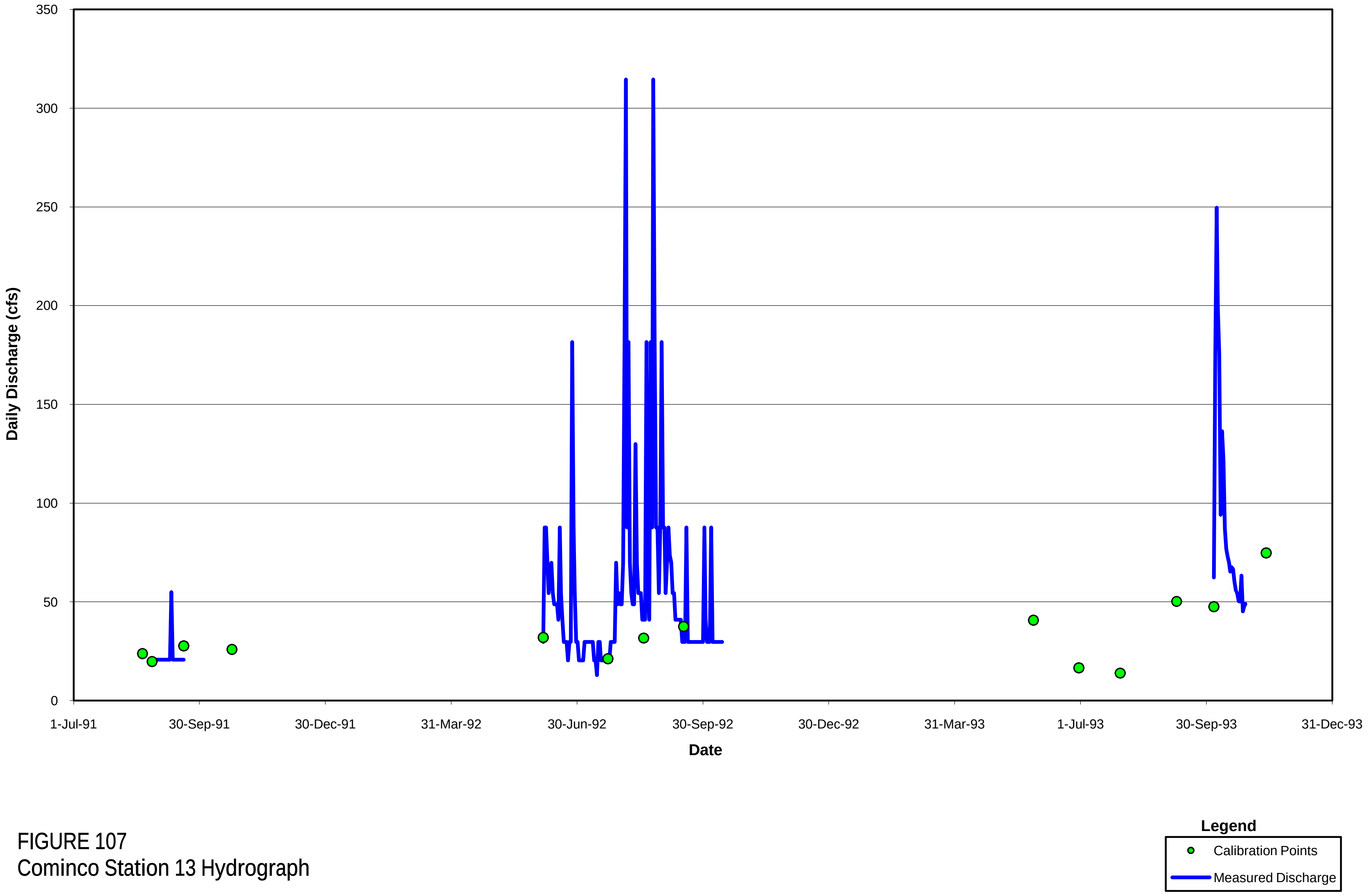


FIGURE 107
Cominco Station 13 Hydrograph

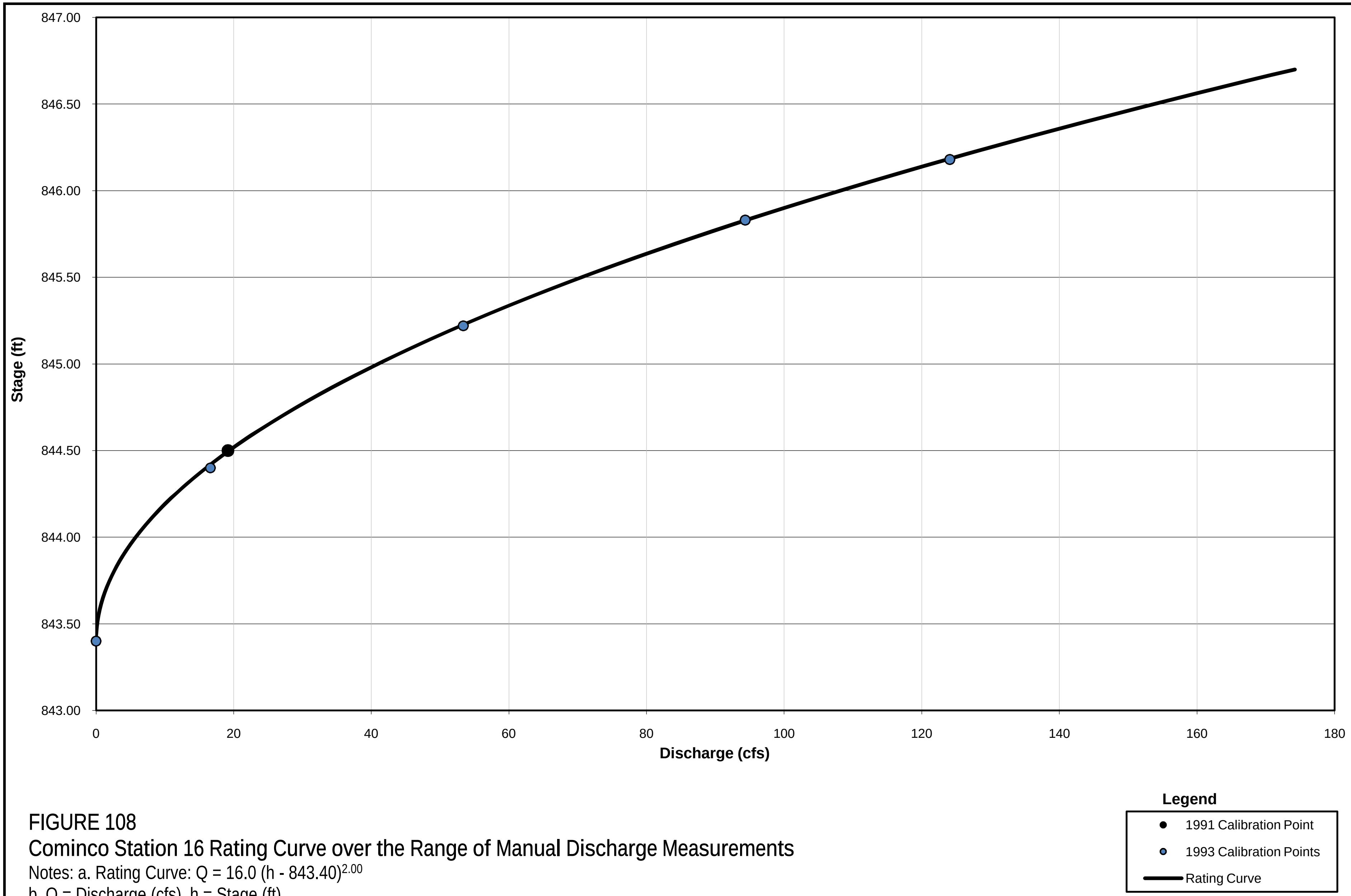


FIGURE 108

Cominco Station 16 Rating Curve over the Range of Manual Discharge Measurements

Notes: a. Rating Curve: $Q = 16.0 (h - 843.40)^{2.00}$

b. Q = Discharge (cfs), h = Stage (ft)

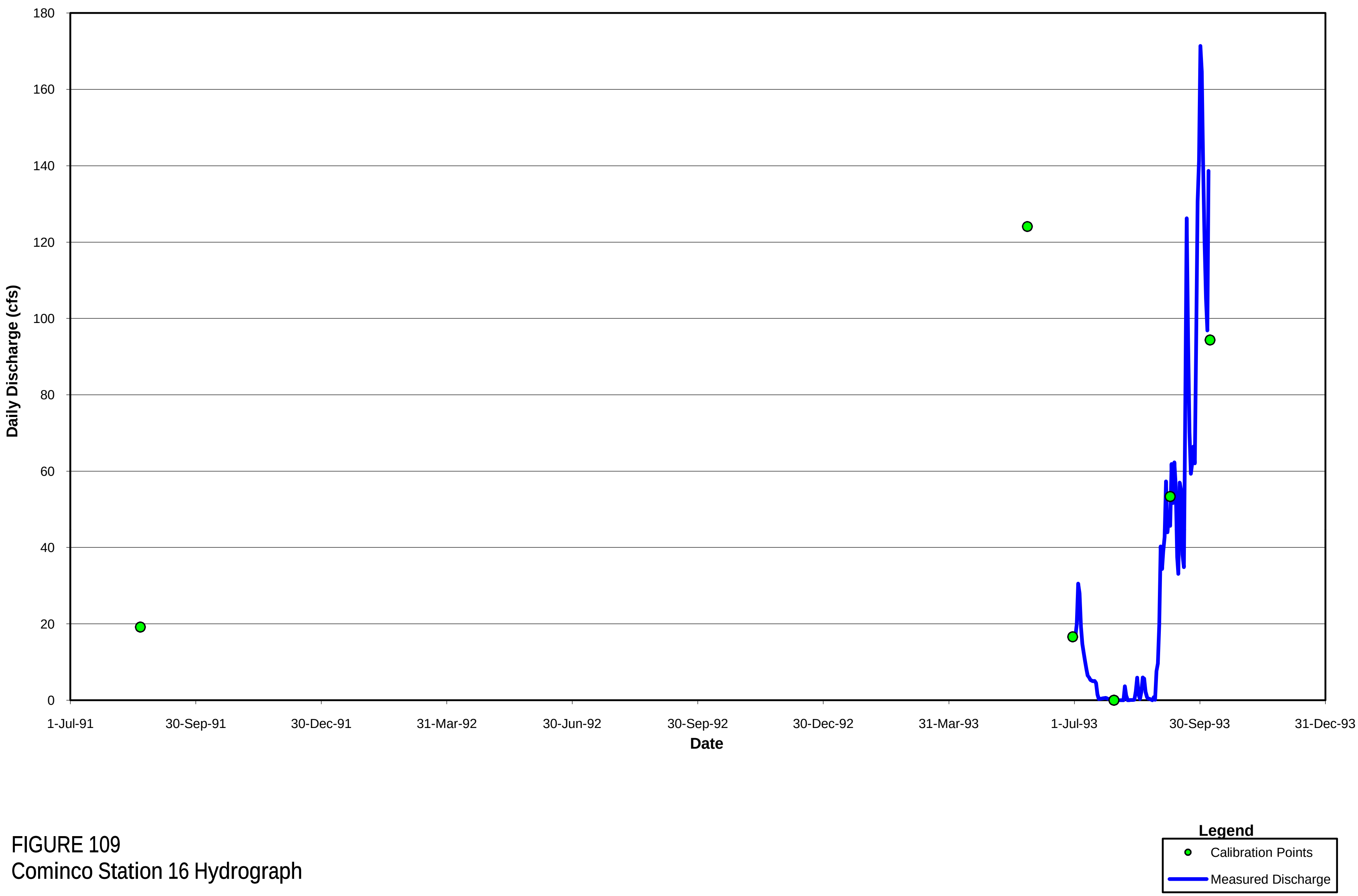


FIGURE 109
Cominco Station 16 Hydrograph

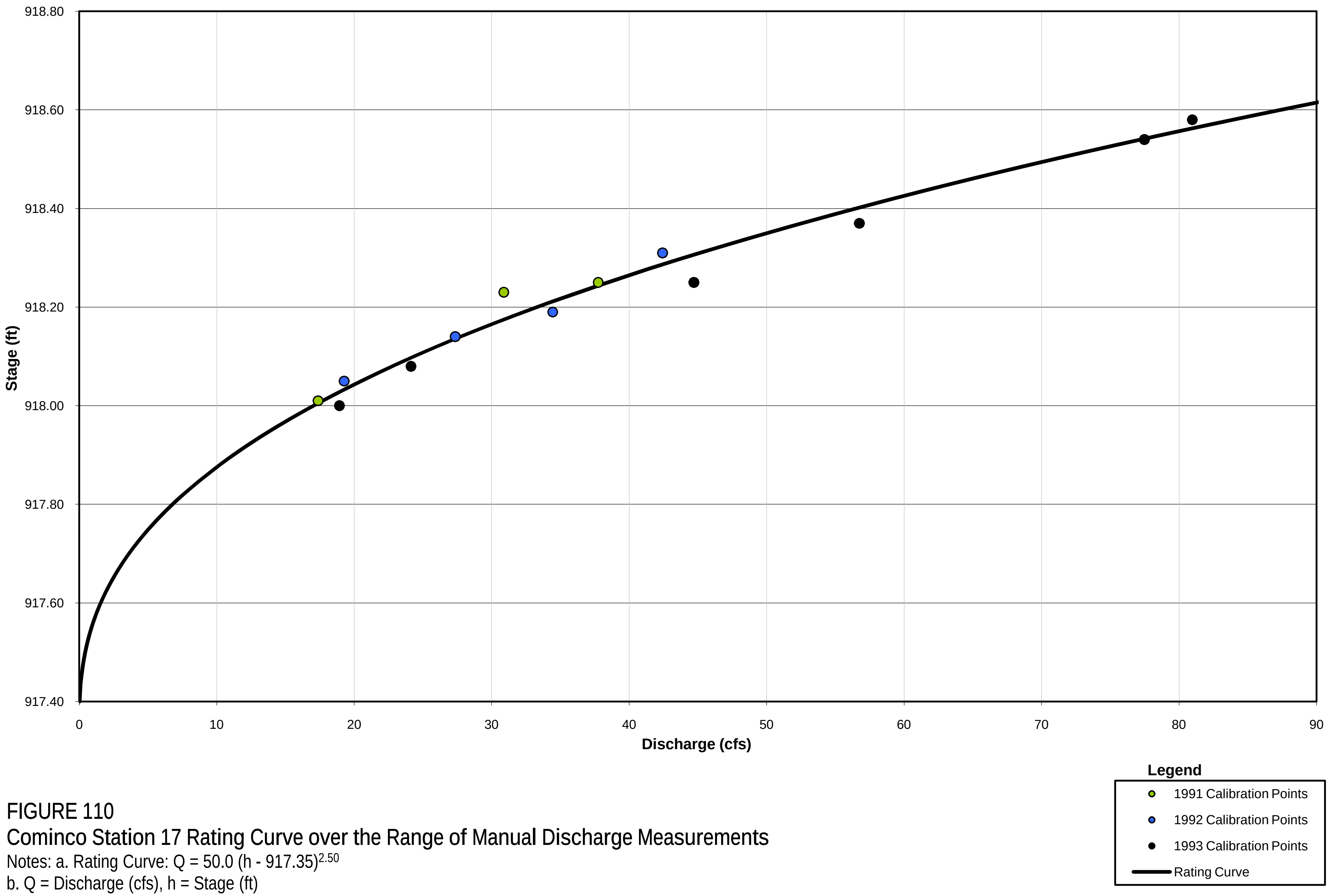


FIGURE 110

Cominco Station 17 Rating Curve over the Range of Manual Discharge Measurements

Notes: a. Rating Curve: $Q = 50.0 (h - 917.35)^{2.50}$

b. Q = Discharge (cfs), h = Stage (ft)

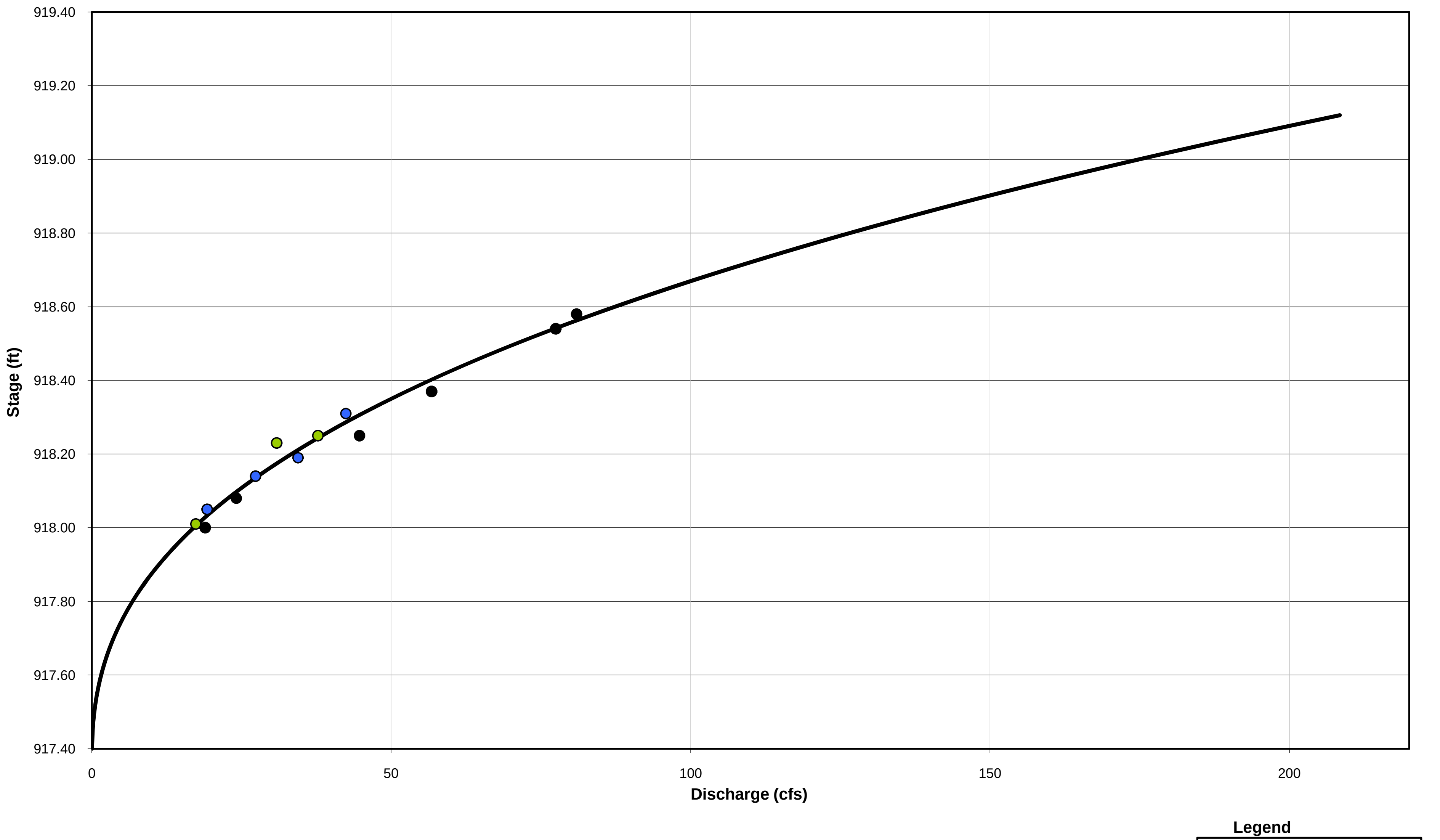


FIGURE 111
Cominco Station 17 Rating Curve over the Range of Recorded Stage
Notes: a. Rating Curve: $Q = 50.0 (h - 917.35)^{2.50}$
b. Q = Discharge (cfs), h = Stage (ft)

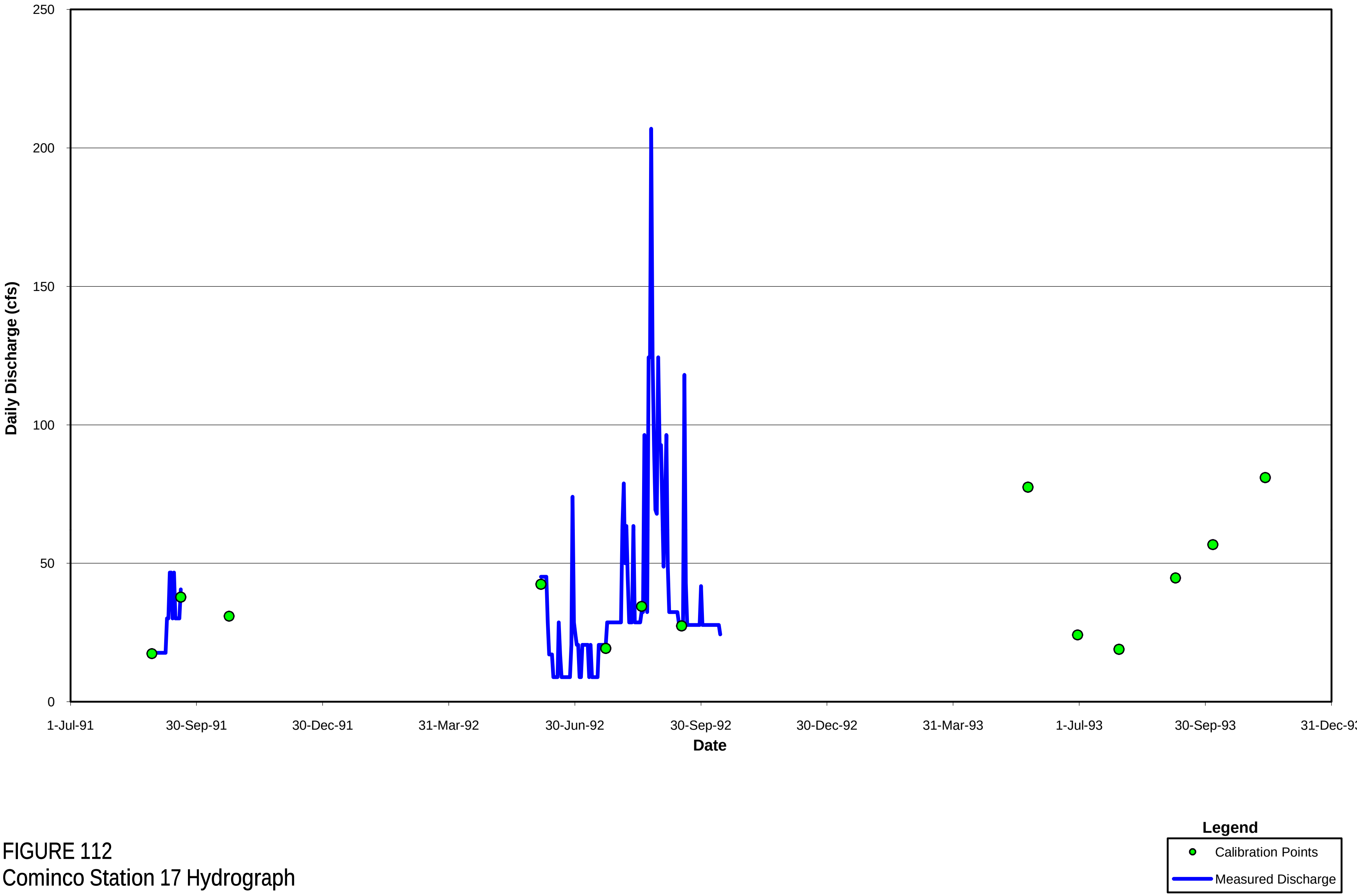


FIGURE 112
Cominco Station 17 Hydrograph

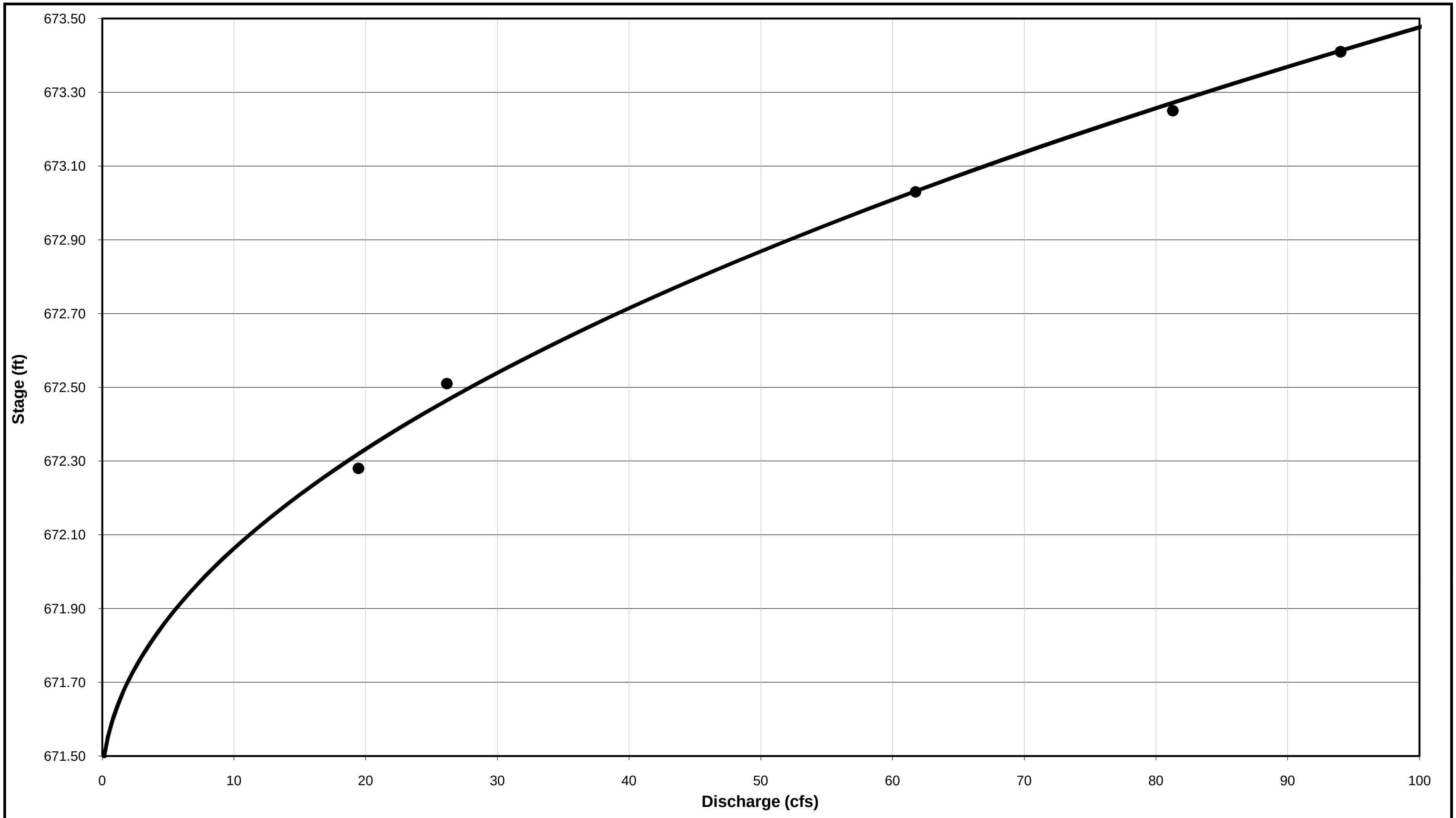


FIGURE 113

Cominco Station 19 Rating Curve over the Range of Manual Discharge Measurements

Notes: a. Rating Curve: $Q = 24.0 (h - 671.42)^{1.98}$

b. Q = Discharge (cfs), h = Stage (ft)

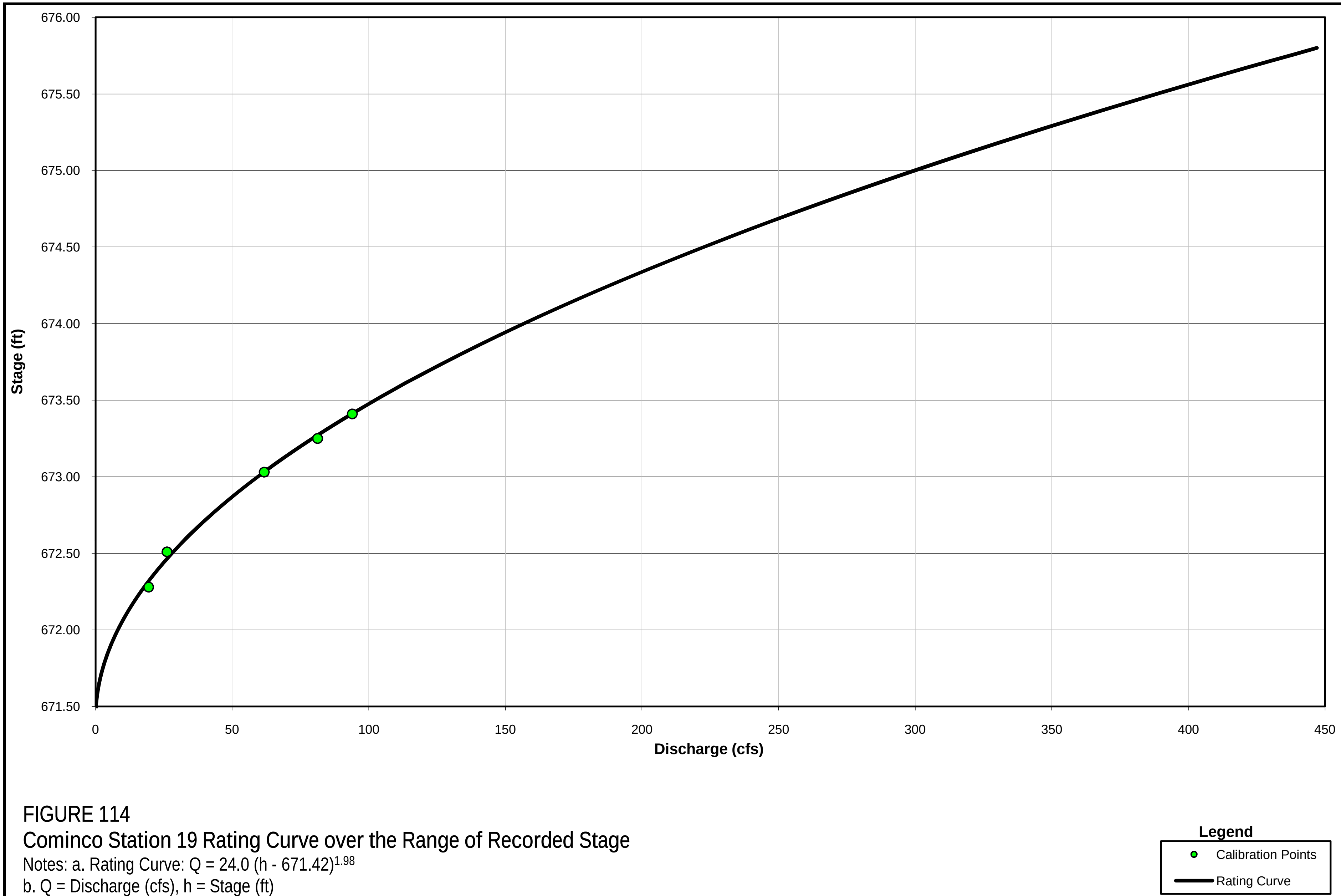


FIGURE 114

Cominco Station 19 Rating Curve over the Range of Recorded Stage

Notes: a. Rating Curve: $Q = 24.0 (h - 671.42)^{1.98}$

b. Q = Discharge (cfs), h = Stage (ft)

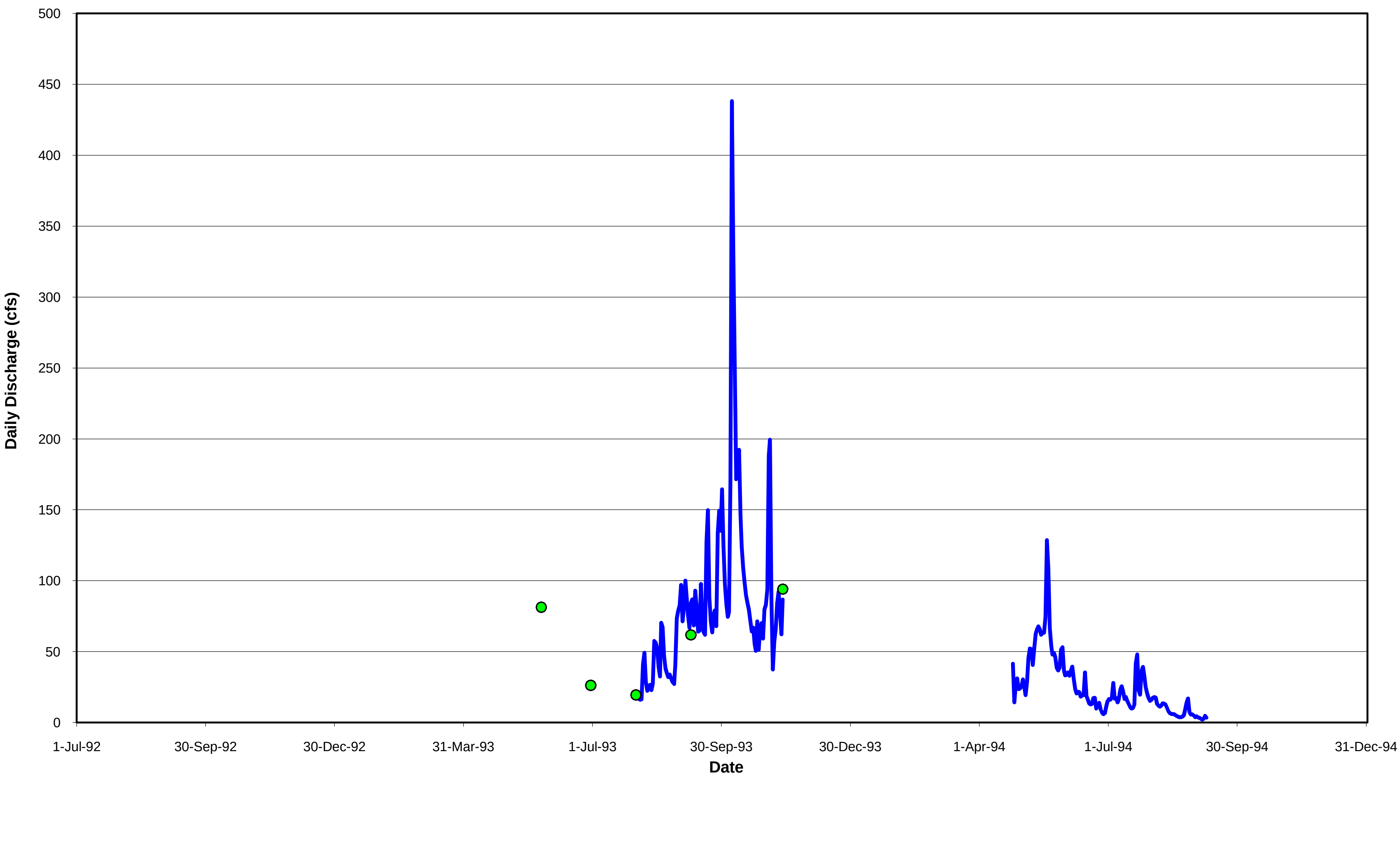


FIGURE 115
Cominco Station 19 Hydrograph

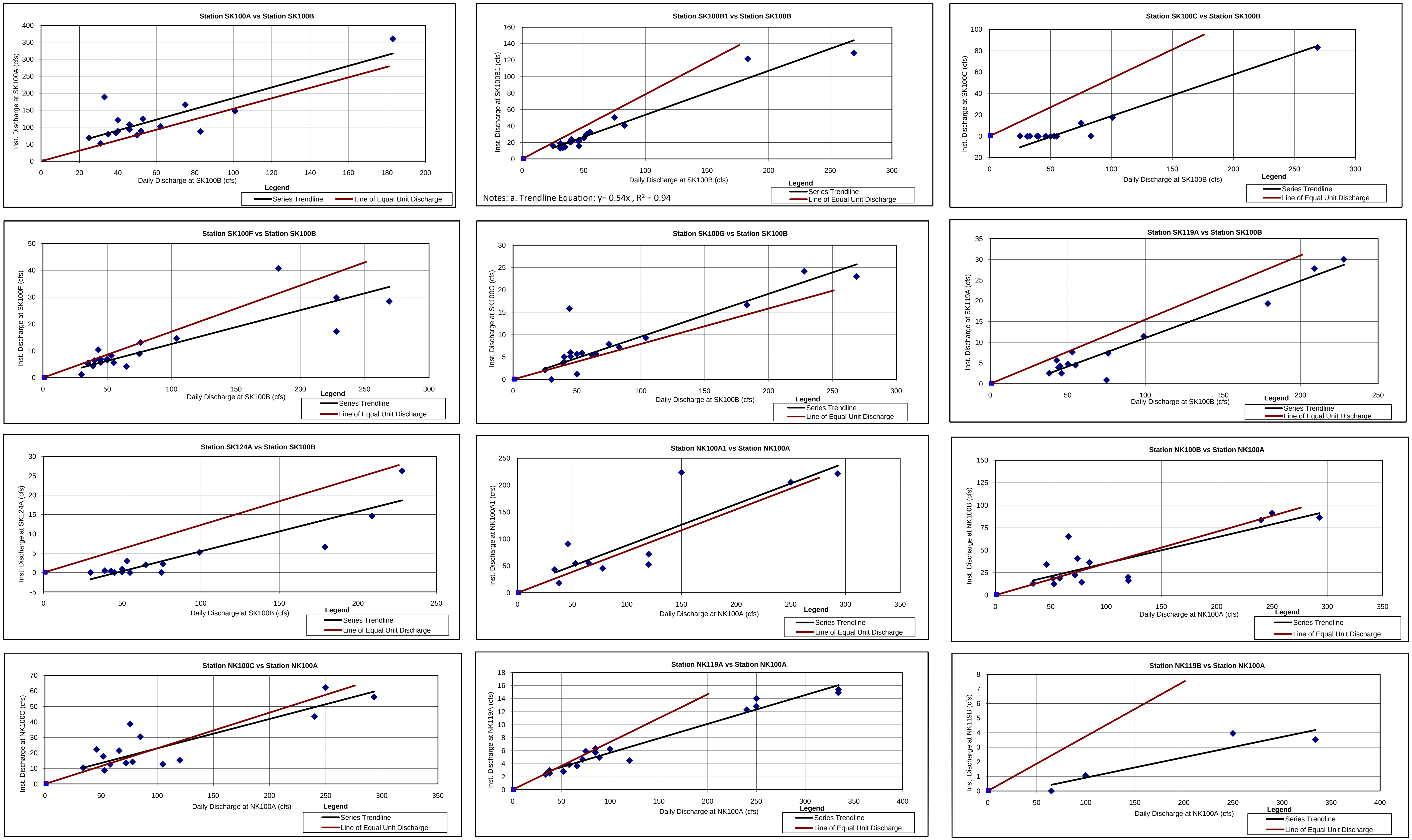


FIGURE 116

Winter Regression Analysis of Instantaneous Discharge at SK and NK Stations versus Daily Discharge at Stations SK100B and NK100A

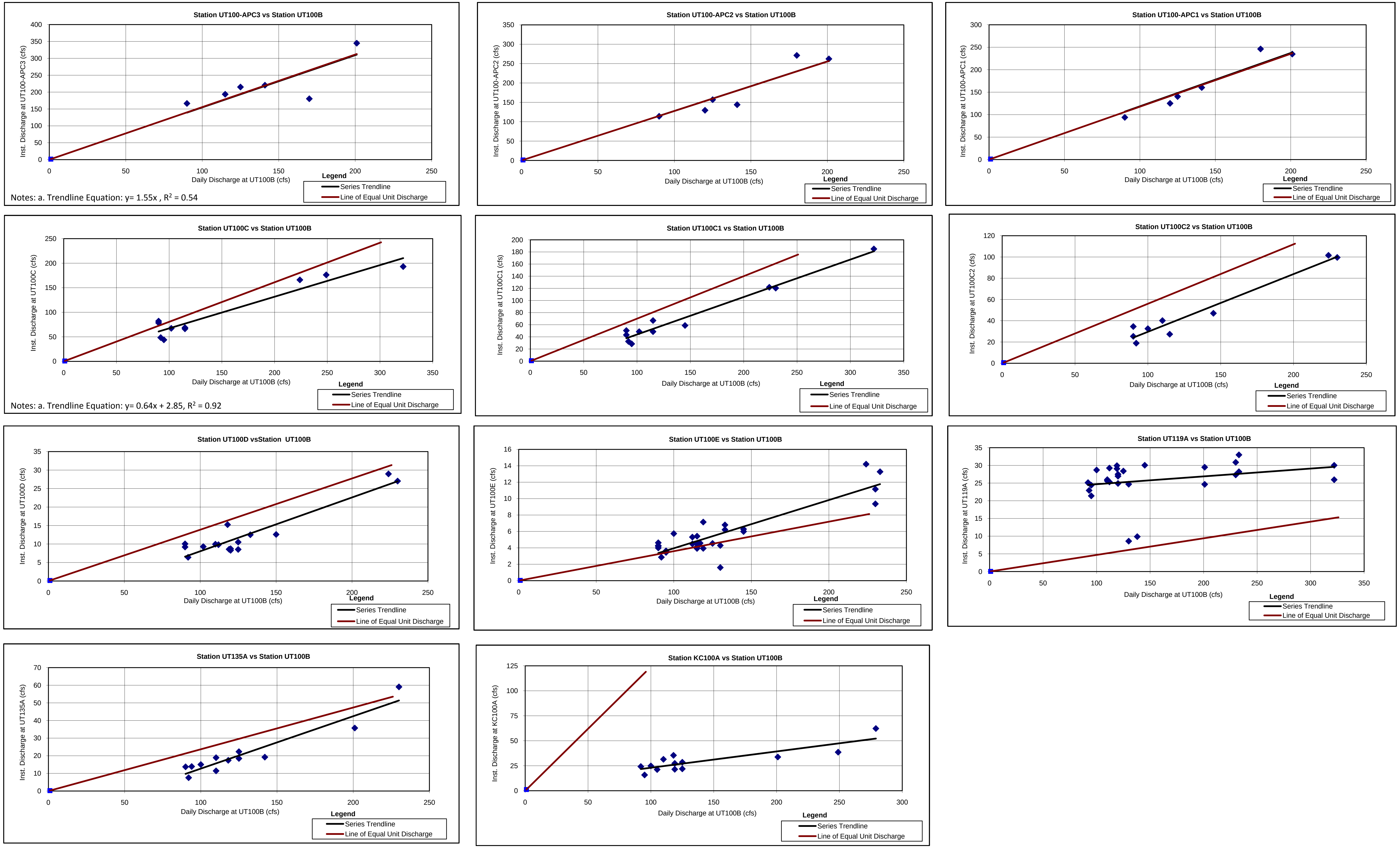


FIGURE 117

Winter Regression Analysis of Instantaneous Discharge at UT and KC Stations versus Daily Discharge at Station UT100B

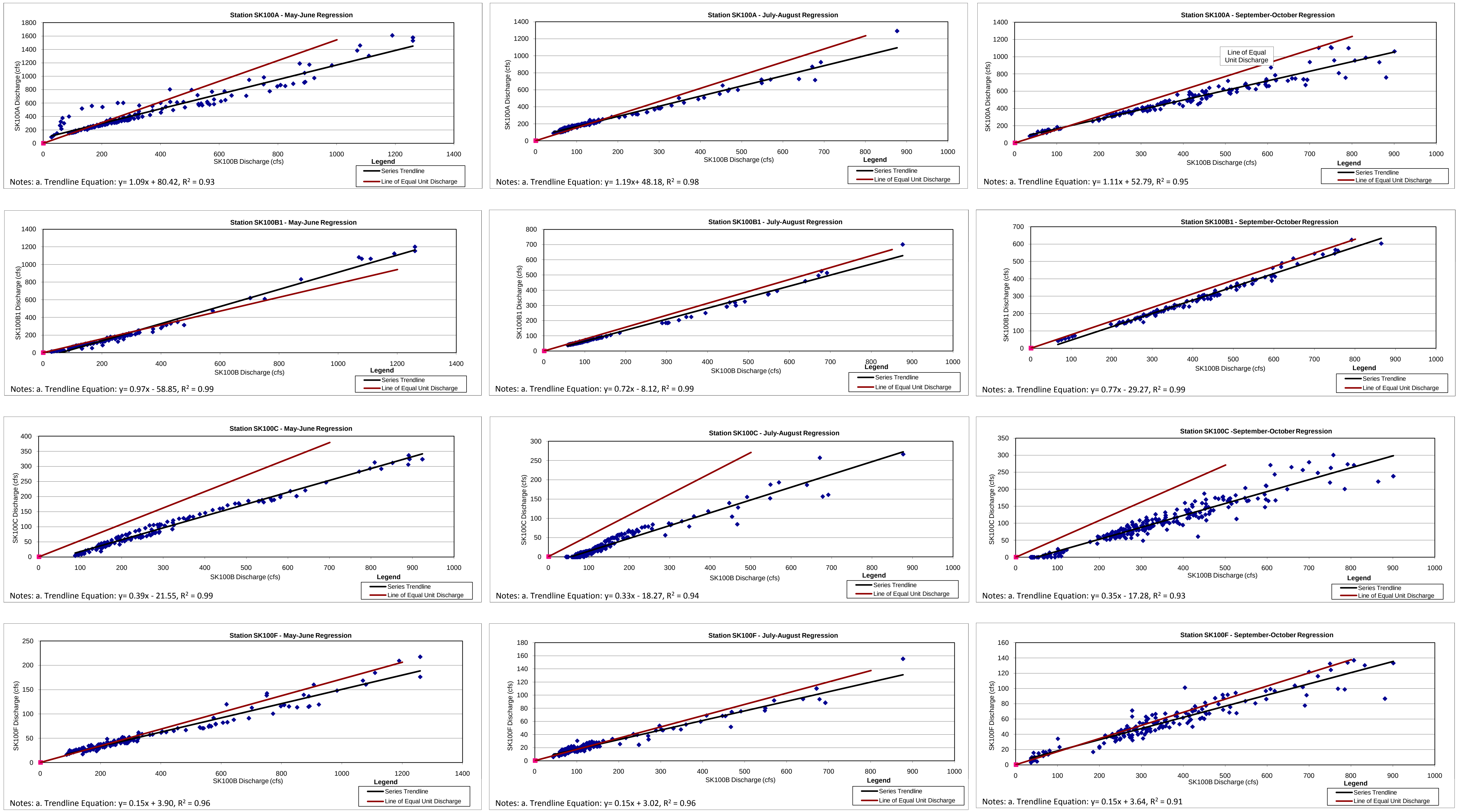


FIGURE 118

Seasonal Regression Analysis of Daily Discharge: Stations SK100A, SK100B1, SK100C, and SK100F versus Station SK100B

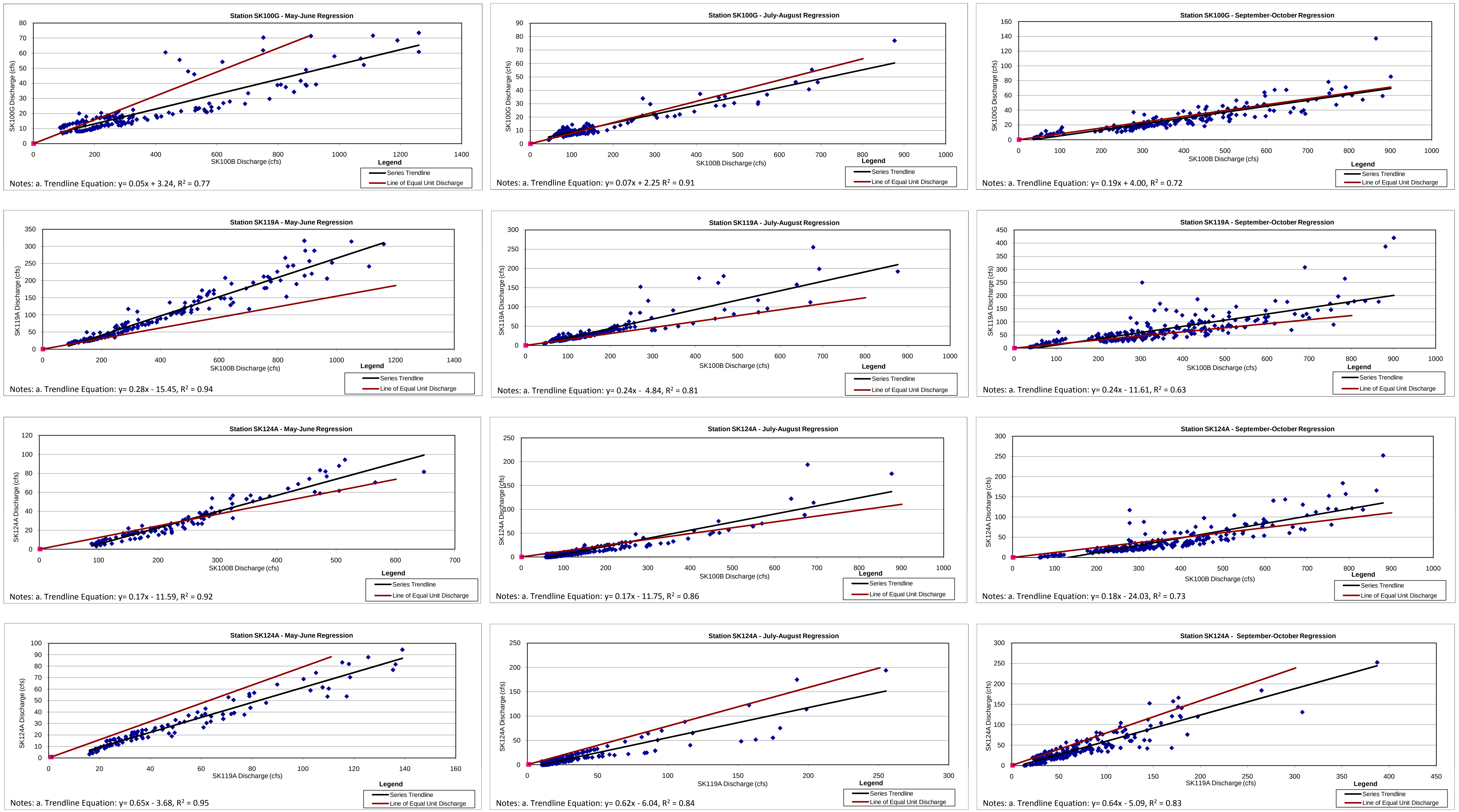


FIGURE 119

Seasonal Regression Analysis of Daily Discharge: Stations SK100G, SK119A, and SK124A versus SK100B; and SK124A versus Station SK119A

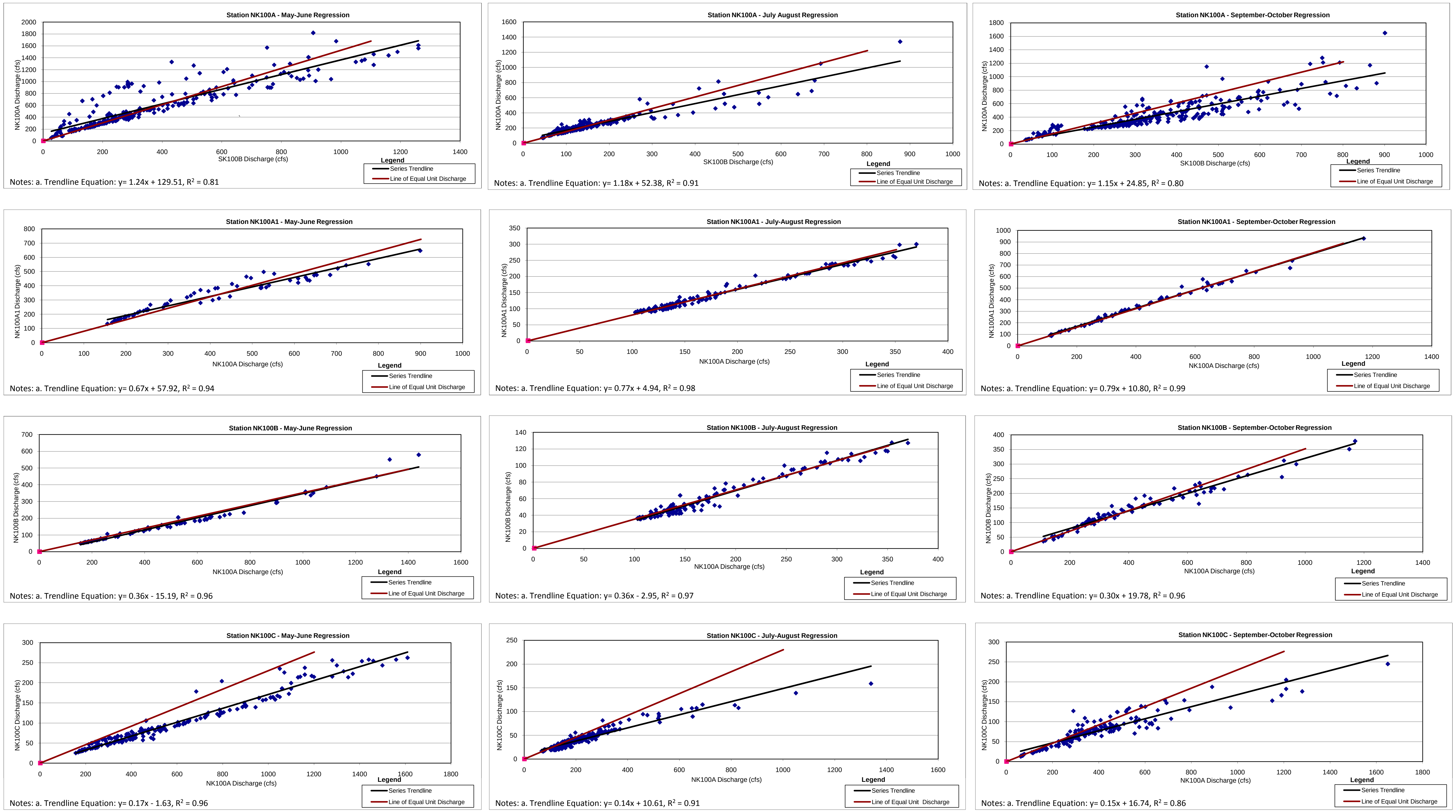


FIGURE 120

Seasonal Regression Analysis of Daily Discharge: Station NK100A versus Station SK100B; and Stations NK100A1, NK100B, and NK100C versus Station NK100A

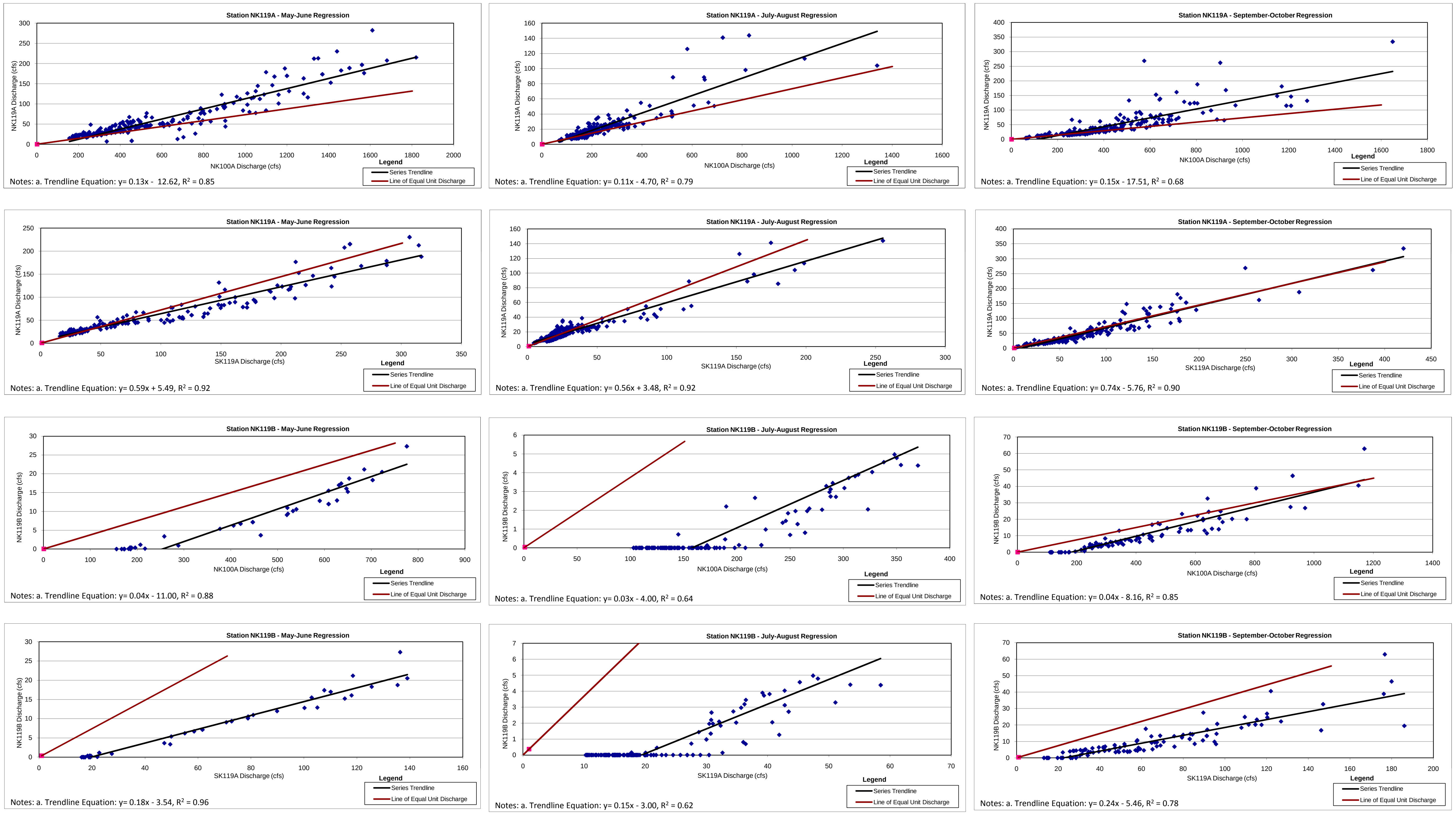


FIGURE 121

Seasonal Regression Analysis of Daily Discharge: Stations NK119A and NK119B versus Stations NK100A and SK119A

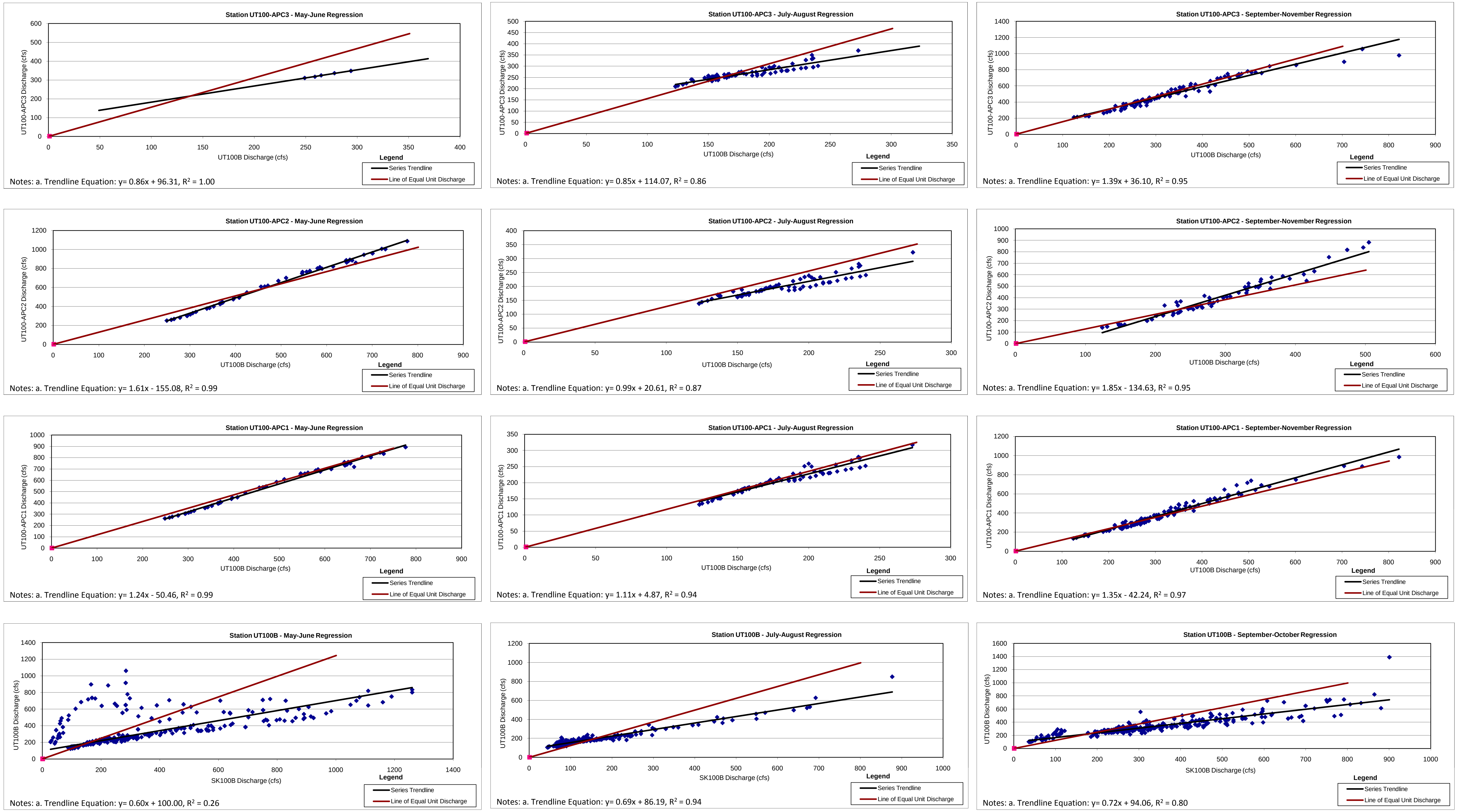


FIGURE 122

Seasonal Regression Analysis of Daily Discharge: Stations UT100-APC3, UT100-APC2, and UT100-APC1 versus UT100B; and UT100B versus Station SK100A

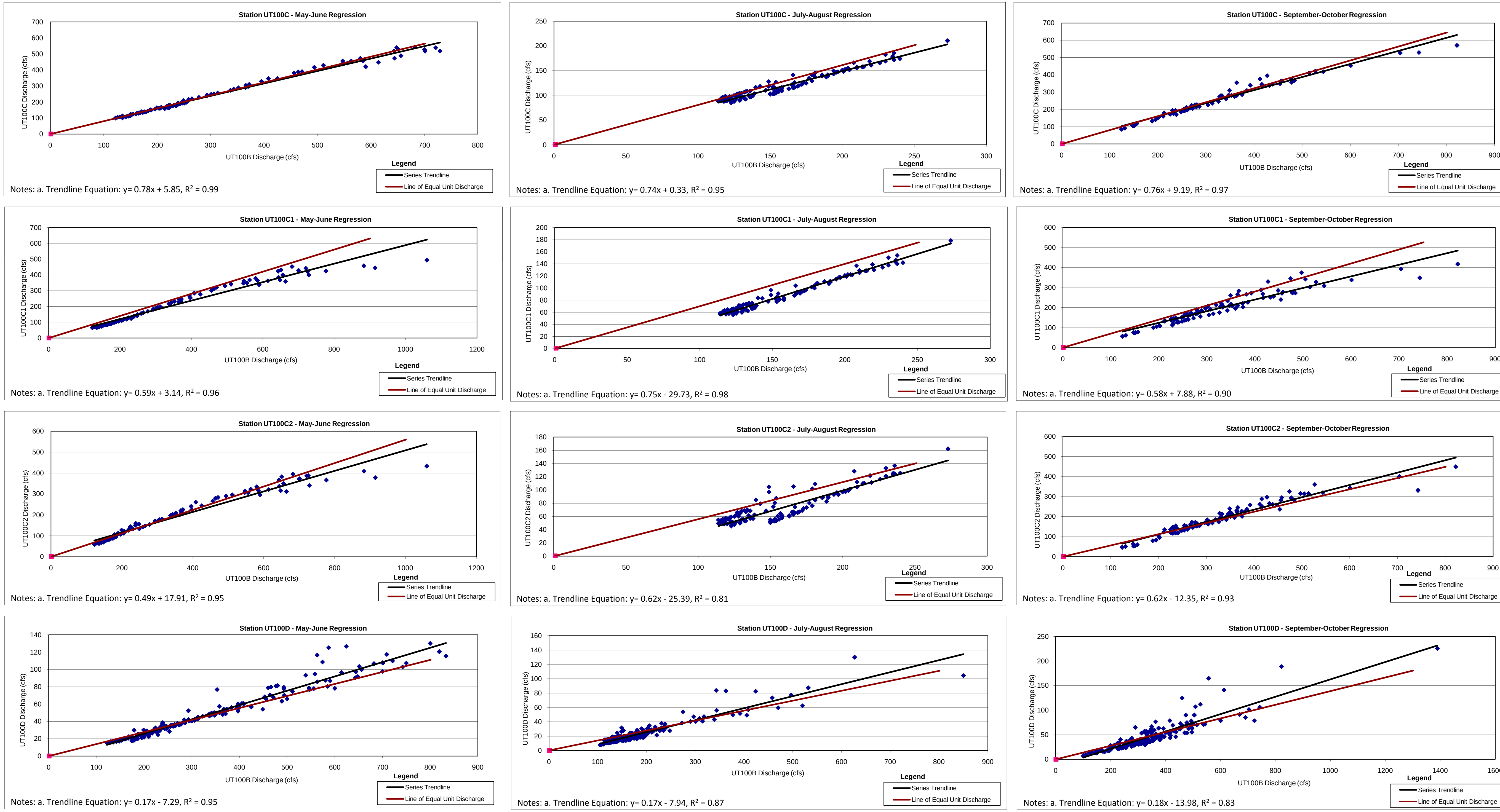


FIGURE 123

Seasonal Regression Analysis of Daily Discharge: Stations UT100C, UT100C1, UT100C2, and UT100D versus Station UT100B

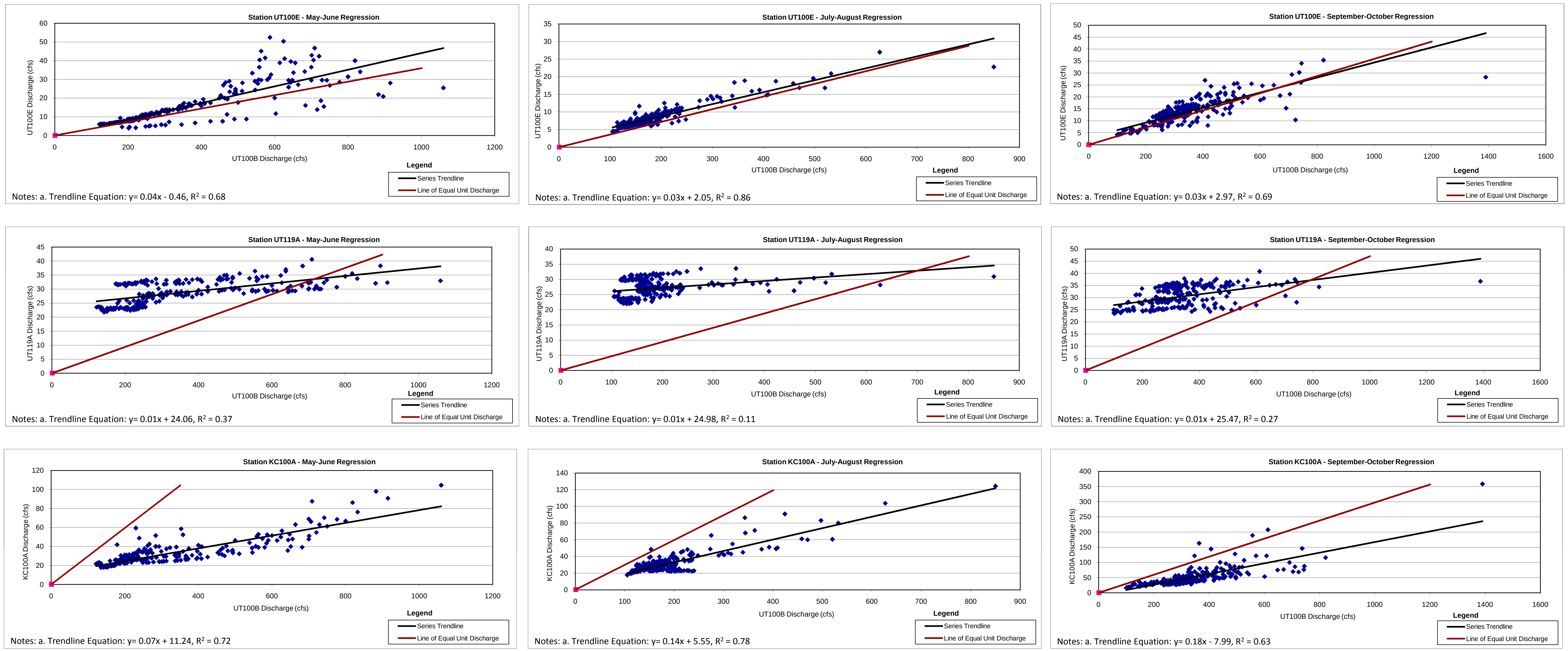


FIGURE 124

Seasonal Regression Analysis of Daily Discharge: Stations UT100E, UT119A, and KC100A versus Station UT100B

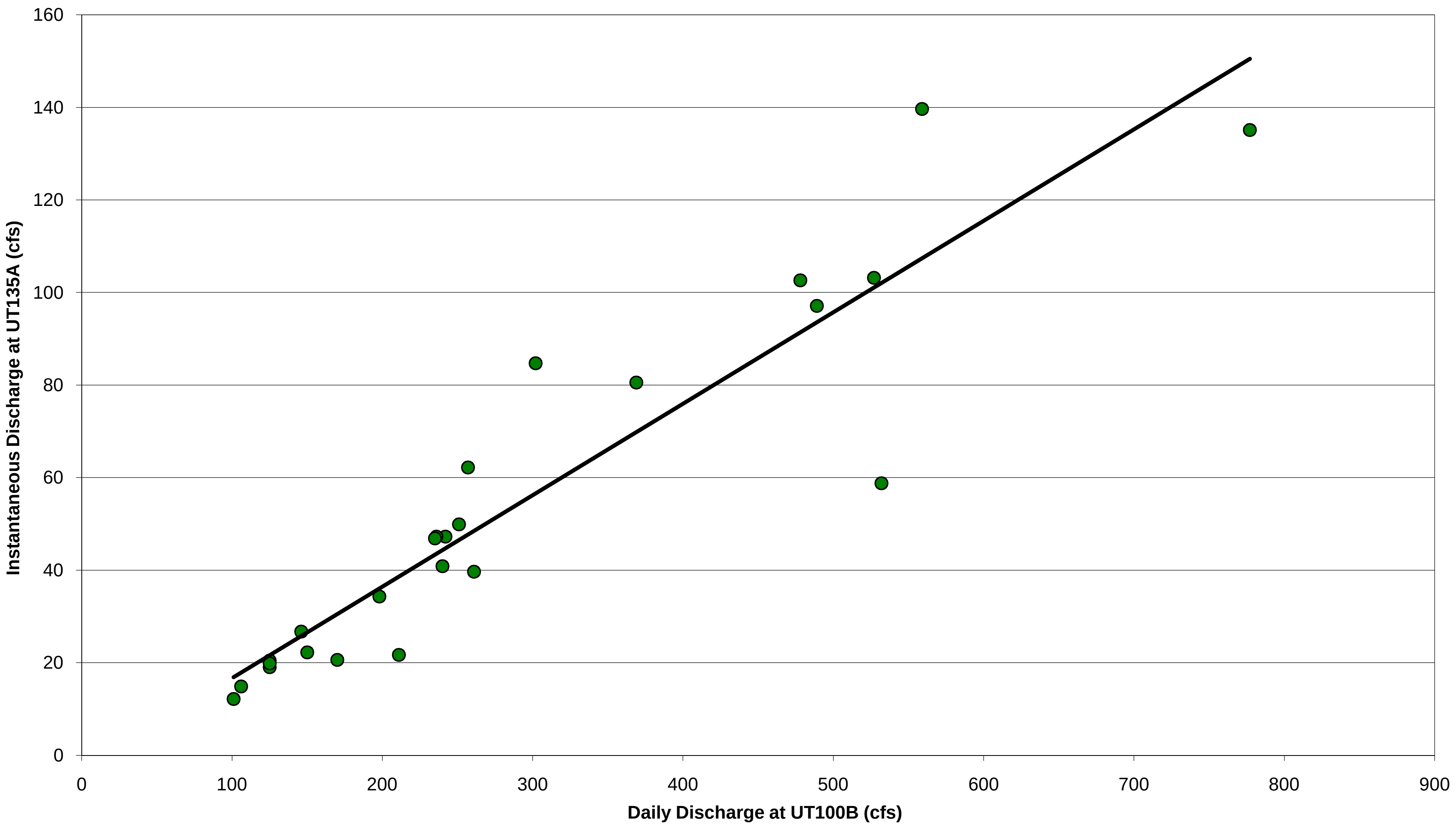


FIGURE 125

May to October Regression Analysis of Instantaneous Discharge at UT135A versus Daily Discharge at UT100B

Notes: a. Regression Equation: Qi = 0.1977*Qd - 3.1241, Coefficient of Determination of Regression Equation: R^2 = 0.8529

b. Qi = Instantaneous Discharge (cfs), Qd = Daily Discharge (cfs)

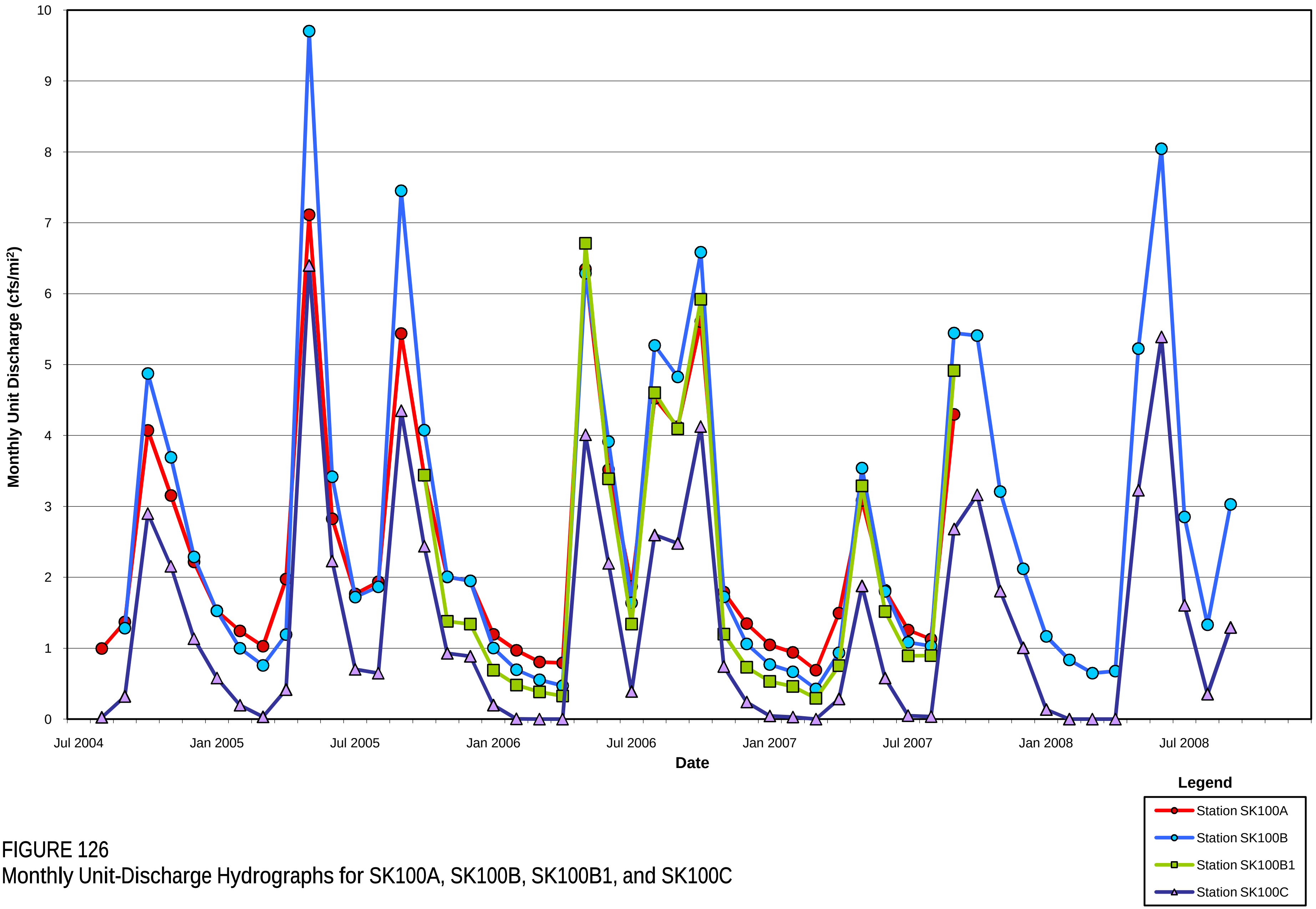


FIGURE 126
Monthly Unit-Discharge Hydrographs for SK100A, SK100B, SK100B1, and SK100C

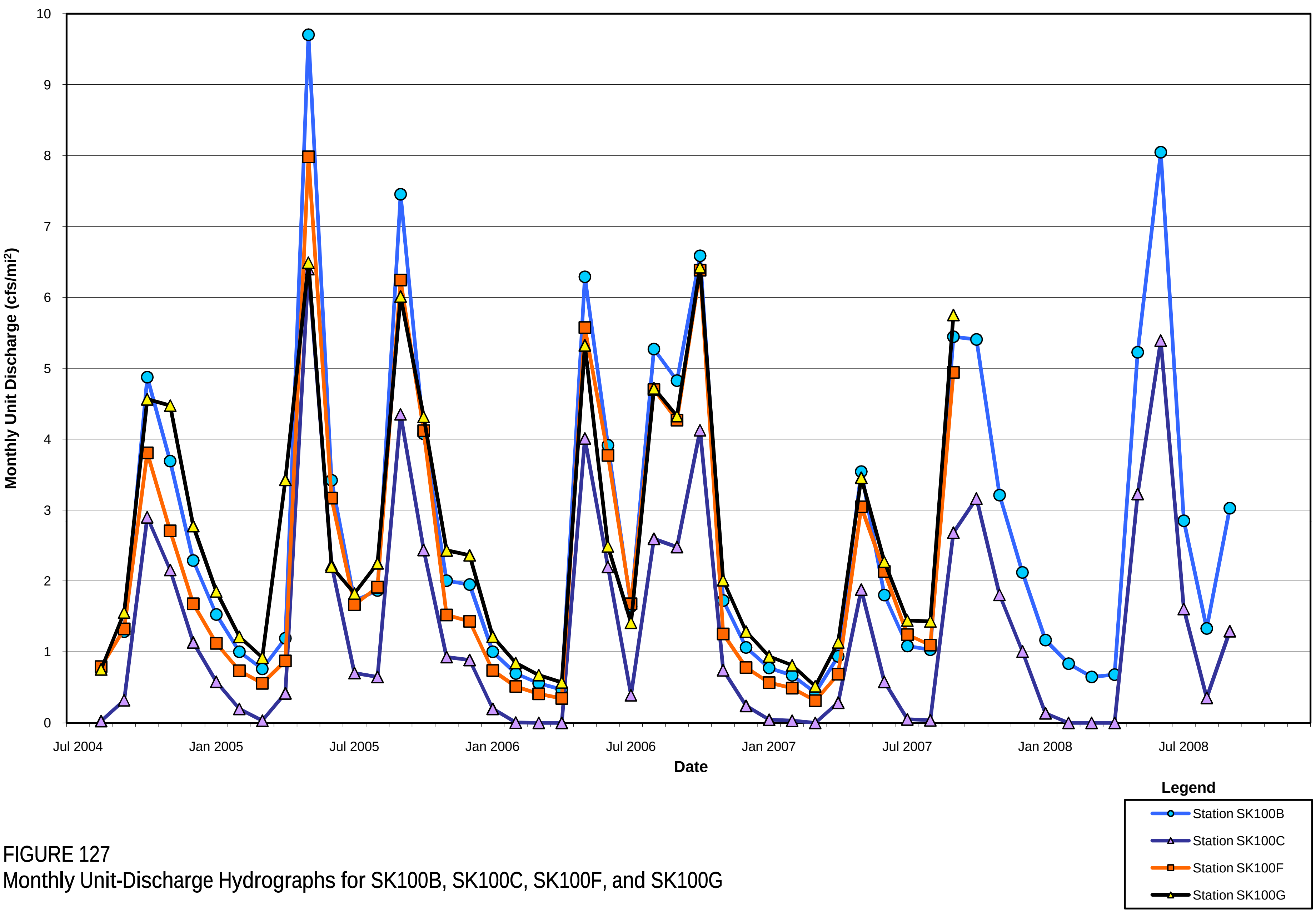


FIGURE 127
Monthly Unit-Discharge Hydrographs for SK100B, SK100C, SK100F, and SK100G

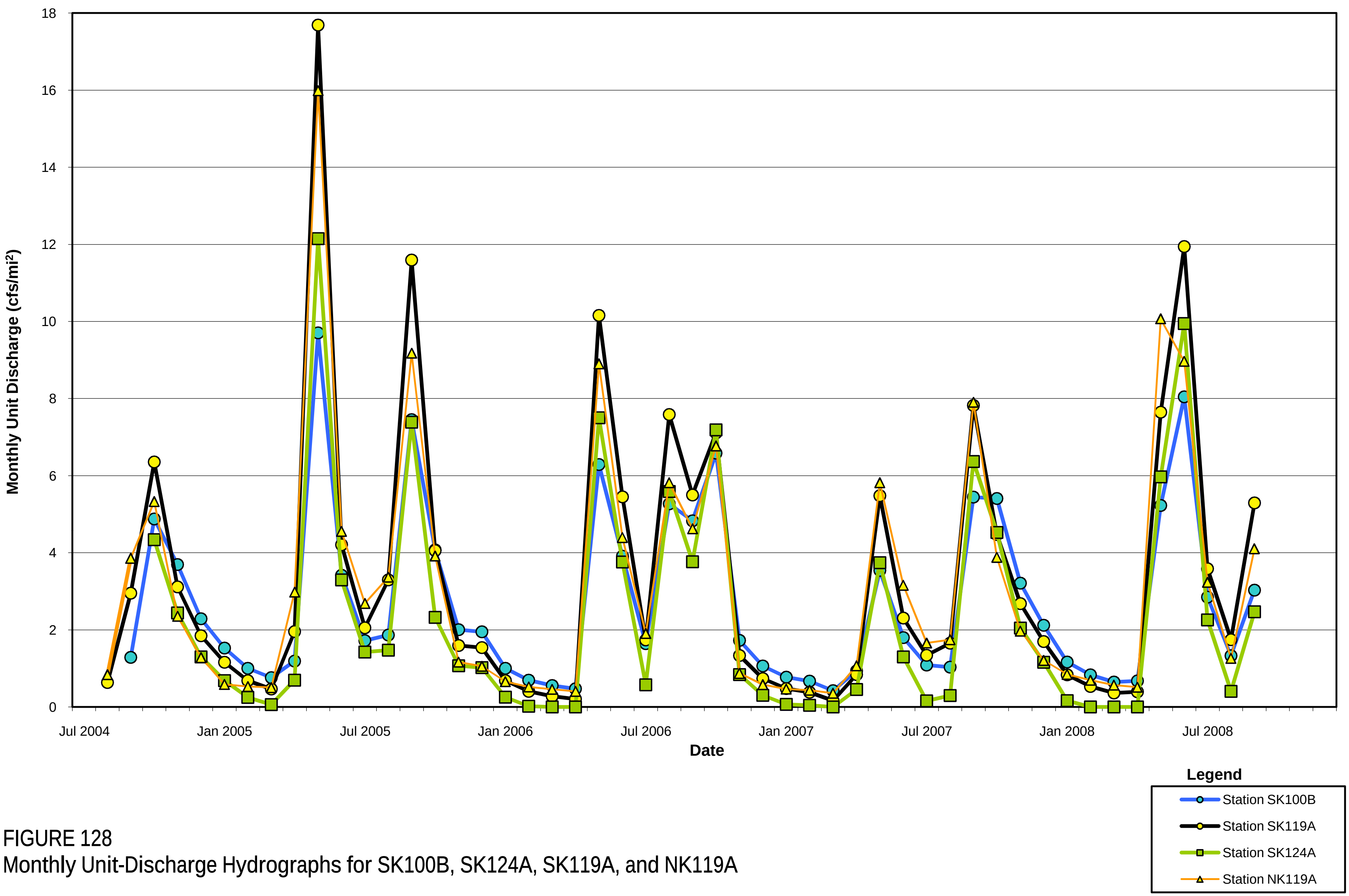


FIGURE 128
Monthly Unit-Discharge Hydrographs for SK100B, SK124A, SK119A, and NK119A

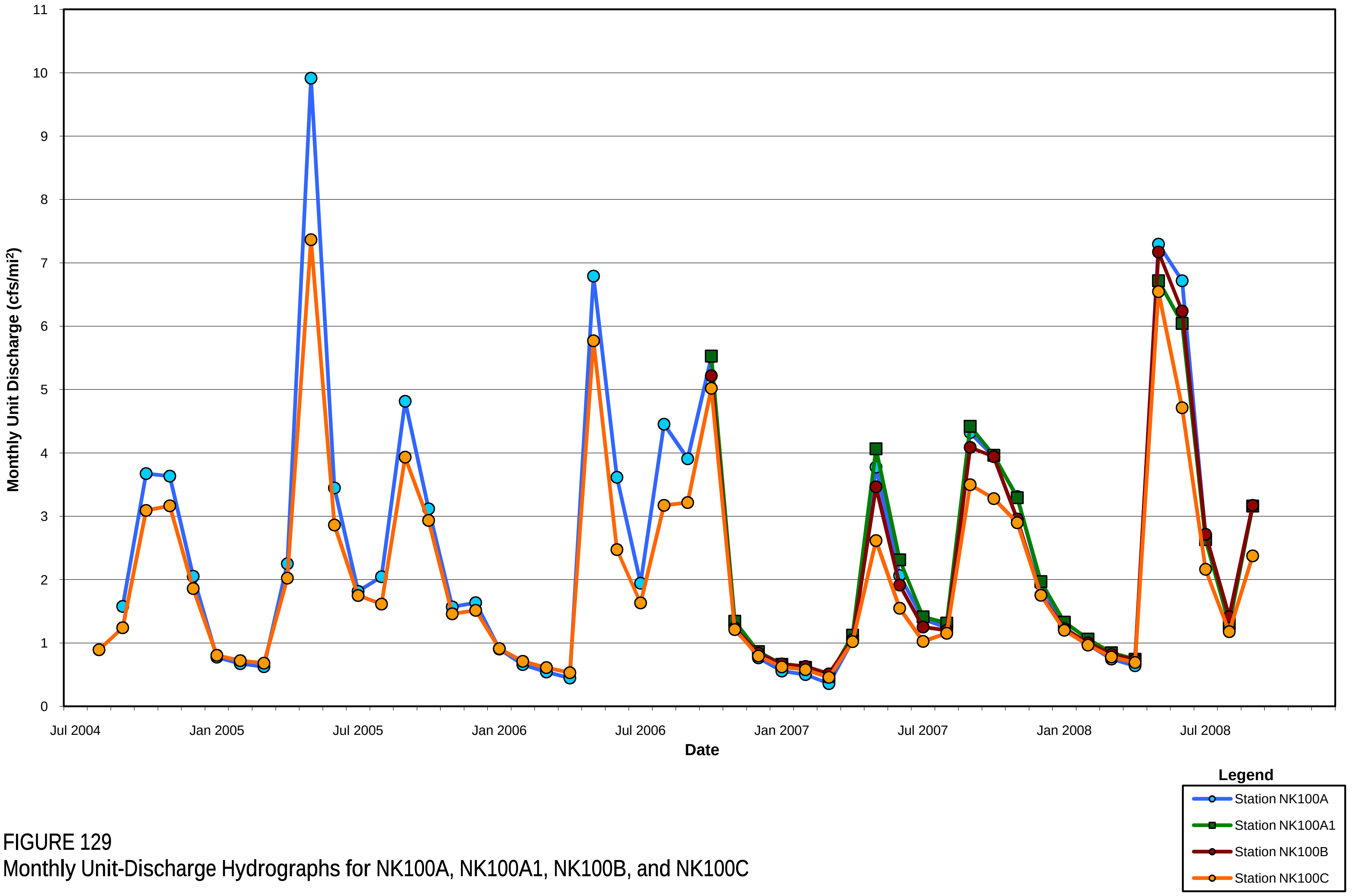


FIGURE 129
Monthly Unit-Discharge Hydrographs for NK100A, NK100A1, NK100B, and NK100C

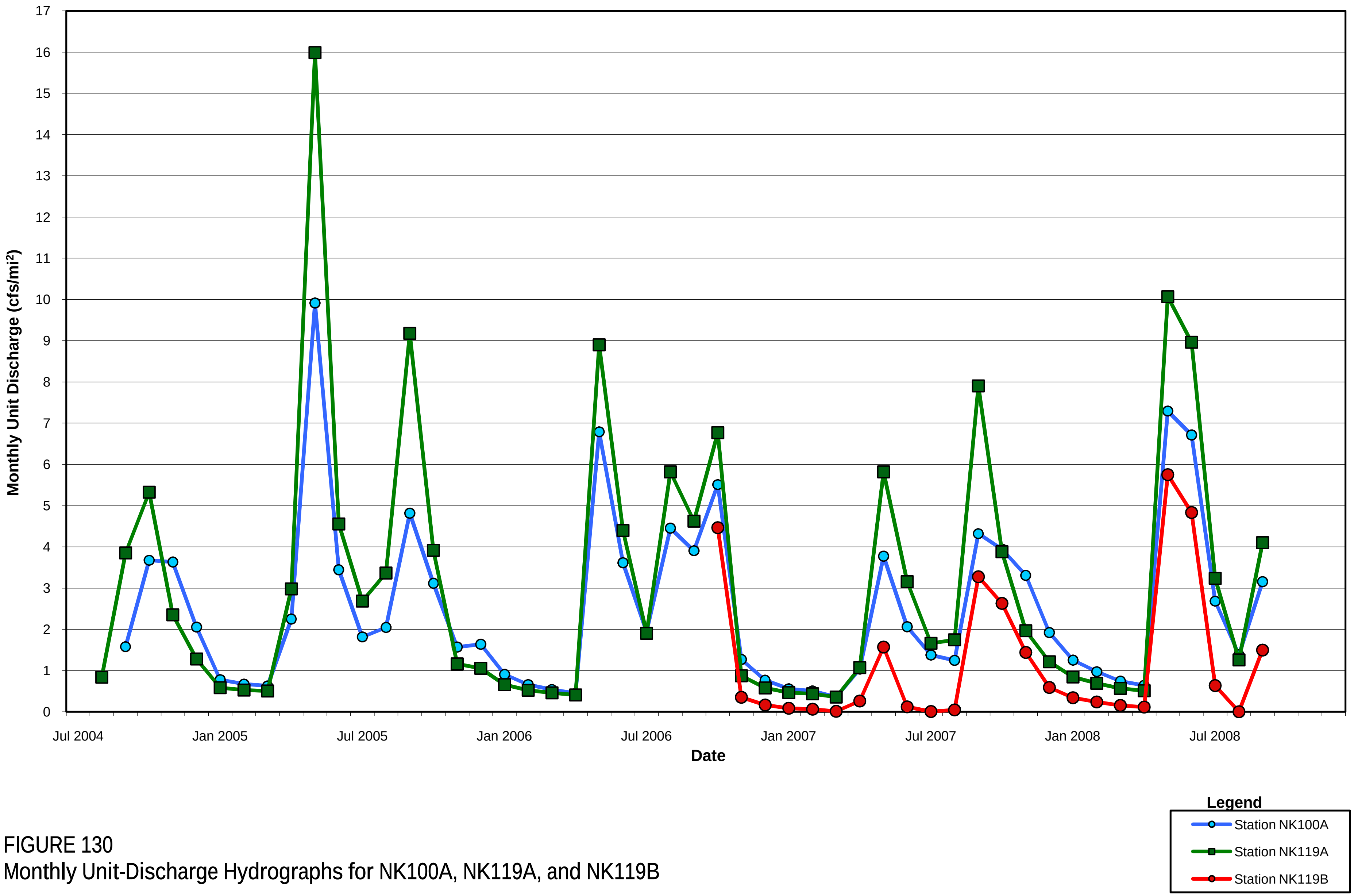


FIGURE 130
Monthly Unit-Discharge Hydrographs for NK100A, NK119A, and NK119B

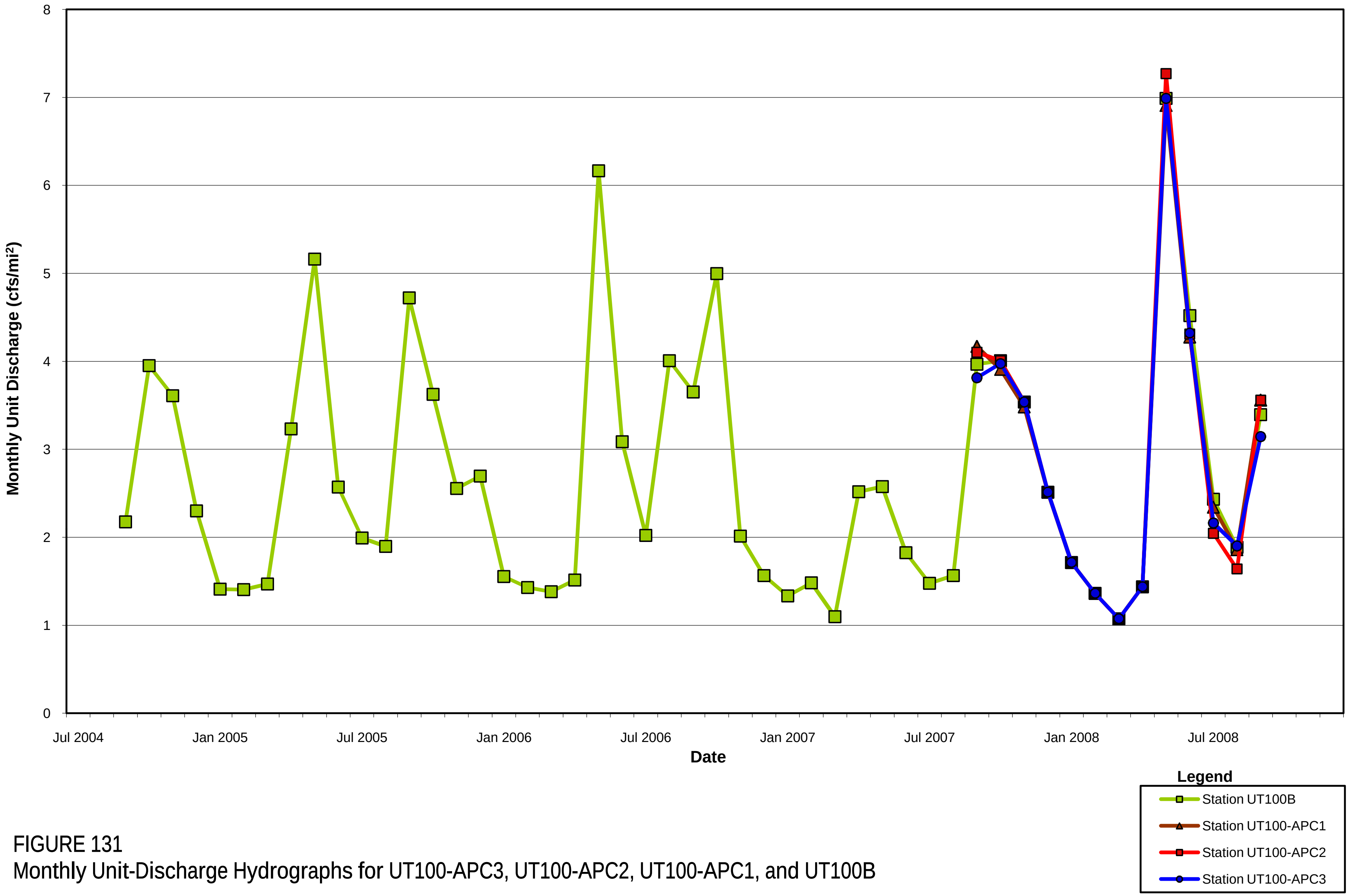


FIGURE 131
Monthly Unit-Discharge Hydrographs for UT100-APC3, UT100-APC2, UT100-APC1, and UT100B

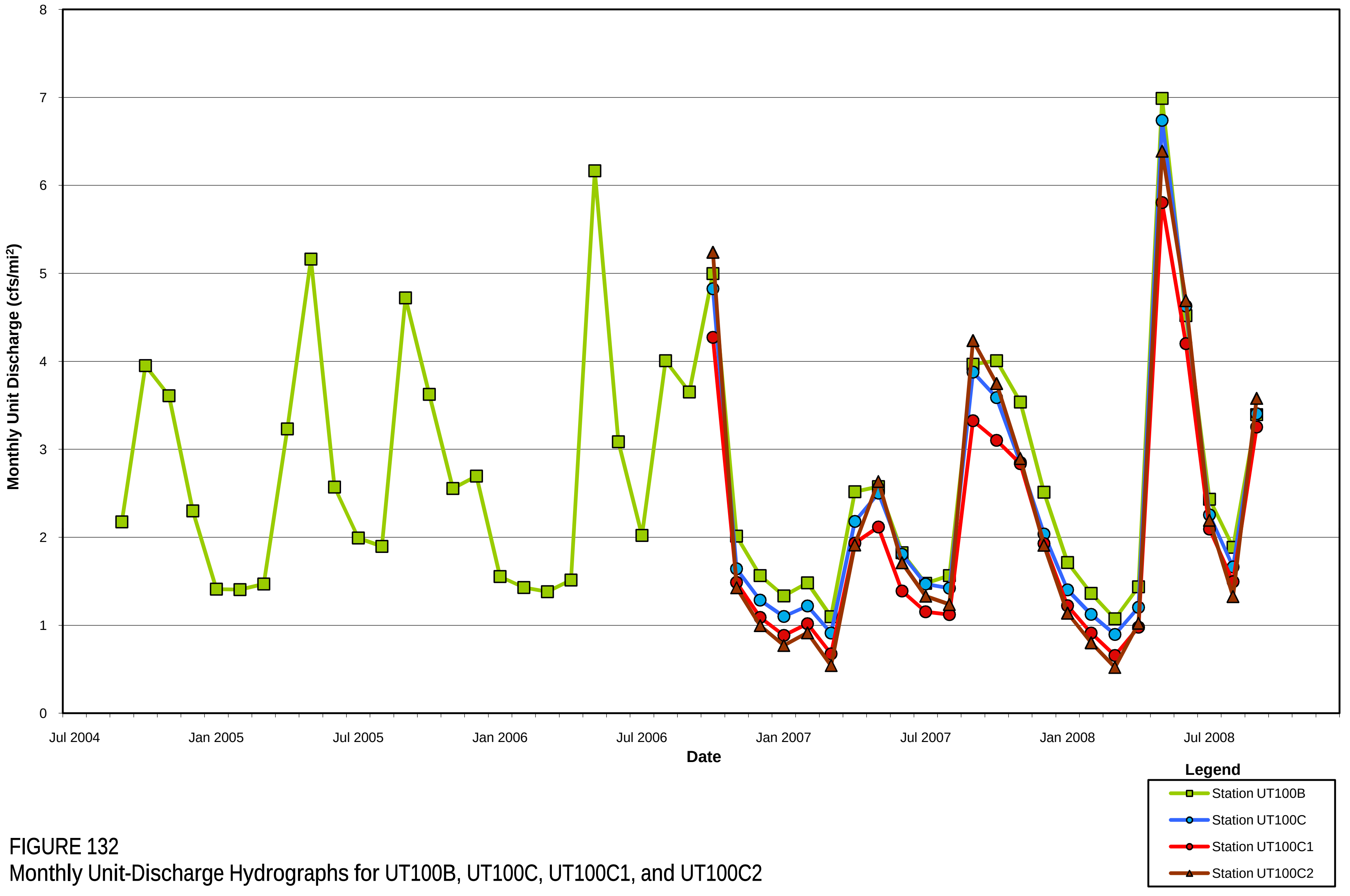


FIGURE 132
Monthly Unit-Discharge Hydrographs for UT100B, UT100C, UT100C1, and UT100C2

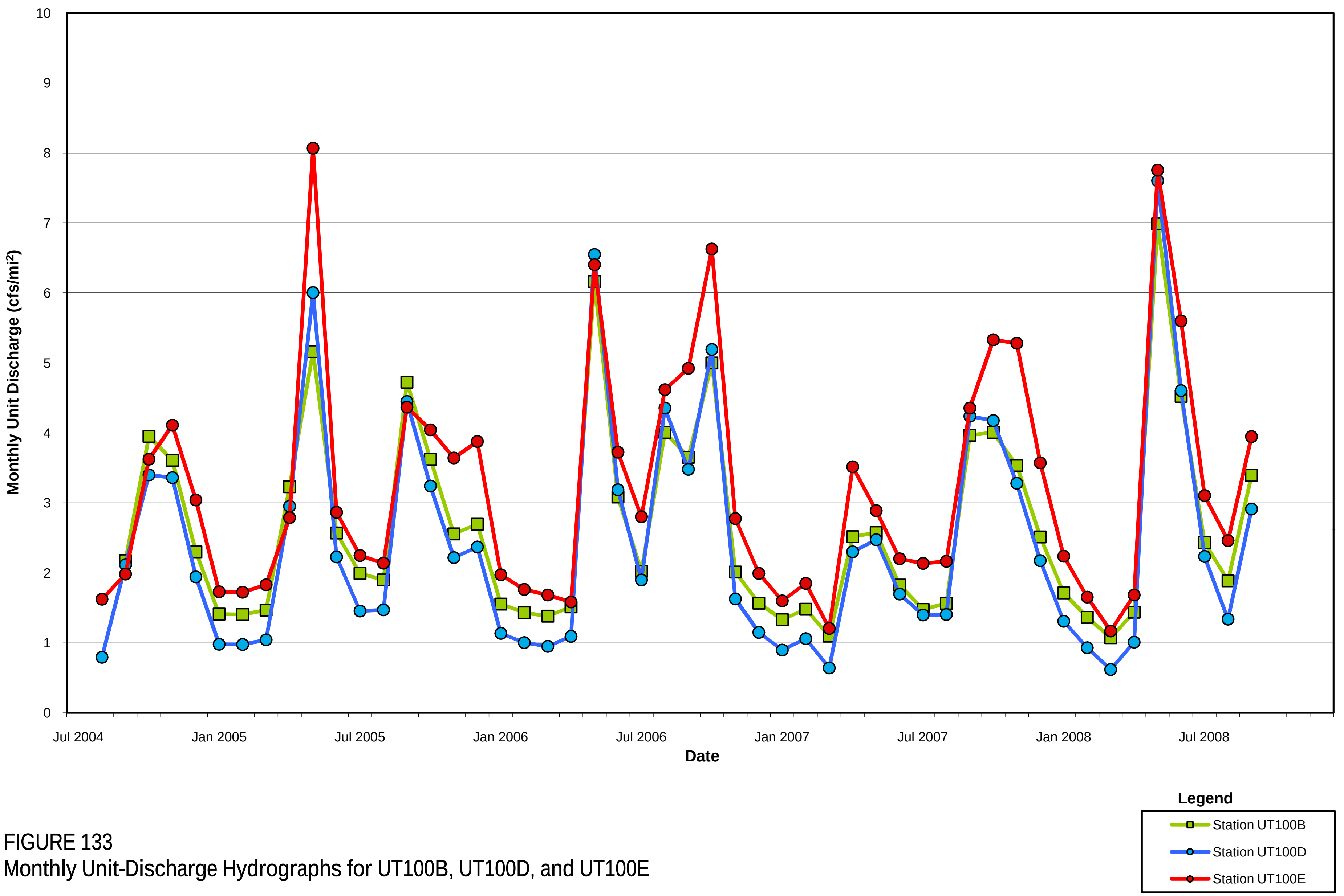


FIGURE 133
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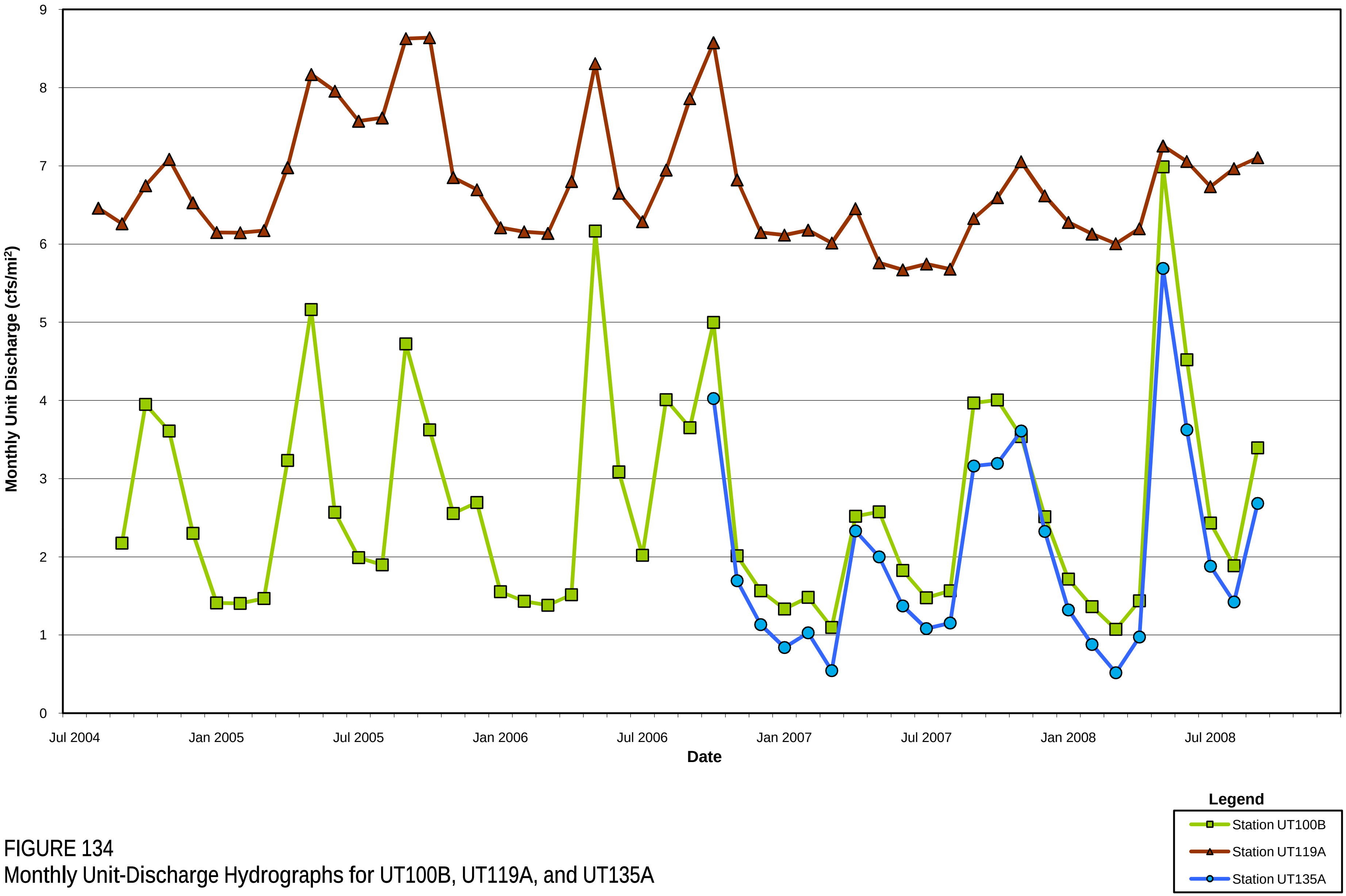

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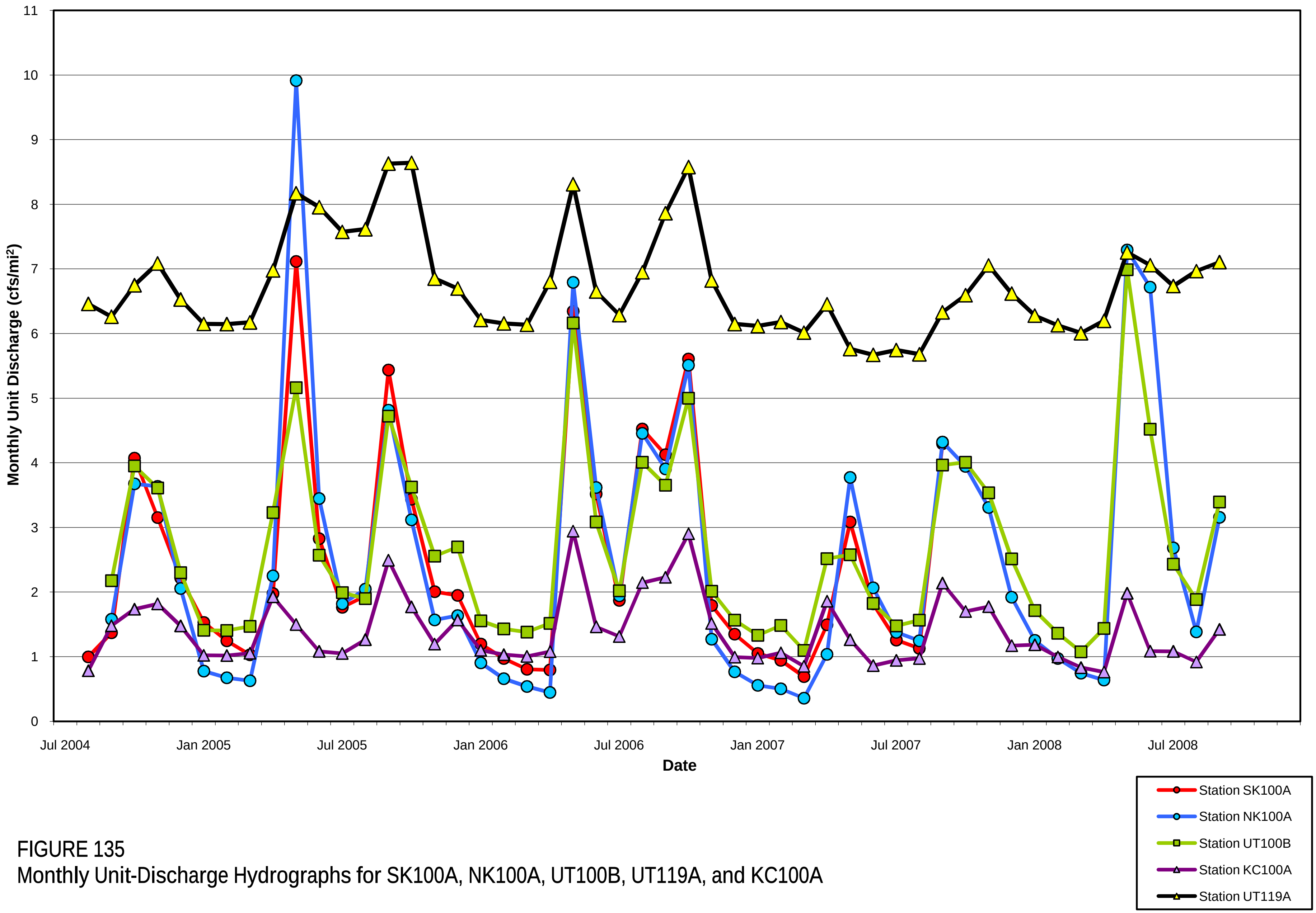
Monthly Unit-Discharge Hydrographs for UT100B, UT119A, and UT135A



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APPENDIX 7.2B

Low Flow Analysis

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ACRONYMS AND ABBREVIATIONS

cfs	cubic feet per second
GPS	global positioning system
mi^2	square miles
NK	North Fork Koktuli River
SK	South Fork Koktuli River
USGS	U.S. Geological Survey
URO	Runoff per Unit Area
UT	Upper Talarik Creek
WMC	Water Management Consultants

1. LOW FLOW ANALYSIS

1.1 Introduction

The low flow analysis, described in this technical report, is part of the 2004 through 2008 Pebble Project surface hydrology baseline study program. The information presented in this report is a combination of data collection efforts by CH2M Hill, Inc.; HDR Alaska, Inc. (HDR); and Knight Piésold Ltd.

Low flow conditions occur when stream discharge is supplied by inflow of groundwater (baseflow) in the absence of direct runoff from precipitation or snow melt. These conditions occur during winter freeze and occasionally during dry summers. Patterns of groundwater flow and surface upwelling are controlled by the hydraulic conductivity of underlying sediment and bedrock, as well as buried bedrock topography. The uneven distribution of groundwater in the study area results in gaining and losing reaches along rivers and tributaries. Streams lose flow to groundwater in areas underlain by permeable glacial deposits where the water table lies below the stream bed elevation, and gain flow from springs and groundwater upwelling zones where the stream channel intersects the water table. These patterns are most discernable during winter low flow periods when some stream reaches run dry, while nearby reaches contain flow under ice or are ice-free because of the input of relatively warm groundwater.

Groundwater flow is known to cross beneath the topographic divide between the SK and UT watersheds, providing steady, ice-free winter flows in the receiving UT tributary. The analysis of low flows throughout the study area was used to investigate the potential for other inter-basin flows.

2. STUDY OBJECTIVES

The objectives of the low flow analysis for the surface water hydrology study include the following:

- Characterize baseline low flow conditions in order to identify gaining and losing stream reaches within the study area.
- Supply data to complement groundwater studies and the calibration of a site-wide water balance model (Chapter 8).
- Support the assessment of water quality and fish habitat during baseflow conditions (Chapters 9 and 15).

3. STUDY AREA

The low flow analysis study area consists of the three major basins in the mine study area, which are shown on Figure 1: the South Fork Koktuli River (SK), the North Fork Koktuli River (NK), and Upper Talarik Creek (UT). Kaskanak Creek (KC) was not considered in this analysis.

Low flow sampling sites were selected to delineate the gaining and losing reaches of NK, SK, and UT, and areas of potential inter-basin groundwater exchange. Detailed maps illustrating the separate drainages are shown on Figures 2 through 4.

4. SCOPE OF WORK

The low flow project activities during 2004 through 2008 consisted of instantaneous discharge measurements, field observations of open water patterns, data reduction, and analysis. Data used for low flow analysis were collected in September 2004, March 2005, February and April 2006, March and April 2007, and March 2008. Data were collected during regular monthly baseline field events and specific baseflow (low flow) field events. The field work followed the protocols described in Chapter 4, Surface Water Hydrology, of the consolidated study program for Pebble Project (a copy of which is provided in Appendix E of this environmental baseline document). Data collection was performed by CH2M Hill, HDR, Knight Piésold, and the U.S. Geological Survey (USGS). HDR performed the data reduction and analysis.

5. METHODS

5.1 Station Selection and Nomenclature

Low flow measurements were taken at existing surface hydrology baseline stations (described in Appendix 7.2A) and additional low-flow only stations. Low flow stations were selected by HDR and Water Management Consultants (WMC) groundwater specialists within the NK, SK, and UT drainages based on proximity to existing stations and suspected gaining and losing reaches.

The final sampling locations were determined in the field by considering site conditions such as the presence of open water, ice obstructions, and/or snow drifts.

Low flow station nomenclature is as follows:

- Existing surface water hydrology stations are designated by their drainage basin initials (NK, SK, or UT), mainstem or tributary number (100 for mainstem, and 101, 102, etc., for tributaries), and sample site identifier (A, B, C, etc.). Tributary and sample site identifiers are sequential, moving in an upstream direction.
- Low flow specific stations are designated with their initials, mainstem or tributary number (e.g., SK100), the letters “LF” meant for low flow, and sequential numbering in the downstream direction.

The low flow stations are listed in Table 1 and displayed on Figures 2 through 4.

5.2 Field Methods

Generally, field crews attempted to sample all stations within a specific drainage in 1 day from the furthest downstream station to the upstream-most station. This sampling scheme allows for direct spatial comparisons of the discharge values without need to adjust for day-to-day changes in streamflow. Field crews collected instantaneous discharge measurements using either current meter or salt dilution methods following standard USGS protocols (Rantz, 1982; Kilpatrick and Cobb, 1985). Field crews followed USGS methods for flow measurements under ice in ice-affected reaches (Nolan and Jacobson, 2000).

Current meters are appropriate where flow is relatively uniform (smooth). Field crews used top-setting wading rods with either Marsh-McBirney Flo-Mate Model 2000 or Price AA flow meters to measure 20-30 velocities at intervals intended to capture 5 percent or less of the flow for each velocity measurement. Crews were unable to complete 20 measurements in channels with 4 feet or less active flow width because velocity measurements begin to overlap at about 0.2 feet. Discharge calculated from ice-affected current meter measurements is subject to errors of 15 to 25 percent (Nolan and Jacobson, 2000).

The salt dilution method is appropriate for more turbulent (rough) flow. Prior to each salt dilution measurement, field crews calibrated each of two Unidata Model 6308A/AUE conductivity probes using stream water in the reach and known concentrations of salt. Field crews then placed the two probes in the stream and injected a known amount of common table salt (sodium chloride) several hundred yards upstream (approximately 20 to 25 times the mean stream width). The probes recorded the conductivity of the salt slug after it fully mixed across the channel. Discharge was then calculated from the area underneath the resultant conductivity versus time curve. Technical papers detailing the applicability and success of the salt dilution method in similar environmental settings to that of the low flow study area include Hudson and Fraser (2005) and Moore (2004a, 2004b, and 2005).

Open water surveys were conducted aerially and by foot in 2006, 2007, and 2008 to determine the extent of open water, ice cover, and dry sections along the streams. Survey points were collected using handheld global positioning system (GPS) equipment. GPS coordinates mark stretches of open water, intermittent open water, and off-channel open water. Dry zones were delineated from auger holes drilled through ice during foot surveys or from discrete station measurements.

5.3 Sampling Events

5.3.1 September 2004

CH2M Hill collected instantaneous flow measurements at 22 stations as part of their monthly baseline field event from September 14 through 17, 2004, using the current meter method. Field crews sampled the NK and SK each in 1 day and completed the UT measurements in 2 days. Evaluation of the continuous discharge records for the three USGS stations within the study area indicates that these flows represent the lowest summer flows in the current period of record. These are the only summer low flow data collected.

5.3.2 March 2005

Field personnel used the current meter method to collect instantaneous flow measurements at 21 stations during the monthly baseline event from March 15 to March 20, 2005, and at 14 additional stations from March 20 to March 23, 2005, specifically for low flow. A notable amount of freeze-thaw was observed during these sampling events, thus some measurements may include surface runoff in addition to baseflow.

5.3.3 February 2006

Field crews surveyed all major stream channels from February 7 to February 11, 2006, to determine the extent of open water, ice cover, and dry channels along the streams. These surveys were conducted aerially and by foot.

5.3.4 April 2006

Field crews from HDR and Knight Piésold worked together to collect 24 instantaneous flow measurements during the April 1 through April 4, 2006, low flow event. The NK, SK, and UT were each sampled in 1 day. Field crews used the salt dilution method at more turbulent stations and the current meter method at more laminar stations. Where possible, field crews took measurements using both methods.

5.3.5 March/April 2007

Field crews collected 28 instantaneous flow measurements from March 30 through April 2, 2007, using the current meter and/or salt dilution methods. The SK was sampled in 1 day, all but two stations on the NK (NK100C and NK 100LF5) were sampled in 1 day, and the UT was sampled over 2 days. Field crews surveyed all major stream channels to determine the extent of open water, ice cover, and dry channels along the streams. These surveys were conducted aerially and by foot.

5.3.6 March 2008

Field crews collected 41 instantaneous flow measurements from March 25 through March 28, 2008, using the current meter and/or salt dilution methods. All mainstem sites on the SK, UT, and NK were sampled in 1 day per drainage, with the exception of one dry site on the SK that was sampled at the end of the field event. Tributaries in each drainage were not always sampled on the same day as the mainstem. Additionally, field crews aerially surveyed all major stream channels to determine the extent of open water.

5.4 Data Analysis

5.4.1 Discharge Calculations

Hydrologists calculated discharge values for both salt dilution and current meter measurements following standard USGS procedures (Rantz, 1982; Kilpatrick and Cobb, 1985). Two salt dilution values (one for each probe) were calculated for each station in each event and averaged. When field crews collected both current meter and salt dilution measurements, the degree of turbulence determined which method was most appropriate for the analysis.

5.4.2 Identification of Gaining and Losing Reaches

Hydrologists identified gaining and losing reaches along streams using profiles of discharge, profiles of runoff per unit area (URO), and observations of open water and dry reaches based on the explanation below. The ArcHydro software tools within the ArcGIS Geographic Information System were used to delineate drainage basin area upstream of each station to calculate URO.

In an idealized drainage basin with uniform terrain and groundwater conditions, a stream will receive relatively constant rates of groundwater input along the channel during baseflow conditions. In such a case, discharge increases in a downstream direction along the stream channel in proportion to drainage area, and URO is constant along the channel. This condition describes a uniformly gaining channel, where gaining refers to an increase in surface flow derived from groundwater flow. Drainage basin terrain and groundwater conditions are never uniform, however, and the exchange of flows between surface channels and groundwater typically varies longitudinally along a channel. In general, any stream reach in which discharge increases in a downstream direction during baseflow conditions is a gaining reach. The downstream rate of flow increase may be less than the rate of drainage area increase, in which the URO declines in a downstream direction, and the reach can be considered to be weakly gaining. If the rate of flow increase is greater than the rate of drainage area increase, in which case the URO increases in a downstream direction, then the reach can be considered to be strongly gaining. These are the gaining reaches of most interest in the study area as they are often associated with open water conditions during the winter baseflow period. Losing reaches are those in which absolute discharge decreases in a downstream direction along a channel during baseflow conditions due to the transfer of surface flow to groundwater. In extreme cases, losing reaches can go dry during baseflow periods.

The streams in the study area flow through geologically distinct areas with differing hydraulic conductivity and permeability, and groundwater conditions are not uniform. In reaches underlain by deep, permeable material, the water table may be lower than the channel surface, and the channel may lose water to ground. In this case, both discharge and URO decrease in a downstream direction along the reach where there is a loss. In some cases, this may manifest itself as a dry reach in between two flowing reaches. If the stream channel intersects an area where bedrock or impermeable layers force the water table to the surface, there will be an upwelling of groundwater along the reach. In this case, both discharge and URO increase, and there may be visible open water where the warmer groundwater prevents the stream from freezing over. In reaches where discharge is relatively constant or increases only slightly along a reach and URO decreases, there may be a combination of groundwater gains and losses along the reach.

6. RESULTS AND DISCUSSION

6.1 Results

Most stations in the mine study area have some flow during the lowest flow period in late winter, despite thick ice and snow cover (Table 1). During low flow conditions, the downstream-most stations on the NK have URO of 0.5 to 0.7 cubic feet per second (cfs) per square mile (mi^2) (compared to annual averages of 2.4 to 2.6 cfs/mi^2); those on the SK measure 0.6 to 0.8 cfs/mi^2 (compared to annual averages of 2.5 to 2.8 cfs/mi^2); and those on the UT measure around 1.1 cfs/mi^2 (compared to annual averages of 2.7 cfs/mi^2). The range of URO values upstream in the drainage basins is much greater and reflects the uneven distribution of groundwater in the landscape. The lower reaches of tributary UT 1.190 (stations UT119A and UT119LF1) have the highest URO during low flow conditions, ranging from 5.3 to 6.8 cfs/mi^2. Several stations go dry during low flow conditions, most along the main SK channel downstream of

Frying Pan Lake (SK100D, SK100C, and SK100LF4.9). NK119B is the only other channel that has been dry during low flow events.

The 2004 and 2005 low flow measurements were not of sufficient density or timed closely enough to be useful for delineating gaining and losing reaches along the main channels of NK, SK, and UT. Patterns of gaining and losing reaches in 2006, 2007, and 2008 are consistent, although the same array of stations was not surveyed each year (Figures 5, 6, and 7). The amount of open water varied between 2006, 2007, and 2008, but gross patterns of open water and dry reaches were similar between years (Figures 8, 9, and 10).

6.1.1 North Fork Koktuli River Gaining and Losing Reaches

Figure 5 displays profiles of low-flow discharge and URO for 2006 through 2008 low flow events. In general, discharge was approximately constant and URO declined between NK100C (the upstream-most measured station) to NK100LF3, indicating an approximately neutral gain/loss condition. Field crews observed open water around NK100C in 2006 and 2008, but no open water was observed between NK100B and NK100LF1.

Between NK100LF3 and NK100LF5, discharge increased in a downstream direction at a greater rate than drainage area (i.e., URO increased in a downstream direction) in 2006, 2007, and 2008, indicating a strongly gaining reach. Results of open water surveys from 2006 show almost complete open water conditions in the reach, while those from 2007 and 2008 show only intermittent open water or off-channel open water (Figures 8, 9 and 10). The upwelling of relatively warm groundwater inhibited the freezing process in this reach.

6.1.2 South Fork Koktuli River Gaining and Losing Reaches

Surface flow was recorded at SK100F and/or SK100G in 2006, 2007, and 2008, but field crews did not observe any open water in the SK drainage basin upstream of SK100F. Both discharge and URO decreased downstream of SK100F, and most of the reach between SK100D and SK100C was dry in 2006, 2007, and 2008 (Figure 6). Measurements in 2008 documented that the dry reach extended to SK100B2 (this station was not measured in 2006 or 2007). The reach between SK100F and SK100B2 is a losing reach.

Discharge and URO increased sharply between SK100B2 and SK100LF9 in 2006, 2007, and 2008, from zero to around 35 cfs over a distance of less than 5 miles, indicating a strongly gaining reach (Figure 6). Ice-free open water in the channel and off-channel springs in 2006, 2007, and 2008 are consistent with an influx of groundwater between SK100B2 and SK100LF9.

Another losing reach occurred between SK100LF9 and SK100LF10, where discharge and URO decreased in a downstream direction in all 3 years, indicating loss to groundwater. Discharge and URO then increased from SK100LF10 to SK100A, coincident with intermittent stretches of open water, indicating another strongly gaining reach.

6.1.3 Upper Talarik Creek Gaining and Losing Reaches

The reach immediately upstream of UT100E was open and flowing during the 2006, 2007, and 2008 open water surveys, and the URO at UT100E was high (1.1 to 1.5 cfs/mi^2). Downstream of UT100E, discharge increased at a lower rate than the drainage area between UT100E and UT100C2 (i.e., URO decreased in the downstream direction), indicating a weakly gaining reach. Downstream of UT100C2, discharge increased more rapidly than drainage area between UT100C2 and UT100B (i.e., URO increased in the downstream direction), indicating a strongly gaining reach. A localized drop in discharge occurred in some years at UT100LF7, located just upstream of UT100B, but the general pattern consists of strongly gaining surface flows between UT100C2 and UT100B.

Open or intermittently open water appeared in the UT channel between UT100LF3 and UT100LF4, and continued downstream to just before UT100LF7. Open water reappeared just above the confluence with tributary UT 1.190 and continued to at least UT100LF8 in 2006, 2007, and 2008.

The biggest gaining reach in the UT basin is on tributary UT 1.190 between UT119B and UT119A. UT119B has a relatively low baseflow URO of around 0.4 cfs/mi^2, while UT119A has a baseflow URO of 5.3 to 6.1 cfs/mi^2, three times larger than any other UT station (apart from the nearby low flow station UT119LF1). Results of open water surveys show this tributary and several miles of the mainstem below it to be completely open.

6.2 Discussion

A common pattern in all three main drainages is moderate to high URO in the headwaters, a section of surface flow losses or relatively low surface flow gains in the middle part of the basin, and strongly gaining flows lower in the basin. The surface flow losses or low surface flow gains in the mid-basins of SK and NK coincide with thick, permeable glacial sediments and a drop in the water table. The strongly gaining reaches downstream coincide with a thinning of the glacial sediments and a narrowing of the bedrock valleys, both contributing to a rise in the water table.

6.2.1 North Fork Koktuli River

The NK appeared to lose discharge to groundwater, or maintained an approximate balance between losses and gains, where it passes through permeable valley fill of outwash sands and gravels downstream of NK100C. The NK rapidly gained discharge where the valley narrows and bedrock is nearer to the surface between NK100LF3 and NK100LF5. Finer-scale, localized exchanges of groundwater and surface water likely occurred between the measurement stations. Small gains and losses along the mainstem occurred in different years, and several small open reaches of channel were visible above and below the main gaining reach. Tributary NK 1.190 does not have a consistent low flow trend in the years for which data have been collected, but further measurements may provide better information.

6.2.2 South Fork Koktuli River

Surface flows out of Frying Pan Lake were consistently lost to ground between SK100LF2 and SK100B2, where the SK flows across thick, permeable glacial deposits that fill a broad bedrock valley. Some groundwater leaves the SK basin within this reach and re-emerges in UT tributary 1.190. The main upwelling reach of the SK occurred between SK100B2 and SK100LF9, which coincides with the narrowing of the SK valley and a thinning of the glacial deposits. The average rate of baseflow in the UT tributary was approximately 22 cfs, while the baseflow rate at SK100LF9 was typically around 35 cfs.

6.2.3 Upper Talarik Creek

Relatively high baseflows are sustained at UT100E in the UT headwaters by a number of sources: aquifer storage in the outwash deposits, pond and wetland storage, an interbasin groundwater transfer from a downstream UT tributary that feeds the springs upstream of UT100E, and a potential interbasin transfer of groundwater from NK to UT above UT100E. The UT is weakly gaining between UT100E and UT100C2, with a low rate of surface flow gain due to limited groundwater storage in the glacio-lacustrine basin between these two stations. A large aquifer along the east side of the UT between UT100C2 and UT100B contributes relatively large baseflow inputs, making this a strongly gaining reach with intermittent open water conditions. The interbasin groundwater transfer from the SK enters the UT just upstream of UT100B via tributary 1.190. The tributary and the UT mainstem downstream of the confluence always had open water conditions during baseflow periods.

7. SUMMARY

This low flow analysis provides physical flow information for baseflow conditions in the three main drainage basins in the mine study area. Field crews measured one summer and four winter low flows in the three study drainages. Only one summer low flow period was sampled because frequent rain maintained relatively high flows during the other ice-free seasons in the mine study area.

Gaining and losing reaches and inter-basin transfer are largely controlled by glacial deposits of varying permeability and thickness, and by buried bedrock topography. Discharge profiles indicate losing and gaining reaches on all three of the sampled rivers. The occurrence of open water during late winter baseflow periods was well-correlated with strongly gaining reaches, including the UT tributary that receives the inter-basin flow transfer from the SK watershed. No other clear evidence of inter-basin transfer was found. Local patterns of discharge losses and gains and the distribution of late-winter open water conditions varied from year to year, but consistent generalized reach characteristics were identified.

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TABLES

TABLE 1
2004-2008 Low Flow Measurements and URO Values

STATION	Drainage Area (mi²)	Distance Downstream [a] (miles)	September 2004 Baseline		March 2005 Baseline [b]		March 2005 Baseflow		April 2006 Baseflow		March/April 2007 Baseflow		March 2008 Baseflow	
			Discharge (cfs)	Unit Runoff (cfs/mi²)	Discharge (cfs)	Unit Runoff (cfs/mi²)	Discharge (cfs)	Unit Runoff (cfs/mi²)	Discharge (cfs)	Unit Runoff (cfs/mi²)	Discharge (cfs)	Unit Runoff (cfs/mi²)	Discharge (cfs)	Unit Runoff (cfs/mi²)
North Fork Koktuli [c]														
Mainstem														
NK100A	105.86	19.56	57.7	0.5	110.2	1.0	-	-	-	-	-	-	-	-
NK100A1	81.97	14.33	-	-	-	-	-	-	-	-	43.0	0.5	55.3	0.7
NK100LF5	71.91	9.97	-	-	-	-	-	-	57.9	0.8	-	-	48.0	0.7
NK100LF4	67.28	8.88	-	-	-	-	53.1	0.8	48.1	0.7	44.9	0.7	44.5	0.7
NK100LF3	53.49	5.48	-	-	-	-	22.0	0.4	19.9	0.4	4.1	0.1	9.9	0.2
NK100LF1	40.17	1.35		-	-	-	-	-	15.9	0.4	9.1	0.2	15.8	0.4
NK100B	37.32	0.62	22.0	0.6	65.0	1.7	-	-	*18.5*	0.5	12.9	0.3	25.5	0.7
NK100C	24.35	0.00	15.5	0.6	21.5	0.9	-	-	*17.9*	0.7	10.5	0.4	14.9	0.6
Tributaries														
NK108LF1	1.33	-	-	-	-	-	-	-	-	-	-	-	0.1	0.1
NK119A	7.76	-	5.1	0.7	3.7	0.5	-	-	*2.8*	0.4	*2.4*	0.3	*2.9*	0.4
NK119B	3.97	-	4.9	1.2	4.3	1.1	-	-	-	-	0.0	0.0	0.0	0.0
NK119BLF1	3.37	-	-	-	-	-	-	-	-	-	-	-	1.4	0.4
South Fork Koktuli [c]														
Mainstem														
SK100A	106.92	35.99	84.9	0.8	125.0	1.2	-	-	79.7	0.7	69.0	0.6	87.8	0.8
SK100LF10	87.17	29.33	-	-	-	-	-	-	12.7	0.1	11.6	0.1	24.6	0.3
SK100B	69.33	20.58	41.1	0.6	65.0	0.9	45.7	0.7	-	-	-	-	-	-
SK100LF9	68.56	20.07	-	-	-	-	-	-	35.7	0.5	30.7	0.4	36.3	0.5
SK100B1	54.41	17.87	-	-	-	-	-	-	14.3	0.3	16.3	0.3	21.3	0.4

STATION	Drainage Area (mi²)	Distance Downstream [a] (miles)	September 2004 Baseline		March 2005 Baseline [b]		March 2005 Baseflow		April 2006 Baseflow		March/April 2007 Baseflow		March 2008 Baseflow	
			Discharge (cfs)	Unit Runoff (cfs/mi²)	Discharge (cfs)	Unit Runoff (cfs/mi²)	Discharge (cfs)	Unit Runoff (cfs/mi²)	Discharge (cfs)	Unit Runoff (cfs/mi²)	Discharge (cfs)	Unit Runoff (cfs/mi²)	Discharge (cfs)	Unit Runoff (cfs/mi²)
SK100LF8	54.41	17.79	-	-	-	-	26.8	0.5	-	-	-	-	-	-
SK100LF7	51.76	15.92	-	-	-	-	9.6	0.2	-	-	-	-	-	-
SK100B2	51.57	15.65	-	-	-	-	-	-	-	-	-	-	0.1	0.0
SK100LF6	49.7	14.92	-	-	-	-	0.3	0.0	-	-	-	-	-	-
SK100C	37.5	13.80	0.0	0.0	0.0	0.0	-	-	-	-	0.0	0.0	0.0	0.0
SK100LF5	0.29	9.62	-	-	-	-	-	-	0.0	0.0	0.0	0.0	-	-
SK100LF4.9	28.34	9.57	-	-	-	-	-	-	-	-	-	-	0.0	0.0
SK100LF4	28.91	8.95	-	-	-	-	4.9	0.2	-	-	-	-	-	-
SK100D	16.22	6.45	2.0	0.1	6.1	0.4	-	-	0.0	0.0	0.0	0.0	0.7	0.0
SK100LF2	15.14	4.31	-	-	-	-	-	-	*4.0*	0.3	-	-	-	-
SK100F	11.91	2.08	6.7	0.6	8.3	0.7	-	-	5.1	0.4	-	-	6.3	0.5
SK100G	5.49	0.00	1.9	0.3	6.0	1.1	-	-	-	-	2.1	0.4	4.0	0.7
Tributaries													-	-
SK119A	10.73	-	4.9	0.5	7.6	0.7	-	-	-	-	-	-	1.8	0.2
SK131A	2.37	-	1.3	0.5	0.9	0.4	-	-	-	-	-	-	0.7	0.3
SK133A	0.74	-	0.2	0.3	-	-	-	-	-	-	-	-	0.2	0.3
SK134A	1.14	-	0.6	0.5	2.4	2.1	-	-	-	-	-	-	0.6	0.5
Upper Talarik [c]														
Mainstem														
UT100A	101.45	28.08	114.4	1.1	175.0	1.7	-	-	-	-	-	-	-	-
UT100LF8	89.6	23.53	-	-	-	-	137.8	1.5	95.6	1.1	111.1	1.2	104.1	1.2
UT100B	86.23	22.05	99.5	1.2	153.5	1.8	132.7	1.5	92.8	1.1	101.7	1.2	99.7	1.2
UT100LF7	71.72	20.44	-	-	-	-	97.5	1.4	*33.4*	0.5	69.9	1.0	69.2	1.0
UT100C	69.46	19.06	-	-	-	-	-	-	-	-	48.5	0.7	78.5	1.1

STATION	Drainage Area (mi²)	Distance Downstream [a] (miles)	September 2004 Baseline		March 2005 Baseline [b]		March 2005 Baseflow		April 2006 Baseflow		March/April 2007 Baseflow		March 2008 Baseflow	
			Discharge (cfs)	Unit Runoff (cfs/mi²)	Discharge (cfs)	Unit Runoff (cfs/mi²)	Discharge (cfs)	Unit Runoff (cfs/mi²)	Discharge (cfs)	Unit Runoff (cfs/mi²)	Discharge (cfs)	Unit Runoff (cfs/mi²)	Discharge (cfs)	Unit Runoff (cfs/mi²)
UT100LF6	70.72	18.83	-	-	-	-	78.1	1.1	55.5	0.8	-	-	-	-
UT100LF5	65.35	15.77	-	-	-	-	-	-	36.7	0.6	47.8	0.7	50.3	0.8
UT100C1	60.37	14.18	-	-	-	-	-	-	-	-	32.4	0.5	43.4	0.7
UT100LF4	59.57	13.89	-	-	-	-	-	-	*28.2*	0.5	-	-	-	-
UT100LF3	48.55	10.36	-	-	-	-	-	-	*27.1*	0.6	-	-	-	-
UT100C2	48.26	9.54	-	-	-	-	-	-	-	-	18.9	0.4	25.3	0.5
UT100D	11.96	5.20	7.9	0.7	10.5	0.9	-	-	8.3	0.7	6.4	0.5	10.0	0.8
UT100LF1	6.36	2.77	-	-	-	-	6.8	1.1	-	-	-	-	-	-
UT100E	3.1	0.00	3.9	1.3	4.3	1.4	4.6	1.5	-	-	*3.5*	1.1	*4.3*	1.4
Tributaries														
UT119A	4.05	-	25.2	6.2	24.7	6.1	-	-	*21.9*	5.4	*22.9*	5.7	*21.6*	5.3
UT119B	1.72	-	0.6	0.3	1.2	0.7	-	-	-	-	*0.1*	0.1	0.1	0.1
UT119LF1	2.32	-	-	-	-	-	-	-	-	-	-	-	15.7	6.8
UT122LF1	0.06	-	-	-	-	-	1.1	17.3	-	-	-	-	-	-
UT123LF1	1.49	-	-	-	-	-	-	-	-	-	-	-	1.1	0.7
UT132LF1	1.24	-	-	-	-	-	-	-	-	-	-	-	0.5	0.4
UT135A	20.42	-	12.2	0.6	22.3	1.1	-	-	-	-	7.6	0.4	13.7	0.7
UT136LF1	1.57	-	-	-	-	-	-	-	-	-	-	-	0.6	0.4

Notes:

a. Distances are referenced to the upstream-most gaging station on each mainstem channel.

b. The March 2005 Baseline flow measurements in the NK basin were spread over a period of 5 days.

c. Italicized discharge values were measured by salt dilution method (all others by current meter); " - " indicates no measurement taken.

d. cfs = cubic feet per second, mi^2 = square mile(s).

FIGURES

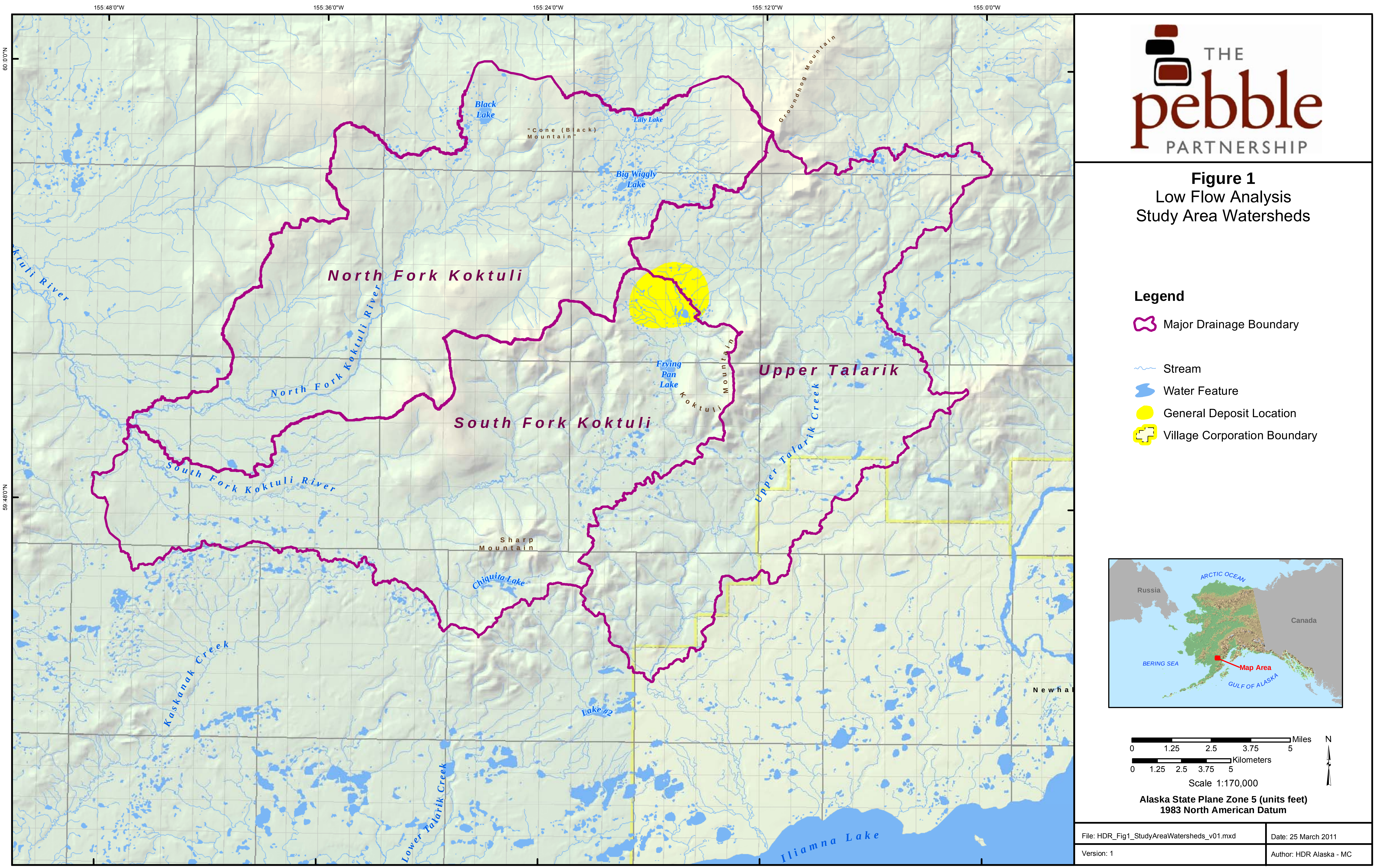

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Figure 1
Low Flow Analysis
Study Area Watersheds
Legend
Major Drainage Boundary
Stream
Water Feature
General Deposit Location
Village Corporation Boundary
North Fork Koktuli
South Fork Koktuli
Upper Talarik
Black Lake
"Cone (Black) Mountain"
Lilly Lake
Big Wiggly Lake
Groundhog Mountain
Frying Pan Lake
Koktuli Mountain
North Fork Koktuli River
South Fork Koktuli River
Koktuli River
Upper Talarik Creek
Sharp Mountain
Chiquita Lake
Kaskanak Creek
Lake #2
Lower Talarik Creek
Iliamna Lake
Newhal
155:48'0"W
155:36'0"W
155:24'0"W
155:12'0"W
155:0'0"W
60:0'0"N
59:48'0"N
Russia
ARCTIC OCEAN
Canada
BERING SEA
Map Area
GULF OF ALASKA
0 1.25 2.5 3.75 5 Miles
0 1.25 2.5 3.75 5 Kilometers
N
Scale 1:170,000
Alaska State Plane Zone 5 (units feet)
1983 North American Datum
File: HDR_Fig1_StudyAreaWatersheds_v01.mxd
Date: 25 March 2011
Version: 1
Author: HDR Alaska - MC

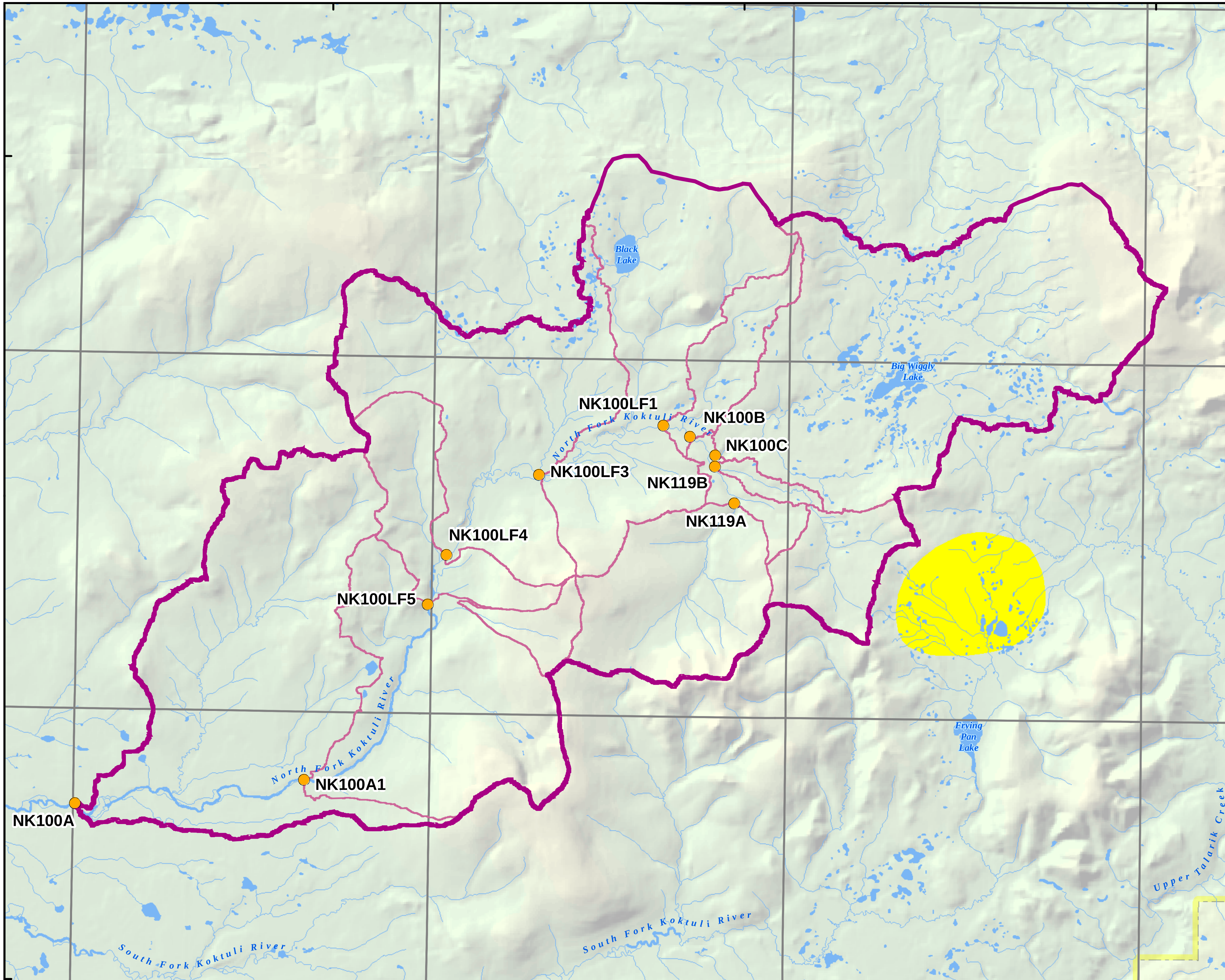

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Figure 2
Low Flow Analysis
Drainage Basins
North Fork Koktuli River

Legend

NK100A: Example of Baseflow Station Identification Label

- Baseflow Station
- Drainage Boundary
- Sub Drainage Boundary
- Stream
- Water Feature
- Village Corporation Boundary
- General Deposit Location

Miles: 1.25 2.5 3.75 5
Kilometers: 1.25 2.5 3.75 5
N
Scale 1:105,000

Alaska State Plane Zone 5 (units feet)
1983 North American Datum

File: HDR_Figure2_NFK_LowFlowStations.mxd	Date: 25 March 2011
Version: 1	Author: HDR - RB, MC

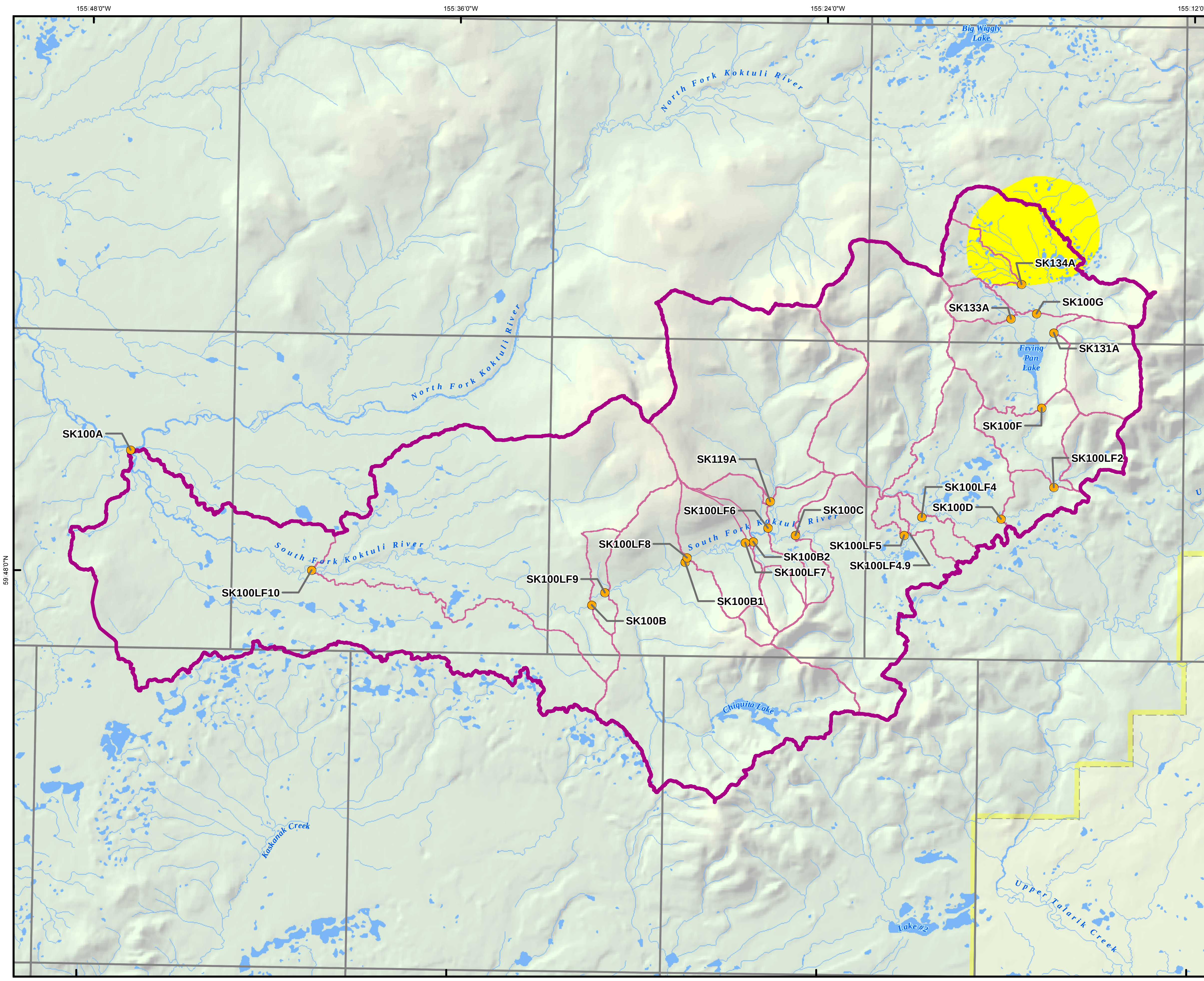

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Figure 3
Low Flow Analysis
Drainage Basins
South Fork Koktuli River

Legend

SK100B: Example of Baseflow Station Identification Label

- Baseflow Station
- Drainage Boundary
- Subdrainage Boundary
- Stream
- Water Feature
- Village Corporation Boundary
- General Deposit Location

Miles: 1.25 | 2.5 | 3.75 | 5

Kilometers: 1.25 | 2.5 | 3.75 | 5

N

Scale 1:115,000

Alaska State Plane Zone 5 (units feet)
1983 North American Datum

File: HDR_Figure3_SFK_LowFlowStations.mxd	Date: 25 March 2011
Version: 1	Author: HDR - RB,MC

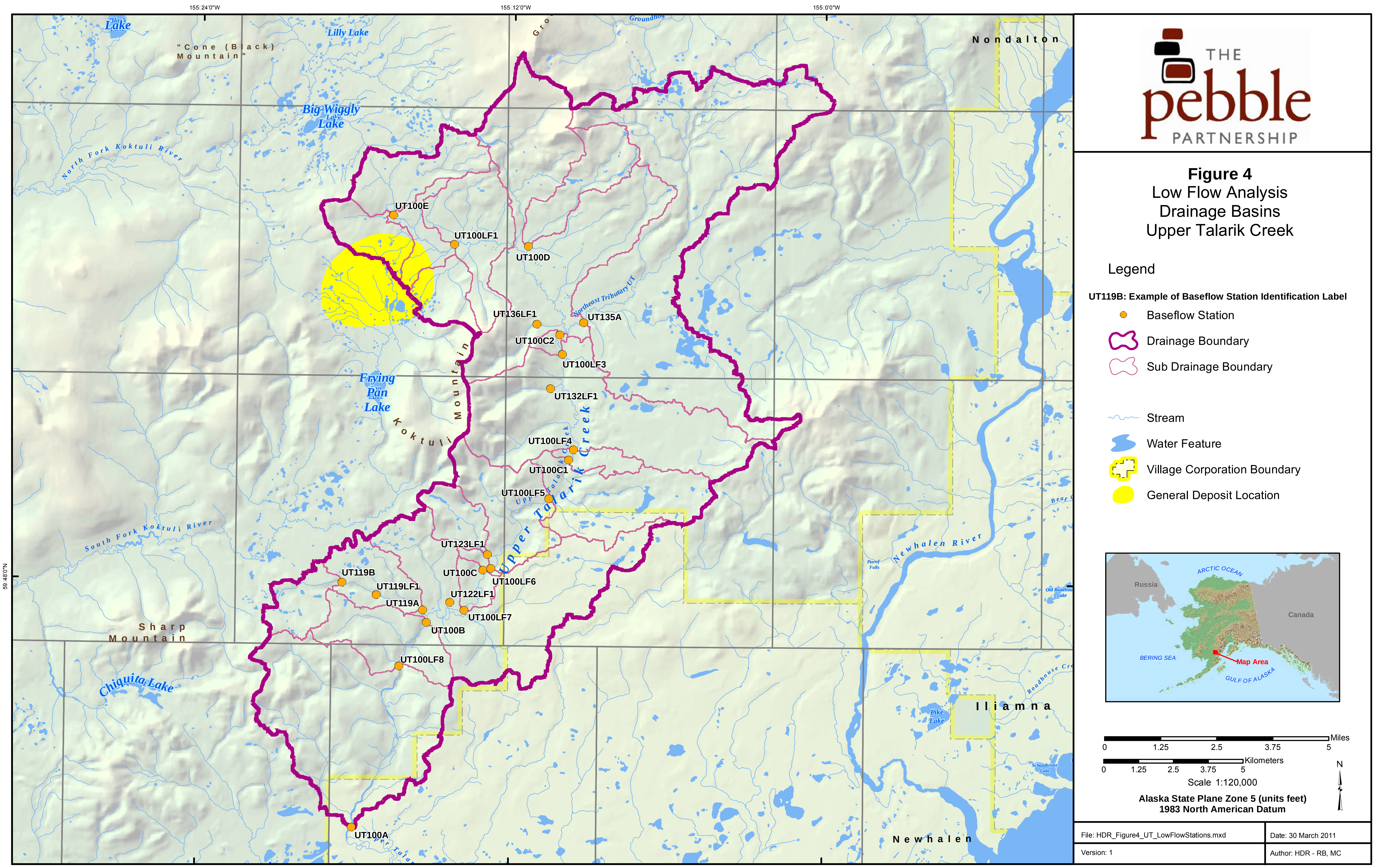


Figure 4
Low Flow Analysis
Drainage Basins
Upper Talarik Creek

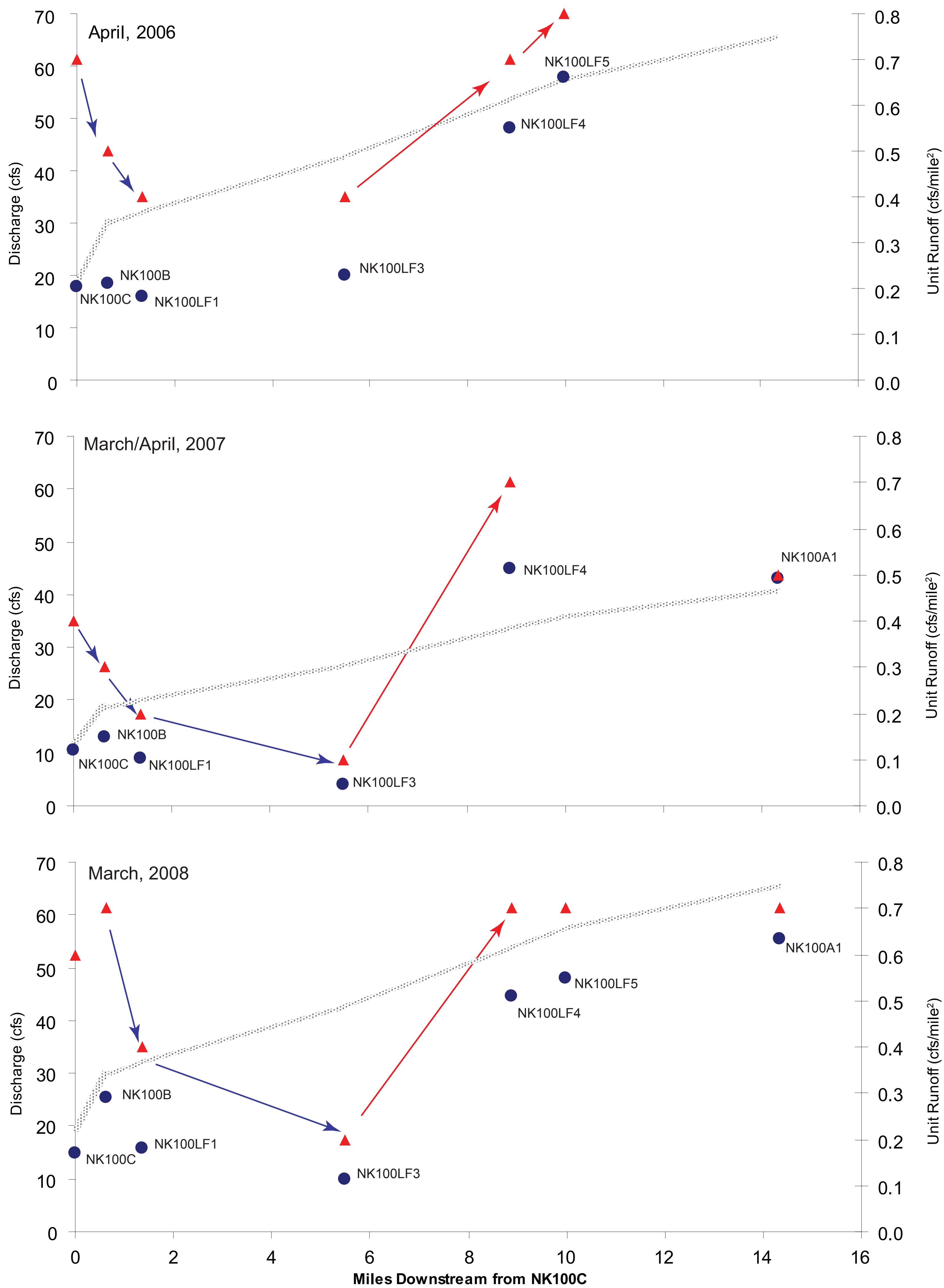
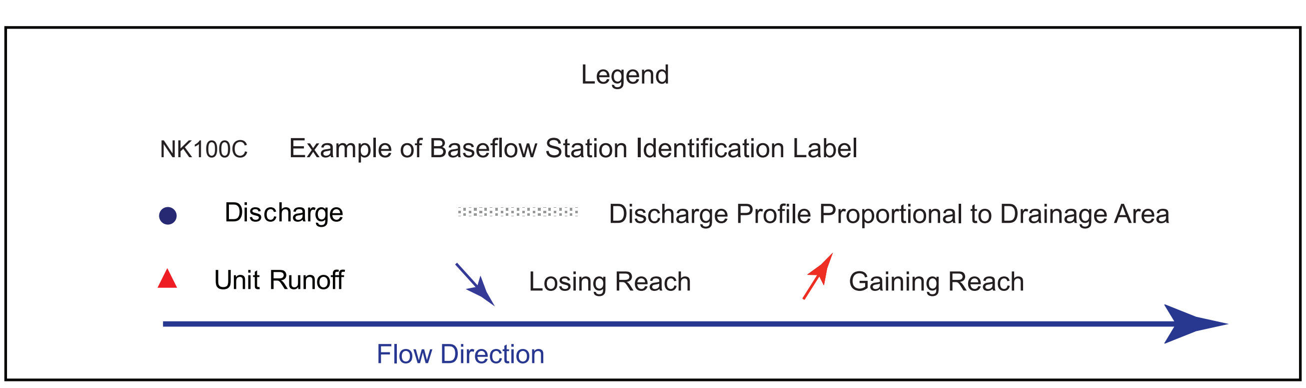


Figure 5. North Fork Koktuli River Low Flow Discharge and Unit Runoff Profiles



Note: NK low flow discharge and unit runoff profiles for 2006, 2007, and 2008. 2004 and 2005 low flow measurements were not of sufficient density or timed closely enough to be useful for delineating gaining and losing reaches. The line of "discharge proportional to drainage area" is a theoretical discharge profile calculated by assuming constant URO for each station (0.7 cfs/mi² for 2006 and 2008, and 0.5 cfs/mi² for 2007) and multiplying this value by drainage area.

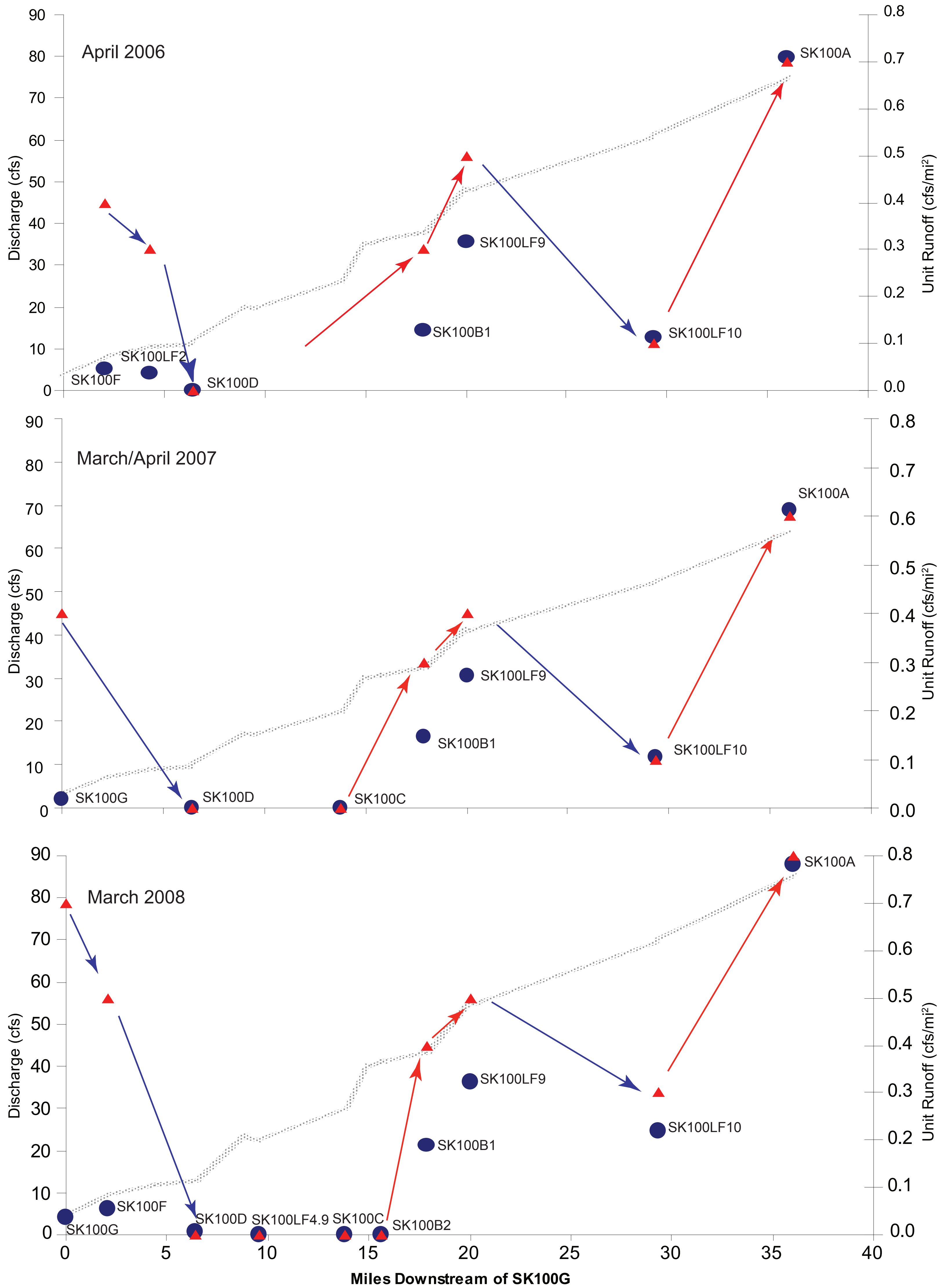
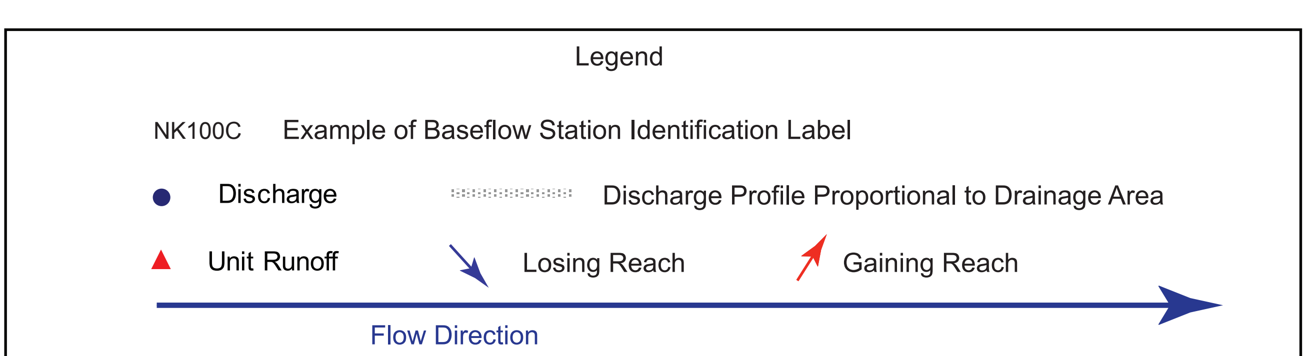


Figure 6. South Fork Koktuli River Low Flow Discharge and Unit Runoff Profiles



Note: SK low flow discharge and URO profiles for 2006, 2007, and 2008. 2004 and 2005 low flow measurements were not of sufficient density or timed closely enough to be useful for delineating gaining and losing reaches. The line of "discharge proportional to drainage area was calculated by assuming constant URO for each station (0.7 cfs/mi^2 for 2006, 0.6 cfs/mi^2 for 2007, and and 0.8 cfs/mi^2 for 2008) and multiplying URO by drainage area.

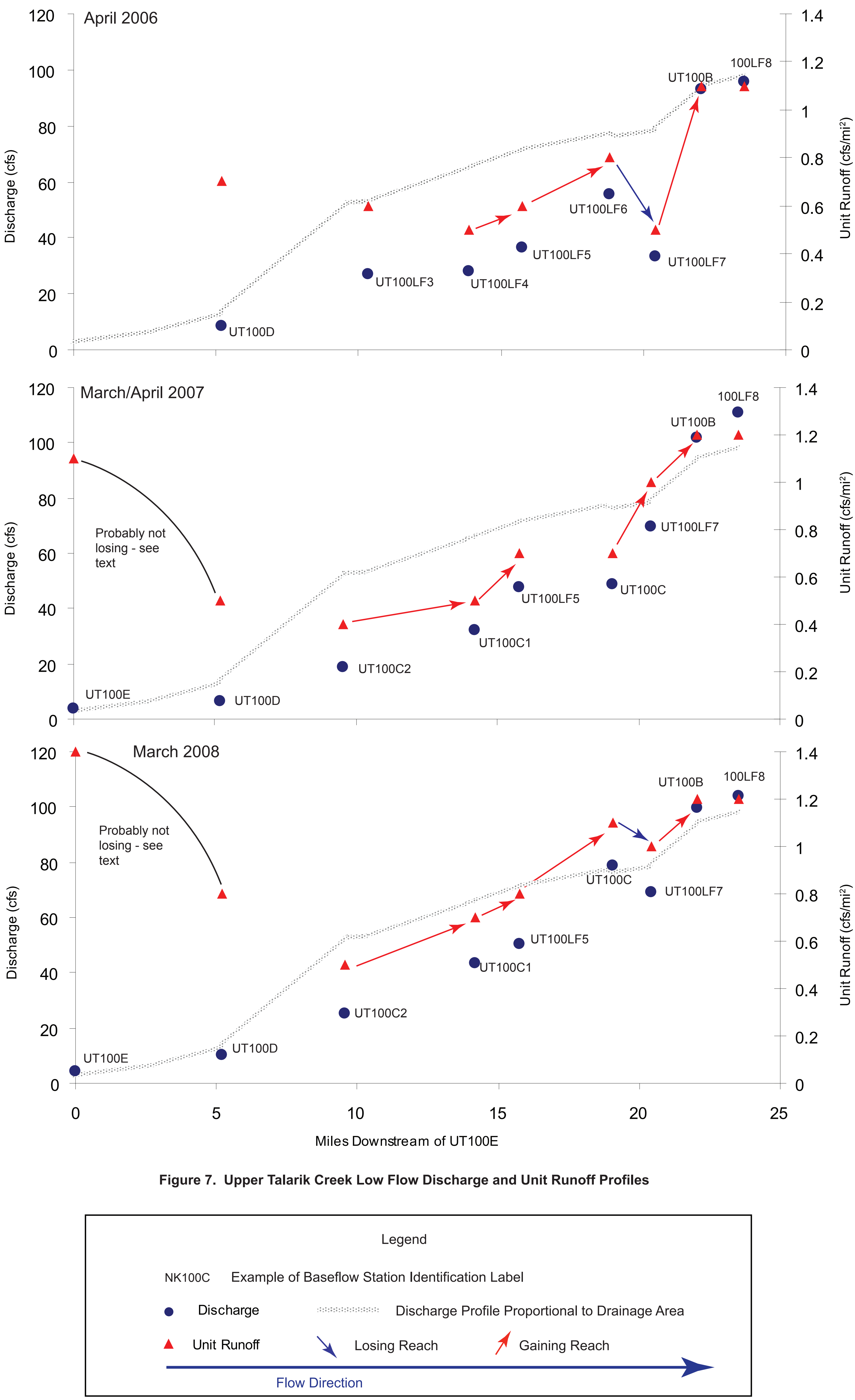


Figure 7. Upper Talarik Creek Low Flow Discharge and Unit Runoff Profiles

Note: UT low flow discharge and unit runoff profiles for 2006, 2007, and 2008. 2004 and 2005 low flow measurements were not of sufficient density or timed closely enough to be useful for delineating gaining and losing reaches. The line of "discharge proportional to drainage area" is calculated by assuming a constant URO for each station of 1.1 cfs/mi^2.

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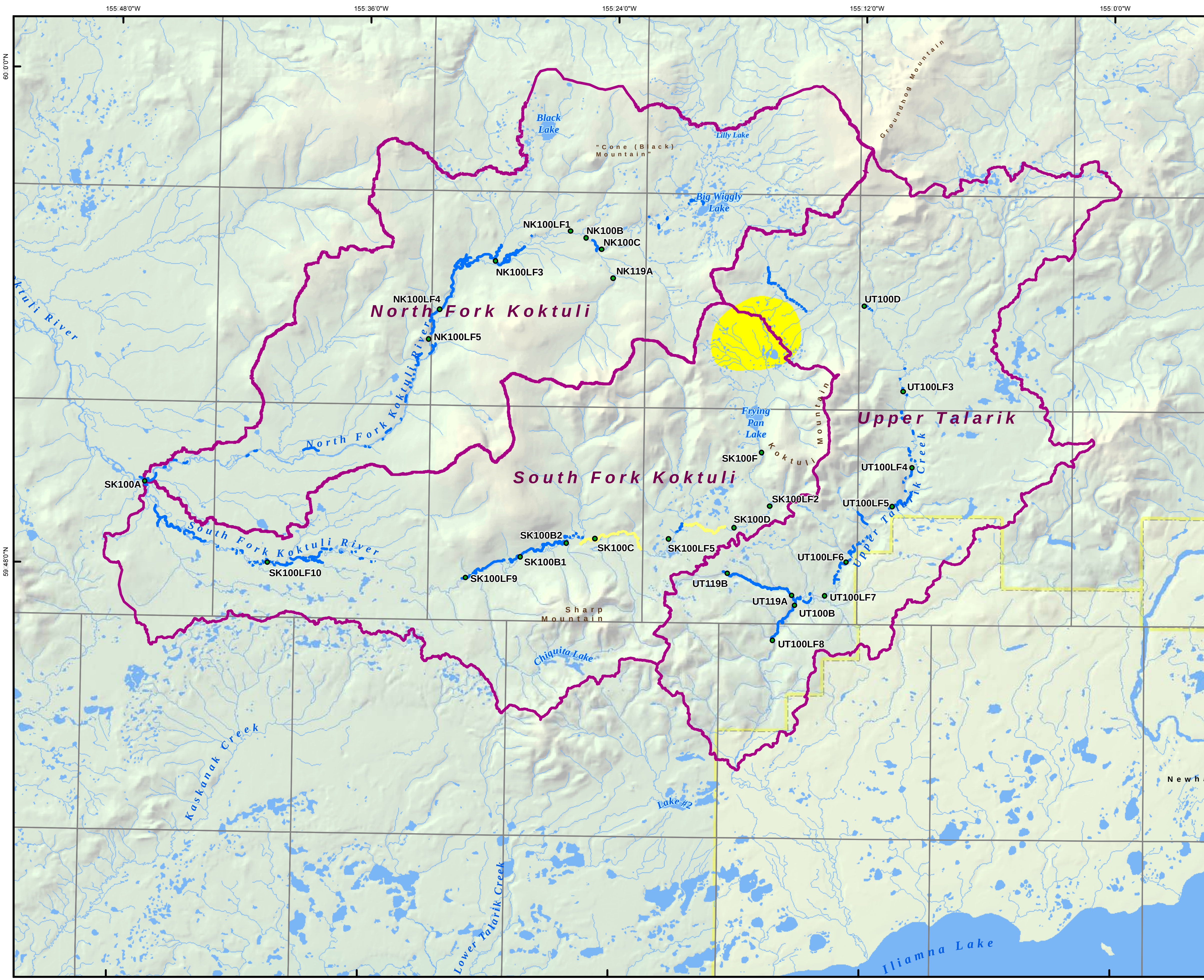
Figure 8
Low Flow Analysis
2006 Open Water Surveys



Legend

SK100A: Example of Baseflow Station Identification Label

- 2006 Baseflow Stations
- Major Drainage Boundary
- Water Feature
- General Deposit Location
- Village Corporation Boundary

2006 Open Water Survey

- No Flow
- Intermittently Open
- Open Water
- Ice Covered/Not Surveyed

Miles: 0 1.25 2.5 3.75 5

Kilometers: 0 1.25 2.5 3.75 5

N

Scale 1:170,000

Alaska State Plane Zone 5 (units feet)
1983 North American Datum

File: HDR_Fig8_openwater_v01.mxd	Date: 30 March 2011
Version: 1	Author: HDR Alaska

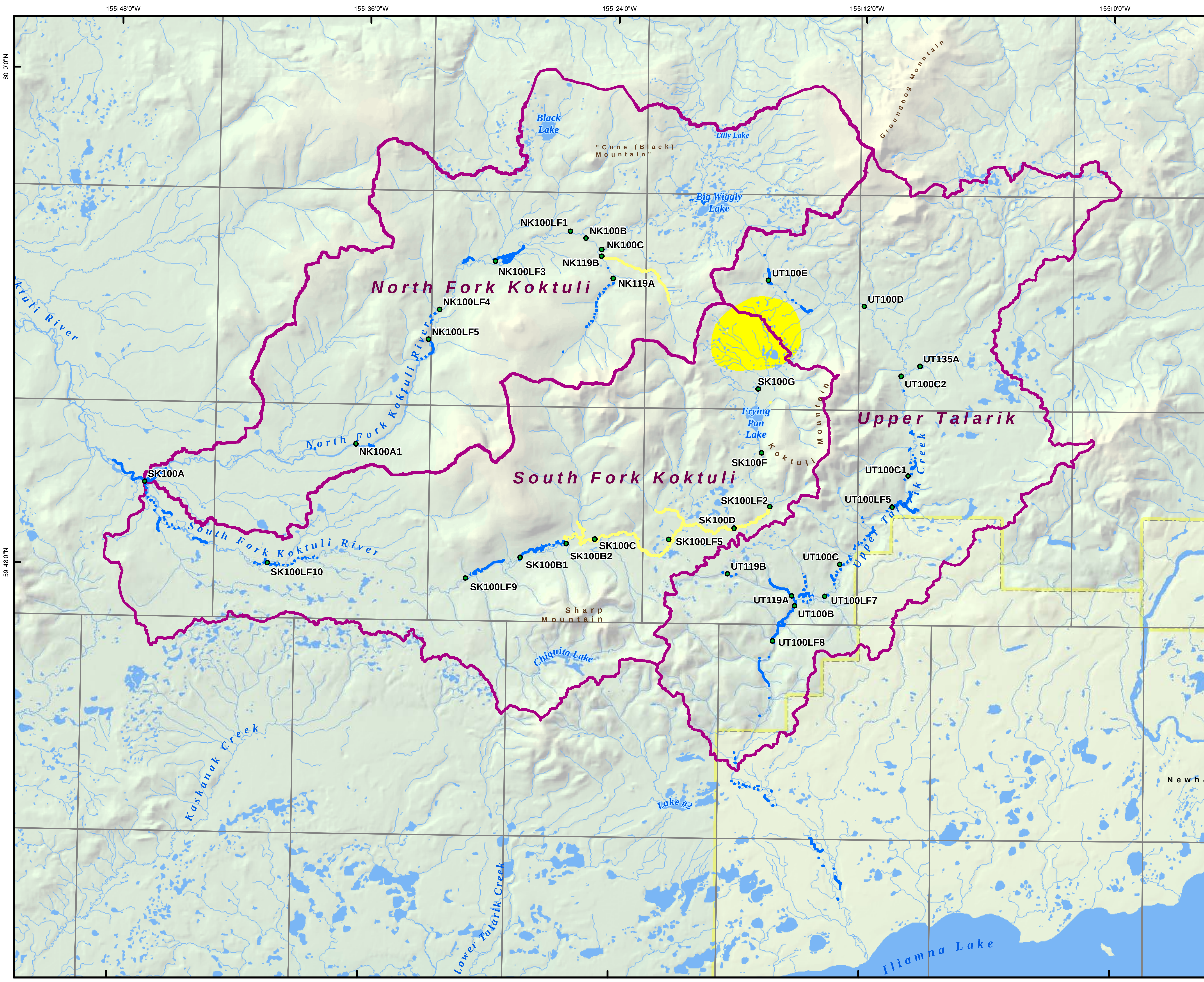


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Figure 9
Low Flow Analysis
2007 Open Water Survey

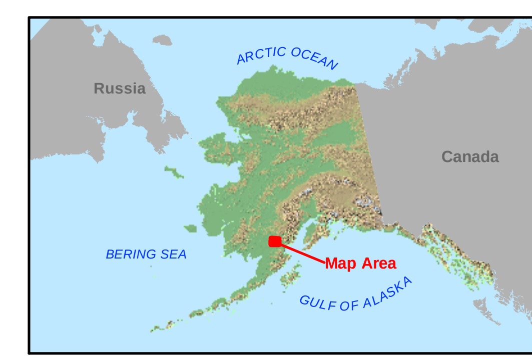
Legend

SK100A: Example of Baseflow Station Identification Label

- 2007 Baseflow Stations
- Major Drainage Boundary
- Water Feature
- General Deposit Location
- Village Corporation Boundary

2007 Open Water Survey

- Intermittently Open
- No Flow
- Open Water
- Ice Covered/Not Surveyed



0 1.25 2.5 3.75 5 Miles
0 1.25 2.5 3.75 5 Kilometers
N
Scale 1:170,000

Alaska State Plane Zone 5 (units feet)
1983 North American Datum

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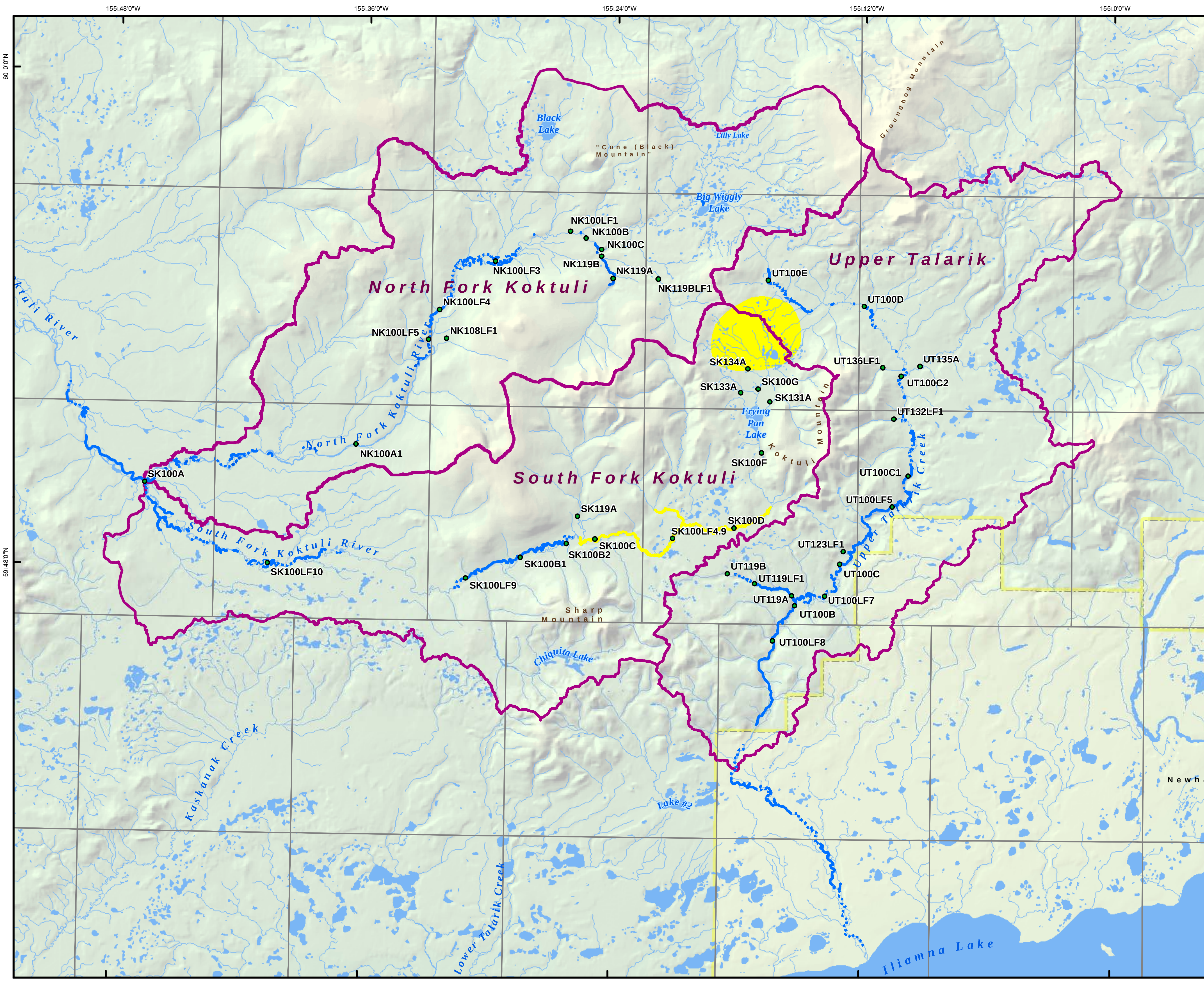

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Figure 10
Low Flow Analysis
2008 Open Water Surveys

Legend

SK100A: Example of Baseflow Station Identification Label

- 2008 Baseflow Stations
- Major Drainage Boundary
- Water Feature
- General Deposit Location
- Village Corporation Boundary

2008 Open Water Survey

- Intermittently Open
- No Flow
- Off-Channel Springs
- Open Water
- Ice Covered / Not Surveyed

Miles: 0, 1.25, 2.5, 3.75, 5
Kilometers: 0, 1.25, 2.5, 3.75, 5
Scale 1:170,000
N

Alaska State Plane Zone 5 (units feet)
1983 North American Datum

File: HDR_Fig10_openwater_v01.mxd	Date: 25 March 2011
Version: 1	Author: HDR Alaska

APPENDIX 7.2C

Peak Flow Analysis

TABLE OF CONTENTS

LIST OF TABLES

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ACRONYMS AND ABBREVIATIONS

cfs	cubic feet per second
Cs	coefficient of skewness
Cv	coefficient of variation
DEM	digital elevation model
GIS	geographic information system
GPS	global positioning system
KC	Kaskanak Creek
NK	North Fork Koktuli River
SK	South Fork Koktuli River
USGS	United States Geological Survey
UT	Upper Talarik Creek

PEAK FLOW ANALYSIS

1. INTRODUCTION

This report presents the findings of a peak flow analysis for streams in the Pebble mine study area. Peak flow typically refers to the maximum instantaneous discharge within a specified interval, such as a rainstorm event, a snowmelt or rainstorm season, or a calendar year or water year. Maximum daily flows are also considered in peak flow analyses in some cases – for example, maximum daily discharge is a more useful value for geomorphic assessments of channel processes as it represents an average sustained flow condition capable of performing geomorphic work (i.e., sediment erosion, transport, and deposition), as opposed to an instantaneous condition. Approximate scaling ratios can be developed to relate peak instantaneous and peak daily flows for a given recurrence interval at a given site.

Flood frequency distributions (relationships between peak discharge and probability of event occurrence) are developed from long-term stream gaging records and used for estimating the magnitude and frequency of rare events. At least 10 years of continuous discharge data are considered necessary for establishing a flood frequency curve (USGS, 1982). At locations for which there are less than 10 years of gaging data, or none at all, flood frequency distributions are commonly estimated on the basis of regional regression equations that relate peak flows from gaged basins to basin characteristics. Such equations have been developed by the U.S. Geological Survey (USGS) for regions in all states of the United States, including Alaska. These regression equations produce peak discharge estimates for 2- to 500-year return intervals from inputs of simple basin characteristics that can be measured (Curran et al., 2003). The accuracy of predicted flows depends on the error inherent in the regression model and measured flows for the region, the similarity of an ungaged basin with the gaged basins in the region, and the accuracy of measurement of the regression variables. At gaged sites with greater than 10 years of record, the standard approach for flood estimation is to develop a weighted flood-frequency relation based on the local gage data and the regional regression results. Curran et al. (2003) specify a weighting procedure based on the length of the local gaging record and the predictive error in the regional regression equations.

Streams in the Pebble mine study area were gaged at 29 locations from 2004 through 2008, as shown on Figure 1. Of these, 14 gages were installed in 2004 and have at least 3 years of record up to the end of the 2007 through 2008 water year (September 30, 2008), including three stations that were installed and are operated by the USGS. The other gages were installed in 2007 or 2008 and so have shorter periods of record. The streamflow gaging program in the mine study area is presented in detail in Appendix 7.2A.

The peak flow analysis presented in this document relies partially on the local gage records and is limited to the stations installed in 2004. The analysis was based on annual flood peaks defined by calendar years rather than water years since the water year break occurs within the middle of the autumn rainstorm season. Daily and peak instantaneous discharge data are currently available for the USGS stations only up until September 30, 2008, so the peak flow analysis in this document is based on flood peaks recorded prior to December 31, 2007.

The local records are less than 10 years in length, so the USGS regional regression equations have been used to predict flood-frequency relations in the mine study area. However, the USGS gaging network is sparse in the region surrounding the mine study area, and the terrain and climate are variable throughout the region, resulting in large predictive errors in the regression equations. Therefore, a modified approach has been developed to incorporate the mean annual peak flow magnitudes recorded at the gages in the mine study area into the regionally based flood-frequency relations.

2. STUDY OBJECTIVES

The ultimate objective of the surface-water peak flow study is to develop a site-specific methodology for generating reasonable and appropriate peak flow estimates for return periods from 2 to 500 years at all continuous gaging stations in the mine study area. This includes the following steps:

- Present peak flow results from the gaging network in the mine study area for the period of record (2004 through 2007).
- Characterize spatial variability in peak flow due to basin characteristics throughout the mine study area.
- Characterize the seasonal characteristics of peak flows (spring snowmelt floods versus autumn rainfall floods).
- Characterize peak flow magnitudes and characteristics in the mine study area relative to longer-term gaging records in the surrounding region.
- Use the USGS regional regression equations to estimate peak flows at all continuous gaging stations in the mine study area for return periods from 2 to 500 years.
- Use the local gaging records to make alternative peak-flow estimates at gaging stations in the mine study area for return periods from 2 to 5 years; develop and apply scaling relations to the 2-year floods in order to make alternative peak-flow estimates for return periods from 10 to 500 years.

3. STUDY AREA

3.1 Mine Study Area

The general deposit location straddles the boundary of the Nushagak and Kvichak River watersheds, both of which drain into Bristol Bay. More specifically, the general deposit location straddles the watershed boundary of the South Fork Koktuli River (SK) and Upper Talarik Creek (UT), and lies close to the headwaters of the North Fork Koktuli River (NK). The mine study area comprises the drainages of these three watercourses, as well as the headwaters of Kaskanak Creek (KC), which is located adjacent to the lower part of SK basin. The NK, SK, UT, and KC watersheds encompass a combined area of 373 square miles above the lowermost gaging station on each watercourse, including the general deposit area. The four study area watersheds and the general deposit location are shown on Figure 1.

The terrain in the mine study area for the NK, SK and UT watersheds consists of small mountains and ridges separated by broad valleys containing numerous lakes, ponds, and wetlands. Upland areas range in elevation from 2,000 to 2,600 feet, while the main valley bottoms lie at 600 to 900 feet elevation. Mean basin elevations range from approximately 1,000 feet in the UT to almost 1,300 feet in the NK. The KC watershed lacks any significant upland areas and has a mean basin elevation of 605 feet. Basin elevations and other basin characteristics for each of the 14 gaging stations installed within the mine study area in 2004 are presented in Table 1.

The mean annual precipitation at the Iliamna Airport is 26 inches, and the maximum recorded daily precipitation in the 53-year record is 3.5 inches. The Iliamna Airport is located in a lowland area on the north shore of Iliamna Lake at an elevation of 160 feet. Precipitation is higher in the mine study area than at Iliamna due to orographic effects, and varies throughout the study area due to topographic variability. The study area also experiences significant redistribution of snow due to wind. The prevailing winds are southeasterly, so maximum snow accumulation occurs on the northwestern (leeward) slope of ridges and hills. The redistribution of snow adds additional variability to stream runoff throughout the mine study area.

The mean annual unit discharge at the USGS gages on the lower reaches of the SK, NK, and UT mainstem channels (SK100B, NK110A, and UT100B, respectively) averaged between 2.6 to 2.8 cubic feet per second (cfs) per square mile (mi^2) during the period of record, as shown in Table 1. This equates to approximately 35 to 38 inches of annual runoff, considerably greater than the annual precipitation at Iliamna. The mean annual unit discharge in the KC watershed – which lies at a lower elevation than the other three watersheds and lacks major snow accumulation areas – was 1.4 cfs/mi^2, which equates to 19 inches of annual runoff. The mean annual unit discharge in small upland tributary catchments, represented by gaging stations SK119A and NK119A, ranged from 3.2 to 3.4 cfs/mi^2, which equates to 43 to 46 inches of annual runoff.

3.2 Bristol Bay Region

The Pebble mine study area lies within Region 4, as defined by the USGS for regional flood frequency analysis in Alaska (Curran et al., 2003). The extent of Region 4 is shown on Figure 2. Region 4 consists of two main parts of approximately equal area: the drainage area of Bristol Bay in the southwest, which includes the mine study area, and the drainage area of Cook Inlet to the northeast. Region 4 is bounded to the south and east by Region 3, which consists of a thin strip of territory along the windward (southern and eastern) slopes of the coastal mountains. Region 3 has a more maritime climate than Region 4, with milder temperatures and greater precipitation. Region 4 is bounded to the north by Region 6, which consists of the interior region of Alaska, where the climate is generally drier and more continental than Region 4.

The USGS has historically operated 22 gaging stations within the Bristol Bay portion of Region 4, as presented in Table 2. Of those, only eight are currently active and so have records overlapping with the Pebble stations. The eight active USGS gages include the three gages within the mine study area, three other gages on relatively small streams near the mine study area (Roadhouse Creek, Bear Creek, and Kaskanak Creek), and one gage on a larger stream along the eastern part of the transportation corridor (Iliamna River). Station location coordinates and summaries of the historical flow records for the USGS gaging stations are presented in Table 2.

The daily discharge and peak flow record for the Iliamna River started in 1996, making it the longest of the gaging stations listed above. The daily discharge records for Roadhouse and Bear Creeks started in 2005, although they both have historical peak flow records from crest gages. The historical peak flow record for Roadhouse Creek extends from 1973 through 1983 and has 10 peaks (1977 is missing). The historical peak flow record for Bear Creek contains only two peaks (1965 and 1968). The Kaskanak Creek record started in 2008.

Roadhouse Creek and Bear Creek are located less than 10 miles east of the UT watershed. The Roadhouse Creek watershed comprises mostly lowland areas with a small amount of hillslope drainage from the south flank of Roadhouse Mountain, which is similar in elevation to the summits in the mine study area. Roadhouse Creek has a relatively low average annual runoff of 1.2 cfs/mi^2, which is reflective of its low-elevation watershed. The Roadhouse Creek runoff value is similar to the average annual runoff in Kaskanak Creek (1.4 cfs/mi^2), the lowest elevation watershed in the mine study area. The Bear Creek watershed is located adjacent to the Roadhouse Creek watershed and also has a mix of lowland and upland terrain, but the proportion of upland terrain is greater in the Bear Creek watershed. This is reflected in the higher average annual runoff of 3.1 cfs/mi^2, which is similar to the upland tributary streams in the mine study area (gaged at SK119A and NK119A).

The Iliamna River flows into the eastern end of Iliamna Lake, approximately 50 miles east of the mine study area. The Iliamna River drains a mountainous watershed near the Region 3 boundary and has a considerably wetter climate than the mine study area. The average annual runoff is 6.9 cfs/mi^2, which is two to three times greater than the mine study area.

4. SCOPE OF WORK

Local stream gaging records collected by the USGS and by Pebble Partnership contractors between the summer of 2004 and December 2007 were used in this peak flow analysis. Stream gaging records collected by Cominco Ltd. (Cominco) from 1991 through 1994 were not included in the analysis due to data uncertainties and discontinuities. The USGS, Pebble Partnership, and Cominco gaging records are presented in detail in Appendix 7.2A.

Annual and seasonal peak flows were extracted from the local gaging records. Spatial and seasonal characteristics were examined and compared to peak flows at USGS gaging stations in the surrounding region.

The USGS regional regression equations were applied to produce peak flow estimates at all continuous gaging stations in the mine study area for return periods from 2 to 500 years. The following basin characteristics were required as input to the regional regression equations:

- Gaging station coordinates.
- Drainage area.
- Lake and pond storage area, as a percentage of drainage area.
- Mean annual precipitation.

Alternative peak flow estimates were produced for 2- and 5-year return periods using the local gaging records. Scaling relations were developed and applied to the 2-year peak flow estimates in order to make alternative peak flow estimates for return periods from 10 to 500 years.

5. METHODS

5.1 Peak Flow Measurement at Gaging Stations in the Mine Study Area

Discharge records were collected within the mine study area following standard USGS procedures, as described in Appendix 7.2A. The USGS operated three gaging stations and Pebble Partnership contractors operated 11 stations that were installed in 2004. At all stations, continuous records of stage (water level) were recorded at 15-minute intervals, and stage-discharge rating curves were required to transform the continuous stage records into continuous records of discharge. Stage-discharge rating curves were developed for each gaging station based on a series of instantaneous discharge measurements taken over a range of flow conditions. A curve was drawn through the measured stage-discharge points and extrapolated to the maximum recorded stage, allowing the corresponding peak discharge to be estimated. Typically, the highest directly measured discharge was considerably less than the annual peak discharge due to the short duration and difficult working conditions associated with flood events. Therefore, considerable care was required in the extrapolation of rating curves to estimate peak flows, since assumptions about rating curve form can potentially introduce significant error in peak flow estimates. The rating-curve extrapolation procedure applied to Pebble Partnership gaging stations is described in detail in Appendix 7.2A and includes an assessment of channel geometry, overhanging vegetation, and agreement of rating curve form with hydraulic theory.

In general, rating-curve extrapolation for peak flow estimation is considered reliable at gaging stations on the main channels of SK, NK, UT, and KC. This is because the amount of vegetation overhang is small relative to channel width, and peak flows are moderated by basin area, pond storage, and deep surficial materials and thus are not drastically larger than the highest measured flows. However, some of the main channel stations were affected by variations in downstream control, which reduces the confidence in peak flow estimates. For example, SK100F was affected by variable backwater influence from beaver activity, and SK100G was affected by variable downstream water levels in Frying Pan Lake. At other stations, the rating curves are considered reliable under normal flow conditions, but site characteristics caused systematic problems with peak flow data collection due to deep snow drifting and/or ice jam formation in the spring. The most reliable main channel gaging stations with records starting in 2004, with respect to peak flow estimation, are SK100A, SK100B, NK100A, UT100B, UT100D, UT100E, and KC100A.

Rating-curve extrapolation is subject to greater error at gaging stations on steeper, upland tributaries. This applies to SK119A and NK119A. The difficulties are due to the greater comparative influence of overhanging vegetation relative to channel width and the brief, flashy nature of flood peaks that result from rapid runoff on steep terrain with thin surficial materials. Overall, the peak flow estimates for these gages are expected to be over-estimates of the actual flows experienced and so are conservative in terms of flood hazards.

The Pebble Partnership gaging stations were operated seasonally. Gaging equipment was installed each spring prior to the snowmelt freshet and removed each autumn around freeze-up. The USGS stations remain in place year-round, although special estimation procedures are required for frozen conditions as rating curves are not applicable in the presence of ice. High streamflows occur each year in spring due to snowmelt, and in autumn due to frequent frontal rainstorms. In some cases, Pebble Partnership gaging stations could not be installed prior to spring freshet due to accessibility constraints, so the spring peak flows were not recorded. In other cases, large rainstorms occurred in late autumn following the removal of gaging stations. Pebble Partnership gaging records for each station and each year were compared to

USGS gaging records to assess whether any seasonal peak flows had likely been missed. Any spring or autumn seasons in which the peak daily flow was likely to have been missed were identified and the missing values were estimated by regression analysis, as described in Appendix 7.2A. Missing peak instantaneous flows (assumed to coincide with peak daily flow dates) were not estimated and any seasons with missing data were excluded from further analysis of instantaneous peak flows.

Maximum daily and instantaneous flows were compiled from the local gaging stations for each peak flow season. The spring snowmelt season was defined as April through July, and the autumn rainstorm season was defined as August through November. Annual peak flows always occurred within one of these two seasonal periods. The standard water year starts on October 1 of each year, bisecting the annual rainstorm season. Thus, for this analysis, it made more sense to adopt the calendar year for the definition of seasonal and annual peak flows. This results in three spring snowmelt seasons (2005 through 2007) and four autumn rainstorm seasons (2004 through 2007) for peak flow analysis.

5.2 Regional Peak Flow Regression Equations

The USGS performed a least squares regression analysis on peak flow records from 361 gaging stations in Alaska and contiguous basins in Canada (Curran et al., 2003). These gaging stations were separated into seven regions that exhibit similar climatic and physiographic characteristics. In each region, peak flow estimates were calculated by using Log Pearson Type III analysis and were regressed against nine basin characteristics. From this least squares regression analysis, the USGS computed the best-fit set of equations for each region. Each equation returns an estimate of peak instantaneous discharge for a given return interval. For example, the first equation provides an estimate of Q_2, or the discharge that has an estimated average return interval of 2 years. The equations for Region 4, which encompasses the study area, are listed in Table 3. Only three of the nine variables were found by the USGS to be significantly correlated with peak flow in this region: drainage area, precipitation, and area of lakes and ponds as a percentage of watershed area.

Curran et al. (2003) stated explicitly how these basin variables were defined for the regression analysis, and that these same methods should be used when predicting flows for ungaged stations. For instance, although stream runoff data indicate that mean annual precipitation is greater than 34 inches in the mine study area, the USGS map indicates that an annual precipitation of 26 inches should be used. Substituting a better estimate of precipitation into the regression equations would not necessarily improve accuracy, and it would invalidate the error calculations associated with each regression. In order to increase accuracy, updated precipitation data would be needed for the entire region, and new regression equations would have to be developed based on the updated data.

The standard error of prediction for the Region 4 regression equations ranges from 38 to 52 percent of the predicted peak flow, depending on the return period in question. The regression equations have a predictive accuracy similar to 1 year of gaging data for the 2-year peak flow, and similar to 7 years of gaging data for the 500-year peak flow. The 3.5 years of gaging data in the mine study area provide a more accurate basis for estimating peak flows up to the 10-year return period than do the regional regression equations.

5.3 Basin Characteristics

5.3.1 Drainage Area Delineation

Station location data were collected by using handheld global positioning system (GPS) equipment. Drainage basin boundaries were delineated in the geographic information system (GIS), ArcGIS 9.1

5.3.2 Precipitation

The USGS regional regression equations were based on a 1:2,500,000-scale precipitation map of Alaska produced by Jones and Fahl (1994). The mine study watersheds lie between the 20-inch and 30-inch isohyets (contours of mean annual precipitation) on the state precipitation map. The estimated value of mean annual precipitation for the entire mine study area based on this map is 26 inches, which matches the mean annual precipitation at Iliamna, but under-represents the true precipitation in the mine study area based on the annual stream runoff results presented in Appendix 7.2A.

5.3.3 Area of Lakes and Ponds

The area of lakes and ponds (in percentage of drainage area) was calculated in GIS by overlaying the hydrographic data set (USGS 2002) referenced in Curran et al. (2003) on the drainage basins.

6. RESULTS AND DISCUSSION

6.1 Results

6.1.1 Peak Flows Recorded in the Mine Study Area

Maximum daily and instantaneous peak flows recorded at continuous gaging stations in the mine study area are presented by season and by year in Tables 4 through 7. Tables 4 and 5 present maximum daily discharges and maximum daily unit-area discharges, respectively. Tables 6 and 7 present maximum instantaneous discharges and maximum instantaneous unit-area discharges, respectively. The spring snowmelt season is defined as April through July, and the autumn rainstorm season is defined as August through November, although it is recognized that rainfall may contribute to spring peaks and the melting of snow may contribute to autumn peaks. Annual peaks are based on calendar years rather than water years to avoid breaking autumn rainstorm seasons into two water years. The 2004 peak flows are based on the autumn season only, since the continuous gage records did not begin until the summer of that year. A number of peak flow values are missing due to the likely occurrence of a peak flow outside of the period of gage operation. In some cases, maximum daily flows have been estimated by regression analysis against concurrent flows at one of the USGS gages in the mine study area, as described in Appendix 7.2A. The estimated values are italicized in Tables 4 and 5. Missing instantaneous peak flows were not estimated.

6.1.2 Peak Flows Recorded in Region 4

Annual maximum daily and instantaneous peak flows recorded at Roadhouse Creek, Bear Creek, and the Iliamna River are presented in Table 8. The historical peaks in Roadhouse Creek and Bear Creek occurred in both spring and autumn, but the more recent peaks (i.e., since 2005) have all occurred in autumn. Given the relatively low elevations and low snow accumulations in these watersheds, and the Roadhouse Creek watershed in particular, it seems reasonable to expect that autumn rainfall would be a relatively more dominant flood-generating mechanism there than in the mine study area. The annual peaks in the Iliamna River occurred in both spring and autumn.

6.2 Discussion

6.2.1 Peak Flow Characteristics in the Mine Study Area

The temporal and spatial characteristics of recorded and estimated peak flows are presented below. The lowermost gaging stations on the main stream channels (NK100A, SK100A, UT100B, and KC100A) represent the four main watersheds (NK, SK, UT, and KC). The basins above these gaging stations have the lowest mean basin elevations and presumably the lowest average and extreme rates of precipitation of the basins considered. The peak flows at these stations are also subject to the greatest amount of attenuation due to the cumulative effects of lake and pond storage and long groundwater and channel pathways within the respective watersheds. At the other extreme, the peak flows at gaging stations on two upland tributaries (SK119A and NK119A) are generated by heavier precipitation and snow accumulation, due to orographic enhancement, and are subject to the least amount of attenuation, due to the lack of lakes and ponds, the relatively steep terrain and shallow surficial materials, and the short channel lengths present within these basins. The peak flows at most of the other gaging stations are expected to reflect intermediate attenuation effects. The exceptions are SK100C, where continual losses of surface flow to the subsurface results in anomalously low peak flows, and UT119A, where continual groundwater inflows constitute a large proportion of the peak flows. The interactions between surface and subsurface flows at these two stations are described in Appendix 7.2A.

6.2.1.1 Seasonal Occurrence of Peak Flows

The peak flow results presented in Tables 4 through 7 indicate considerable variability from year to year. Annual peaks occur in both spring and autumn, with neither season exhibiting systematically higher peaks than the other. This applies to the gaging stations on the main stream channels as well as the upland tributaries. Autumn peaks displayed considerably less variability from 2005 to 2007 than did spring peaks, so the seasonal occurrence of the annual peak in any given year depended mainly on the magnitude of the spring peak in that year. In 2005, the spring and autumn peaks at each station (daily and instantaneous) were similar in magnitude, with approximately half of the stations recording higher peaks in spring and the other half recording higher peaks in autumn. In 2006, most stations recorded higher peaks in spring than in autumn. This was due to the occurrence of higher spring peaks in 2006 than in 2005, with similar autumn peaks in both years. In 2007, all stations recorded higher peaks in autumn than in spring, this time due to much lower spring peaks in 2007 than in 2005 and 2006. The frequency analyses of the site data did not consider the spring and autumn datasets separately, but rather considered them as coming from a single population of values, since the use of special techniques developed to consider mixing of flood populations does not produce substantially different results (Mtiraoui, 2004) and is not warranted with such small datasets.

6.2.1.2 Maximum Recorded Peak Flows

The largest peak flow recorded at any gaging station during the study period was 2,240 cfs at USGS gaging station NK100A on November 27, 2004. This equates to a unit-area discharge of 21.2 cfs/mi^2, as shown on Table 7. Other gaging stations on the lower portions of the main SK and UT stream channels (SK100A, SK100B, and UT100B) have recorded maximum peak flows over 1,000 cfs, with unit-area discharges of 15 to 25 cfs/mi^2. It should be noted that *peak* values for USGS gages SK100B and UT100B for autumn 2004 are not presented in Table 7 because the maximum *daily* values for those gages in autumn 2004 occurred on September 30, 2004, and the USGS peak flow records do not begin until 1 day later on October 1, 2004 – the start of the first water year after gage installation in August 2004. UT100B recorded its daily flood of record on September 30, 2004, with a value (1,390 cfs) that exceeds any peak instantaneous value recorded since then. Therefore, the highest instantaneous peak discharge of record must have occurred on September 30, 2004, but is not included in the Table 7 dataset.

Further upstream on the main channels and in tributary streams, the absolute value of maximum recorded peak flows is smaller, but the unit-area discharges are larger. The largest unit-discharge peak flows have been recorded at the two gages on upland tributaries with the steepest slopes, smallest area of lakes and ponds, and relatively thin surficial materials: SK119A and NK119A. Both of these gages have recorded peaks greater than 60 cfs/mi^2, with a maximum of 71.7 cfs/mi^2 recorded at SK119A on September 9, 2005.

The maximum recorded and estimated daily peak flows followed the same general pattern. The maximum daily unit-area discharges at the lowermost stations on the three main stream channels ranged from 15.1 to 17.2 cfs/mi^2. These values equate to daily runoff depths of 0.56 to 0.64 inches. The maximum daily unit-area discharges at the upland tributary stations ranged from 33.2 to 47.4 cfs/mi^2. These values equate to daily runoff depths of 1.2 to 1.8 inches.

6.2.1.3 Mean Annual Peak Flows

Mean annual peak flows were computed for each gaging station based on 4 calendar years of data and assuming that the flood peaks in autumn 2004 represent the annual peaks for that year. Eight of the 14 gaging stations in operation at that time experienced their largest autumn floods in 2004 (based on daily discharge), including five of the 14 stations that experienced their daily floods of record in 2004. Without streamflow data for spring 2004, it is not possible to state with certainty that the autumn 2004 floods represent the annual peaks for 2004 at all 14 stations, but it is a reasonable assumption to make for the purposes of preliminary flood frequency estimation.

Mean annual daily peak flows at the lowermost stations on the main stream channels range from 9.2 cfs/mi^2 at KC100A, which represents the outlet of the lowest-elevation watershed, to 14.8 cfs/mi^2 at NK100A, which represents the outlet of the highest-elevation watershed. The SK and UT watersheds (SK100A and UT100B) have similar mean annual peak flows of around 11 cfs/mi^2. These peak flow values equate to daily runoff depths of 0.34 to 0.55 inches. The mean annual daily peak flows in the upland tributary streams gaged by SK119A and NK119A ranged from 24.0 to 38.2 cfs/mi^2. These peak flow values equate to daily runoff depths of 0.89 to 1.42 inches.

The mean annual daily and instantaneous discharge values for the Pebble gaging stations are plotted versus drainage area on Figures 3 and 4, respectively. As expected, the absolute value of peak flows generally increases with drainage area. Deviations from the trend-line (i.e., deviations from the average unit discharge) are due to the watershed characteristics and groundwater interactions described above. The dataset of daily peak flows is more complete than the dataset of instantaneous peak flows and provides a more useful dataset for analysis. An improved plot of mean annual daily peak flows is presented on Figure 5 with log-log axes and with UT119A removed due to the anomalous influence of groundwater inflows on its peak flows. The opposite effect (loss of surface flow) occurs at SK100C but has a relatively less significant effect on peak flows. A best-fit power function has been fitted to the main stream channel peak flows on Figure 5. The equation has an exponent of 0.97, which is very close to 1, and indicates that mean annual peak flows are almost directly proportional to drainage area, over the range of drainage areas studied. This is not unexpected for a region where peak flows are generated by snowmelt or frontal rainfall, as opposed to more locally concentrated convective rainfall, and where dense ground vegetation, abundant ponds and wetlands, and thick surficial materials provide storage at all scales of drainage areas. The two upland tributaries stand out as having distinctly higher mean annual daily peak flows than the main stream channel trend. An approximate trend line has been plotted through the upland tributary points, with the assumption that the trend line should converge toward the main channel trend line toward the main watershed outlets. This requires a lower exponent, indicating a greater dependence on drainage area in steep upland basins, which makes sense given the relatively lower storage in these watersheds and the greater sensitivity to lag time effects with increasing drainage area. The two upland tributaries are not sufficient for defining the form of the trend line on their own because their drainage areas are too closely clustered around 8 to 11 square miles.

6.2.1.4 Instantaneous to Daily Peak Flow Ratios

Ratios between annual instantaneous and daily peak flows are presented in Table 9 and on Figure 6. The two gaging stations on upland tributary streams have relatively high ratios of instantaneous to daily flows, with average ratios between 1.6 and 1.7. This is indicative of the rapid runoff response in these basins, which results in peak instantaneous flows much larger than the average daily flow during the flood event. At the other gaging stations, the average ratios typically range from 1.1 to 1.3.

6.2.1.5 Storm Hydrograph Analysis

Rainstorm hydrographs from representative gaging stations on the lower reach of a main channel (SK100A) and on an upland tributary (SK119A) were examined in an effort to characterize runoff response times. The 15-minute discharge data from SK100A and SK119A for Autumn 2006 rainstorm season are presented on Figure 7. Three storm hydrographs with rapid, uninterrupted rising limbs at both gaging stations were identified. The peaks and troughs were marked and the time to peak was measured for each event. The results are summarized in Table 10. The average time to peak at SK119A was around 10.5 hours. The average time to peak at SK100A was roughly double at around 21 hours.

6.2.2 Peak Flow Characteristics in Region 4

6.2.2.1 Mean Annual Peak Flows

The mean annual instantaneous peak flow in Roadhouse Creek, including the historical record, is 7.1 cfs/mi^2. Since 2005, the mean peak flow is 12.2 cfs/mi^2, which is similar to the values for SK100A and UT100B in this period (around 13 cfs/mi^2). The mean annual instantaneous peak flow in Bear Creek, including the historical record, is 19.6 cfs/mi^2. Since 2005, only one peak flow has been reported (2006) with a value of 14.7 cfs/mi^2. The Bear Creek peak flow record is scant, but the values are similar to NK100A (17.8 cfs/mi^2). The average ratios of maximum instantaneous to maximum daily discharges are around 1.1, similar to the larger watersheds and lower-elevation sub-catchments in the mine study area, as shown on Figure 6.

The annual peaks in the Iliamna River occur in both spring and autumn. The unit discharge values are much larger than those for the mine study area. The mean annual peak instantaneous unit discharge is 127 cfs/mi^2, which is an order of magnitude greater than the main stream channels in the mine study area and two to three times greater than the upland tributaries in the mine study area. The average ratio of maximum instantaneous to maximum daily discharges is 1.52, which is similar to the upland tributaries in the mine study area, as shown on Figure 6.

6.2.2.2 Hydrograph Comparisons

The hydrograph of daily unit discharge at SK100A is compared to the hydrographs from Roadhouse Creek, Bear Creek, and the Iliamna River on Figures 8, 9, and 10, respectively. SK100A was selected as a representative gaging station from a main watershed outlet in the mine study area. The hydrographs show that autumn rainfall events are generally synchronous at SK100A, Roadhouse Creek, and Bear Creek, as expected due to their close proximity. Maximum daily unit values are similar in magnitude at SK100A and Bear Creek, and generally lower at Roadhouse Creek, in accordance with the lower elevation and smaller orographic influence in the Roadhouse Creek watershed. Rainfall events at SK100A and the Iliamna River are less closely related in timing, magnitude, and relative magnitude.

The spring snowmelt freshet is generally synchronous at SK100A and Bear Creek on a seasonal basis, but the relative timing and magnitude of maximum daily values varies from year to year. Roadhouse Creek has distinctly shorter freshet durations and lower unit discharges than SK100A and Bear Creek. The Iliamna River has longer freshet durations and higher unit discharges than SK100A.

The daily unit-discharge hydrograph from SK119A is compared to the hydrographs from Roadhouse Creek, Bear Creek, and the Iliamna River on Figures 11, 12, and 13, respectively. SK119A was selected as a representative gaging station for an upland tributary in the mine study area. The hydrographs show that autumn rainfall events are generally synchronous at SK119A, Roadhouse Creek, and Bear Creek, as expected due to their close proximity. Maximum daily values are greater at SK119A than at Bear Creek and much greater than at Roadhouse Creek, in accordance with relative topographic watershed characteristics (elevation and slope). Rainfall events at SK119A and the Iliamna River are less closely related in timing, magnitude, and relative magnitude.

The spring snowmelt freshet at SK119A is not well related to Roadhouse Creek, Bear Creek, or the Iliamna River. The SK119A freshet is similar in duration to Roadhouse Creek and Bear Creek but has higher unit discharge, and the maximum flows are not synchronous. The SK119A freshet is shorter in duration than the Iliamna River freshet, has lower unit discharge, and the maximum flows are not synchronous.

6.2.3 Regional Peak Flow Estimates

6.2.3.1 Standard Approach

The Region 4 peak flow regression equations were applied to the gaging stations in the mine study area to produce instantaneous peak flow estimates for return periods from 2 to 500 years. The results are presented in Table 11. For comparison, the mean and maximum instantaneous peak flows recorded during the study period are also shown. The regression-based return periods for the recorded peak flows are presented in the two right-hand columns (for mean and maximum recorded peak flows).

Table 11 shows that the regional regression equations assign very high return periods to the recorded peak flows. The recorded mean annual peak flows for gaging stations on main stream channels have predicted return periods of 5 to 20 years, except at SK100C, where a portion of the flow is lost to the subsurface. The maximum recorded peak flows at these gages, based on record lengths of 4 years (or less), have predicted return periods of 10 to 200 years.

The recorded mean annual peak flows for gaging stations on steep upland tributaries (SK119A and NK119A) have return periods of greater than 50 years. The maximum recorded peak flows at these gages, based on record lengths of 4 years (or less), have predicted return periods of greater than 100 years.

These results indicate that the regional regression equations likely underestimate peak flows in the mine study area in general and in upland tributaries within the mine study area in particular. Thus, alternative approaches to peak flow estimation are considered.

6.2.3.2 Alternative Approach #1: Revised Annual Precipitation

The standard application of the USGS regional regression equations requires the use of a mean annual precipitation value obtained from a regional map. However, local gaging data indicate that precipitation and runoff vary substantially within and around the mine study area. As an alternative approach, more realistic precipitation values based on local stream runoff records were input into the regression equations. Rather than using the recommended precipitation value of 26 inches throughout the mine study area, a more realistic value of 50 inches was applied to the upland tributary gaging stations (SK119A and NK119A) and 40 inches was applied to all other stations. The revised peak flow results obtained using these precipitation values in the regional equations are presented in Table 12.

The recorded mean annual instantaneous peak flows at the gaging stations on steep upland tributaries have return periods of 5 to 20 years according to the revised regression results. The recorded mean annual peak flows for the other gaging stations have return periods of less than 2 years to 5 years. The results presented in Table 12 are more in line with expectations than the results obtained using the standard precipitation value (Table 11). However, the peak flow predictions for the upland tributaries still appear to be too low, resulting in unreasonably high return periods for the recorded mean annual peak flows. This is explained by the lack of variables in the regression formulas that account for basin topography, and the under-representation of similar watersheds in the regional gaging network upon which the regression formulas were developed.

The maximum recorded instantaneous peak flows at the gaging stations on steep upland tributaries, based on record lengths of 4 years (or less), have predicted return periods of 10 to 50 years. The maximum recorded peak flows at the other gages have predicted return periods of 2 to 10 years. Again, these results are more in line with expectations than the results obtained using the standard precipitation value (Table 11), but the peak flow predictions for the upland tributaries still appear to be too low, resulting in unreasonably high return periods for the maximum recorded peak flows.

6.2.3.3 Alternative Approach #2: Frequency Analysis of Local Gage Records

An alternative set of peak flow estimates was developed for the gaging stations in the mine study area based on flood frequency analysis of the local gage data. The records are too short to develop reasonable estimates of long return period floods, but given the relatively low level of confidence in the regional regression equations, a frequency analysis of the local gage records has a similar or better level of confidence for predicting return periods up to 10 years.

Standard flood frequency analysis techniques were applied to the records of annual daily peak flows, including estimated values, assuming a Log Pearson Type III distribution for all datasets. The daily peak flow sets are more complete than the instantaneous peak flow sets due to the estimation of missing values by regression against other stations, as previously discussed. The predicted daily peak flows for return periods of 2 to 10 years are presented in Table 13. Instantaneous peak flows were then estimated by applying the average ratios of instantaneous-to-daily peak flows for each station to the predicted daily peak flows for that station. The results are presented in Table 14.

A special procedure was applied to the frequency analysis of daily peak flows at UT119A. Groundwater comprises a large portion of the streamflow, even during peak flow conditions. For example, the relatively constant baseflow of around 22 cfs represents 42 percent of the maximum recorded instantaneous peak flow, and thus represents an even greater component of recorded daily peak flows. Therefore, the flood frequency analysis was performed only on the storm runoff portion of the daily peak flows (i.e., the baseflow of 22 cfs was subtracted from the peak flows before analysis). For each return period, the peak flow values were then reconstituted by adding the baseflow component to the frequency analysis results.

As expected, the mean annual daily peak flows recorded at each gaging station have predicted return periods of less than 2 to 5 years, as shown in Table 13. The maximum recorded daily peak flows have return periods of 5 to greater than 10 years. These are more reasonable results than those obtained by means of the previous approaches, but the frequency analysis of the local gage records is not considered appropriate for estimating peak flow values for return periods greater than 10 years.

The mean annual instantaneous peak flows recorded at each gage also have predicted return periods of less than 2 to 5 years, as shown in Table 14. Most of the maximum recorded peak flows have return periods of 10 years or more.

6.2.3.4 Alternative Approach #3: Combined Local and Regional Approach

The local gage records are considered to provide the best estimates of daily and instantaneous peak flows for short return periods. As an alternative to flood frequency analysis of the recorded peaks to estimate longer return period peak flows, the regional regression equations can be considered as a tool for scaling 2-year peak flow estimates based on local records to longer return periods. First, an analysis of the scaling characteristics of the regional regression equations is warranted.

The regional regression equations predict that 2-year flows scale with drainage area according to a power function with an exponent of 0.95, based on an assumed lake storage area of 3 percent and mean annual precipitation of 26 inches, as shown on Figure 14. This compares well with the observed scaling relation for mean annual daily peak flows at main channel gaging stations in the mine study area, as shown on Figure 5. In that case, the power function exponent was 0.97.

The regional regression equations predict that longer return period peak flows scale with drainage area according to power functions with decreasing exponents as return period increases. Presented another way, the ratio between the *n*-year peak flow and the 2-year peak flow decreases with increasing drainage area, as shown on Figure 15. The negative slopes of the curves on Figure 15 equate to a decrease in the values of the scale and/or shape parameters of the frequency distribution with increasing basin scale, as is typical of coastal areas (Cathcart, 2001). This tendency is reflected in the scaling patterns of peak daily flood statistics, and in particular those of the coefficients of variation (Cv) and skewness (Cs), which respectively are measures of the spread and asymmetry of a dataset. A review of the Cv statistics of the recorded daily peak flows at the Pebble gaging stations demonstrates a similar declining trend with increasing basin scale, as shown on Figure 16. In this instance, the statistics were calculated by linear moments to reduce the effects of outliers in the small sample sets (and therefore prefixed by the letter "L"). The L-Cv value for UT119A is anomalously low because of the large groundwater component. The L-Cv trend with respect to drainage area is more distinct when the L-Cv value for UT119A is omitted, as shown on Figure 16.

Based on the above analysis, the general form of the regional regression equations matches the available evidence of flow-area scaling relations in the mine study area. However, the actual ratios of *n*-year peak flows and 2-year peak flows can not be adequately evaluated from the local gage data. The scaling ratios at a given drainage area are indicative of the spread and skewness in the flood-frequency distribution, and these statistics, and particularly the skewness, could not be properly estimated from the short gage records. It is noted that Region 4 has the highest generalized skewness (0.60) of any region in Alaska (Curran et al., 2003). It will be assumed herein that the generalized skewness for Region 4 is applicable to the mine study area.

The alternative peak flow estimates based on a combined local-regional approach are presented in Table 15. The 2-year and 5-year instantaneous peak flows were taken from the flood frequency analyses of the local gage records, as presented in Table 14. The peak flows for return periods of 10 years or more were scaled from the 2-year values assuming the same ratios between *n*-year and 2-year peak flows for each station as derived from Table 12.

According to the peak flow results presented in Table 15, the return periods for the recorded mean annual peak flows are less than 2 to 5 years. The return periods for the maximum recorded peak flows are between 2 and 10 years. The peak flow results are presented in terms of unit-area discharge in Table 16. The 200-year instantaneous unit-area discharge estimates range from around 35 to 80 cfs/mi^2 in the main stream channels, and from 200 to 300 cfs/mi^2 in the upland tributaries. For comparison, the maximum recorded peak flow in the 12-year record on the Iliamna River is 414 cfs/mi^2.

7. SUMMARY

The gaging stations in the mine study area can be categorized as main-channel stations and upland tributary stations. The tributary gaging station UT119A is anomalous because groundwater inflows form a major component of peak flows. In the upland tributary channels represented by gaging stations SK119A and NK119A, unit-area peak flows and ratios between instantaneous and daily peak flows are much greater than in the main channels due to the steep terrain, shallow surficial materials and lack of pond storage.

Annual peaks occurred in both spring and autumn during the study period, with neither season exhibiting systematically higher peaks than the other. This applies to the gaging stations on the main stream channels as well as the upland tributaries. The snowmelt peaks have been more variable from year to year within the study period, and are more difficult to measure due to problems with gage stability and ice-related backwater effects during the spring freshet. The mixture of runoff mechanisms also results in increased uncertainty in statistical analyses since rainfall and snowmelt floods may produce different long-term flood-frequency distributions.

The mine study area is located within USGS Region 4, which is a large and sparsely gaged region with variable terrain, climate, and hydrology. The regional regression equation developed by the USGS for Region 4 underestimate peak flows in the mine study area, particularly in the upland tributaries. A combined local-regional approach was developed to improve the peak flow estimates. This approach uses 2-year and 5-year peak flow estimates developed from flood-frequency analyses of the local gage records, then scales these to longer return periods using the ratios between *n*-year and 2-year peak flows inherent in the regional equations. The results are presented in Tables 15 and 16.

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TABLES

TABLE 1
Gaging Stations Installed in the Mine Study Area in 2004

Watershed	Station [a, b]	Period of Record	Drainage Basin Characteristics: Basin Area (mi^2)	Lake & Pond Area	Mean Basin Elev. (feet)	Mean Basin Slope	Mean Annual Discharge: Discharge (cfs)	Unit Discharge (cfs/mi^2)
South Fork Koktuli River	SK100A	2004-07	106.92	1.74%	1,115	11.8%	269.3	2.52
	SK100B	2004-08	69.33	1.67%	1,255	15.5%	191.0	2.76
	SK100C	2004-08	37.50	2.20%	1,230	14.8%	52.2	1.39
	SK100F	2004-07	11.91	4.16%	1,270	13.7%	28.1	2.36
	SK100G	2004-07	5.49	3.83%	1,200	10.6%	14.7	2.68
	SK119A	2004-08	10.73	0.03%	1,575	19.4%	36.9	3.44
North Fork Koktuli River	NK100A	2004-08	105.86	1.71%	1,280	9.2%	270.3	2.55
	NK100C	2004-08	24.35	4.96%	1,360	7.4%	52.4	2.15
	NK119A	2004-08	7.76	0.02%	1,645	14.3%	24.6	3.17
Upper Talarik Creek	UT100B	2004-08	86.24	1.77%	1,055	11.1%	231.7	2.69
	UT100D	2004-08	11.96	1.08%	1,110	10.1%	29.5	2.47
	UT100E	2004-08	3.10	0.98%	1,225	8.7%	10.1	3.27
	UT119A	2004-08	4.05	2.13%	882	8.8%	27.4	6.77
Kaskanak Creek	KC100A	2004-08	25.64	6.23%	605	4.3%	36.1	1.41

Notes:

a. Excludes historical gaging stations operated by Cominco from 1991-1994.

b. Excludes gaging stations installed in 2007 or 2008.

c. cfs = cubic feet per second, Elev. = Elevation, mi^2 = square mile(s).

TABLE 2
USGS Streamflow Gaging Stations in the Bristol Bay Drainage

Station [a]			Location		Period of Record			Drainage	Mean Annual	Mean Annual Unit
USGS ID	USGS Name	Pebble ID	Lat. (N)	Long. (W)	Start	End	Length (Year) [b]	Area (mi²)	Discharge (cfs)	Runoff (cfs/mi²)
15303100	East Creek Near Dillingham AK		59°11'32"	158°49'53"	Aug-73	Sep-75	2	2.12	16	7.3
15300100	Bear Creek Near Iliamna AK		59°49'28"	154°52'56"	Jul-05	-	3	2.59	8	3.1
15303011	Wood River Tributary Near Aleknagik AK		59°12'26"	158°40'02"	May-90	Sep-93	0	3.35	-	-
15303010	Silver Salmon Creek Nearr Aleknagik AK		59°13'34"	158°40'21"	Oct-84	Sep-89	2	4.46	12	2.6
15302840	Elva Lake Outlet Near Aleknagik AK		59°36'15"	159°06'50"	Oct-79	Jun-82	2	9.00	64	7.1
15297900	Eskimo Creek At King Salmon AK		58°41'08"	156°40'08"	Oct-73	Sep-84	10	16.1	14	0.9
15300200	Roadhouse Creek Near Iliamna AK		59°45'26"	154°50'49"	May-05	-	3	20.8	24	1.2
15302800	Grant Lake Outlet Near Aleknagik AK		59°47'43"	158°33'07"	Jul-59	Jul-65	6	34.3	90	2.6
15302200	Koktuli River Near Iliamna AK	SK100B	59°47'36"	155°31'21"	Aug-04	-	4	69.1	188	2.7
15300250	Upper Talarik Creek Near Iliamna AK	UT100B	59°47'12"	155°15'11"	Aug-04	-	4	86.6	225	2.6
15302250	North Fork Koktuli River Near Iliamna AK	NK100A	59°50'35"	155°42'59"	Aug-04	-	4	106	260	2.5
15303150	Snake River Near Dillingham AK		59°08'54"	158°53'14"	Aug-73	Sep-83	10	113	545	4.8
15300300	Iliamna River Near Pedro Bay AK		59°45'31"	153°50'41"	May-96	-	12	128	889	6.9
15298000	Tanalian River Near Port Alsworth AK		60°11'20"	154°15'30"	Aug-51	Sep-56	5	200	637	3.2
15301500	Allen River Near Aleknagik AK		60°09'00"	158°44'00"	Jun-63	Sep-66	3	270	1,420	5.3
15299900	Tazimina River Near Nondalton AK		59°55'05"	154°39'34"	Feb-81	Sep-86	5	327	869	2.7
15300520	Kaskanak Creek Near Igiugig AK		59°20'18"	156°04'31"	Jun-08	-	0	343	-	-
15303000	Wood River Near Aleknagik AK		59°16'30"	158°35'37"	Sep-57	Sep-70	13	1,110	4,823	4.3
15302000	Nuyakuk River Near Dillingham AK		59°56'08"	158°11'16"	Mar-53	-	47	1,490	5,563	3.7
15300000	Newhalen River Near Iliamna AK		59°51'34"	154°52'24"	Jul-51	Sep-86	20	3,478	9,021	2.6
15300500	Kvichak River At Igiugig AK		59°19'44"	155°53'57"	Aug-67	Sep-87	20	6,500	17,180	2.6
15302500	Nushagak River At Ekwok AK		59°20'57"	157°28'23"	Oct-77	Sep-93	16	9,850	23,606	2.4

Notes:

a. Gaging stations are ranked in order of ascending drainage area.

b. Record length refers to the number of complete water years up to September 2008.

c. Yellow shading indicates active gaging stations, including the three USGS stations operated within the Pebble mine study area.

d. Lat (N) = Latitude (North), Long (W) = Longitude (West), cfs = cubic feet per second, mi^2= square mile(s).

Source: http://waterdata.usgs.gov/usa/nwis/sw; accessed on May 11, 2010.

TABLE 3
Regression Equations for Estimating Peak Streamflows in Unregulated Streams in Region 4, Alaska

Regression equation for specified recurrence interval, Q_T [a, b]	Average standard error of prediction (%)	Average equivalent years of record
$Q_2 = 0.2535\ A^{0.9462}\ (ST+1)^{-0.1981}\ P^{1.201}$	42	1.0
$Q_5 = 0.5171\ A^{0.9084}\ (ST+1)^{-0.2128}\ P^{1.162}$	39	2.2
$Q_{10} = 0.7445\ A^{0.8887}\ (ST+1)^{-0.2204}\ P^{1.147}$	38	3.5
$Q_{25} = 1.091\ A^{0.8686}\ (ST+1)^{-0.2273}\ P^{1.131}$	39	5.0
$Q_{50} = 1.395\ A^{0.8563}\ (ST+1)^{-0.2313}\ P^{1.120}$	41	5.9
$Q_{100} = 1.738\ A^{0.8457}\ (ST+1)^{-0.2347}\ P^{1.109}$	44	6.6
$Q_{200} = 2.124\ A^{0.8363}\ (ST+1)^{-0.2377}\ P^{1.099}$	47	7.1
$Q_{500} = 2.704\ A^{0.8253}\ (ST+1)^{-0.2413}\ P^{1.088}$	52	7.4

Notes:

a. Q_T = T-year peak streamflow, in cubic feet per second; A = drainage area, in square miles; ST = area of lakes and ponds (storage), as a percentage of drainage area; P = mean annual precipitation, in inches.

b. Equations are developed for basins where A is between 1.07 and 19,400, ST is between 0 and 28, and P is between 20 and 158.

Source: Curran et al. 2003.

TABLE 4
Annual and Seasonal Maximum Daily Discharge at Pebble Gaging Stations (cfs)

Period	Station SK100A	SK100B	SK100C	SK100F	SK100G	SK119A	NK100A	NK100C	NK119A	UT100B	UT100D	UT100E	UT119A	KC100A
Aug - Nov/04	1061	901	281	133	85	509	1650	277	257	1390	195	28	40	359
Apr - Jul/05	1174	984	*368*	160	73	369	1820	244	173	858	121	52	35	113
Aug - Nov/05	987	881	*281*	137	60	467	904	*225*	206	691	134	25	41	208
Apr - Jul/06	1610	1260	*487*	218	73	*411*	1610	299	222	896	133	47	41	*213*
Aug - Nov/06	1292	877	291	155	78	312	1340	228	122	850	133	34	37	144
Apr - Jul/07	425	325	101	51	*26*	148	552	111	68	342	38	20	28	*81*
Aug - Nov/07	957	865	315	*121*	137	254	1170	*221*	148	822	192	35	37	161
2004 Calendar Year	1061	901	281	133	85	509	1650	277	257	1390	195	28	40	359
2005 Calendar Year	1174	984	*368*	160	73	467	1820	244	206	858	134	52	41	208
2006 Calendar Year	1610	1260	*487*	218	78	*411*	1610	299	222	896	133	47	41	*213*
2007 Calendar Year	957	865	315	*121*	137	254	1170	*221*	148	822	192	35	37	161
Maximum Recorded	1610	1260	*487*	218	137	509	1820	299	257	1390	195	52	41	359
Mean Annual	1200	1003	363	158	93	410	1563	260	208	992	163	41	40	235
Ratio, Maximum/Mean	1.34	1.26	1.34	1.38	1.47	1.24	1.16	1.15	1.24	1.40	1.19	1.29	1.03	1.53

Notes:

a. cfs = cubic feet per second.

TABLE 5
Annual and Seasonal Maximum Daily Unit Discharge at Pebble Gaging Stations (cfs/mi²)

	Station													
Period	**SK100A**	**SK100B**	**SK100C**	**SK100F**	**SK100G**	**SK119A**	**NK100A**	**NK100C**	**NK119A**	**UT100B**	**UT100D**	**UT100E**	**UT119A**	**KC100A**
Aug - Nov/04	9.9	13.0	7.5	11.2	15.6	47.4	15.6	11.4	33.2	16.1	16.3	9.1	9.9	14.0
Apr - Jul/05	11.0	14.2	9.8	13.4	13.2	34.4	17.2	10.0	22.3	10.0	10.1	16.9	8.6	4.4
Aug - Nov/05	9.2	12.7	7.5	11.5	11.0	43.5	8.5	9.2	26.5	8.0	11.2	8.2	10.1	8.1
Apr - Jul/06	15.1	18.2	13.0	18.3	13.4	38.3	15.2	12.3	28.6	10.4	11.1	15.1	10.0	8.3
Aug - Nov/06	12.1	12.6	7.8	13.0	14.3	29.1	12.7	9.3	15.7	9.9	11.1	11.0	9.3	5.6
Apr - Jul/07	4.0	4.7	2.7	4.3	4.7	13.8	5.2	4.5	8.7	4.0	3.2	6.6	7.0	3.2
Aug - Nov/07	9.0	12.5	8.4	10.1	25.0	23.6	11.1	9.1	19.1	9.5	16.1	11.4	9.1	6.3
2004 Calendar Year	9.9	13.0	7.5	11.2	15.6	47.4	15.6	11.4	33.2	16.1	16.3	9.1	9.9	14.0
2005 Calendar Year	11.0	14.2	9.8	13.4	13.2	43.5	17.2	10.0	26.5	10.0	11.2	16.9	10.1	8.1
2006 Calendar Year	15.1	18.2	13.0	18.3	14.3	38.3	15.2	12.3	28.6	10.4	11.1	15.1	10.0	8.3
2007 Calendar Year	9.0	12.5	8.4	10.1	25.0	23.6	11.1	9.1	19.1	9.5	16.1	11.4	9.1	6.3
Maximum Recorded	15.1	18.2	13.0	18.3	25.0	47.4	17.2	12.3	33.2	16.1	16.3	16.9	10.1	14.0
Mean Annual	11.2	14.5	9.7	13.3	17.0	38.2	14.8	10.7	26.8	11.5	13.7	13.1	9.8	9.2
Drainage. Area (mi²)	106.92	69.33	37.50	11.91	5.49	10.73	105.86	24.35	7.76	86.23	11.96	3.10	4.05	25.64

Notes:

a. cfs = cubic feet per second, mi² = square mile(s).

TABLE 6
Annual and Seasonal Maximum Instantaneous Discharge at Pebble Gaging Stations (cfs)

Period	Station													
	SK100A	SK100B	SK100C	SK100F	SK100G	SK119A	NK100A	NK100C	NK119A	UT100B	UT100D	UT100E	UT119A	KC100A
Aug - Nov/04	1314	--	306	161	102	658	2240	443	503	--	230	40	47	447
Apr - Jul/05	1288	--	--	172	99	517	--	266	219	1280	144	66	52	143
Aug - Nov/05	1162	1440	--	151	86	769	--	--	354	--	191	35	48	328
Apr - Jul/06	1781	1560	--	249	93	--	1910	326	308	1230	166	68	48	--
Aug - Nov/06	1484	--	308	174	103	628	--	253	259	--	171	40	45	233
Apr - Jul/07	489	--	113	54	--	209	--	141	94	--	52	28	30	--
Aug - Nov/07	1197	854	332	--	192	567	1490	--	240	817	279	44	43	251
2004 Calendar Year	1314	--	306	161	102	658	2240	443	503	--	230	40	47	447
2005 Calendar Year	1288	1440	--	172	99	769	--	266	354	1280	191	66	52	328
2006 Calendar Year	1781	1560	--	249	103	--	1910	326	308	1230	171	68	48	--
2007 Calendar Year	1197	854	332	--	192	567	1490	--	240	817	279	44	43	251
Maximum Recorded	1781	1560	--	249	192	769	2240	443	503	1280	279	68	52	447
Mean Annual	1395	1285	319	194	124	665	1880	345	351	1109	218	55	48	342
Ratio, Maximum/Mean	1.28	1.21	--	1.28	1.55	1.16	1.19	1.28	1.43	1.15	1.28	1.25	1.09	1.31

Notes:

a. Station hydrographs were compared to determine periods in which seasonal flood peaks had likely been missed at any given station. No estimates of maximum instantaneous discharge were made for periods of missing record (see text for details).

b. cfs = cubic feet per second.

TABLE 7
Annual and Seasonal Maximum Instantaneous Unit Discharge at Pebble Gaging Stations (cfs/mi²)

Period	Station													
	SK100A	SK100B	SK100C	SK100F	SK100G	SK119A	NK100A	NK100C	NK119A	UT100B	UT100D	UT100E	UT119A	KC100A
Aug - Nov/04	12.3	--	8.2	13.5	18.6	61.3	21.2	18.2	64.8	--	19.2	12.9	11.6	17.4
Apr - Jul/05	12.0	--	--	14.4	18.0	48.2	--	10.9	28.2	14.8	12.0	21.3	12.8	5.6
Aug - Nov/05	10.9	20.8	--	12.7	15.7	71.7	--	--	45.6	--	16.0	11.3	11.9	12.8
Apr - Jul/06	16.7	22.5	--	20.9	16.9	--	18.0	13.4	39.7	14.3	13.9	21.9	11.9	--
Aug - Nov/06	13.9	--	8.2	14.6	18.8	58.5	--	10.4	33.4	--	14.3	12.9	11.1	9.1
Apr - Jul/07	4.6	--	3.0	4.5		19.5	--	5.8	12.1	--	4.3	9.0	7.4	--
Aug - Nov/07	11.2	12.3	8.9	--	35.0	52.8	14.1	--	30.9	9.5	23.3	14.2	10.6	9.8
2004 Calendar Year	12.3	--	8.2	13.5	18.6	61.3	21.2	18.2	64.8	--	19.2	12.9	11.6	17.4
2005 Calendar Year	12.0	20.8	--	14.4	18.0	71.7	--	10.9	45.6	14.8	16.0	21.3	12.8	12.8
2006 Calendar Year	16.7	22.5	--	20.9	18.8	--	18.0	13.4	39.7	14.3	14.3	21.9	11.9	--
2007 Calendar Year	11.2	12.3	8.9	--	35.0	52.8	14.1	--	30.9	9.5	23.3	14.2	10.6	9.8
Maximum Recorded	16.7	22.5	--	20.9	35.0	71.7	21.2	18.2	64.8	14.8	23.3	21.9	12.8	17.4
Mean Annual	13.0	18.5	8.5	16.3	22.6	61.9	17.8	14.2	45.3	12.9	18.2	17.6	11.7	13.3
Drainage. Area (mi²)	106.92	69.33	37.50	11.91	5.49	10.73	105.86	24.35	7.76	86.23	11.96	3.10	4.05	25.64

Notes:

a. Station hydrographs were compared to determine periods in which seasonal flood peaks had likely been missed at any given station. No estimates of maximum instantaneous discharge were made for periods of missing record (see text for details).

b. cfs = cubic feet per second, mi^2= square mile(s).

TABLE 8
Annual Peak Discharges at Regional Gaging Stations

	Iliamna River				Roadhouse Creek				Bear Creek				Ratios of Maximum Instantaneous/Maximum Daily Discharge		
	Discharge (cfs)		Unit Discharge (cfs/mi^2)		Discharge (cfs)		Unit Discharge (cfs/mi^2)		Discharge (cfs)		Unit Discharge (cfs/mi^2)				
Water Year	Daily	Inst.	Daily	Inst.	Daily	Inst.	Daily	Inst.	Daily	Inst.	Daily	Inst.	Iliamna	Roadhouse	Bear
1965	--	--	--	--	--	--	--	--	--	58	--	22.4	--	--	--
1966	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
1967	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
1968	--	--	--	--	--	--	--	--	--	56	--	21.6	--	--	--
1973	--	--	--	--	--	96	--	4.6	--	--	--	--	--	--	--
1974	--	--	--	--	--	75	--	3.6	--	--	--	--	--	--	--
1975	--	--	--	--	--	152	--	7.3	--	--	--	--	--	--	--
1976	--	--	--	--	--	77	--	3.7	--	--	--	--	--	--	--
1977	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
1978	--	--	--	--	--	70	--	3.4	--	--	--	--	--	--	--
1979	--	--	--	--	--	50	--	2.4	--	--	--	--	--	--	--
1980	--	--	--	--	--	280	--	13.5	--	--	--	--	--	--	--
1981	--	--	--	--	--	240	--	11.5	--	--	--	--	--	--	--
1982	--	--	--	--	--	150	--	7.2	--	--	--	--	--	--	--
1983	--	--	--	--	--	90	--	4.3	--	--	--	--	--	--	--
1996	3,570	5,040	27.9	39.4	--	--	--	--	--	--	--	--	1.41	--	--
1997	7,980	9,300	62.3	72.7	--	--	--	--	--	--	--	--	1.17	--	--
1998	12,300	22,300	96.1	174.2	--	--	--	--	--	--	--	--	1.81	--	--
1999	12,100	20,000	94.5	156.3	--	--	--	--	--	--	--	--	1.65	--	--
2000	7,830	13,700	61.2	107.0	--	--	--	--	--	--	--	--	1.75	--	--
2001	7,460	14,400	58.3	112.5	--	--	--	--	--	--	--	--	1.93	--	--
2002	4,820	6,260	37.7	48.9	--	--	--	--	--	--	--	--	1.30	--	--

	Iliamna River				Roadhouse Creek				Bear Creek				Ratios of Maximum Instantaneous/Maximum Daily Discharge		
	Discharge (cfs)		Unit Discharge (cfs/mi^2)		Discharge (cfs)		Unit Discharge (cfs/mi^2)		Discharge (cfs)		Unit Discharge (cfs/mi^2)				
Water Year	Daily	Inst.	Daily	Inst.	Daily	Inst.	Daily	Inst.	Daily	Inst.	Daily	Inst.	Iliamna	Roadhouse	Bear
2003	9,470	17,400	74.0	135.9	--	--	--	--	--	--	--	--	1.84	--	--
2004	33,800	53,000	264.1	414.1	--	--	--	--	--	--	--	--	1.57	--	--
2005	4,700	5,940	36.7	46.4	267	282	12.8	13.6	31	--	12.0	--	1.26	1.06	--
2006	7,480	8,270	58.4	64.6	189	226	9.1	10.9	35	38	13.5	14.7	1.11	1.20	1.09
2007	13,200	19,200	103.1	150.0	146	--	7.0	--	45	--	17.4	--	1.45	--	--
Maximum Recorded	33,800	53,000	264.1	414.1	267	282	12.8	13.6	45	58	17.4	22.4	1.93	1.20	1.09
Mean Annual	10,393	16,234	81.2	126.8	201	149	9.6	7.2	37	51	14.3	19.6	1.52	1.13	1.09
Drainage Area (mi^2)	128	128	--	--	20.8	20.8	--	--	2.59	2.59	--	--	--	--	--

Notes:

a. Blank cells indicate that no data was available.
b. inst. = instantaneous, cfs = cubic feet per second, mi^2 = square mile(s).

TABLE 9
Average Ratios of Maximum Instantaneous and Daily Discharge at Pebble Gaging Stations

	Station													
Period	**SK100A**	**SK100B**	**SK100C**	**SK100F**	**SK100G**	**SK119A**	**NK100A**	**NK100C**	**NK119A**	**UT100B**	**UT100D**	**UT100E**	**UT119A**	**KC100A**
Aug - Nov/04	1.24	--	1.09	1.21	1.19	1.29	1.36	1.60	1.95	--	1.18	1.42	1.17	1.25
Apr - Jul/05	1.10	--	--	1.07	1.36	1.40	--	1.09	1.26	1.49	1.19	1.26	1.49	1.26
Aug - Nov/05	1.18	1.63	--	1.10	1.43	1.65	--	--	1.72	--	1.42	1.37	1.18	1.58
Apr - Jul/06	1.11	1.24	--	1.14	1.27	--	1.19	1.09	1.39	1.37	1.25	1.45	1.18	--
Aug - Nov/06	1.15	--	1.06	1.12	1.32	2.01	--	1.11	2.13	--	1.29	1.17	1.20	1.62
Apr - Jul/07	1.15	--	1.12	1.06	--	1.41	--	1.27	1.39	--	1.37	1.37	1.05	--
Aug - Nov/07	1.25	0.99	1.05	--	1.40	2.24	1.27	--	1.62	0.99	1.45	1.24	1.16	1.56
Average	1.17	1.29	1.08	1.12	1.33	1.67	1.27	1.23	1.64	1.29	1.31	1.33	1.21	1.45

TABLE 10
Station SK100A and Station SK119A Storm Hydrograph Analysis, Autumn 2006

	Station SK100A			Station SK119A		
Event	**Date**	**Time**	**Time to Peak (hour)**	**Date**	**Time**	**Time to Peak (hour)**
1	18-Aug-06	7:52	21.75	18-Aug-06	4:12	13.25
	19-Aug-06	5:37		18-Aug-06	17:27	
2	14-Sep-06	0:10	21.50	14-Sep-06	1:42	10.00
	14-Sep-06	21:40		14-Sep-06	11:42	
3	21-Sep-06	15:40	20.50	21-Sep-06	13:42	8.50
	22-Sep-06	12:10		21-Sep-06	22:12	
Average			21.25			10.58

TABLE 11
Estimated Instantaneous Peak Flows in the Mine Study Area based on USGS Regional Regression Equations (P = 26 inches) [a, b]

		Peak Flows Estimated from Regression Equations (cfs) [c]								Recorded Peak Flows (cfs)		Predicted Return Period (year)	
Watershed	**Station**	Q_2	Q_5	Q_{10}	Q_{20}	Q_{50}	Q_{100}	Q_{200}	Q_{500}	Q_{Mean}	$Q_{Maximum}$	Q_{Mean}	$Q_{Maximum}$
South Fork Koktuli River	SK100A	864	1282	1591	2000	2320	2645	2986	3471	1395	1781	5-10	10-20
	SK100B	576	870	1089	1381	1611	1845	2091	2443	1285	1560	10-20	20-50
	SK100C	311	479	606	777	913	1052	1198	1408	319	--	2-5	--
	SK100F	96	153	197	257	306	356	410	487	194	249	5-10	10-20
	SK100G	47	77	100	133	160	188	218	261	124	192	10-20	100-200
	SK119A	119	196	256	339	406	476	551	659	665	769	> 500	> 500
North Fork Koktuli River	NK100A	858	1273	1580	1988	2307	2630	2969	3452	1880	2240	10-20	20-50
	NK100C	183	283	360	464	546	631	720	849	345	443	5-10	10-20
	NK119A	88	146	192	257	309	363	421	506	351	503	50-100	200-500
Upper Talarik Creek	UT100B	703	1052	1311	1655	1925	2200	2488	2899	1109	> 1390	5-10	--
	UT100D	115	186	241	318	379	443	510	608	218	279	5-10	10-20
	UT100E	32	55	73	99	121	143	167	202	55	68	5	5-10
	UT119A	38	64	84	113	136	161	187	226	48	52	2-5	2-5
Kaskanak Creek	KC100A	185	285	361	464	546	630	718	845	342	447	5-10	10-20

Notes:

a. Mean annual precipitation (P) of 26 inches assumed for all gaging stations, as per Curran et al. (2003).

b. Basin-specific values used for basin area (A) and lake storage (ST), as shown in Table 1.

c. Q_T refers to peak streamflow with average recurrence interval of T years.

d. cfs = cubic feet per second.

TABLE 12
Estimated Instantaneous Peak Flows in the Mine Study Area based on USGS Regional Regression Equations (Local P Estimates) [a, b]

Watershed	Station	Peak Flows Estimated from Regression Equations (cfs) [c]								Recorded Peak Flows (cfs)		Predicted Return Period (year)	
		Q_2	Q_5	Q_{10}	Q_{20}	Q_{50}	Q_{100}	Q_{200}	Q_{500}	Q_{Mean}	$Q_{Maximum}$	Q_{Mean}	$Q_{Maximum}$
South Fork Koktuli River	SK100A	1450	2115	2607	3256	3759	4265	4794	5546	1395	1781	< 2	2-5
	SK100B	967	1434	1784	2248	2610	2975	3357	3903	1285	1560	2-5	5-10
	SK100C	522	790	993	1265	1479	1696	1924	2250	319	--	< 2	--
	SK100F	160	252	322	419	496	575	658	778	194	249	2-5	2-5
	SK100G	78	126	164	217	259	303	350	417	124	192	2-5	10-20
	SK119A	261	418	542	711	845	983	1130	1343	665	769	10-20	20-50
North Fork Koktuli River	NK100A	1439	2100	2590	3236	3737	4241	4766	5515	1880	2240	2-5	5-10
	NK100C	306	467	590	755	885	1017	1156	1356	345	443	2-5	2-5
	NK119A	193	312	407	537	642	749	864	1030	351	503	5-10	10-20
Upper Talarik Creek	UT100B	1180	1735	2148	2695	3119	3547	3994	4632	1109	> 1390	< 2	--
	UT100D	193	307	395	517	614	714	819	972	218	279	2-5	2-5
	UT100E	54	91	120	162	195	230	268	323	55	68	2	2-5
	UT119A	64	105	138	184	221	260	301	360	48	52	< 2	< 2
Kaskanak Creek	KC100A	310	470	592	756	884	1015	1153	1351	342	447	2-5	2-5

Notes:

a. Local estimates of mean annual precipitation (P) assumed, based on mean annual runoff in study area.
   P = 50 inches for SK119A and NK119A.
   P = 40 inches for all other gages.

b. Basin-specific values used for basin area (A) and lake storage (ST), as shown in Table 1.

c. Q_T refers to peak streamflow with average recurrence interval of T years.

d. cfs= cubic feet per second.

TABLE 13
Estimated Daily Peak Flows in the Mine Study Area based on Flood Frequency Analysis of Local Gaging Records

Watershed	Station	Daily Peak Flows Estimated from Local Gaging Records (cfs)[a, b]								Recorded Peak Flows (cfs)		Predicted Return Period (year)	
		Q_2	Q_5	Q_{10}	Q_{20}	Q_{50}	Q_{100}	Q_{200}	Q_{500}	Q_{Mean}	$Q_{Maximum}$	Q_{Mean}	$Q_{Maximum}$
South Fork Koktuli River	SK100A	1130	1390	1590	--	--	--	--	--	1200	1610	2-5	> 10
	SK100B	954	1110	1240	--	--	--	--	--	1003	1260	2-5	> 10
	SK100C	343	426	488	--	--	--	--	--	363	487	2-5	~ 10
	SK100F	148	187	218	--	--	--	--	--	158	218	2-5	~ 10
	SK100G	84	109	131	--	--	--	--	--	93	137	2-5	> 10
	SK119A	428	511	543	--	--	--	--	--	410	509	< 2	~ 5
North Fork Koktuli River	NK100A	1610	1800	1870	--	--	--	--	--	1563	1820	< 2	5-10
	NK100C	260	290	306	--	--	--	--	--	260	299	~ 2	5-10
	NK119A	213	249	265	--	--	--	--	--	208	257	< 2	5-10
Upper Talarik Creek	UT100B	904	1130	1330	--	--	--	--	--	992	1390	2-5	> 10
	UT100D	161	192	212	--	--	--	--	--	163	195	~ 2	~ 5
	UT100E	40	50	56	--	--	--	--	--	41	52	~ 2	5-10
	UT119A	40	41	42	--	--	--	--	--	40	41	~2	~5
Kaskanak Creek	KC100A	212	288	352	--	--	--	--	--	235	359	2-5	> 10

Notes:

a. Q_T refers to peak streamflow with average recurrence interval of T years.

b. The relatively short local gaging records were not used to estimate peak flows with recurrence intervals greater than 10 years.

c. cfs = cubic feet per second.

TABLE 14

Estimated Instantaneous Peak Flows in the Mine Study Area based on Flood Frequency Analysis of Local Gaging Records

Watershed	Station	Instantaneous Peak Flows Estimated from Local Gaging Records (cfs) [a, b, c, d]								Recorded Peak Flows (cfs)		Predicted Return Period (year)	
		Q_2	Q_5	Q_{10}	Q_{20}	Q_{50}	Q_{100}	Q_{200}	Q_{500}	Q_{Mean}	$Q_{Maximum}$	Q_{Mean}	$Q_{Maximum}$
South Fork Koktuli River	SK100A	1356	1668	1908	--	--	--	--	--	1395	1781	2-5	5-10
	SK100B	1145	1332	1488	--	--	--	--	--	1285	1560	2-5	> 10
	SK100C	412	511	586	--	--	--	--	--	319	--	< 2	--
	SK100F	178	224	262	--	--	--	--	--	194	249	2-5	5-10
	SK100G	101	131	157	--	--	--	--	--	124	192	2-5	> 10
	SK119A	728	869	923	--	--	--	--	--	665	769	< 2	2-5
North Fork Koktuli River	NK100A	1932	2160	2244	--	--	--	--	--	1880	2240	< 2	~ 10
	NK100C	312	348	367	--	--	--	--	--	345	443	~ 5	> 10
	NK119A	362	423	451	--	--	--	--	--	351	503	< 2	> 10
Upper Talarik Creek	UT100B	1085	1356	1596	--	--	--	--	--	1109	> 1390	2-5	--
	UT100D	193	230	254	--	--	--	--	--	218	279	2-5	> 10
	UT100E	48	60	67	--	--	--	--	--	55	68	2-5	~ 10
	UT119A	48	51	52	--	--	--	--	--	48	52	~ 2	~ 10
Kaskanak Creek	KC100A	254	346	422	--	--	--	--	--	342	447	~ 5	> 10

Notes:

a. Q_T refers to peak streamflow with average recurrence interval of T years.

b. The relatively short local gaging records were not used to estimate peak flows with recurrence intervals greater than 10 years.

c. Instantaneous peak flows for various return periods estimated by applying average inst./daily ratios to daily peak flow values.

d. Ratios of instantaneous/daily peak flows:

Q_I/Q_D = 1.7 for Station SK119A and Station NK119A.

Q_I/Q_D = 1.2 for all other gages.

e. cfs = cubic feet per second.

TABLE 15
Estimated Instantaneous Peak Flows in the Mine Study Area based on a Combined Local-Regional Approach

		Estimated Instantaneous Peak Flows (cfs) [a, b]								Recorded Peak Flows (cfs)		Predicted Return Period (year)	
Watershed	Station	Q_2	Q_5	Q_{10}	Q_{20}	Q_{50}	Q_{100}	Q_{200}	Q_{500}	Q_{Mean}	$Q_{Maximum}$	Q_{Mean}	$Q_{Maximum}$
South Fork Koktuli River	SK100A	1356	1668	2439	3046	3517	3990	4484	5188	1395	1781	2-5	5-10
	SK100B	1145	1332	2112	2661	3090	3522	3975	4621	1285	1560	2-5	5-10
	SK100C	412	511	784	998	1167	1338	1518	1776	319	--	< 2	--
	SK100F	178	224	357	464	549	637	729	862	194	249	2-5	5-10
	SK100G	101	131	212	280	335	392	452	539	124	192	2-5	5-10
	SK119A	728	869	1508	1979	2354	2739	3148	3739	665	769	< 2	2-5
North Fork Koktuli River	NK100A	1932	2160	3478	4345	5017	5693	6399	7405	1880	2240	< 2	5-10
	NK100C	312	348	601	768	901	1035	1177	1380	345	443	~ 5	5-10
	NK119A	362	423	765	1010	1206	1409	1624	1936	351	503	< 2	5-10
Upper Talarik Creek	UT100B	1085	1356	1975	2477	2867	3261	3672	4258	1109	> 1390	2-5	--
	UT100D	193	230	397	519	616	716	822	975	218	279	2-5	5-10
	UT100E	48	60	107	143	173	204	237	286	55	68	2-5	5-10
	UT119A	48	51	78	97	112	128	145	169	48	52	~ 2	~ 5
Kaskanak Creek	KC100A	254	346	486	621	726	834	947	1109	342	447	~ 5	5-10

Notes:

a. Q_T refers to peak streamflow with average recurrence interval of T years.

b. Peak flows for return periods 10 years or more are scaled from the 2-year peak flows assuming the same ratios as derived from Table 12.

c. cfs = cubic feet per second

TABLE 16
Estimated Instantaneous Unit-Area Peak Flows in the Mine Study Area based on a Combined Local-Regional Approach

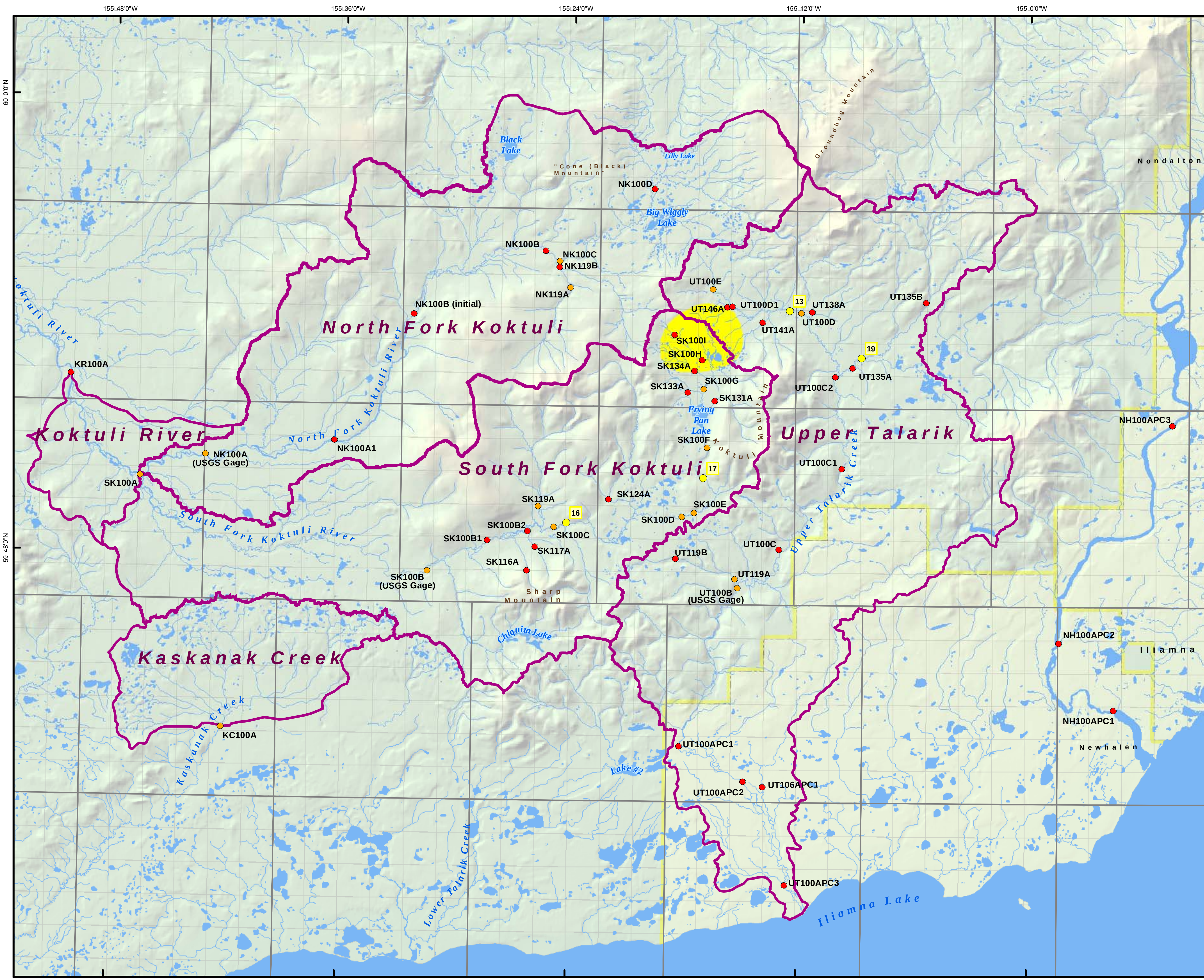
Watershed	Station	Estimated Instantaneous Unit-Area Peak Flows (cfs/mi^2) [a]								Recorded Peak Flows (cfs/mi^2)		Predicted Return Period (year)	
		Q_2	Q_5	Q_{10}	Q_{20}	Q_{50}	Q_{100}	Q_{200}	Q_{500}	Q_{Mean}	$Q_{Maximum}$	Q_{Mean}	$Q_{Maximum}$
South Fork Koktuli River	SK100A	12.7	15.6	22.8	28.5	32.9	37.3	41.9	48.5	13.0	16.7	2-5	5-10
	SK100B	16.5	19.2	30.5	38.4	44.6	50.8	57.3	66.7	18.5	22.5	2-5	5-10
	SK100C	11.0	13.6	20.9	26.6	31.1	35.7	40.5	47.3	8.5	--	< 2	--
	SK100F	14.9	18.8	30.0	39.0	46.1	53.5	61.2	72.4	16.3	20.9	2-5	5-10
	SK100G	18.4	23.8	38.7	51.1	61.0	71.3	82.3	98.2	22.6	35.0	2-5	5-10
	SK119A	67.8	81.0	140.6	184.4	219.4	255.3	293.4	348.5	61.9	71.7	< 2	2-5
North Fork Koktuli River	NK100A	18.3	20.4	32.9	41.0	47.4	53.8	60.4	69.9	17.8	21.2	< 2	5-10
	NK100C	12.8	14.3	24.7	31.6	37.0	42.5	48.3	56.7	14.2	18.2	~ 5	5-10
	NK119A	46.7	54.5	98.6	130.2	155.5	181.5	209.3	249.5	45.3	64.8	< 2	5-10
Upper Talarik Creek	UT100B	12.6	15.7	22.9	28.7	33.2	37.8	42.6	49.4	12.9	> 16.1	2-5	--
	UT100D	16.2	19.3	33.2	43.4	51.5	59.8	68.7	81.5	18.2	23.3	2-5	5-10
	UT100E	15.5	19.4	34.4	46.2	55.8	65.8	76.5	92.2	17.6	21.9	2-5	5-10
	UT119A	11.9	12.6	19.3	24.0	27.7	31.6	35.7	41.7	11.7	12.8	~ 2	~ 5
Kaskanak Creek	KC100A	9.9	13.5	19.0	24.2	28.3	32.5	36.9	43.3	13.3	17.4	~ 5	5-10

Notes:

a. Q_T refers to peak streamflow with average recurrence interval of T years.

b. cfs = cubic feet per second, mi^2 = square mile(s).

FIGURES



THE pebble PARTNERSHIP

Figure 1
Peak Flow Analysis
Surface Hydrology Stations
Mine Study Area

Legend

SK100B1: Example of Hydrology Station Identification Label

Baseline Hydrologic Stations

- Continuous, > 3 years
- Other Pebble Project Stations
- Cominco Stations

- Major Drainage Boundary
- Stream
- Water Feature
- General Deposit Location
- Village Corporation Boundary

Miles: 0 1.25 2.5 3.75 5

Kilometers: 0 1.25 2.5 3.75 5

N

Scale 1:185,000

Alaska State Plane Zone 5 (units feet)
1983 North American Datum

File: SurfHydroStations_Cominco_v3.mxd	Date: 30 March 2011
Version: 1	Author: HDR - MC, PJ

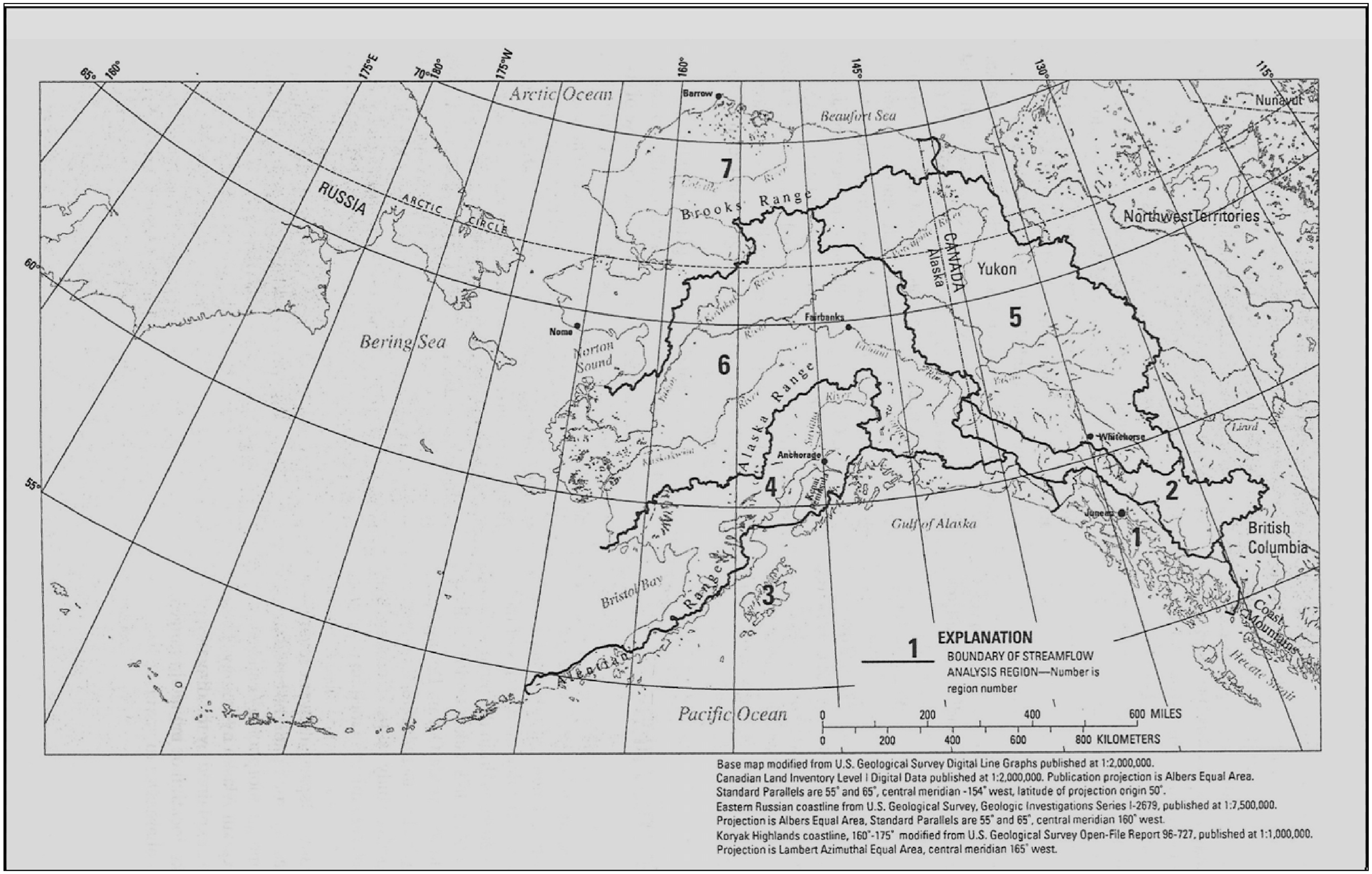


FIGURE 2
USGS Peak Flow Regions of Alaska

Source: Curran et al., 2003.

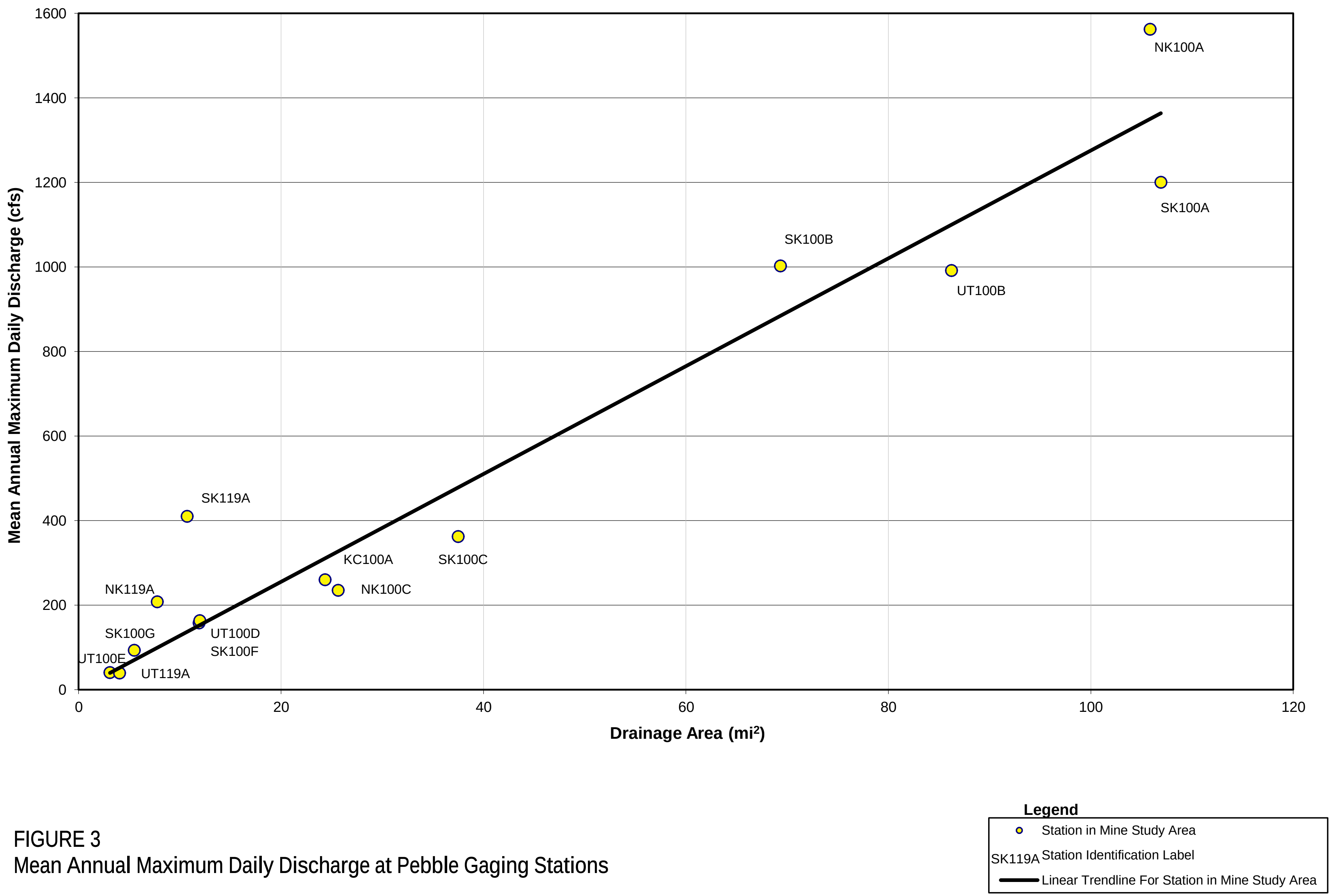


FIGURE 3
Mean Annual Maximum Daily Discharge at Pebble Gaging Stations

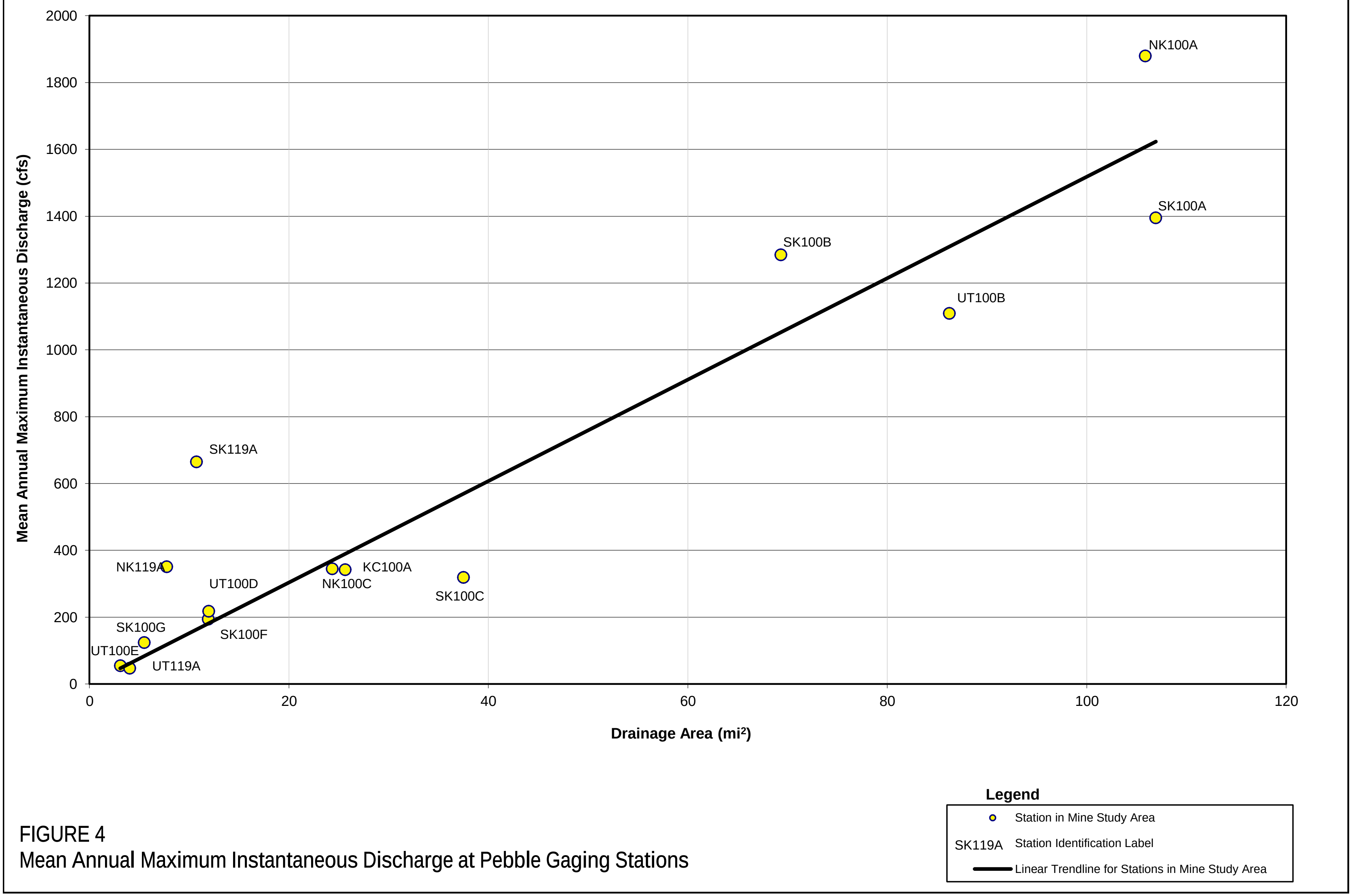


FIGURE 4
Mean Annual Maximum Instantaneous Discharge at Pebble Gaging Stations

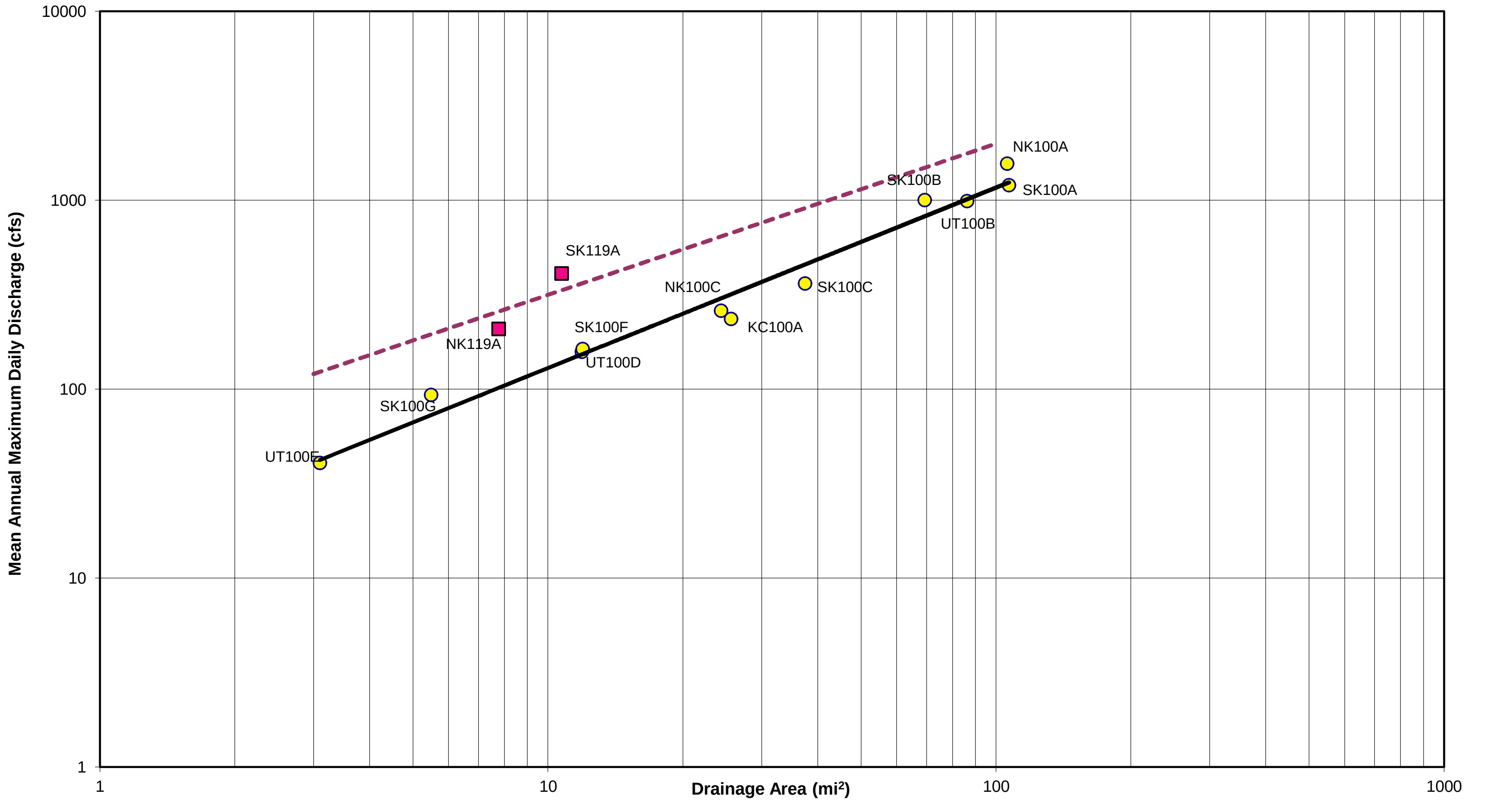


FIGURE 5
Mean Annual Maximum Daily Discharge at Pebble Gaging Stations with Trend Lines for Main Channels and Upland Tributaries

Notes: a. Trendline Equation for Upland Tributary Stations: $Q = 50 A^{0.80}$
b. Trendline Equation for Main Stream Channel Stations: $Q = 14 A^{0.97}$
c. UT119A excluded from analysis.
d. Q = Discharge (cfs), A = Drainage Area (mi^2)

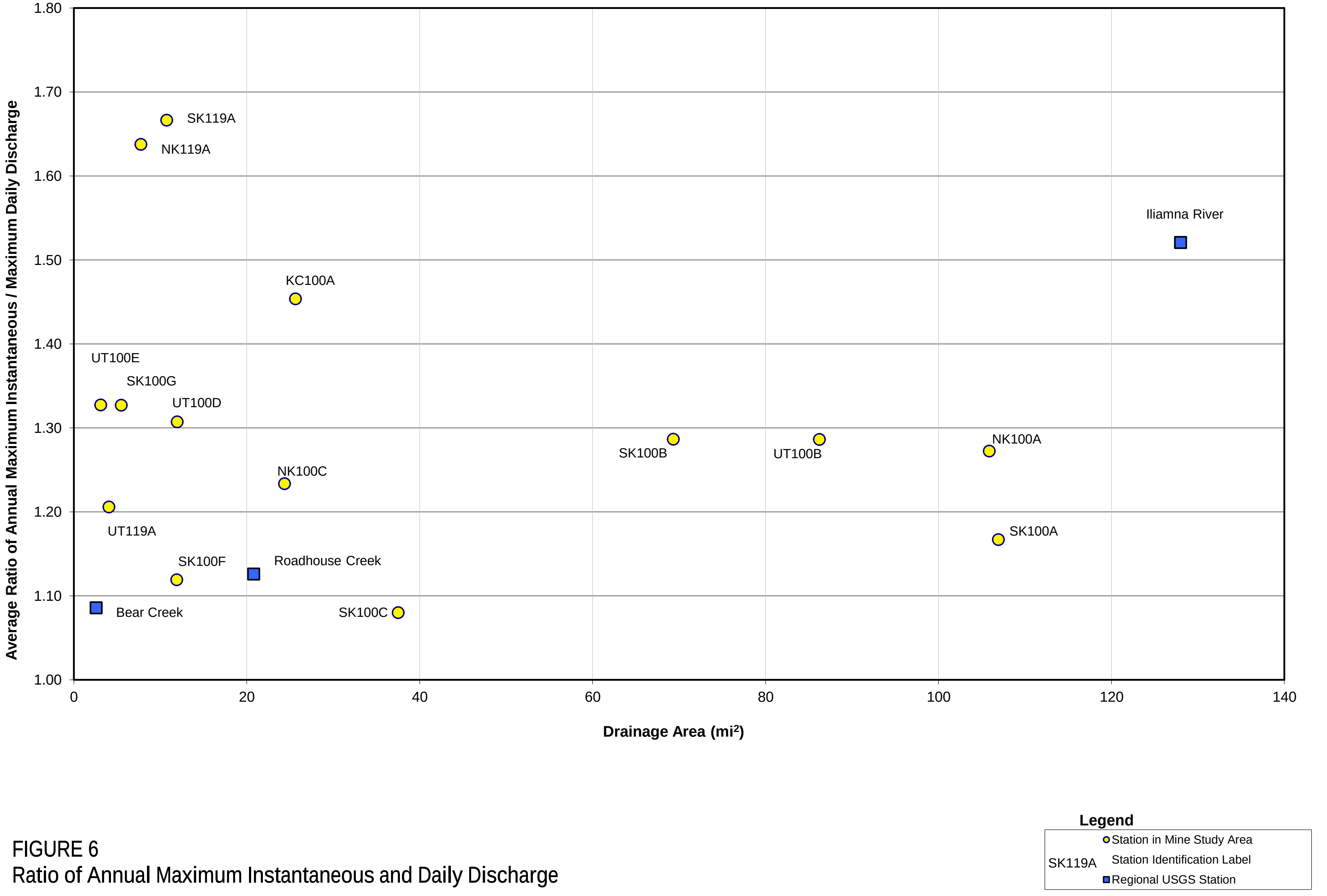


FIGURE 6
Ratio of Annual Maximum Instantaneous and Daily Discharge

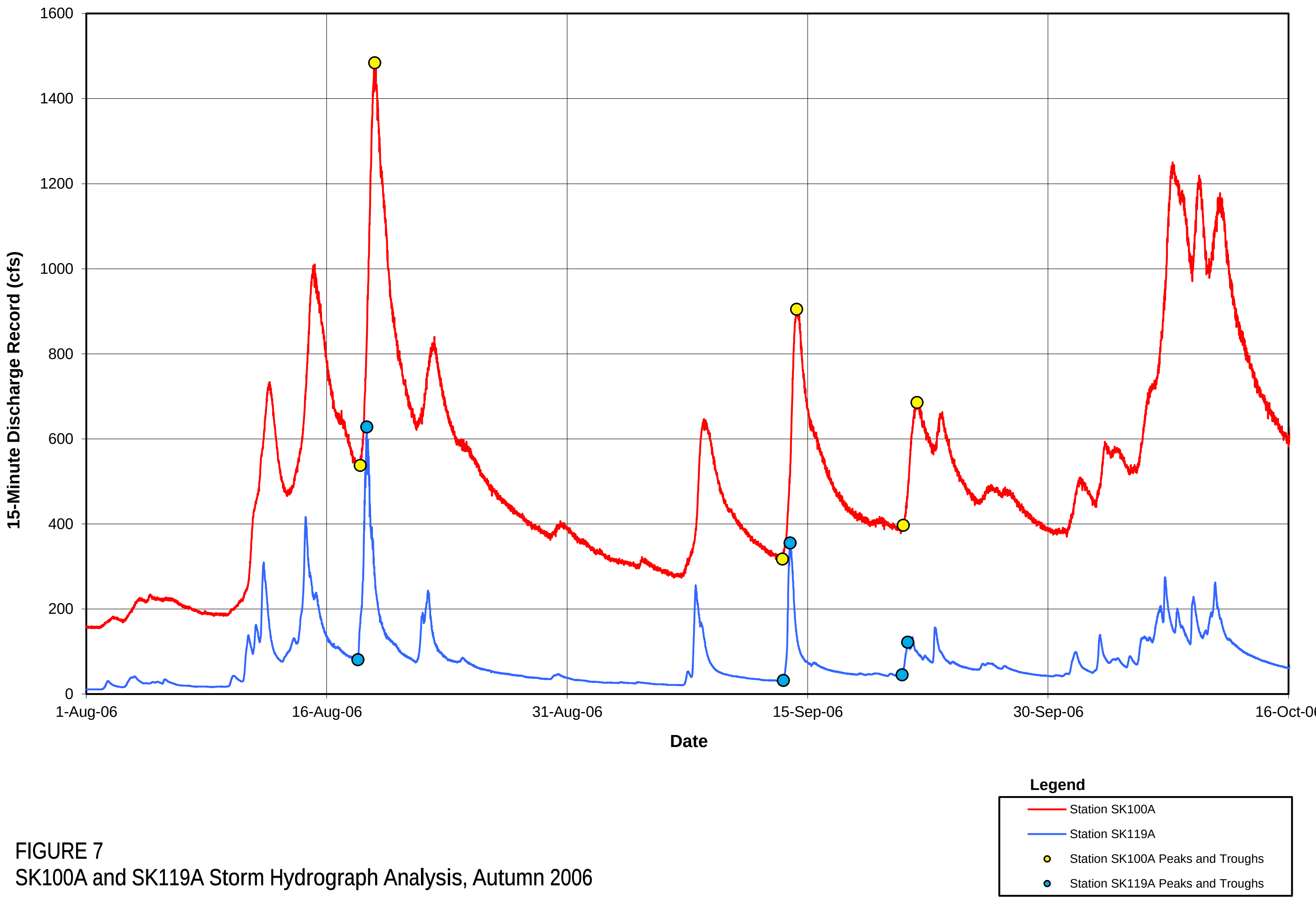


FIGURE 7
SK100A and SK119A Storm Hydrograph Analysis, Autumn 2006

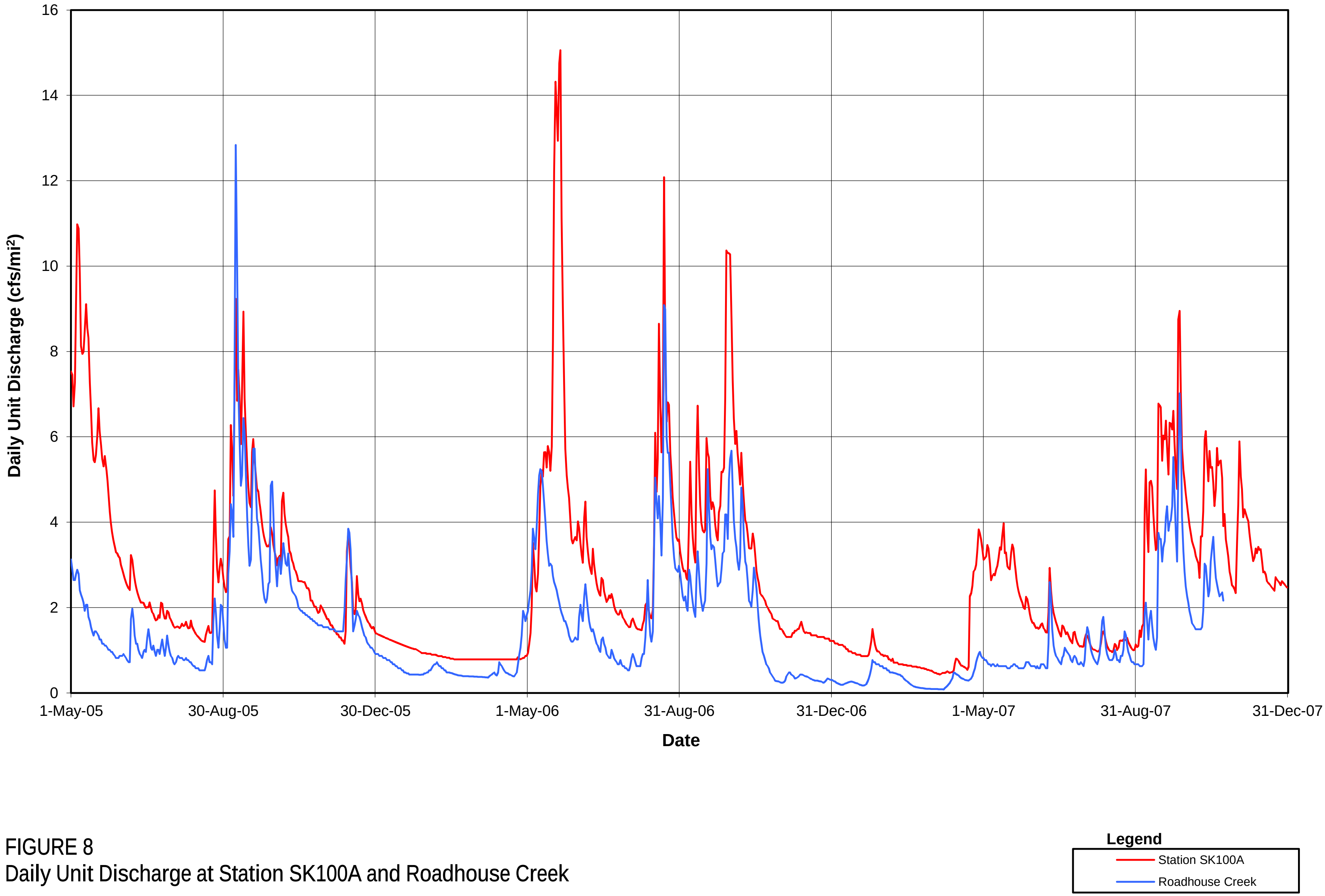


FIGURE 8
Daily Unit Discharge at Station SK100A and Roadhouse Creek

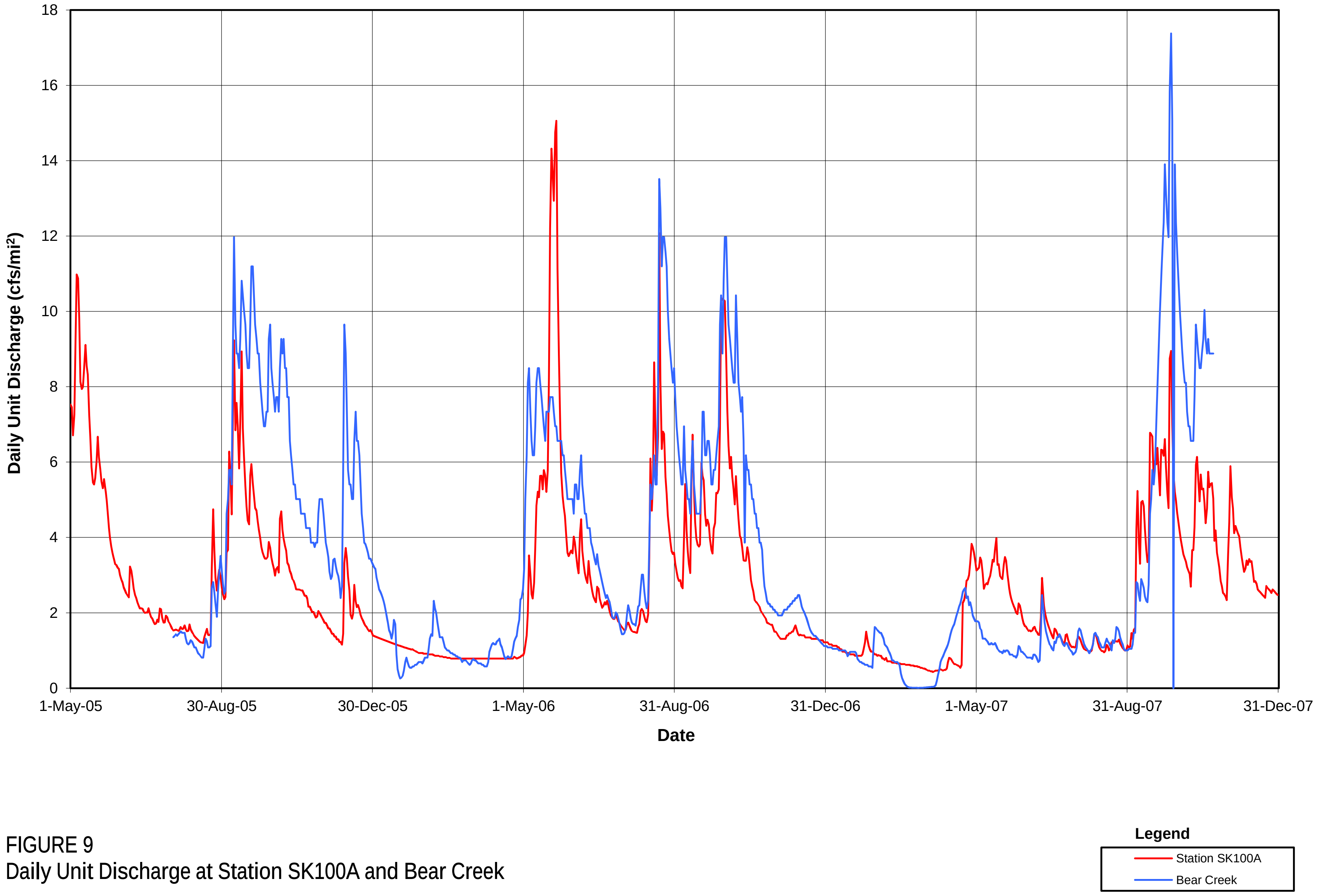


FIGURE 9
Daily Unit Discharge at Station SK100A and Bear Creek

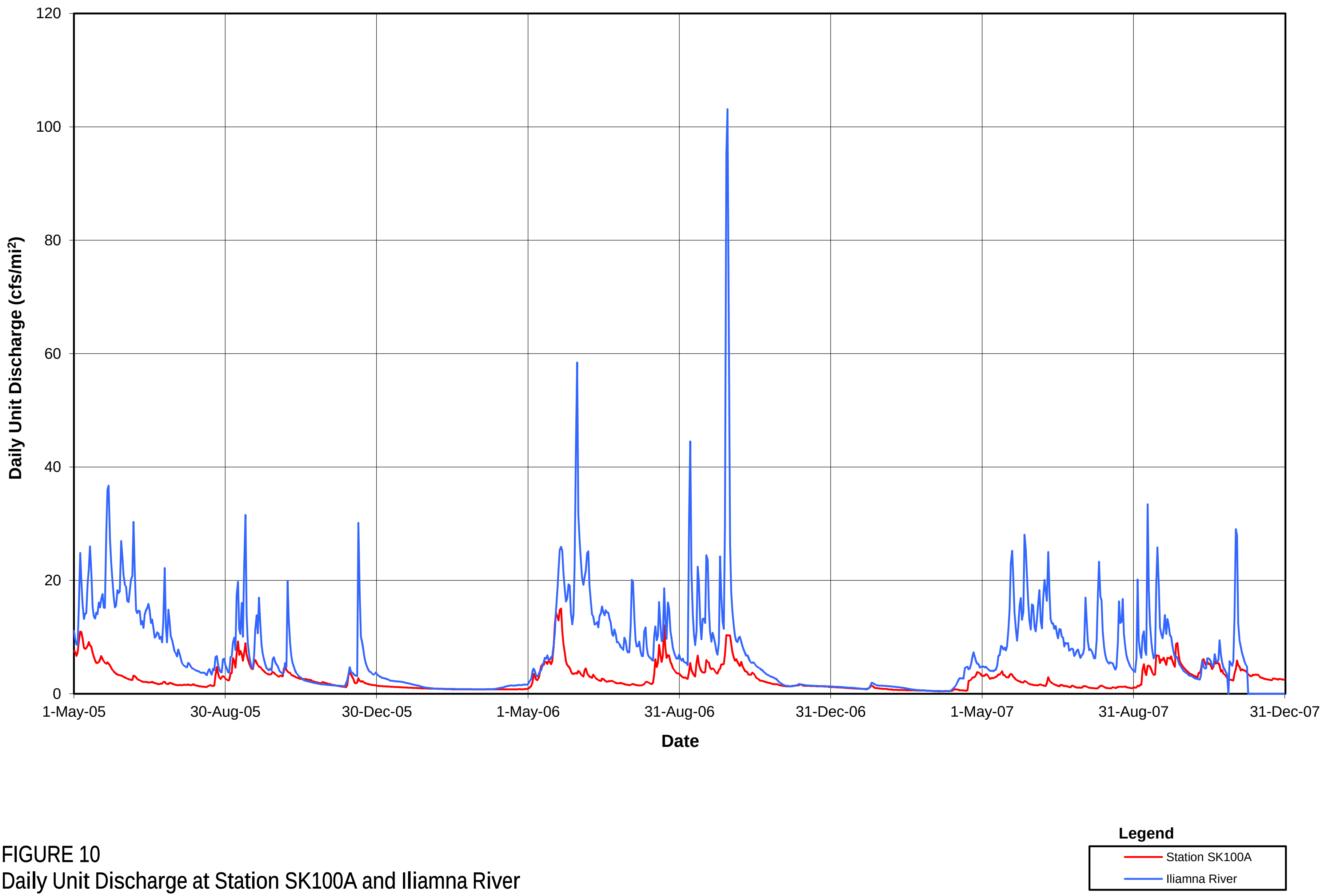


FIGURE 10
Daily Unit Discharge at Station SK100A and Iliamna River

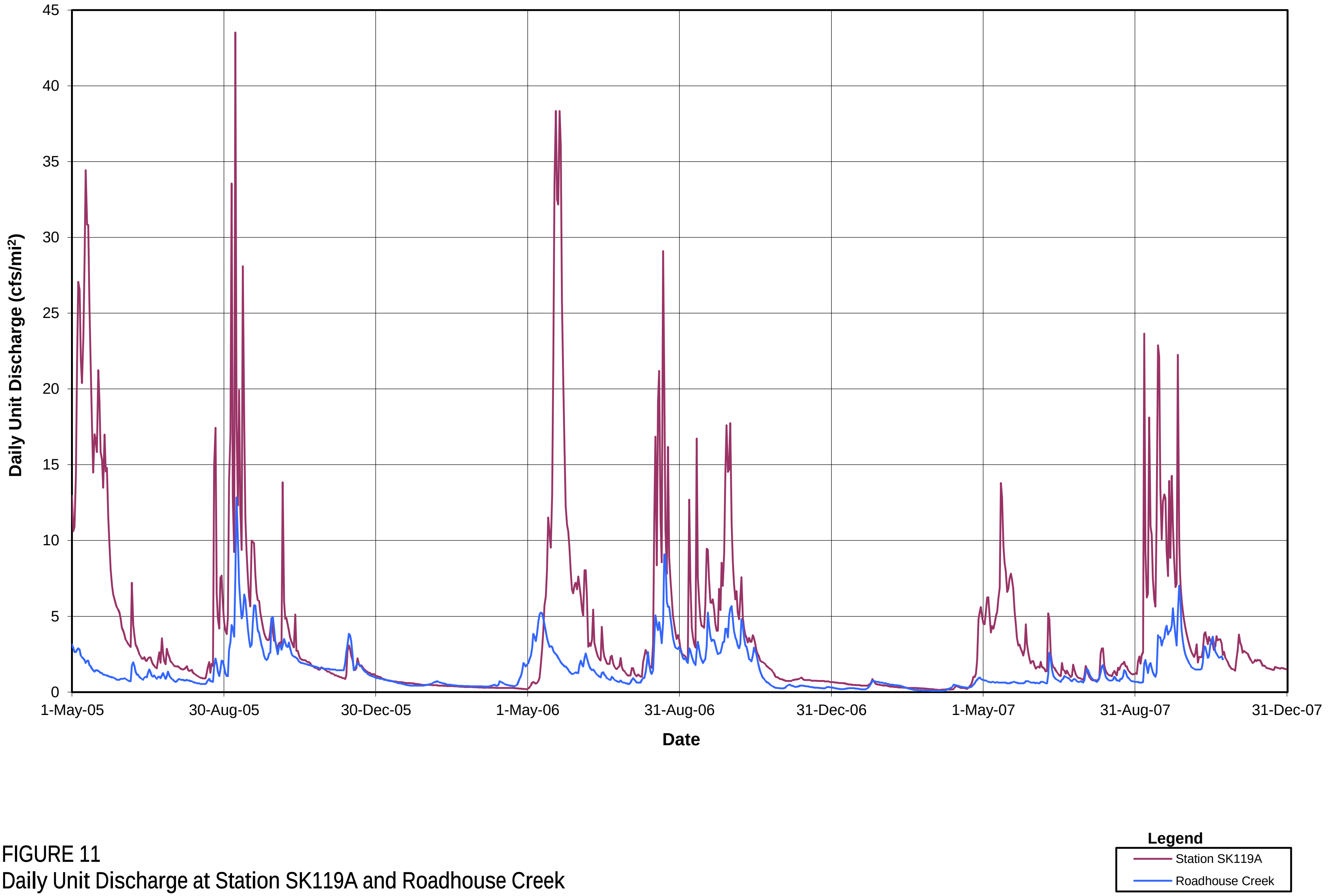


FIGURE 11
Daily Unit Discharge at Station SK119A and Roadhouse Creek

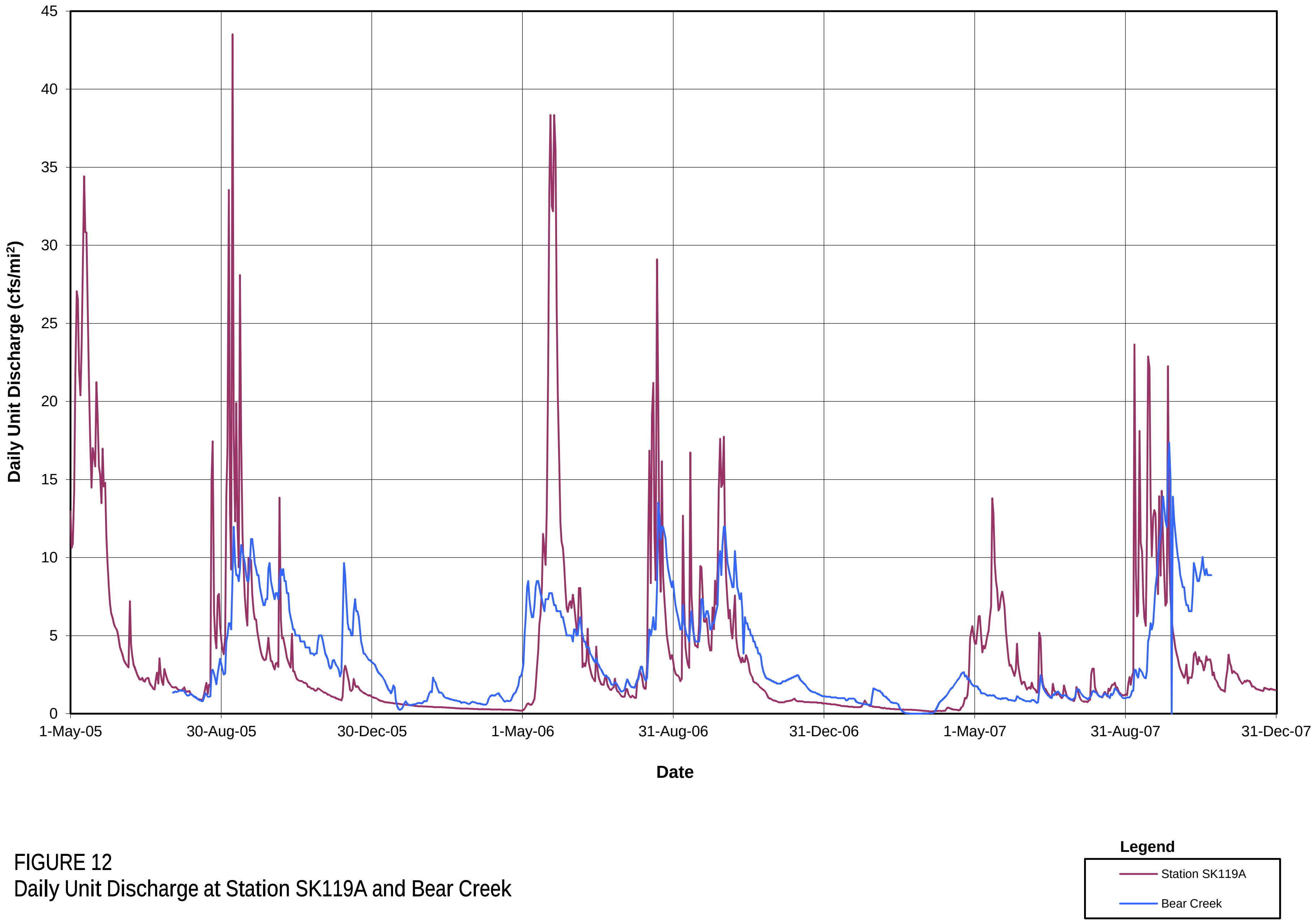


FIGURE 12
Daily Unit Discharge at Station SK119A and Bear Creek

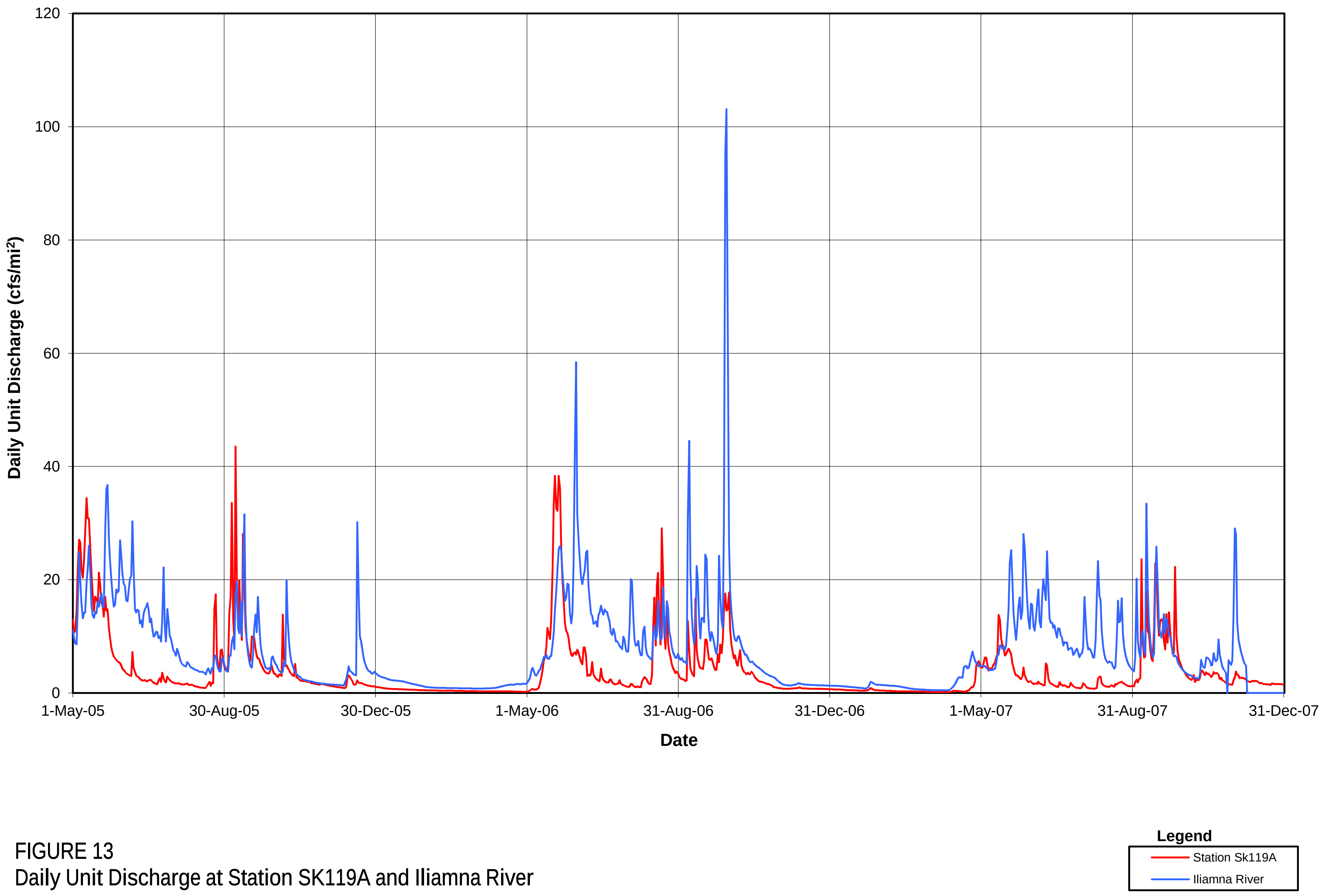


FIGURE 13
Daily Unit Discharge at Station SK119A and Iliamna River

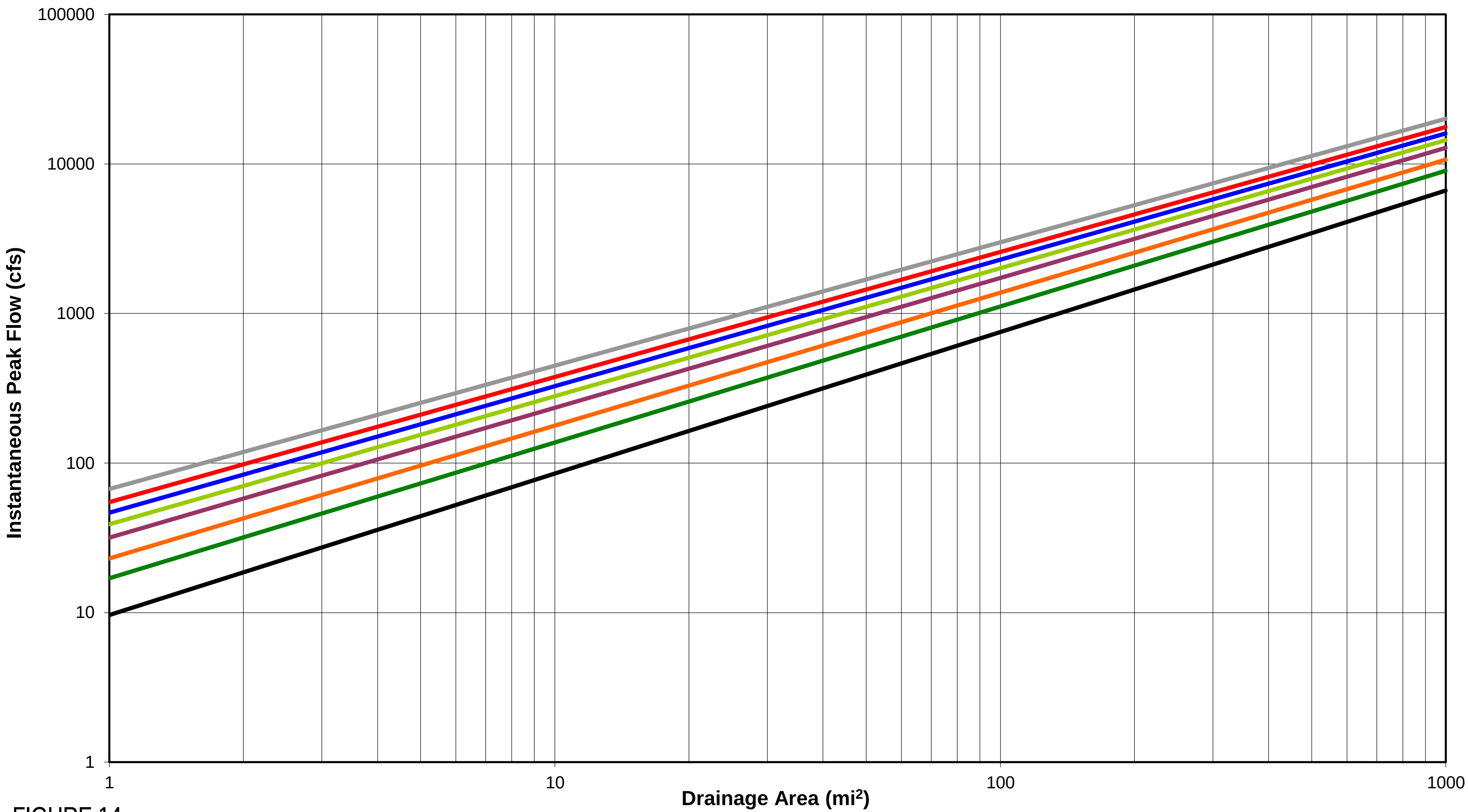


FIGURE 14

Peak Flows Predicted by Region 4 Regression Equations

Notes: a. These curves are applicable for gages with lake storage equal to 3.0% of drainage area and mean annual precipitation equal to 26 inches.

b. 500 year peak flow equation: $Q = 67 A^{0.83}$

c. 2 year peak flow equation: $Q = 10 A^{0.95}$

d. Q = Discharge (cfs), A = Drainage Area (mi^2).

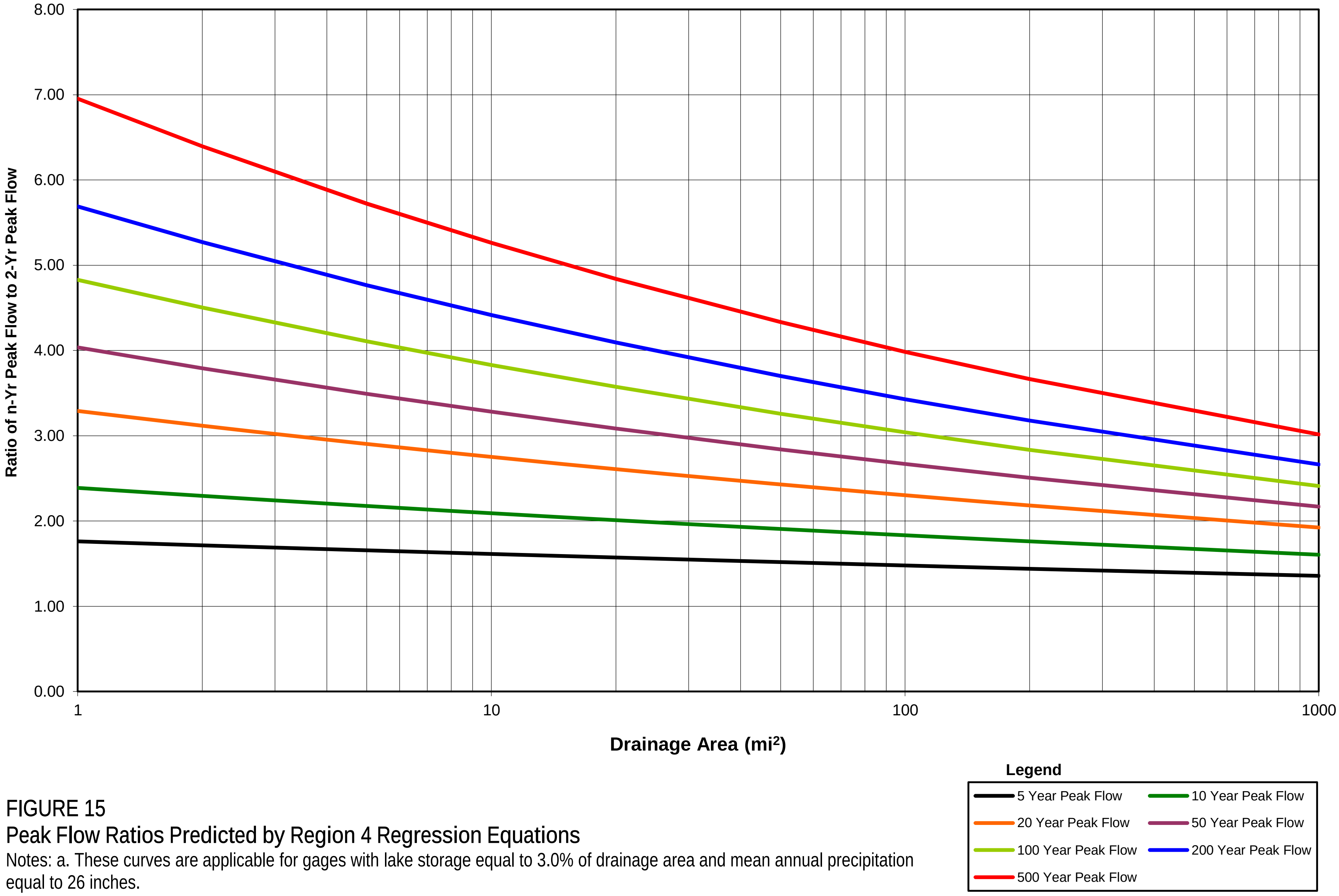


FIGURE 15
Peak Flow Ratios Predicted by Region 4 Regression Equations
Notes: a. These curves are applicable for gages with lake storage equal to 3.0% of drainage area and mean annual precipitation equal to 26 inches.

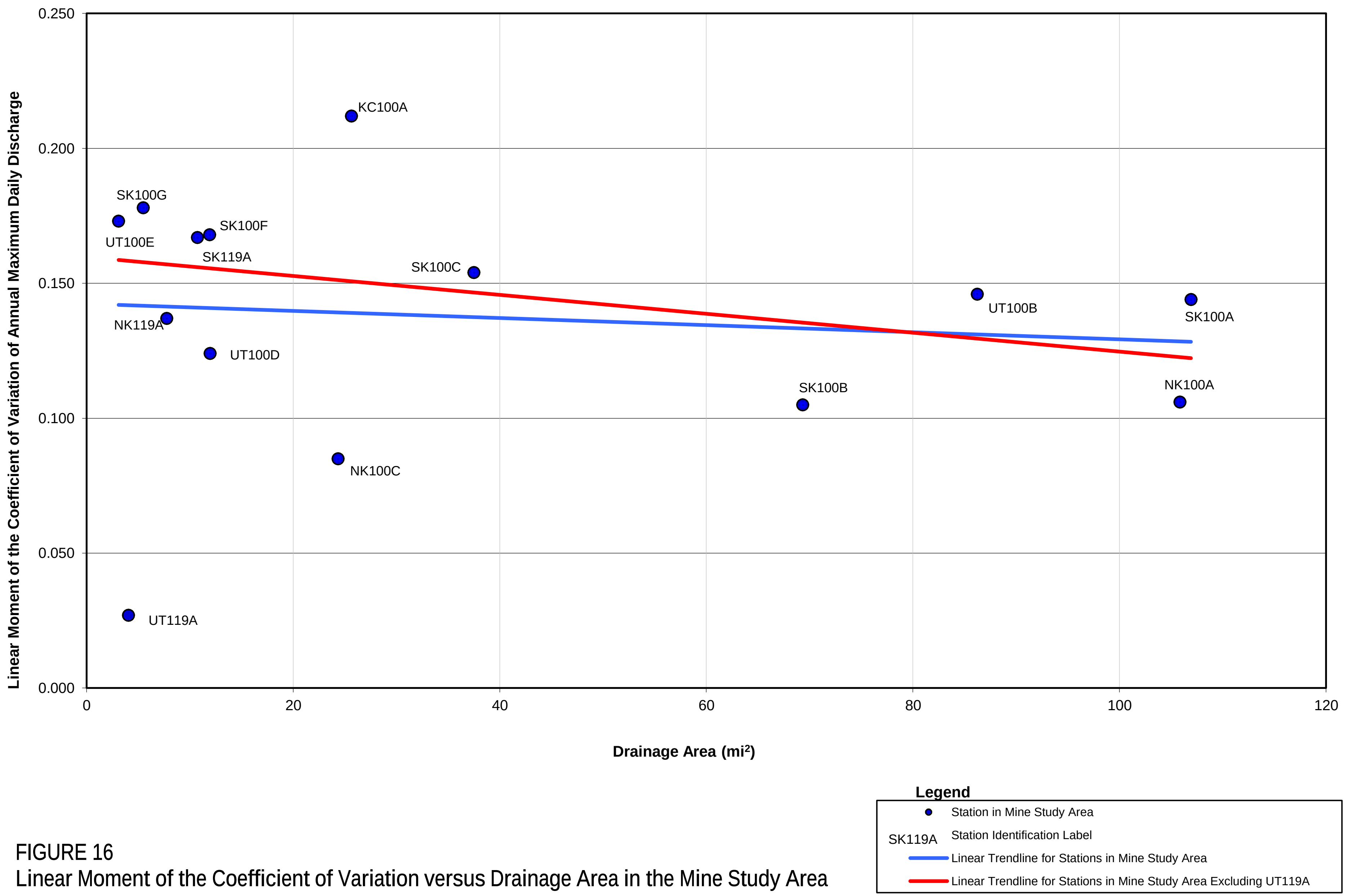


FIGURE 16
Linear Moment of the Coefficient of Variation versus Drainage Area in the Mine Study Area

APPENDIX 7.2D

Snow Distribution Surveys
Mine Study Area

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ACRONYMS AND ABBREVIATIONS

ABR	ABR, Inc.—Environmental Research & Services
AIC_c	Akaike Information Criterion adjusted for small sample sizes
ω_i	Akaike weights
DEM	digital elevation model
EOS	Earth-Observing System
ETM+	Enhanced Thematic Mapper Plus
Hoefler	Hoefler Consulting Group
in.	inch(es)
GDEM	Global Digital Elevation Model
GPS	global positioning system
LAADS	Level 1 and Atmosphere Archive and Distribution System
LIDAR	Light Detection and Ranging (also Lidar or LiDAR)
µm	micrometer
MODIS	Moderate Resolution Imaging Spectroradiometer
NDSI	Normalized Difference Snow Index
NIR	near-infrared
NRCS	Natural Resources Conservation Service
SD	standard deviation
SNOTEL	Snow Telemetry
SRTM	Shuttle Radar Topography Mission
ss1	Pebble Snow Course 1
ss2	Pebble Snow Course 2
SWE	snow water equivalent
SWIR	short-wavelength Infrared
TM	Thematic Mapper
UTC	Coordinated Universal Time
VIS	visible
WRS2	World Reference System 2
WWS	Wyoming wind screen

SNOW DISTRIBUTION SURVEYS, MINE STUDY AREA

1. INTRODUCTION

Snow surveys and distribution-mapping studies were conducted in the mine study area of the Pebble Project from 2004 through 2008. In 2007, the studies were expanded to include lower reaches of the mine area drainages. Snow is a key component of the water-balance in drainages of the mine study area. On average, 30 to 35 percent of precipitation at the proposed mine site falls as snow between October and April, and most becomes available as meltwater in the spring. Snow distribution surveys are designed to complement concurrent surface-water hydrology studies by characterizing the distribution, snow water equivalent (SWE), and ablation (melting and sublimation) rates of late-season snow (before break-up) across the landscape in the mine study area. The results of snow distribution and ablation field surveys along with preliminary modeling results are presented in this appendix.

2. STUDY OBJECTIVES

The objective of the snow distribution study is to characterize snow distribution and ablation for the mine study area. Specific goals include the following:

- Map late-season snow distribution using data from field surveys, terrain characteristics, and climate data.
- Map snowpack ablation rates from field-survey data, terrain characteristics, climate data, and satellite imagery.
- Compare field measurements of snow depths and water equivalents at meteorological stations with automated precipitation-gage measures.
- Evaluate records from proximal snow-survey sites administered by the Natural Resources Conservation Service (NRCS) as appropriate proxies for historical snowpack data.
- Compare the snow distribution and ablation model outputs with daily hydrograph data (2006 through 2008).

3. STUDY AREA

The study area includes the North Fork Koktuli River, South Fork Koktuli River, and Upper Talarik Creek—and adjacent areas (Figure 7.2D-1). The snow distribution study was initially focused around the mine study area, defined by the basins above the NK100B, SK100B1, and UT100D gaging stations. In 2007, the study area was expanded to the full extent of the North Fork Koktuli River, South Fork Koktuli River, and Upper Talarik Creek basins and the headwaters of Kaskanak Creek (the “extended mine study area”). The extended mine study area is defined by the basins above the NK100A, SK100A, UT100APC3, and KC100A gaging stations. Throughout the study, field survey sites were concentrated around the general deposit location. Additional plots sampled in 2007 and 2008 were distributed throughout the extended mine study area. The snow depth LIDAR survey (acronym for light detection and ranging) acquired in April 2008 covered a subset of the mine study area: the basins above the NK119A, NK119B, SK100F, SK119A, SK124A, and UT100D gaging stations, and portions of surrounding basins.

4. PREVIOUS STUDIES

Some of the dominant regional winter weather flows are depicted on Figure 7.2D-2 (Albanese, pers. comm., 2008). In the main part of the Bristol Bay drainage that is comprised of the Nushagak and Kvichak River watersheds, the climate is transitional between maritime and continental. Regional precipitation is greatest from late summer through early winter and is primarily generated by maritime storm systems. The most common circulation pattern consists of atmospheric lows moving in from the North Pacific Ocean along the Aleutian Island chain into the central and eastern Bering Sea (Albanese, pers. comm., 2008). These storms produce southeasterly winds near the ground surface that spiral in a counter-clockwise direction toward the center of the low pressure cell. The storms produce heavy precipitation along the southeastern flanks of the Alaska and Aleutian ranges, outside of the Bristol Bay drainage. Considerable precipitation also occurs within the study area, especially on higher terrain with southerly to easterly exposure. Less frequently, atmospheric lows situated at Kodiak Island and the Shelikof Strait area result in northeasterly winds. Moisture is much lower with this flow pattern, but it still may produce precipitation in the study area. By mid-winter, the lows tend to move into the central to eastern Gulf of Alaska, resulting in northerly to northwesterly surface-level air flows of colder, drier, continental air.

The global snow cover classification system of Sturm et al. (1995) mapped the snow cover in the study area as “maritime.” Maritime snow covers are warm and deep, and accumulated snow commonly includes melt features throughout the snow column along with basal melting. The study area is near the northern limit of the maritime snowpack in the region, and is therefore likely to be cooler and shallower than typical maritime snowpacks. Much of the study area could also be described by the special “mountain” snow cover class, which was described by Sturm et al. (1995) but not mapped. Mountain snow cover is highly variable due to the local effects of wind, solar radiation, and elevation.

No pertinent local investigations of snow distribution were conducted in the mine study area before the Pebble Project studies from 2004 through 2008. Six NRCS snow courses are within 100 miles of the Pebble snow courses (Figure 7.2D-2). No automated NRCS snow telemetry (SNOTEL) sites are operated within 100 miles of the Pebble snow courses. Three of the NRCS snow courses are located at mountainous sites northeast of the general deposit location (Fishtrap Lake at 1,800 feet elevation above sea level, Upper Twin Lakes at 2,000 feet elevation, and Telaquana Lake at 1,550 feet elevation), one at a valley site northeast of the general deposit location (Port Alsworth at 270 feet elevation), and two are south of the general deposit location (Brooks Camp at 150 feet elevation and Three Forks at 900 feet elevation). The closest NRCS snow course is Port Alsworth, approximately 35 miles from the Pebble snow courses. Data collection from these six NRCS snow courses was inconsistent, and for certain locations and years, no April or March snow data were collected (Table 1). No data were collected at these NRCS snow courses prior to 1992.

5. SCOPE OF WORK

The research and field work for this study were conducted during 2004 through 2008. The study was conducted by senior scientists with assistance from research biologists and an IT professional, all of ABR, Inc. Environmental Research and Services (ABR) Fairbanks and Anchorage, Alaska. The study was conducted according to the approach described in the proposed 2004 through 2008 study plans (Appendix E). Field surveys, data analysis, and reporting were performed by scientists from ABR in consultation with surface water hydrology project leaders from HDR, Inc. and Knight Piesold Ltd.

The scope of work included the following:

- Perform field surveys in mid-April to determine the general distribution of snow across the local landscape.
- Perform additional surveys in April and May to document the rate of ablation of the snowpack during breakup.
- Compare field measurements with snow cover estimates derived from satellite imagery.
- Estimate ablation rates through the combination of periodic spring field surveys, analysis of moderate resolution imaging spectroradiometer (MODIS) satellite imagery, climate data, and stream discharge measurements (data currently collected by USGS, APCS and HDR, Inc.).
- Compile the 5 years of survey data (2004 through 2008) to produce modeled snow distribution maps of the mine study area.

6. METHODS

6.1 FIELD SURVEYS

During each field survey, snow samples—primarily SWE and snow depth measurements—were collected at defined plot locations. Plots were grouped into transects, including snow courses, mountain transects, and valley transects. Snow courses were intended to provide data suitable for comparison with existing NRCS snow course sites and to provide inter- and intra-annual comparison of SWE. Mountain and valley transects were established to represent predominant slope, aspect, and elevation spans of the study area.

A set of transects was measured over a period of several days during each snow survey. Snow distribution surveys, conducted during early-to-mid April in 2004 through 2008, covered the largest number of sites and were intended to document snow conditions near peak SWE across the study area. Snow ablation surveys were conducted at 2- to 3-week intervals following the initial snow distribution surveys. Ablation surveys characterized snow conditions during late spring by resurveying the snow course plots.

6.1.1 SNOW SAMPLES

6.1.1.1 SNOW WATER EQUIVALENT (SWE)

Snow water equivalent (SWE) is the amount of water contained within the snowpack. It is equivalent to the depth of liquid water that would result if the snowpack were instantaneously melted. Data for SWE calculations comprised snow depth, snow weight, and tare weight. Up to four replicate SWE measurements were recorded at each plot where SWE was sampled. Percentage of snow cover over a 15-foot radius was visually estimated, and the conditions at the snow-ground interface (frozen, dry, damp, or wet) were noted.

Each sample was checked for evidence that the snow core was complete. Evidence could include a plug of tundra or soil in the tube below the snow core, or particles of rock or soil in the snow at the bottom of the tube. In shallow snow it was often possible to cover the bottom of the tube with a glove or shovel, though this required disturbance of the plot and was not done at sites where revisits were planned. Basal ice often occurred below the snowpack and could prevent the collection of plugs or ground particles. In these cases, a depth probe was used (if available) to determine whether the ice layer was at the base or in the middle of the snowpack or a new core was attempted. A note was recorded in the field if the field sampler knew that the core was incomplete or thought the core was likely incomplete.

In 2004 through 2007, SWE measurements were collected using a standard Federal snow sampling tube and spring scale. In 2008, a Snow-Hydro snow sampling tube was used in addition to the Federal tube. In that year, some replicate data were collected using different sampling tubes at the same plot to quantify the error introduced by sampling equipment.

Deep snow drifts with ice layers were challenging to sample. In 2004 through 2006 and 2008, there were some plots where the snowpack was not sampled to the bottom. In 2004, only three snow tubes were used, so that snow deeper than 90 inches could not be sampled without digging. From 2005 forward, two extra lengths of snow tube were available, allowing sampling up to 150 inches. However, the fifth tube broke early in the 2005 surveys, resulting in an effective range of 120 inches. The broken tube was repaired and reinforced before the 2006 surveys. Starting in 2007, snow depth probes were used to ensure that a complete depth was recorded for each sample. Depth probes are also more capable of penetrating some of the thick ice layers that the tube could not penetrate. The Snow-Hydro snow tube used in 2008 could sample cores up to 79 inches, though this range was extended by digging.

At several deep plots each year, the sampling tube did not reach the ground with the first sample, due to thick ice layers and the tube freezing in the snowpack. The standard snow sampling protocol when the tube cannot penetrate to the ground (USDA-SCS, 1984) is to carefully remove the tube, weigh the first core, empty the tube, and then return the tube carefully into the hole to obtain further samples as necessary, until the ground is reached. However, the densities obtained from this method were often too high (greater than 60 percent). Seasonal snow does not exceed a density of 60 percent and typically is in the range of 33 to 50 percent. Despite careful removal and reinsertion of the tube, snow from the side of the hole was apparently falling to the bottom of the hole, resulting in overestimation of SWE in some deep snow drifts. Starting in 2007, the depths and weights of each partial core were recorded. If the first core measured at least 60 percent of the total snow depth, then the density from the first core was multiplied by the total depth to estimate SWE. Otherwise, the snow density model (described in section 6.3 below) was used to estimate snow density and SWE.

Data from SWE samples were reviewed in the office, and snow samples with densities greater than 60 percent were flagged. For these samples, the SWE was recalculated by multiplying an estimated density by the measured snow depth. If possible, the mean density of other sample replicates from the same plot was used. For other samples in 2004 through 2006, a mean density of 40 percent was used, except for a few samples where the field notes indicated that the multiple-core sampling method had been used. For those samples, a mean density of 45 percent was used, based on the density of first cores from multiple-core samples measured in 2007. For the single-core 2007 and 2008 samples flagged for high density, the density model (described in Section 6.3 below) was used to estimate snow densities.

6.1.1.2 SNOW DEPTH

In 2007 through 2008, additional depth-only plots were established to better support snow transport calculations and snow distribution modeling. Metal snow depth probes were used to rapidly collect snow depth measurements at supplemental plots located between the primary plots where SWE data were collected. The snow depth probes were longer, allowing measurement of snow depths up to 37.7 feet when the longest probe kit was used. Snow depth probes were also better able to penetrate dense, deep snow, particularly when ice layers were present, and they allowed measurements of the entire snowpack at some sites where the snow tubes could not penetrate to the ground.

6.1.1.3 SNOW SURFACE

For the 2007 and 2008 surveys, Trimble R8 GPS receivers, with a data dictionary on a Trimble TSC2 Survey Controller, were used to record the precise location and elevation for each sample. In some cases, measurements of the location of the snow surface were taken alone. The location measurements were more rapid than using snow depth probes and could be completed on slopes where it was impractical to operate the probe due to poor footing. The snow surface measurements document the shape of snow drifts and allow estimation of snow depth through subtraction of the ground surface elevation (derived from a digital elevation model [DEM]) from the measured snow surface elevation.

6.1.1.4 SNOW TEMPERATURE PROFILES

In 2008, snow temperature profiles were collected at some of the plots where SWE was measured. Snow temperature measurements were collected at various depths within the snowpack, usually at the surface, middle, and base. The temperature and the depth for each measurement were recorded.

6.1.1.5 SNOW PITS

Seven snow pits were sampled in 2008. The snow pits were approximately 36 inches wide and up to 80 inches deep. Snow pit density profiles provide a check on the snow density data obtained from snow tubes, and observations of layers and other features in the snow pits yields information about snow transport and melt events. At snow pits, snow density data and temperature profiles were collected, and the presence and hardness of layers were noted. Snow density samples were collected at regular depth intervals using a density cutter and were weighed using a spring scale or an electronic scale.

6.1.2 SNOW PLOTS

Sampling occurred at discrete plots that were selected from topographic maps of the study area. At each snow sampling plot, one or more types of snow sample data were collected, with the categories of data collected determined by the plot type. The plot locations were recorded in a global positioning system (GPS) during the first visit, and GPS navigation was used to revisit the plot locations. When the same plot was visited multiple times during a year, the tracks from the previous visit could often be followed, and the previous sampling holes could sometimes be observed. In those cases, care was taken to obtain repeat measurements near the original holes but in areas without visible disturbance from the earlier visit.

6.1.2.1 PRIMARY PLOTS

Primary plots were located at regular intervals along snow courses, mountain transects, and valley transects (details of plot spacing are discussed in the snow transect section, below). At each primary plot, data for SWE calculations were collected and two photos across the slope were taken. Percentage of snow cover over a 15-foot radius was visually estimated, and the conditions at the snow-ground interface (frozen, dry, damp, or wet) were noted. Primary plots were the only plot type sampled from 2004 through 2006. In 2007 through 2008, the primary plots continued to be sampled, while additional measurements were obtained at locations between the primary plots.

Snow measurements were made at 311 primary plots throughout the mine study area. Of these plots, 45 plots were sampled in all 5 years, 95 plots were sampled in 4 or more years, 147 plots were sampled in 3 or more years, and 190 plots were sampled in 2 or more years.

6.1.2.2 SUPPLEMENTAL PLOTS

Starting in 2007, supplemental plots were located at regular intervals between primary plots (generally about 150 feet) and in areas with large and/or highly variable snow accumulations (drifts). At supplemental plots, only the snow depth (or the absence of snow) was usually recorded. However, when SWE data could not be collected at primary plots due to exceptionally deep or impenetrable snow, SWE data were collected at a nearby supplemental plot. Most supplemental plots established in 2007 were revisited in the subsequent year, and snow depths (or the absence of snow) were recorded each time.

6.1.2.3 METEOROLOGICAL STATION PLOTS

Additional field measurements were made at proposed or actual meteorological station locations in 2004, 2005, and 2007. In 2004 and 2005, up to four samples of snow depth and water equivalent were measured in a 10-foot radius around the proposed sites, although the stations later were installed at different locations. In 2006, snow was not sampled at the meteorological stations because it had been determined from previous sampling that their exposed locations led to scouring of snow from the sites. In 2007, the three established meteorological stations (Pebble 1, 3, and 4) were visited, and sampling was conducted nearby, though not in their immediate vicinity, which was again scoured of snow.

6.1.2.4 OPPORTUNISTIC PLOTS

Opportunistic plots were not associated with a particular point, transect, or profile and were not revisited. These plots often characterized small, highly variable snow features or were intended to be associated with an established plot, but were more than 25 feet distant from the established plot center (see Section 6.1.5 on data management below for details on distance criteria).

6.1.3 SNOW TRANSECTS

Plots that were sampled on foot sequentially (usually on a single day) were grouped into transects. The transects included 2 snow courses, 22 mountain transects, and 8 valley transects. The snow courses were sampled several times each year, during a distribution survey and ablation surveys. The mountain and valley transects were sampled during the distribution surveys. Individual transects were occasionally sampled more than once a year (i.e., during an ablation survey) if time allowed. Limited sampling occurred at two additional types of snow transects: extensive grid transects and profile transects.

6.1.3.1 SNOW COURSES

Two permanent snow courses were established in 2004 and sampled annually to provide data suitable for comparison with existing NRCS snow course sites and to provide inter- and intra-annual comparison of SWE. Pebble Snow Course 1 was located at the 2,000-foot elevation on a shoulder of Groundhog Mountain (Transect ss1, Figure 7.2D-3), while Pebble Snow Course 2 was placed at the 1,200-foot elevation on an isolated hill in the headwaters of Upper Talarik Creek (Transect ss2, Figure 7.2D-3). Each snow course comprised a 1- to 2-mile circuit around a small ridge or knob with 10 to 13 primary plots located at nearly equal elevations (Figure 7.2D-4). Primary plots were located at equal elevations along each snow course and were approximately 700 to 1,200 feet apart. These plots were permanently marked with flagging (although the flagging is generally not visible until much of the snow has melted), and the locations were recorded with handheld GPS units during the initial field survey. These plot locations have been unchanged for the duration of the study.

Two of the stations on Pebble Snow Course 1 had both high snow accumulations and highly variable snow accumulation between surveys. Small variations in the selected sampling location (within the error of handheld GPS navigation) were observed to have large effects on measured SWE. The effect was most noticeable when comparing SWE from multiple samples during a single visit and SWE from multiple visits during a single season. The results from this snow course are reported twice. Average values computed from all the stations are reported as Pebble Snow Course 1, while average values computed from all the stations except plot ss1_c and ss1_h are reported as Pebble Snow Course 1A (Table 1).

6.1.3.2 MOUNTAIN TRANSECTS

Mountain transects were established to represent predominant slope, aspect, and elevation spans of the three major drainages and were distributed across basin and smaller catchment areas to correspond with planned gaging station locations (Figure 7.2D-3). The sampling effort was concentrated in the headwaters of the three major drainage basins within the study area: North Fork Koktuli River, South Fork Koktuli River, and Upper Talarik Creek. Transects ranged from 0.6 to 1.9 miles in length with at least two transects per major aspect category (north, south, east, west).

On mountain transects, primary plots were located at approximately 100-foot elevation intervals along transects with supplemental depth samples at 164-foot horizontal intervals. Mountain transects extended from ridge tops to valley bottoms. Locations of plots established in 2004 and 2005 were adjusted in the field for uniform slope, aspect, and vegetation type. Locations of plots established in 2007 and 2008 were not adjusted in the field.

6.1.3.3 VALLEY TRANSECTS

In flat or undulating terrain, primary plots were sampled at 820-foot horizontal intervals with supplemental depth samples at 164-foot horizontal intervals. Valley transects were linear and were either oriented parallel to the valley or else across the valley (sampling a variety of elevations and slope features). One valley transect (Transect 51) included a right angle and sampled both parallel to and across a valley.

6.1.3.4 EXTENSIVE GRID TRANSECTS

Extensive grid transects were sampled on a regular grid covering outlying portions of the extended mine study area in 2007. Each transect included primary (SWE) and supplemental (depth-only) plots, with several SWE samples covering a representative range of snow depths sampled at each transect. At each extensive grid transect, a short (up to 225 feet) transect leg was sampled along a random direction with samples between 7 and 60 feet apart. The distance between these samples was paced out. The distance between plots increased so that the second plot was 2 paces from the start of the transect, the third plot was 2 paces from the second, the fourth plot was 5 paces from the third, the fifth plot was 5 paces farther, and so on. The typical plot spacing was 2, 2, 5, 5, 10, 10, 20, and 20 paces. This approach ensured that a representative portion of the local landscape was sampled, and it also provided a variety of spacing distances to support geostatistical analysis. In areas of highly variable snow cover and depth, a second and third transect leg were sampled along a direction that was offset by 120 degrees clockwise from the direction of the previous transect, so that the cluster of plots ended near the original starting location.

6.1.3.5 PROFILE TRANSECTS

Profile transects were sampled in 2007 and 2008. Profile transects were measured while navigating a linear course between a start point and an end point. These transects were primarily sampled by snow depth and snow surface elevation measurements, although SWE measurements were occasionally made. The distance between samples varied, but samples were more closely spaced than on other transects and were intended to characterize the snow surface and snow depth over a discrete drift. These plots were established with the intention of characterizing drift volume and snow transport along a profile that could be re-measured during later surveys

6.1.4 SNOW SURVEYS

6.1.4.1 SNOW DISTRIBUTION SURVEYS

Spring snow distribution was measured in the mine study area in mid-April 2004, 2005 and 2006, and in early April 2007 and 2008. Sampling in mid-April generally captured nearly all of the snowfall of the year, yet occurred before major snowmelt at intermediate and higher elevations. Surveys were moved to an earlier date in 2007 due to expanded sampling at lower elevations and a thinner snow cover. In 2008, an additional distribution survey that concentrated on valleys and lower elevations was conducted in mid-March. The snow courses were surveyed during the snow distribution survey in each year. The other transects surveyed each year are summarized below:

- **2004:** Snow depth and water equivalent were measured along one valley transect (Transect 12) and 11 mountain transects.
- **2005:** Seven of the 2004 transects were not sampled and seven replacement transects were established based on revised development planning and the locations of new gaging stations. A valley transect (Transect 27) was added to improve estimates of SWE in low-elevation flats. The seven replacement transects were located on slopes and aspects similar to those they replaced. Two valley transects and 11 mountain transects were sampled.
- **2006:** These same transects and one transect (Transect 5) that was not sampled in 2005 were sampled again for a total of two valley transects and 12 mountain transects.
- **2007:** One valley transect and 18 mountain transects were sampled, including all of the 2006 transects, with the exception of the low elevation transect established in 2005, which had negligible snow. Four new transects were established to cover under-represented basins, and Transects 4 and 9 from 2004 were sampled again. In addition, 22 drift profiles and 21 extensive grid plots were sampled in 2007.
- **2008:** Six new valley transects were sampled in the mid-March valley snow distribution survey. During the early April mountain snow distribution survey, 15 of the mountain transects that were sampled in 2007 were again sampled. The two valley transects that were sampled in 2005 and 2006 were also sampled.

6.1.4.2 SNOW ABLATION SURVEYS

Ablation measurements were obtained by resurveying the snow course plots at approximately 2- to 3-week intervals following the initial snow distribution surveys. Data collection concentrated on SWE sampling at primary plots, with depth data also collected at supplementary plots in 2007 and 2008. In addition to plot data, aerial photos of the central mine study area were taken during each survey trip. These photos were used to determine large-scale patterns of snow accumulation and ablation in the mine study area.

Ablation rates (inches per day) were calculated as:

> (Average SWE at Earlier Survey + New Precipitation – Average SWE at Later Survey)/(Number of Days Elapsed)

This formulation reports a decrease in the snowpack as a positive ablation rate. Snow samples were collected near the middle of the day, so half of the precipitation measured on the date when snow courses were surveyed was treated as new precipitation in ablation rate calculations. Because no quantitative meteorological data on new precipitation were available until spring 2005, the new precipitation term was omitted from the ablation rate measurements for 2004. In 2006 through 2008, new precipitation was estimated from the SnowModel output (see Section 6.7), which spatially distributed the meteorological station data over the domain, while in 2005 the meteorological station precipitation record from Pebble 1 was used directly.

6.1.4.3 SNOW RECONNAISSANCE SURVEYS

In 2007 and 2008, brief snow surveys were conducted in early March. An airborne LIDAR survey (described below) was being considered, and it was desirable to schedule the LIDAR acquisition during a year with deeper-than-average snow. The reconnaissance surveys were intended to validate preliminary reports of general snow depth in 2007 and 2008, and targeted plots where deep snow was regularly observed in 2004 through 2006.

6.1.5 DATA MANAGEMENT

All of the snow sample measurements were recorded in the field using electronic forms. In 2004 through 2006, a stand-alone pocket PC form was used. The location for each plot was provided by entering the plot name in the form, and no specific information on the location of replicate samples was recorded. For the 2007 and 2008 surveys, a Trimble R8 GPS receiver with a data dictionary on a Trimble TSC2 Survey Controller was used to record the field measurements as well as precise locations for each sample.

The survey GPS locations were used to assist in the assignment of samples to plots for 2007 and 2008. The location for each plot was established based on the GPS location recorded when the plot was first visited. For plots established in 2004 through 2006, this was a recreation-grade GPS location measurement, while in 2007 and 2008 this was a survey-grade GPS location measurement. The location of each sample was recorded in 2007 and 2008, and the distance from the sample to the nearest plot was calculated. Samples collected within 25 feet of a plot were assigned to the nearest plot, while other samples were assigned to the opportunistic plot type. This procedure ensured that samples inadvertently collected more than 25 feet from the plot center were not applied to that plot.

The data were then combined into a single Microsoft Access database, which stored the data in four linked tables. The tables corresponded to the following four major headings, which were used to organize data collection, as previously described in the field surveys section.

- Snow Samples
- Snow Plots
- Snow Transects
- Snow Surveys

The Snow Samples table was linked to data tables containing proofed field data, including the following:

- Snow Data Location: The precise location of the sample, including elevation, measured at the top of the snowpack.
- Snow Data SWE: Snow depth, snow weight, tare weight, and percent snow cover were recorded. SWE and snow density were calculated.
- Snow Data Depth: Snow depth and percent snow cover were recorded. Estimated snow density and SWE were calculated.
- Snow Data Absence: Stored data for plot visits that occurred when no snow was present.

- Snow Data Temperature Profile: Snow depth and snow temperature at specified depths were recorded.
- Snow Data Pit: Snow depth, integrated snow density, and SWE were calculated based on snow pit data sheet.

Most of the raw field data were then linked to the data tables to facilitate quality control. Much of the quality control took place in the field, through careful data entry, because minor data entry errors would not be detectable back in the office (though electronic data entry eliminated the need for manual transcription from paper forms). Snow density (SWE in inches divided by snow depth in inches) was calculated in the office, and samples with very low or very high density were scrutinized. Starting in 2007, each record was reviewed for errors, and the initials of the reviewer, date and the nature of any errors found, and any changes made to the raw data were recorded.

Two teams sampled during the April 2008 distribution survey. In addition to the new metric scales and a metric sampling tube, new metric depth probes were added to accommodate the additional team. As a result, there was a mixture of English units (inches, inches SWE) and metric units (centimeters, grams, kilograms). Therefore, the electronic form was modified to explicitly record the unit of measure for each sample and the name of the sampling equipment that was being used. In the Access database, conversion factors were applied to the data to standardize all depth measurements to inches, and all weight measurements to inches SWE.

6.2 METEOROLOGICAL DATA

Meteorological data from the Pebble site were provided by Hoefler Consulting Group (Hoefler). The data were analyzed to provide information on winter weather patterns, total winter precipitation, snow transport by wind, and as input into the snow model.

Multiple wind and precipitation instruments were maintained at several stations. Based on discussions with Hoefler (Shallies, pers. comm., 2007), only data from the Climatronics wind gage (fixed cup and vane) and the ETI NOAH II precipitation gages shielded by Wyoming wind screens (WWS) were used. In some cases when the preferred instruments were not installed or malfunctioned, data from alternate instruments were used with caution.

The meteorological data were provided in an hourly format. These data were screened using plots to flag some suspect data, including long periods of near-zero winds or zero precipitation at a particular station. Suspect data were filtered out. For plotting and for some model runs, the hourly data were aggregated to a daily time step. The resultant daily wind direction and wind speed were computed from hourly data, while other data were averaged or summed, as appropriate.

Winter climatology charts, summarizing daily precipitation, temperature, wind, and radiation, were constructed for the three winters with fairly complete meteorological data at Pebble 1 (winters 2005/2006, 2006/2007, and 2007/2008). These charts facilitated inter-annual comparisons of winter weather and allowed comparisons of multiple variables (e.g., identifying dominant wind directions during and soon after major precipitation events).

Due to the persistent high winds at the Pebble site, it is expected that the precipitation gages have a catch efficiency of 67 percent or lower (Shallies, pers. comm., 2007). A precipitation correction factor (the inverse of catch efficiency) was estimated based on review of station precipitation, aggregate model and LIDAR SWE (described below), and field survey results. The precipitation correction factor that resulted in the best aggregate agreement between field data, modeled SWE, and LIDAR-derived SWE was applied to the station data used for the snow transport calculations and snow model input (see Section 7.6).

6.3 SNOW DENSITY MODELING

6.3.1 STANDARDIZATION OF SNOW DENSITY MEASURED USING DIFFERENT EQUIPMENT

Federal snow sampling tubes are the standard equipment used in the United States by the NRCS. There is evidence that these snow tubes overestimate SWE in deep snow (Farnes et al., 1983) due to the design of the cutter teeth and possibly the slots in the side of the tube. In 2004 through 2007, SWE was measured using only the Federal snow tube. In 2008, in addition to the Federal tube, a 2-meter Snow-Hydro tube was used by one crew to measure SWE and density cutters were used to measure density for several snow pit profiles. Several transects were sampled using both of the snow tubes, with snow samples acquired adjacent to each other.

The snow density data from the different tubes were compared for the paired samples. A systematic difference between snow densities from different sampling tubes was observed, and a simple correction factor was then developed to normalize the data collected with different tubes.

6.3.2 ESTIMATING SNOW DENSITY FROM SNOW DEPTH

After the snow density measurements were normalized for different tubes, models were developed to estimate snow density for snow depth-only samples. (For the depth-only samples, snow weights were not collected to use in the direct determination of density for each sample.) All of the available snow density data points were analyzed to develop models that could predict snow density at plots where only snow depth was measured. Simple linear regression was used to estimate the relationship between snow depth and snow density within the range of snow depths for which snow density data were collected. Various nonlinear relationships used in other studies were also tested, but it was found that these relationships fit poorly to the data collected in this study. This was likely due to the high variability in snow density, relatively small sample size, and the tendency for shallow snow to have a relatively high density in this study (likely due to the effect of wind and the timing of the surveys near the end of the snow accumulation season). Therefore, a linear relationship was used instead of the more complex nonlinear relationships.

To determine the best variables to estimate snow density, the data were first divided between distribution surveys and ablation surveys. For each data set, an information–theoretic approach (Anderson et al., 2000; Burnham and Anderson, 2002) was used to compare a predetermined set of candidate models with different combinations of independent variables. Akaike Information Criteria with the adjustment for small sample size (AIC_c) was calculated and the Akaike weights (ω_i) were used to estimate the relative probability of each model being the most parsimonious model in the candidate set.

For spring surveys, the candidate model set included all combinations of the independent variables: snow depth (continuous variable), shrubs (presence or absence), and year (categorical variable; 2004 through 2008), with and without interaction terms, and including an intercept-only model. The shrub variable was based on the tall shrub vegetation class (described in Section 6.7.1.2 below). With three main effects (snow depth, shrubs, and year), there were four possible interaction terms (one 3-way and three 2-way interactions). For example, a model with shrub and year could also have a shrub by year interaction that would allow the model to have different effects of shrubs in different years. The combination of main effects, interactions, and intercept resulted in a total of 19 different candidate snow density models.

For ablation surveys, the same model set was used, except the year variable was replaced with an individual survey because multiple ablation surveys were conducted in each year, and the snow densities were expected to change rapidly during late spring. The shrub independent variable was replaced with the variable elevation (less than 1,500 feet or greater than 1,500 feet) because there could potentially be large differences in snow density by elevation during the ablation period; most of the data came from two snow courses at distinctly different elevations; and the effect of shrubs should be diminished in melting snow.

Snow density increases asymptotically at larger depths beyond the range of the observed density samples (e.g., Tabler et al., 1990). Extrapolating the linear models would produce unrealistic densities for deep snow and, consequently, the linear density model was replaced with density curves derived from the literature for deep snow. Tabler et al. (1990) estimated density of deep snow drifts (formed by wind) before melting:

$$\rho_s = (522 - (20{,}470/d_s) * (1 - \exp (-d_s/67.3))/1{,}000$$

Where:

ρ_s = Integrated density of deep snow drifts in grams per cubic centimeter.

d_s = Snow depth in centimeters.

The transition from the linear fit to the deep drift curve was made at the intersection of the linear and the exponential fit described by the above equation. In cases where the linear fit was always greater than the deep drift curve, it was assumed that some melt had occurred resulting in a higher density. For these cases, an alternate exponential density curve was obtained by replacing the 522 value with 550 in the above equation (this value controls the asymptote of the exponential function).

6.4 SNOW DEPTH MAPPING WITH LIDAR

Snow surface elevations were mapped using the April 6, 2008, airborne LIDAR survey over the mine study area. Snow depth was then determined by subtracting the bare earth elevation from the snow surface elevation (Deems and Painter, 2006; Deems et al., 2006). The resulting map delineated snow depths in the mine study area, particularly the location, extent, and the volume of large snow drifts. A snow density model developed using field data from the 2008 snow distribution surveys was used to estimate SWE from snow depth. The resulting SWE map was used to calibrate and validate the snow distribution model and to estimate snow transport rates.

Field sampling near the date of the LIDAR survey was concentrated within the area covered by the LIDAR. Field and LIDAR measurements of snow depth were compared to estimate the accuracy of the LIDAR snow depth mapping.

6.5 SNOW-COVERED AREA MAPPING

The snow-covered area was mapped using satellite imagery from Landsat (30-meter resolution) and Moderate Resolution Imaging Spectroradiometer (MODIS, 500-meter resolution) sensors. Snow-covered area data from different dates during the winter and spring were used to quantify landscape-scale patterns of snow accumulation, transport, and ablation. The data were used to characterize inter-annual variability, and to calibrate and validate the snow distribution and ablation models.

Snow is one of the only natural materials that is both highly reflective in visible wavelengths and absorbed in the middle infrared wavelengths; therefore, satellite snow-mapping algorithms are based on these properties (Hall et al., 2001). The Normalized Difference Snow Index (NDSI) tends to be high when snow is present in a remote sensing pixel and is calculated from the visible and short-wavelength infrared wavelengths as follows:

$$NDSI = (VIS - SWIR) \div (VIS + SWIR)$$

Where:

VIS = Top-of-atmosphere reflectance in a visible wavelength, typically about 0.55 micrometer (μm)

SWIR = Top-of-atmosphere reflectance in a short-wavelength infrared, typically about 1.64 μm

The Snowmap algorithm (Hall et al., 2001) classifies pixels as snow if the following conditions are met: NDSI is greater than 0.4, visible reflectance is greater than 0.10, and near-infrared (NIR, about 0.85 μm) reflectance is greater than 0.11.

6.5.1 LANDSAT

Landsat 4 and 5 Thematic Mappers (TM) and Landsat 7 Enhanced Thematic Mapper Plus (ETM+) images over the study area were reviewed. The study area was covered by Path 71, Row 15, and Path 72, Row 15, in the World Reference System 2 (WRS2). The Landsat sensor acquires images of the study area once every eight days, but most acquisitions are cloudy, and cloud-free images are relatively rare. To obtain a suitable number of images, the entire archive of Landsat 4, 5, and 7 images was considered (1982 to present) rather than the 2004 through 2008 period only. Images with substantial cloud-free area were ordered from the U.S. Geological Survey. The images were processed to the top-of-atmosphere reflectance using the most current calibration coefficients (Chander et al., 2009) and were then re-projected to Alaska State Plane Zone 5 (NAD 1983 horizontal datum) at 96-foot resolution using the nearest-neighbor re-sampling method. To facilitate visual interpretation, all the images were processed to a standardized, full-resolution browse image type (versions of the satellite data that could be viewed in an internet browser or photo program).

A set of snow presence/absence/unknown maps was generated from images from February through August with no cloud cover over the extended study area. The scan line corrector on the Landsat 7 ETM+

sensor failed in May 2003, and Landsat 7 data collected since then have gaps that cover about 20 percent of each scene. These gaps were coded as unknown (9) in the snow presence/absence maps, while the remainder was mapped to snow presence (1) or absence (0) using the Snowmap algorithm (using Landsat bands 2, 4, and 5 for the VIS, NIR, and SWIR bands, respectively). The image dates and snow state were extracted for each 96-foot pixel in the extended study area. A logistic regression was performed for each pixel using the day of year as the predictor and the presence or absence of snow as the response variable. Unknown values were excluded. The snow-free date (at 50 percent likelihood) was calculated from the logistic parameters solved for each pixel. In the case of complete separation (a condition where the predictor perfectly predicts the target value (e.g., all dates before April 5 have snow and all dates after are snow-free), the mean value between the last snow-covered day of year and the first snow-free day of year was used for the 50 percent likelihood.

Typical snow-covered area for each day of the year was estimated by calculating the total number of pixels with a typical snow-free date greater than or equal to the day of interest. For example, May 15 typically had snow for each Landsat pixel with a typical snow-free date greater than May 15, and no snow for each pixel with a typical snow-free date of May 15 or earlier. For each day of the year, the count of typically snow-covered pixels divided by the total number of pixels yielded the typical snow-covered area.

6.5.2 MODIS

The Earth-Observing System (EOS) Terra and Aqua satellites launched in 1999 and 2002, respectively, each carry a MODIS sensor. MODIS data from the Terra platform were used to characterize snowmelt over the study area. At least one satellite image over the study area was acquired daily between 20:00 and 24:00 Coordinated Universal Time (UTC) (12:00 and 16:00 local time). Browse images were reviewed, and those with substantial cloud-free views of the study area were identified. For each date, the following data products were obtained from the Level 1 and Atmosphere Archive and Distribution System (LAADS, Goddard Space Flight Center, Greenbelt, Maryland):

- MOD02HKM (MODIS/Terra Calibrated Radiances 5-Min L1B Swath, 500 meters)
- MOD03 (MODIS/Terra Geolocation Fields 5-Min L1A Swath, 1 kilometer)

A binary snow map is calculated from MODIS Terra imagery with MODIS bands 4, 2, and 6 for the VIS, NIR, and SWIR bands, respectively. This binary map is of limited usefulness during the period of active snowmelt, when snowdrifts and patchy snow conditions occur at much finer scales than 500-meter pixels. Salomonson and Appel (2004) developed a fractional snow-covered area algorithm. They compared binary snow maps from 30-meter Landsat 7 imagery to MODIS NDSI and developed a simple linear function to calculate subpixel-scale snow fraction from the MODIS NDSI:

$$\text{Snow Fraction} = 0.06 + (1.21 * \text{NDSI}).$$

Subpixel-scale snow cover was calculated during late winter and spring 2000 through 2008 using the Salomonson and Appel (2004) algorithm. No attempt was made to optimize the algorithm based on Landsat scenes or other higher-resolution data acquired in the mine study area. MOD02HKM swath granules were reprojected to Alaska State Plane 5 (NAD 1983 horizontal datum) at 384-foot resolution using the nearest neighbor re-sampling method. Digital number values were converted to reflectance using the scale factor from the metadata. After the NDSI was calculated, the subpixel-scale snow fraction was calculated. Pixels with missing, cloud-obscured, or otherwise bad data were masked. The standard quality assurance and quality control data and cloud mask were considered to exclude suspect data; however, because the cloud mask frequently misclassified cloud-free pixels having partial snow cover as clouds, substantial amounts of valid data would have been excluded. A simple cloud mask detection method was developed using MODIS Band 7 (2.105 to 2.155 µm). Pixels were classified as clouds if Band 7 reflectance was greater than 0.2. However, this test would not identify all clouds, and in particular, ice clouds would be misclassified as snow. Further visual screening excluded images with ice clouds from the analysis. Clouds could be distinguished easily from snow visually using a false-color display of MODIS bands 7, 6, and 5.

Fractional snow-covered area for the dates with MODIS imagery was summarized by basin. Basins with partial cloud cover or other bad data were flagged.

6.6 SNOW TRANSPORT

Dominant wind directions were assessed based on current and historical meteorological data from stations near the deposit area, drift patterns observed in the Landsat snow-cover imagery and the LIDAR snow depth map, and field observations during snow surveys. Historical data were obtained from meteorological stations established for Teck Cominco Limited. These stations collected data in the winters ending in 1992 and 1993 (Hoefler, 2006b). Meteorological data for winters ending in 2005 through 2008 were obtained from stations established for the Pebble Partnership (Hoefler, 2006a).

Annual wind roses were constructed for each meteorological station for all data available during the November 1 to April 30 time frame. Wind data were collected from both 10-meter and 3-meter towers, depending on the station and the type of instrumentation. To improve comparability between tower heights, the 10-meter winds were normalized to 3-meter heights assuming a logarithmic increase in wind speed with height and a Davenport-Wiering roughness length coefficient (z_0) of 0.005 meters (Stull, 1999).

The exact wind velocity required to transport snow depends on the temperature and structure of the existing snowpack (Li and Pomeroy, 1997; Sturm et al., 2001). Observations from the Canadian prairies (using wind speeds measured at 10 meters above ground level) show that the mean wind velocity threshold was 9.9 meters per second for wet snow and 7.7 meters per second for dry snow (Li and Pomeroy, 1997). At 3-meter towers, these mean wind velocities would equate to thresholds of 8.3 meters per second for wet snow and 6.5 meters per second for dry snow. Threshold wind values for the Arctic, where the snowpack is colder and drier, are 5 meters per second (Sturm et al., 2001). In this study, the wind data were assessed using 5-meters-per-second and 10-meters-per-second thresholds to determine the predominant winds that would result in redistribution of snow across the landscape.

The spatial distribution of net snow transport for winter 2007/2008 was estimated using the LIDAR estimated SWE and a modeled estimate of winter precipitation (Section 6.7 below). Winter precipitation was calculated for each grid cell from the snow model outputs as (Precipitation – Runoff – Static Surface Sublimation). This formulation was used because it excluded early season rain, which was converted to runoff in the model, but it included any mid-winter rain that became integrated into the snowpack. The model outputs were used because they provided a spatially distributed precipitation field. The estimated winter precipitation grid was subtracted from the LIDAR SWE grid, resulting in a map of net snow transport. Areas with negative net transport values have less snow than would be expected from precipitation (i.e., they are scour areas), while areas with positive net transport values are snow deposition zones.

Actual snow transport was estimated by profiling snow drifts in 2007 and 2008. Snow present in a drift was either precipitated directly onto the drift or else was transported by wind. Snow drift profiles were measured during field surveys in 2007 and 2008, and were also derived from LIDAR data collected in 2008. Snow depths were converted to snow water equivalent using the snow density model, and snow water profiles were then integrated to calculate snow water volume. The direct snow precipitation for each profile was estimated from the snow model outputs (as described above). Direct snow precipitation was subtracted from the total snow water volume in the drift, resulting in the transported snow volume. Transport rates were estimated for several drift profiles at different orientations and elevations within the study area. The drift cross-sectional area (in square inches SWE) was converted to tons of snow per linear foot, a standard measure of snow transport magnitude. The snow transport rates were categorized using a snow transport severity classification (Tabler, 2003).

The SnowTran-3D submodel of SnowModel (Liston and Sturm, 1998; Liston et al., 2007) explicitly calculates transport of snow by both saltation (bouncing) and suspension. Snow transport was one of the model variables summarized for the study area and for individual basins, as described in the next section.

6.7 SNOW MODELING

The snow cover in the study area is highly variable in space and time, due to the spatial variability of topography and vegetation, and the spatial/temporal variability of meteorological conditions. SnowModel, a spatially distributed snow-evolution modeling system (Liston and Elder, 2006b), was used to model snow accumulation, transport, and ablation for winters 2005/2006, 2006/2007, and 2007/2008. These were the winters during the study period that had continuous meteorological data available, including wind, temperature, relative humidity, and winter precipitation.

Other modeling approaches to snow modeling were considered. Ordinary least squares general linear models were also evaluated, but were not found to realistically represent the dramatic snow redistribution observed in the study area. Other statistical modeling techniques that have been applied to alpine snow distribution modeling recently include binary regression trees (Winstral et al., 2002; Erxleben et al., 2002) and kriging (Erickson et al., 2005). Geostatistical techniques addressing spatial correlation of residuals (Erxleben et al., 2002; Erickson et al., 2005) may improve the predictive ability of the models and provide a way to assess the statistical power of sampling methods. The physical modeling approach was selected because it was thought to have the most potential for capturing the complex and dynamic patterns of snow distribution and redistribution, and because it simulates runoff and ablation processes as well as snow accumulation.

SnowModel is composed of four submodels. MicroMet ingests the meteorological station data and distributes it across the domain at each time step. EnBal models surface energy exchanges, SnowPack models the evolution of snow depth and snow density, and SnowTran-3D handles snow transport by wind. SnowModel was run at both daily and hourly time steps, and at both 96-foot and 384-foot resolutions. Required inputs were elevation, vegetation, and meteorological data.

6.7.1 MODEL INPUTS

6.7.1.1 TERRAIN

The terrain model was derived from three digital elevation models (DEMs) covering the extended mine study area. The primary elevation source was the 12-foot resolution DEM for the “Pebble Outer Mine Study Area.” The 12-foot DEM was aggregated to 48-foot, 96-foot, and 384-foot resolution. Because this DEM did not cover the entire extended study area, two additional DEM sources were incorporated.

The Shuttle Radar Topography Mission (SRTM) DEM (1 arc second "unfinished") was acquired from the University of Maryland Global Land Cover Facility. The SRTM tiles were re-projected to Alaska State Plane 5 (NAD 1983 horizontal datum) using cubic convolution re-sampling at 48, 96, and 384 foot resolutions. Based on a visual assessment, the SRTM data were the best alternative in areas not covered by the primary DEM. However, there are a few void areas where the SRTM does not have data. To fill these gaps, the Aster global digital elevation model (GDEM; v01, 1 arc second resolution) was acquired from the U.S. Geological Survey Land Processes Distributed Active Archive Center and was processed in a similar manner to the SRTM, except that there were no voids.

For the areas of overlap, the SRTM and GDEM (96-foot resolution) were subtracted from the Pebble DEM (aggregated to 96 feet). It was determined that the SRTM was about 9 feet higher than the Pebble DEM, on average, within the bounds of the extended study area. (Areas with forest had higher offsets but were generally outside the extended study area). An "adjusted" SRTM dataset was generated by subtracting 9 feet. The GDEM was much noisier with some extreme values. The difference histogram was examined and a peak was identified at 25 feet, indicating that the GDEM was on average 25 feet below the Pebble DEM. An "adjusted" GDEM was generated by adding 25 feet.

The three DEMs were then merged together at each resolution (48, 96, and 384 foot). The Pebble DEM took precedence. Outside the bounds of the Pebble DEM, the SRTM data were used. In the few remaining gaps (SRTM voids) the GDEM was patched in. The resulting DEMs were nearly seamless, with only minor artifacts apparent at the merge lines between the Pebble DEM and the SRTM. The GDEM fills were noisier but were extremely limited in extent.

6.7.1.2 VEGETATION

The primary effect of vegetation on snow in the study area is that it increases the surface roughness and, consequently, reduces wind speeds and snow transport until the vegetation is overtopped. SnowModel tracks the snow depth evolution over time and prevents snow transport from model cells where the vegetation snow-holding depth exceeds the snow depth. In the model, snow can blow into these cells, but it cannot blow out.

A detailed vegetation map for the study area is being produced for the wetland and habitat mapping studies; however, it was not yet available when the current snow model runs were performed. A vegetation canopy structure layer for the snow model was developed primarily from a tall vegetation map generated from an analysis of a Landsat 7 ETM+ image acquired in early winter (October 31, 1999). Visual interpretation indicated that taller vegetation was emergent from the snow and was darker in the visible wavelengths, while areas with low vegetation were snow-covered and much brighter. A Normalized Difference Vegetation Index threshold based on summer Landsat imagery was used to ensure that non-vegetated areas were not included in the tall shrub map. The Bristol Bay Land Cover Maps (Wibbenmeyer et al., 1982) were used to define the lower vegetation and non-vegetated types.

The vegetation snow holding depth for the tall vegetation type was set to 2.13 feet (the “erect shrub tundra” type in the SnowModel vegetation classification). The other land cover types had very small snow holding depths ranging from 0.03 to 0.66 feet. The snow holding depth of some tall shrubs (4 to 6 feet or more) and taller forest types was greater than 2.13 feet, and therefore the snow holding depth was underestimated in some areas, but large patches of very tall vegetation were relatively rare in the study area.

6.7.1.3 METEOROLOGICAL DATA

SnowModel requires meteorological inputs of air temperature, wind direction, wind speed, precipitation, and relative humidity for at least one station in the model domain at every time step. The available hourly meteorological data were screened and problematic data were removed. In a few cases, there were hourly time steps without valid data. In these cases, missing data were replaced with values from the nearest time period (before and after) with valid data.

Two techniques were used to manipulate the meteorological data during model calibration. First, a precipitation correction factor was applied. This could be used to increase or decrease precipitation by a specified factor at every time step. Precipitation gage catch efficiency is reduced when wind speeds are high, as they are during most precipitation events in the study area. Model results using the raw precipitation gage data are thus expected to be too low, and applying a precipitation correction factor to increase input precipitation could improve results. A precipitation factor of 2.0 was applied during the final model runs.

Second, a wind clipping routine was developed that could set all wind speeds in excess of some threshold value (and optionally, within a direction range) to a specified threshold value. Since potential snow transport increases with the fourth power of wind speed (Tabler, 2003), a few very high wind speed events may have a large effect on model results. Sensitivity tests were performed with clipped wind speeds to assess the impact of the very high wind speeds on the model outputs.

6.7.2 MODEL DOMAIN

The model domain is defined by the cell size, spatial extent, time step, and date range. The spatial extent was defined to include the bounding box of the extended mine study area, buffered by 3 miles. Test runs were performed at 384 foot resolution, resulting in an array of 486 columns by 431 rows; and at 96 foot resolution (an array of 1,945 columns by 1,725 rows). The latter array was near the upper limit of the size the model could handle, so increasing the spatial resolution further would require switching to a smaller extent.

Both hourly and daily model simulations were performed. The daily simulations are much faster, but some nonlinear processes require code modifications to be represented properly at a daily time step (Liston, pers. comm., 2009). The daily time step also smoothes the meteorological inputs. For example, the mean daily wind speed is always less than the wind speed of the windiest hour. The daily wind speed may not be high enough to initiate snow transport, while at the hourly time step transport can occur. The model was run for one winter at a time, from September 1 or October 1 in the starting year until June 30 or July 31 of the following year.

6.7.3 MODEL OUTPUTS

Spatially distributed model outputs were stored at a daily time step. The results could then be summarized and plotted using the extent of various basins and other units. In addition, the outputs at any time step could be viewed visually using GIS software.

The outputs included snow depth and SWE, and other components of the water balance: solid precipitation (defined as precipitation occurring when the modeled air temperature is less than or equal to 2º C), liquid precipitation, sublimation (partitioned between blowing snow and static surface), snow transport, and runoff. Melting snow initially infiltrates into the snowpack, increasing snowpack density (Liston and Elder, 2006b). When the density increases beyond 0.55 (a threshold defined in the model based on empirical observations), SnowModel adds any additional melting to runoff. Outputs also included the other spatially distributed meteorological variables. These outputs include air temperature, wind speed, and wind direction.

6.8 SNOW HYDROLOGY SYNTHESIS

6.8.1 COMPARISON OF NRCS AND PEBBLE SNOW COURSE DATA

All of the data for the six NRCS snow courses within 100 miles of the regional study area (Figure 7.2D-2) were acquired and compiled, providing regional snow accumulation data from 1992 through the present (though not all NRCS snow courses were surveyed each year). The late winter (late February, March, April, and May) NRCS snow surveys were considered. Data from the NRCS survey near April 1 were preferred; if April 1 data were not available, the highest SWE from the other available dates was selected. To assess the correlation between the NRCS snow courses and the Pebble snow courses, the NRCS SWE was compared to the mean SWE from the distribution surveys at the two Pebble snow courses, and to the mean SWE for the 45 primary plots surveyed during all 5 years of the study. Longer term snow accumulation patterns were assessed by reviewing the peak late-winter SWE at each snow course for its full data record.

6.8.2 COMPARISON OF FIELD SURVEY, SNOWMODEL, AND LIDAR

Field survey SWE values from the snow distribution surveys were overlaid on SnowModel outputs for the same date in order to validate model outputs. The two distribution surveys from 2008 were combined for this analysis: the field data from the earlier valley distribution survey were compared to SnowModel outputs for March 17, 2008, and the field data from the later mountain distribution survey were compared to model outputs for April 6, 2008. In addition, the LIDAR-estimated SWE data were sampled and compared to the SnowModel output for April 6, 2008. For this comparison the LIDAR data were aggregated to 384-foot resolution, the same resolution as the model outputs.

6.8.3 COMPARISON OF SNOWMODEL, HYDROGRAPHS, AND SNOW-COVERED AREA

SnowModel runoff was compared to the available hydrograph data for each basin. SnowModel runoff was converted to cubic feet per second (cfs) and both were normalized to cfs per square mile. In addition, the MODIS-derived snow cover depletion curves for each basin were compared to the hydrograph data and to a modeled snow-covered area derived from the SnowModel outputs. All model cells with any snow were counted as fully snow-covered when summarizing snow cover from SnowModel outputs.

7. RESULTS AND DISCUSSION

7.1 FIELD SURVEYS

7.1.1 2004 FIELD SURVEYS

The first snow distribution survey was conducted April 13 through 18, 2004, during which103 plots were sampled along 12 slope transects and two snow courses (Figure 7.2D-3). Snow depths ranged from zero to more than 94 inches (the limit of the sampling equipment used in 2004, Table 2). Six plots had depths greater than what could be measured with the sampling equipment (approximately 90 inches). SWE values ranged from zero to more than 51.4 inches; mean SWE from field survey values was 13.4 inches. Mean SWE was 11.9 inches at the 45 plots where measurements were repeated each year in 2004 through 2008 (83 percent of the average value).

SWE at the snow courses (mean ± standard deviation [SD]) was 10.5 ± 10.1 inches at Pebble Snow Course 1 (shoulder of Groundhog Mountain, 2,000 feet); 8.2 ± 9.1 inches at Pebble Snow Course 1A (same transect, with two highly variable plots dropped); and 9.8 ± 9.4 inches at Pebble Snow Course 2 (1,200 feet). These SWE values ranged from 80 to 95 percent of the average values for the Pebble Snow Courses. Dropping two plots reduced the average SWE at Pebble Snow Course 1A compared to Pebble Snow Course 1, and as a result Pebble Snow Course 1A actually had lower SWE than the lower elevation Pebble Snow Course 2. This does not indicate less snow at higher elevations; instead, the plots dropped due to high variability also tended to have high SWE.

Of the three proposed meteorological station sites visited, two were snow-free and one had 1.1 inches SWE. These sites were exposed, and it was apparent that snow accumulation at the proposed meteorological station locations was a poor indicator of snow accumulation on the landscape.

In comparison, the SWE in April 2004 for the three mountain NRCS snow courses north of the study area ranged from 4.4 to 8.6 inches and 84 to 98 percent of the long-term average (1992 through 2009; NRCS 2004b, Table 1). At the fourth northern snow course, Port Alsworth (270 feet elevation) SWE was 5.1 inches, 146 percent of the long-term average. No data were collected in March or April 2004 for the two southern NRCS snow courses (Brooks Camp and Three Forks).

The SWE for three transects (Pebble Snow Course 1, Pebble Snow Course 2, and Transect 14) is plotted on Figure 7.2D-5 (2004 data are represented by green dots). Similar plots for other transects are included in Attachment 1.

Some melting and loss of water from the snowpack was apparent in the majority of sample plots by mid-April, indicating that sampling underestimated the total snowpack. Evidence of snowpack-melt included damp or wet duff layers below the snowpack and areas of bare, wet ground. Temperatures were generally well below freezing at night and would climb up to 32 to 35 degrees Fahrenheit during the middle of the day. During the distribution survey, most of the snow at Iliamna melted and snow cover below the 800-foot elevation was sparse.

Ablation surveys were performed on the two snow courses and along selected slope transects on May 2 and 3, and May 15 and 16 (Table 3, Figure 7.2D-6). Determination of ablation rates was made difficult by precipitation events that occurred between and during ablation sampling trips. The amounts of such precipitation were not quantified. As a result, the ablation rates calculated from the measured reduction of the snowpack should be considered underestimates or minimum rates for the period of April 18 to May 16. Because snow or water was added to the snowpack between surveys, the actual loss of water from the snowpack was greater than the observed reduction in SWE. Ablation rates for the Pebble Snow Courses ranged from -0.09 to 0.20 inches per day between the distribution survey and first ablation survey (April 15 to May 2/3), and 0.36 to 0.58 inches per day between the two ablation surveys (May 2/3 to May 15/16). The extreme values of -0.09 and 0.58 inches per day were both on the original Pebble Snow Course 1, which includes two plots where SWE varies over a few feet of distance. The first ablation survey likely happened to sample a deeper patch of the snowpack than the other two visits, resulting in an artificially low ablation rate between the first two visits and an artificially high ablation rate between the latter two visits.

7.1.2 2005 FIELD SURVEYS

In 2005, the snow distribution survey was conducted April 10 through 16. Snow depths and SWE values were generally greater than in 2004. One hundred twenty-eight plots were sampled along 13 slope transects and the two snow courses (Figure 7.2D-3) established in 2004. Snow depths were from zero to more than 124 inches. SWE values ranged from zero to more than 53.3 inches (Table 2). Four plots had depths greater than what could be measured with the sampling equipment (120 inches for three of the plots, and 90 inches for a fourth). There were also three plots where impenetrable ice layers restricted sampling at shallower depths. The mean SWE of the field survey was 16.3 inches. Mean SWE was 16.5 inches at the 45 plots repeated at Pebble in 2004 through 2008 (115 percent of the average value).

SWE values at the snow courses (mean ± SD) were 15.5 ± 14.7 inches at Pebble Snow Course 1; 13.8 ± 15.3 inches at Pebble Snow Course 1A; and 12.0 ± 12.1 inches at Pebble Snow Course 2. Two proposed meteorological station locations were sampled and, as in 2004, low SWE values (1.8 and 4.5 inches) were observed at these exposed locations.

The SWE was higher than average at the three mountain NRCS snow courses north of the study area in 2005 (Table 1; NRCS, 2005b). The SWE in March or April 2005 ranged from 6.4 to 11.7 inches and 103 to 142 percent of the long-term average (1992 through 2009; Table 1). The Port Alsworth snow course was snow-free in early April. No data were collected in March or April 2005 for the two southern NRCS snow courses (Brooks Camp and Three Forks).

The SWE for three transects (Pebble Snow Course 1, Pebble Snow Course 2, and Transect 14) is plotted on Figure 7.2D-5 (2005 data are represented by red dots). Similar plots for other transects are included in Attachment 1.

At the time of the surveys in 2005, snowmelt appeared to be less advanced than during surveys in 2004. The soil surface was usually dry or frozen below the snowpack. However, significant melting of the pack was observed at Transect 20 (a south-facing slope). Along the lower portions of the slope, surface water was flowing under the snowpack in some areas. The soil was generally not well frozen, and the sampling equipment commonly penetrated into thawed soils in areas with relatively deep snow cover. Soils at the toe of slopes and under tall shrub canopies were consistently thawed below the ground surface.

Precipitation data were available from Pebble meteorological stations during late winter and spring 2005. Precipitation was measured with Metone Instruments 370C tipping bucket precipitation gage with a snowfall adapter, which is not as reliable as the NOAH II gages that were installed for subsequent winters. The Metone gage data were used, in combination with field survey results, to calculate ablation rates (Table 3, Figure 7.2D-6). Ablation rates for the Pebble Snow Courses ranged from 0.33 to 0.38 inches per day between the distribution survey and first ablation survey (April 11/12 to April 29), and 0.38 to 0.51 inches per day between the two ablation surveys (April 29 to May 13).

7.1.3 2006 FIELD SURVEYS

In 2006, the snow distribution survey was conducted April 16 through 23, during which 130 plots were sampled along 14 slope transects and the two snow courses (Figure 7.2D-3). On average, snow depth and SWE were less than that in 2005 and slightly greater than that in 2004. Average snow depths at plots ranged from zero to more than 139.5 inches. One plot was incompletely measured, due to ice near the 150-inch limit of the equipment. SWE values ranged from zero to more than 79.1 inches (Table 2). The mean SWE from field survey values was 14.9 inches. Mean SWE was 14.1 inches at the 45 plots repeated at Pebble in 2004 through 2008 (98 percent of the average value).

SWE values at the snow courses (mean ± SD) were 9.7 ± 10.3 inches at Pebble Snow Course 1; 7.5 ± 9.0 inches at Pebble Snow Course 1A; and 8.1 ± 8.1 inches at Pebble Snow Course 2. These SWE values ranged from 73 to 80 percent of the average values for the Pebble Snow Courses.

The SWE was close to the long-term average at four nearby NRCS snow courses in 2006 (Table 1; NRCS, 2006b). The SWE in March or April for the four NRCS snow courses with data collected in 2006 ranged from 1.5 to 5.8 inches and 80 to 107 percent of the long-term (1992 through 2009) average (Table 1). No data were collected for two snow courses (Port Alsworth and Fishtrap Lake) in March or April 2006. For Telaquana Lake and Upper Twin Lakes, no data were reported for April, but data were collected for March.

The SWE for three transects (Pebble Snow Course 1, Pebble Snow Course 2, and Transect 14) is plotted on Figure 7.2D-5 (2006 data are represented by orange dots). Similar plots for other transects are included in Attachment 1.

At the time of the distribution survey, temperatures had remained consistently below freezing in the spring and loss from the snowpack appeared to be minimal across the study area. High winds and snow showers occurred during the surveys, resulting in the deposition of 2 to 3.5 inches of snow across the study area. No evidence of melting (wet duff layers, ponding in low-lying terrain, or surface runoff) was observed during the distribution survey. Patterns of sastrugi (irregular snow ridges formed parallel to prevailing winds) indicated that recent dominant wind directions ranged from northeast to southeast.

The winter weather graphs for winter 2005/2006 (Figure 7.2D-7) indicate that there were several short warm periods of above-freezing temperatures during the winter, but that spring temperatures were below or near freezing until the second week of May. Temperatures and solar radiation were then very high for over 2 weeks, starting about May 22, 2006.

Precipitation data were available from Pebble meteorological stations during winter 2005/2006. An ETI Instruments NOAH II Weighing Precipitation Gage was installed at the Pebble 2 meteorological station at the beginning of winter (October 18 through November 19). That gage was then relocated, and NOAH II gages were in place for the remainder of the winter at the Pebble 3 meteorological station (starting November 19) and at the Pebble 1meteorological station (starting November 20). These gages remained in place through the remainder of the study period. The NOAH II gages are expected to be more reliable than the Metone gages at measuring winter precipitation.

SnowModel precipitation outputs were used in combination with field survey results to calculate ablation rates (Table 3, Figure 7.2D-6). Ablation rates for the Pebble Snow Courses ranged from 0.04 to 0.20 inches per day between the distribution survey and first ablation survey (April 18/20 to May 13), and 0.20 to 0.39 inches per day between the two ablation surveys (May 13 to May 22/23). As in 2004, the extreme values of 0.04 and 0.39 inches per day were both on the original Pebble Snow Course 1, and likely result from sampling a deeper location at one or both of the highly variable plots during the first ablation survey, resulting in an artificially low ablation rate between the first two visits and an artificially high ablation rate between the latter two visits.

Precipitation from the ETI Instruments NOAH II Weighing Precipitation Gage at the Pebble 1 meteorological station was summed for the period October 21, 2005, to April 19, 2006 (Table 1). The former date corresponded to the onset of consistently below-freezing temperatures at Pebble 1 during winter 2005/2006, while the latter date corresponded to the mid-point of the snow course surveys during snow distribution surveys in 2006. Winter precipitation measured at Pebble 1 for winter 2005/2006 totaled 13.3 inches (98 percent of the average value for winters ending 2006 through 2008).

7.1.4 2007 FIELD SURVEYS

In 2007, a preliminary reconnaissance snow survey was conducted March 8 and 9, primarily to verify reports of very low snow accumulation. Twelve plots with high snow accumulations in 2004 through 2006 were visited, and it was confirmed that early March snow accumulation was well below mid-April snow accumulation from prior years. Thick ice prevented sampling at two plots. At the remaining 10 plots, SWE ranged from 49 to 67 percent of the mean SWE at the same plots during April distribution surveys in 2004 through 2006. Total SWE at the 10 plots in March 2007 was 57 percent of the 2004 through 2006 average. As a result, the LIDAR snow depth mapping mission that was being considered for 2007 was postponed to 2008.

The snow distribution survey was conducted April 3 through 16. At most plots, snow depth and SWE were less than that of the previous 3 years. The extensive grid plots, primarily at lower elevations, were sampled first with sampling of transects established in prior years commencing on April 6. One hundred eighty-nine primary plots were sampled (Figures 7.2D-3 and 7.2D-8). Average snow depths at plots on the regular transect and snow courses ranged from zero to more than 134.5 inches (Table 2). SWE values were from zero to more than 66.0 inches with an average of 10.7 inches. Mean SWE was 8.5 inches at the 45 plots repeated at Pebble in 2004 through 2008 (60 percent of the average value).

SWE values at the snow courses (mean ± SD) were 5.8 ± 8.0 inches at Pebble Snow Course 1; 5.3 ± 8.4 inches at Pebble Snow Course 1A; and 6.3 ± 10.0 inches at Pebble Snow Course 2. These SWE values ranged from 48 to 61 percent of the average values for the Pebble Snow Courses.

Similarly, the SWE was well below the long-term average at four nearby NRCS snow courses in 2007 (Table 1; NRCS, 2007b). The SWE in April for the four NRCS snow courses with data collected in 2007 ranged from 1.4 to 4.9 inches and 31 to 61 percent of the long-term average (1992 through 2009; Table 1). No data were collected for two snow courses (Brooks Camp and Three Forks) in March or April 2007.

In addition to the primary plots, 565 supplemental plots that were located at regular intervals between primary plots were sampled (mostly snow depth measurements); 190 opportunistic plots were sampled, and 256 measurements were obtained on 22 drift profiles (ranging from 50 to 2,600 feet in length).

The SWE for three transects (Pebble Snow Course 1, Pebble Snow Course 2, and Transect 14) is plotted on Figure 7.2D-5 (2007 data are represented by purple lines). Similar plots for other transects are included in Attachment 1.

Temperatures at Pebble 1 were extremely cold in the month of March (Figure 7.2D-9) but rose to near freezing on March 31 and ranged from just below to well above freezing for the duration of snow surveys. The lower elevation snowpack was sparse on April 3, and the thin snowpack warmed and melted rapidly during early April. Substantial evidence of melting (wet duff layers and surface runoff) was observed during the distribution survey in valleys and towards the bottom of mountain transects.

Precipitation data were available from Pebble meteorological stations during winter 2006/2007. An ETI Instruments NOAH II Weighing Precipitation Gage was in place at the Pebble 1 meteorological station throughout the winter. SnowModel precipitation outputs were used, in combination with field survey results, to calculate ablation rates (Table 3, Figure 7.2D-6). Ablation rates for the Pebble Snow Courses ranged from 0.13 to 0.22 inches per day between the distribution survey and first ablation survey (April 6/8 to April 23/24), 0.13 to 0.17 inches per day between the first and second ablation surveys (April 23/24 to May 7/8), and 0.16 to 0.23 inches per day between the final two ablation surveys (May 7/8 to May 19/21).

Precipitation from the ETI Instruments NOAH II Weighing Precipitation Gage at the Pebble 1 meteorological station was summed for the period October 20, 2006, to April 7, 2007 (Table 1). The former date corresponded to the onset of consistently below-freezing temperatures at the Pebble 1 meteorological station in winter 2006/2007, while the latter date corresponded to the mid-point of the snow course surveys during snow distribution surveys in 2007. Winter precipitation measured at the Pebble 1 meteorological station for winter 2006/2007 totaled 8.3 inches (61 percent of the average value for winters ending 2006 through 2008).

7.1.5 2008 FIELD SURVEYS

In 2008, a preliminary reconnaissance snow survey was conducted March 1 and 2 to determine if the snowpack was adequate to conduct the LIDAR snow depth mapping data acquisition. Samples at nine primary plots and 31 supplemental plots were collected. At the primary plots, the average SWE ranged from 111 to 244 percent of measurements made at the same plots during the 2004 through 2007 distribution surveys. Based on the above average snow on the ground, the LIDAR survey remained scheduled for 2008.

There were two distribution surveys in 2008. The valley survey was conducted from March 15 through 20 and included lower elevations where snowmelt occurs earlier in the season. Seventy-five primary plots were sampled along six new transects (Figure 7.2D-8). Average snow depths at primary plots ranged from zero to more than 124.0 inches. One of the 2007 extensive grid plots and one plot at the bottom of transect 5 were also sampled. SWE values ranged from zero to 55.8 inches with a mean of 9.6 inches.

The mountain distribution survey was conducted from April 5 through 10 (Figure 7.2D-3). On average, snow depth and SWE was greater than the previous 4 years. One hundred sixty primary plots were sampled. Average snow depths at primary plots ranged from 2.3 to more than 207.7 inches. The snow depth at three plots was incomplete due to impenetrable ice. SWE values ranged from 0.8 to 100.4 inches with a mean of 23.4 inches (Table 2). Mean SWE was 20.4 inches at the 45 plots repeated at Pebble in 2004 through 2008 (143 percent of the average value).

SWE values at the snow courses (mean ± SD) were 19.4 ± 16.9 inches at Pebble Snow Course 1; 16.7 ± 15.3 inches at Pebble Snow Course 1A; and 15.6 ± 16.3 inches at Pebble Snow Course 2. These SWE values ranged from 151 to 162 percent of the average values for the Pebble Snow Courses.

The SWE was above the long-term average at four of the six nearby NRCS snow courses in 2008 (Table 1; NRCS, 2008b). The SWE in March or April 2008 for the three northern, mountain NRCS snow courses ranged from 5.8 to 9.5 inches and 97 to 129 percent of the long-term average (1992 through 2009; Table 1). SWE at the low elevation NRCS snow courses (Port Alsworth and Brooks Camp) was 5.2 inches and 0.8 inches, respectively (137 and 50 percent of the long-term average). At Three Forks, SWE was 3.0 inches, 115 percent of the long-term average. April data were not collected for two snow courses (Fishtrap Lake and Port Alsworth) in 2008, but data were collected at those locations in March.

The SWE for three transects (Pebble Snow Course 1, Pebble Snow Course 2, and Transect 14) is plotted on Figure 7.2D-5 (2008 field data are represented by solid blue lines). Similar plots for other transects are included in Attachment 1.

Snow pit data and temperature profiles were also sampled at several primary plots and a few supplemental plots in 2008. Due to their time-consuming nature only seven snow pits were sampled; one during the reconnaissance survey, three during the valley distribution survey, and three during the mountain distribution survey. Evaluation of data from these samples showed the presence of numerous thick ice layers within the snowpack. In some cases, the SWE data obtained from snow pits were used as replicate data to data collected with the snow tubes; however, due to the small sample size, no significant conclusions could be made about the accuracy of the different methods. Temperature profile data were collected at 89 plots during the April distribution survey. One sample did not include a basal temperature because the snowpack was too deep to measure. During the first, second, and third ablation surveys, 21, 19, and 14 temperature profiles were sampled respectively.

Temperature profiles are helpful in classifying the type of snowpack in a given area and in predicting the beginning of snowmelt. Snow depth of the temperature profiles sampled during the April distribution survey ranged from 4 to 111 inches (Figure 7.2D-10). The shallowest profile measured also had the coldest basal temperature recorded (-9.5 degrees Celsius). The five coldest basal temperatures (less than -6 degrees Celsius) were taken in snow less than 25 inches deep and were within a few degrees of the air temperatures, when air temperature was recorded at plots. Shallow snow with basal temperatures that reflect air temperatures are typical of a tundra/taiga snow class (Sturm et al., 1995). Basal temperatures in deeper snow do not tend to reflect air temperatures. During the April distribution survey these temperatures were often just below freezing. The basal temperature of the deepest profile was -2.8 degrees Celsius and four of the five warmest basal temperatures (- 0.1 degrees Celsius or warmer) were measured in snow more than 50 inches deep. Deep snowpacks with basal temperatures just below freezing are characteristic of a maritime snow class (Sturm et al., 1995). Temperature profiles sampled during the April distribution survey showed that the temperature became colder as the measurements were taken closer to the surface of the snow. During the ablation surveys, profiles showed that snow near the surface warmed first until eventually the entire snowpack reached near 0 degrees Celsius, thus indicating the beginning of snowmelt.

In addition to the primary plots, 586 supplemental plots were sampled (mostly snow depth-only) at regular intervals between primary plots during the April distribution survey. Also, 41 opportunistic plots were sampled, and 1,027 measurements were obtained on seven drift profiles up to 875 feet in length.

The temperatures at the Pebble 1 meteorological station during the winter of 2007/2008 (Figure 7.2D-11) remained at or below freezing until the third week of April resulting in minimal mid-winter snowmelt. Through the April distribution survey, only three plots with less than 50 percent cover of snow were sampled (two during the valley survey and one during the reconnaissance survey). Solar radiation was high most of the month of April, decreased at the end of the month and remained low through the first half of May. Despite lower solar radiation, temperatures rose above freezing in the first week of May and remained there for the duration of the season.

Precipitation data were available from Pebble meteorological stations during winter 2007/2008. An ETI Instruments NOAH II Weighing Precipitation Gage was in place at the Pebble 1 meteorological station throughout the winter. SnowModel precipitation outputs were used, in combination with field survey results to calculate ablation rates (Table 3, Figure 7.2D-6). Ablation rates for the Pebble Snow Courses ranged from 0.04 to 0.10 inches per day between the distribution survey and first ablation survey (April 7/8 to April 22/23), 0.12 to 0.27 inches per day between the first and second ablation surveys (April 22/23 to May 6/7), and 0.38 to 0.46 inches per day between the final two ablation surveys (May 6/7 to May 21/22).

Precipitation from the ETI Instruments NOAH II Weighing Precipitation Gage at the Pebble 1 meteorological station was summed for the period October 6, 2007, to April 6, 2008 (Table 1). The former date corresponded to the onset of consistently below-freezing temperatures at the Pebble 1 meteorological station in winter 2007/2008, while the latter date corresponded to the date of the LIDAR survey. It was also one to two days before the snow courses were surveyed during the 2008 mountain snow distribution survey. Winter precipitation measured at the Pebble 1 meteorological station for winter 2007/2008 totaled 19.2 inches (142 percent of the average value for winters ending 2006 through 2008).

7.1.6 SNOW DISTRIBUTION SURVEY AND WINTER PRECIPITATION SUMMARY

SWE at the snow courses and for the 45 plots surveyed in all 5 years of the study were compared to the measured winter precipitation at the Pebble 1 Meteorological Station (Table 1, Figure 7.2D-12). The comparison was performed for the three winters with a complete precipitation record, based on data from the shielded ETI Instruments NOAH II Weighing Precipitation Gage. There was very good agreement between the general levels of SWE and observed precipitation for the three winters assessed. The relationship between the mean SWE at the 45 plots surveyed in 2004 through 2008, and the observed winter precipitation, was the most linear and was also nearly a one-to-one relationship. The Pebble 1 NOAH II precipitation gage measurements, from the onset of consistently below-freezing temperatures through mid-April, may provide a good index of overall snow accumulation in the mine study area for years when snow surveys are not conducted.

7.1.7 ABLATION SURVEY SUMMARY

Ablation field measurements at the two Pebble snow courses are summarized in Table 3 and on Figure 7.2D-6. The total SWE actually increased at Snow Course 1 (2,000 feet elevation) between the distribution survey and the first ablation survey in 2004, 2006, and 2008. The total SWE increase results largely from increased SWE at two plots: plot ss1_c and especially plot ss1_h. Both of these occur near slope breaks, where shallow or absent snow transitions to a deep snow drift. The high variability of snow depth over short distances, combined with the imprecision of GPS navigation, can result in sampling much deeper snow on some visits. Since the two plots are in areas prone to wind drifting, the sample holes from the previous visit are likely to be covered, so that it is more likely that a slightly different location is sampled. The variability was not apparent at the first site visit in 2004, but it was obvious at later ablation visits, particularly once the pattern of increased SWE at these stations was investigated. The results from Pebble Snow Course 1 are reported according to the original sampling design (all plots). The results are also reported as Pebble Snow Course 1A, which drops plots ss1_c and ss1_h from the results. Because these are among the deeper plots on the snow course, the overall SWE is substantially lower for Pebble Snow Course 1A. However, the ablation patterns within each year are more realistic for Pebble Snow Course 1A than for Pebble Snow Course 1.

Field ablation measurements at Snow Course 2 (1,200-foot elevation) show a consistent decrease in SWE, and nearly all snow was gone at the third visit in 2004, 2005, and 2007. Evaluation of data from the Pebble snow courses indicates that snowmelt was substantially delayed in 2006 and 2008 compared to the three other years.

In most years, Snow Course 1 had more snow than the lower elevation Snow Course 2. Snow usually melted more rapidly at Snow Course 2 during the surveyed time periods. More snow remained at Snow Course 1/1A than at Snow Course 2 by the final ablation survey in each year.

7.2 SNOW DENSITY MODELING

Densities for very shallow snow were highly variable—partly due to the nature of shallow snow, and partly due to measurement error. Shallow snow ranges from light, freshly fallen snow to a dense, icy remnant snowpack, so a wide density range is expected. The measurement method using the Federal tube and Mt. Rose scale also results in larger relative errors in thin snowpacks. SWE is calculated as the difference between the weight of the tube with the snow sample and the weight of the empty tube. A measurement error of 0.5 or 1.0 inch in either of these weights has a large effect on the calculated snow density at low weights. This is particularly true when it is windy, since the light tube is more affected by wind than a heavier tube. Though the densities of shallow snow may be too high or too low, the measured SWE should still be close to the true values. Starting in 2008, to minimize this issue, some samples collected in shallow snowpacks or during windy conditions were weighed in stuffsacks by more precise spring scales or were stored in sealed plastic bags to be weighed indoors in the evening following the sampling.

7.2.1 STANDARDIZATION OF SNOW DENSITY MEASURED USING DIFFERENT EQUIPMENT

In 2008, a new snow tube (Snow-Hydro tube) was also used in addition to the Federal tube. Snow samples were obtained with both the Federal and Snow-Hydro tube at 38 plots during the primary distribution survey and two ablation surveys. Snow densities were computed, and the densities measured with the different tubes were compared. There was a large amount of scatter, especially at the shallow snow plots. To develop a correction, the 19 plots with snow depths in excess of 24 inches were examined. One outlier that had a Federal tube density 1.47 times the Snow-Hydro tube density was excluded—likely, there was either a measurement error or a large void in the snowpack at the Snow-Hydro tube sample. For the remaining 18 samples, the Federal tube density divided by the Snow-Hydro density ranged from 0.89 to 1.16, with a mean value of 1.05.

Results of these comparisons showed that the density of samples taken with the Federal tube were higher than those taken with the Snow-Hydro tube. As a result of this finding all samples taken with the Federal tube were multiplied by 0.956 to adjust for the sampling error.

The selected correction factor excluded data from plots where snow depth was less than 24 inches. The shallow snow plots showed an even greater divergence between the Snow-Hydro and Federal tube densities, with a mean value of 1.15 (excluding one outlier). There were insufficient data to develop a smooth density correction factor from shallow to deep snow. Since much more snow water equivalent is contained in the deeper snow, the simple and more conservative deeper snow correction factor was applied to all the data. To normalize the Federal tube values, all density and SWE measurements collected with the Federal tubes during the study were multiplied by 0.956 (the inverse of 1.05). This was similar to corrections applied in other studies. For example, Tabler et al. (1990) applied a 0.91 correction factor to Federal tube data when developing a snow drift density model.

7.2.2 ESTIMATING SNOW DENSITY FROM SNOW DEPTH

After correcting the Federal tube density and SWE values as described above, 19 different snow density models were tested for snow distribution surveys and the resulting models were compared using the AICc values. The top model in the model set (the model with the lowest AICc value) was the model using the variables of depth, shrub, year, and a depth-times-year interaction. This model had a high probability of being the best model ($\omega_i = 0.66$, where the probabilities of all candidate models sum to 1.00). The only other model with support included the same variables plus a depth-times-shrub interaction, but it had a higher AICc value and a lower probability of being the best model (ω_i=0.29). Thus, the top model was used to estimate snow density. This model gives a different slope and intercept for the relationship between depth and density for each year and has a constant density offset in locations with shrubs present. Shrubs were estimated to decrease snow density by 0.055 grams per cubic centimeter based on the shrub offset parameter of the best model. The presence of tall shrubs may reduce the snowpack density compared to other sites with similar depth through several mechanisms: by supporting the weight of the snowpack (reducing compaction), reducing wind speeds at the snow surface, and allowing snow-free voids to occur beneath stems.

Nineteen snow density models were also tested for ablation surveys, and the resulting models were compared using the AICc values. The top model in the model set (the model with the lowest AICc value) was the model with the variables depth, survey, and depth-times-survey interaction. This model had a high probability of being the best model ($\omega_i = 0.70$). The only other model with support included the same variables plus elevation, but it had an AICc value 2.3 lower and a lower probability of being the best model (ω_i=0.22). Thus, the top model was used to estimate snow density. This model gives a different slope and intercept for the relationship between depth and density for each survey with no effect of elevation.

The density model parameters for each snow survey are summarized in Table 4. The resulting models are plotted in Figure 7.2D-13. Overall, densities during the early April distribution surveys at intermediate depths (about 24 to 72 inches) were higher in 2004, 2005, and 2007 (years with earlier snowmelt) and lower in 2006 and 2008 (years with a delayed melt).

7.3 SNOW DEPTH MAPPING WITH LIDAR

The airborne LIDAR mission was completed on April 6, 2008. There was substantial snowfall immediately before the LIDAR survey: during April 1 through 4, 2008, 0.77 inches of precipitation, equivalent to around 4 inches of fresh snow, was recorded at the Pebble 1 Meteorological Station. Only 0.04 inches of precipitation was recorded at Pebble 1 Meteorological Station during April 5 through 10, 2008.

The project bare earth DEM was subtracted from the snow surface elevations, resulting in a map of snow depth (Figure 7.2D-14). To assess the accuracy of the LIDAR-derived snow depth, this map was compared to the 2008 snow distribution field survey results. During the period April 5 through 10, 2008, 555 field depth measurements were collected within the LIDAR survey area. Of these, 10 measurements were excluded: seven because they were recorded with a note indicating that a complete snow depth was not obtained, and three because comparisons with 2007 data suggested that the full depth was not sampled in 2008. After excluding these measurements, 545 depth measurements remained.

A mean difference was computed by subtracting the LIDAR-derived snow depth from the field-measured snow depth. For the 545 samples, the mean difference was -0.41 feet, with a standard deviation of 2.31 feet and a mean absolute error of 1.75 feet. The vertical accuracy specification for the LIDAR data is 1.0

feet, so the mean difference is well within that specification. The LIDAR snow depth estimate was adjusted by subtracting the mean difference of 0.41 feet from the LIDAR snow depth map. Snow depths less than zero were set to zero. The mean error of the adjusted LIDAR snow depth map was 0.00 feet, with a standard deviation of 2.36 feet and a mean absolute error of 1.72 feet.

The error budget for the LIDAR-derived snow depth estimates has three main sources of error: the inherent variability of snow depth over short distances, errors in the snow surface DEM, and errors in the bare earth elevation DEM. Overall, the LIDAR-derived snow depth estimates are suitable for the main objective of characterizing the extent and volume of large snow drifts. The LIDAR snow depths are of marginal quality for detailed mapping of shallow snow because the typical errors are similar in magnitude to the total snow depth. After adjustment for the 0.41 foot offset between the field-measured and LIDAR-measured snow depths, the LIDAR map is suitable for characterizing the landscape-scale patterns of snow depth in the mine study area.

LIDAR-derived snow depths were converted to SWE (Figure 7.2D-15) using the density model developed from the 2008 distribution survey field measurements (Survey 200802, Table 4). Large snow drifts are prominent on west to north facing slopes below mountain ridges. The drifts appear immediately adjacent to sharp ridges and are offset hundreds of feet or more from rounded mountaintops. Scoured areas with low SWE are evident on east to south facing slopes located on the opposite sides of ridges from the drifts. Deep snow drifts are also common at slope breaks near valley bottoms. At finer scales, the snow distribution is extremely variable, with alternating patterns of shallower and deeper snow, especially in undulating terrain and in patchy vegetation. Overall snow is deeper at higher elevations, though the highest elevations are often scoured.

The SWE for each basin is summarized in Table 5. Mean SWE for basins NK119A, SK119A, and SK124A is about double the mean SWE for basins UT100D and UT100E, with intermediate values for basins NK119B, SK100F, and SK100G.

SWE by elevation and aspect category derived from the LIDAR survey is summarized for the LIDAR survey area in Figure 7.2D-16. Elevations are summarized for 100-foot elevation bands in the elevation histogram plot, with most of the survey area situated in bands between 800- and 2,100-foot elevations and additional terrain at higher elevations up to the 2,700-foot elevation band. The aspect plot indicates that flats (defined as slopes less than 3 degrees) cover about 23 percent of the area; in sloping terrain, east and southeast aspects are most common. The red lines and bars depict the distribution of LIDAR-derived SWE by elevation and aspect within the basin. Mean LIDAR-derived SWE (depicted by the horizontal red line) increases from 10 inches at 500-foot elevations to about 37 inches at the 2,400-foot elevations, then decreases. Within each elevation band, LIDAR-derived SWE is highly variable (the vertical red line depicts the range of ± one standard deviation), and the variability is much higher above 1,500-foot elevations than below. LIDAR-derived SWE is lowest for flats at about 17 inches. On slopes, LIDAR-derived SWE is lowest (near 20 inches) for northeast, east, and southeast aspects; and highest (near 40 inches) for northwest aspects. Attachment 2 presents these results for each basin that is entirely contained within the LIDAR survey area.

7.4 SNOW-COVERED AREA MAPPING

7.4.1 LANDSAT

Thirty-six cloud-free Landsat scenes were identified and analyzed for the period February 9 through August 31, where the dataset included 1991, 1993, and years 1999 through 2009 (Table 6). The scenes in Table 6 are ordered by day of year rather than in chronological order, consistent with how the data were analyzed. The typical snowmelt date was calculated for each 96-foot pixel in the study area (with a 1-mile buffer, Figure 7.2D-17).

The typical snow-free date data are plotted below measured SWE for the two snow courses and Transect 14 in Figure 7.2D-5. There is a very good correspondence between an early snow-free date and plots that were frequently measured with little or no snow. Similarly, the later snow-free dates correspond very well with plots where deep snow was frequently observed, even during a year with relatively low snow accumulation such as 2007. Attachment 1 provides a similar comparison of field SWE and snow-free date for the other transects. The agreement between the snow-free date results and measured SWE provides confidence that the results from the snow-free date analysis can be interpreted to characterize snow patterns across the extended study area, at a moderately fine (96-foot) spatial scale.

For the extended study area, snow-free areas on April 1 (Figure 7.2D-17) are typically limited to the low elevations near the mouth of Upper Talarik Creek (less than 400 feet elevation), hill crests in undulating terrain (generally less than 1,000 feet elevation), and some south-facing slopes and ridges which are exposed to sun and wind. During April most of the snow below approximately 800 feet elevation will typically melt, though drifts persist at cut banks, in depressions, and under some tall vegetation. On May 1, snow is typically patchy up to about 1,200 feet elevation and more continuous at higher elevations. By May 15, snow below 1,200 feet elevation is typically found only in drifts. At higher elevations, snow is patchy, though extensive snow fields persist around the highest peaks. By June 1, snow typically remains only near mountaintops and in drifts. Several large drifts typically persist well into July and the deepest drifts do not melt every year.

The typical snowmelt date is summarized by elevation and aspect for the LIDAR survey area in Figure 7.2D-16. Over a range of elevation bands from 800 feet to 2,400 feet, the typical snow-free date steadily moves later, from May 1 to almost June 1. The standard deviation of the snow-free date has a magnitude of about two weeks across the same range of elevations, indicating that areas with similar elevations commonly become snow-free at dates separated by a month or more. The variation in the date of snowmelt is likely due to both highly variable snow accumulation and different solar radiation for different aspects. The plot depicting snow-free date by aspect shows that snow melts about two weeks earlier on flat terrain and east to south aspects compared with northwest terrain. The standard deviation of the snow-free date is about one week for east to south aspects and about two weeks for northwest aspects. The same data for each basin and study area, summarized by elevation and aspect category, are presented in Attachment 2.

The timelines above describe patterns that are commonly offset to occur two weeks earlier or later (more in some years, see next section). Exceptions to these patterns also occur.

The snow-covered area pane of Figure 7.2D-16 plots the typical snow-covered area by date. The Landsat data are near the middle of the range of snow-covered area depletion curves derived from MODIS data (see next section). The agreement of the two methods supports the approach of combining multiple years of Landsat-derived data into a single typical snow-free date metric with much higher spatial resolution than the MODIS data (96-foot vs. 1,640-foot pixels). The same data for each basin and study area, summarized by elevation and aspect category, are presented in Attachment 2.

The logistic function provides a probability distribution, and the typical snowmelt date is calculated as the midpoint of this distribution. Other likelihoods can be calculated—for example, a map of dates when there is 80 percent of snow cover or 20 percent chance of snow cover. However, the actual distribution of snowmelt dates in the study area is skewed, while the logistic function is symmetric. As a result, the predicted distribution of early and late snowmelt dates is unrealistic. An asymmetric function would likely provide better information about the distribution of early or late snowmelt patterns.

7.4.2 MODIS

The MODIS granules selected for the snow-covered area time series analysis are listed in Table 7. An example of the MODIS imagery for 2006, fractional snow-covered area and resulting depletion curve, is presented on Figure 7.2D-18. Snow-covered area by date in 2000 through 2008 is summarized for the LIDAR survey area in Figure 7.2D-16. The snow-covered area by date for all the basins and study areas is included in the basin characteristic summary graphs (Attachment 2). In the study period (2004 through 2008), the date at which the extended study area reached 50 percent snow cover ranged over nearly a month: approximately April 19 in 2007, approximately May 1 in 2004 and 2005, and May 14 in 2006 and 2008. Satellite records from the preceding period (2000 through 2003) indicate that 2003 was an exceptionally low snow year, with minimal snow cover at lower elevations and early melt at all elevations. Snow-covered area was below 20 percent in early March before rising to about 75 percent and then declining below 50 percent before the end of March. Both 2001 and 2002 saw late snowmelts, similar to 2006 and 2008, while the 2000 snow cover dropped below 50 percent around May 5.

The pattern that emerges from the multi-year analysis is that melt is more gradual in years with early snowmelt. Conversely, the later the snowmelt gets going, the more rapidly it occurs—as evidenced by the steeper depletion curves.

7.5 SNOW TRANSPORT

The available wind speed and direction data are summarized by meteorological station and year on Figure 7.2D-19. The data for Pebble 1 cover 4 years; data for Pebble 2 and 4, and Pebble 3 cover 3 years; Pebble 5, 5A, and 6 cover 1 year; and the early 1990s Cominco station covers 2 years (Pebble 2 and 4 were operated at the same location but in different winters and with some different instrumentation). Major wind events (greater than 10 meters per second) consistently come from the east-southeast, regardless of year or location. This wind vector is also associated with most winter precipitation events in winter 2005/2006, winter 2006/2007, and winter 2007/2008 at Pebble 1 (Figures 7.2D-7, 7.2D-9, and 7.2D-11). There is a secondary dominant wind vector with a direction that varies between the northern and southern meteorological stations. At the northern meteorological stations (Pebble 1, 5, 6, and Cominco), this secondary vector is from the northwest or nearly opposite the primary wind vector. At the southern meteorological stations (Pebble 2 and 4, and Pebble 3), this secondary vector is oriented north/northeast.

At Pebble 5A, a northern meteorological station at the highest elevation of all stations, the secondary vector appears weaker and oriented northeast (however, this station had extended lapses in the record due to icing of instruments). Wind speed also appears to vary substantially between the southern Pebble Stations 2 and 3, though these are less than a mile apart. Wind speeds are lowest at the valley bottom stations, Pebble 3 and 6.

Net snow transport estimated for winter 2007/2008 (Figure 7.2D-20) indicates that winds remove snow from most of the study area (areas shaded red). In particular, south- and east-facing slopes and rounded mountaintops are scoured of snow. In areas of undulating terrain, the peaks are the most scoured. Deposition occurs mainly near the tops of north- and west-facing slopes and in depressions and valley bottoms.

Four drift profiles are summarized in Figure 7.2D-21. Transect D59 and D54 are both located in depressions that can capture snow from both dominant wind directions (SE and NW). The data for these two transects were based on the LIDAR data and so are applicable to transport in winter 2007/2008. In each of these cases, transport is greater from the southeast winds (28.3 and 16.1 tons/linear foot, respectively). Transport due to northwest winds is still substantial. The summed transport from both directions puts transect D59 in the "moderately severe" category and D54 in the "moderate" category in the snow transport classification (Tabler, 2003).

Transect 39 is located on a prominent snow drift east of Frying Pan Lake and was sampled in 2007. The 2007 survey GPS field measurements combined with 2008 LIDAR measurements allow a comparison of transport from two winters. Snow transport in 2007 is estimated at 116.9 tons per linear foot ("severe" snow transport) while 2008 transport was 138.7 tons per linear foot ("extreme" snow transport, the highest category).

Transect D21 is located on a massive mountain drift that persistently occurs on the northwest slope of a mountain. Field survey transect 21 traverses the drift and has been sampled since 2005; however, in 2005 and 2006, only a single point on the drift was sampled, and the equipment did not penetrate to the ground. In 2007 and 2008, field measurements were obtained on the drift, and in 2008 it was also covered by the LIDAR snow depth map. The 2007 survey GPS field measurements combined with 2008 LIDAR measurements were used to estimate drift volume and snow transport. Similar to the Frying Pan Lake drift, the transport was much higher in winter 2007/2008 than in the previous winter. In both years, the bottom of the drift was still extremely steep, indicating that the drift was not near equilibrium (i.e., it could grow much larger, with sufficient wind and snow). The snow transport at this site is classified as "severe" for 2006/2007 and "extreme" for 2007/2008.

7.6 SNOW MODELING

The SnowModel results presented here are based on a run at 384-foot resolution with an hourly time step and a precipitation correction factor of 2.0 (corresponding to a precipitation catch efficiency of 50 percent). This precipitation correction factor was selected based on a comparison of aggregate SWE between the snow model and the LIDAR SWE for the area that the two overlapped. No wind clipping was performed for the model runs described here. The hourly time step was selected because it produced more realistic patterns of drifting and scouring, particularly for winter 2007/2008. A 96-foot resolution run was evaluated, but results were better for the 384-foot resolution run.

Results for the snow model are presented on Figure 7.2D-22. The dates presented are those that correspond to the midpoint of the April snow distribution surveys in 2006, 2007, and 2008. The LIDAR SWE from 2008 is also depicted for comparison. The mean SWE by basin, with a comparison of modeled and LIDAR SWE for 2008, is presented on Figure 7.2D-23. Detailed model outputs for basin NK119A are provided in Figure 7.2D-24 (winter 2005/2006), Figure 7.2D-25 (winter 2006/2007), and Figure 7.2D-26 (winter 2007/2008). A water balance summary for basin NK119A based on model outputs for the three winters is presented in Figure 7.2D-27. Similar plots for all the basins and other extents are provided in Attachment 3.

7.7 SNOW HYDROLOGY SYNTHESIS

7.7.1 COMPARISON OF NRCS AND PEBBLE SNOW COURSE DATA

Comparisons of SWE data collected at the six NRCS snow courses (NRCS, 2009) with the three Pebble snow courses indicate that there is good agreement between the three high-elevation NRCS snow courses (Fishtrap Lake, Upper Twin Lakes, and Telaquana Lake) and the Pebble snow courses (Figure 7.2D-28; Table 1). The relationship holds for Pebble Snow Course 1/1A and Pebble Snow Course 2, and also for the 45 plots repeated at Pebble in 2004 through 2008. Fishtrap Lake is the closest location with an elevation similar to those of the Pebble snow courses (Figure 7.2D-2).

The peak late winter SWE at the Pebble and NRCS snow courses (Figure 7.2D-29) provides a record of regional snow accumulation from 1992 through 2009. Evaluation of these results, based on 18 years of NRCS snow course data, indicate that 2007 was representative of a low snow year in the region. However, higher snow accumulations similar to those observed in 2005 are fairly common, and winters with even higher snow accumulations should be expected at least once or twice per decade. Year 2008 was above average, but not extreme at the regional NRCS snow courses.

For 2004 through 2008, the NRCS snow course data for Fishtrap Lake, Upper Twin Lakes, and Telaquana Lake were often unavailable until June or later. The data are often not included in the April 1 and May 1 basin outlook reports (NRCS, 2008a; NRCS, 2008b NRCS, 2007a; NRCS, 2007b; NRCS, 2006a; NRCS, 2006b; NRCS, 2005a; NRCS, 2005b; NRCS, 2004a; and NRCS, 2004b) but eventually became available in the NRCS historical snowpack database (NRCS, 2009). Thus, while the NRCS snow courses provide a useful historical proxy dataset, they are not necessarily useful for predicting the snowpack in advance of a particular spring.

7.7.2 COMPARISON OF FIELD SURVEY, SNOWMODEL, AND LIDAR

The field measurements and LIDAR-derived SWE were compared to the model outputs to assess how well the model represented snow distribution patterns in the study area (Figure 7.2D-30). Based on the comparison of field data and model outputs, model performance at simulating fine-scale distribution patterns (such as drifted and scoured areas) for 2006 and 2007 was poor. At locations where field surveys measured shallow or absent snow, modeled outputs were highly variable. Where field surveys measured deep snow (above 30 inches SWE in 2006, and above 15 inches SWE in 2007), modeled snow was nearly always too low. Modeled SWE was variable but did not tend to increase much at higher observed SWE.

The winter 2005/2006 field data had the lowest agreement with the model data. There were no supplemental depth-only plots in 2006, so the sample size was much smaller. In 2006, the survey was mostly limited to higher elevations. There were also fewer meteorological stations in operation during that winter, so the existing data were interpolated greater distances within the model domain, perhaps introducing artifacts.

Model performance was better in 2008. Based on comparisons with field measurements, there was still a lot of model variability at locations where shallow snow was observed in the field. The slope of the regression line was higher for the 2008 field data comparison than the other years (0.18 compared to -0.04 and 0.07 for 2006 and 2007, respectively). The R^2 was also higher (0.16 compared to 0.01 and 0.06 for 2006 and 2007, respectively).

The aggregated LIDAR-derived SWE was compared to model outputs for 2008. Results were similar to the comparison based on field surveys. A comparison based on 20,000 randomly selected 384-foot cells in the LIDAR survey indicated that modeled SWE was generally too high where shallow snow was measured by LIDAR (less than about 20 inches LIDAR SWE). Where deeper snow was measured by LIDAR, modeled SWE was generally too low. The slope of the regression line based on the LIDAR data was similar to the comparison based on the field data (0.16 and 0.18, respectively). R^2 was also similar with values of 0.16 and 0.15 for the LIDAR and field comparisons, respectively.

The results were better for 2007 and 2008, when field data covered much of the regional extent, as well as the full range of elevations in the study area, than for 2006. The observed pattern of higher snow accumulation at higher elevations compared to the lower reaches of the major drainages is represented in the model outputs. Capture of snow on slopes and river channels with tall shrubs is also represented in the model outputs. Prominent drifts occur in the model at the northwest-facing slope east of Frying Pan Lake and at other sites where drifts were observed each year (though the 2006 model output also places a drift on the southeast-facing slope to the east of the Frying Pan Lake drift, which is a persistent scour site).

The poor model performance at simulating observed local-scale distribution patterns appears to be driven by considerable scatter around the regression lines (especially for the more frequent plots where shallow snow was observed), and a tendency for the current model outputs to overestimate snow in scour areas and to underestimate drifts. A comparison of model results with field and LIDAR SWE for three transects (Pebble Snow Courses 1 and 2 and Transect 14, Figure 7.2D-31) demonstrates that the model results are far more uniform than the measured SWE. Some drifting patterns are represented reasonably well in the model output. For example, the large drift observed each year on Pebble Snow Course 1 (Transect ss1) between 6,000 and 7,000 feet from the start of the transect is represented in the model output, though the modeled drift is more extensive than the observed drift.

The underestimation of the observed local-scale variability in snow distribution is most likely due to inadequacies in the physical modeling of snow transport processes. Wind fields are complex, with November to April wind events showing two dominant directions at each meteorological station, but some variation in the orientation of the dominant direction among stations (Figure 7.2D-19). Wind speeds are also very high, especially during storms. MicroMet (a submodel of SnowModel) is a meteorological model with a quasi-physical basis (Liston and Elder, 2006a). It is intended to address the wind speed and direction variability problems by spatially distributing the hourly meteorological data across the study area; however, it uses a computationally simple approach that may not adequately represent near-surface wind fields in complex alpine environments (Bernhardt et al., 2009).

The current model uses a simple two-layer snowpack to account for transportable snow. Snow in the soft layer is available for transport when wind speeds exceed a threshold, while snow in the hard layer cannot be moved. This simplification has worked in other environments, but the very high wind speeds that can occur in the study area can probably move snow that the model has assigned to the hard, unmovable layer. There are two triggers in the model that can move snow from the moveable layer to the immoveable layer: the occurrence of above-freezing air temperatures (an event that occurs several times each winter, especially at lower elevations) and a prolonged period of high wind speeds (another common occurrence). The representation of the resulting snowpack as unmovable may explain the exaggerated uniformity of the model outputs. Improvements in the modeling of wind fields and more sophisticated layer accounting could improve snow distribution results. Incorporating information from the detailed vegetation map, and formally incorporating the patterns of where drifts and scoured areas are persistently observed (e.g., by mapping those patterns using the results from the Landsat typical snow-free date analysis) could also improve results.

The snow transport calculations based on measured snow volumes (Section 7.5) are independent of the snow transport processes modeled in the snow model. Therefore the results from the snow transport section provide an alternative method to characterize snow redistribution patterns in the study area.

7.7.3 COMPARISON OF SNOWMODEL, LIDAR, STREAM DISCHARGE, AND SNOW-COVERED AREA

Detailed model outputs for basin NK119A are provided in Figure 7.2D-24 (winter 2005/2006), Figure 7.2D-25 (winter 2006/2007), and Figure 7.2D-26 (winter 2007/2008). A water balance summary for basin NK119A based on model outputs for the three winters is presented in Figure 7.2D-27. Detailed outputs and the water balance summaries from SnowModel runs for the three winters for all basins and study areas are compiled in Attachment 3.

The model output summary plots depict the modeled evolution of the snowpack in each winter (2005/2006, 2006/2007, and 2007/2008). Key factors controlling snow transport are depicted, and the spikes of snow transport and the associated sublimation (modeled) can be interpreted. Though the redistribution of snow associated with transport is not satisfactorily represented by the current model, the transport diagnostics are still useful to estimate the range of values for net transport and sublimation in the overall water balance. Model outputs may be compared to the stream discharge (where available), MODIS snow-covered area, and the LIDAR SWE. In general, there is very good agreement in the timing of the spring runoff. Some winter runoff events are also captured by the model. Snow-covered area from MODIS generally declines before the model snow-covered area. However, this is expected due to a simplification used when calculating the modeled snow-covered area—each 384-foot cell is assumed to be 100 percent snow-covered until it reaches zero SWE, when it is interpreted as snow free. In reality, low SWE in a cell will usually correspond to patchy melting snow (i.e., a snow fraction of less than 100 percent).

For the basins in the LIDAR study area, the LIDAR SWE on April 6, 2008, is plotted for comparison to the modeled SWE curve. For the LIDAR survey area as a whole and for several basins, the agreement is quite good (e.g., NK119B, SK100F, and SK100G). The modeled SWE is much higher than the LIDAR SWE for basins UT100D and UT100E, which are relatively low elevation compared to the other basins in the LIDAR study area. The discrepancy may be partly explained by an early winter melt observed in the hydrograph record in November 2007 but less evident in the model output. Temperatures were near freezing, and the model may have underestimated the actual rain and melting in November, resulting in more snow in April.

LIDAR SWE is much higher than model SWE for basins SK119A, SK124A, and NK119A. Two of these (SK119A and NK119A) have extensive high-elevation slopes facing southeast, and may receive more orographic precipitation from the moisture-bearing storm tracks (a pattern that occurs at a scale not captured by the meteorological stations or the MicroMet model). The wind fields at these high elevations are also the most complex, and the simplified wind distribution function of MicroMet may not represent the snow-redistributing winds correctly.

Based on comparisons with stream discharge and satellite imagery, the overall performance of the model is adequate for simulating the seasonal pattern of snow accumulation and ablation at the regional and basin scale. The model represents the variation in the timing of snowmelt among different years. The model also captures the coincident pattern of snowmelt in valleys occurring while snow accumulation continues in the mountainous headwaters. Some limitations result from the complexity of precipitation patterns and the comparatively poor performance of the snow redistribution component of the model.

8. SUMMARY

Information from extensive field surveys conducted at Pebble from 2004 through 2008 and from six NRCS snow courses within 100 miles of the Pebble snow courses indicate that the NRCS snow course patterns for the three high-elevation snow courses (Telequana Lake, Upper Twin Lakes, and Fishtrap Lake) are quite similar to the SWE pattern observed at the Pebble snow courses. Based on the long-term NRCS snow course records (1992 to 2009) (Table 1; Figure 7.2D-29), SWE for spring 2004 and 2006 was close to the long-term averages at the high-elevation NRCS snow courses; SWE for spring 2005 and 2008 was somewhat above average; and SWE for spring 2007 was well below average. The full record for these NRCS snow courses (1992 to 2009) suggested that 2007 was among the lowest snow years on record.

Good agreement was found between the measured winter precipitation at the Pebble 1 Meteorological Station and the measured SWE in the study area, based on precipitation data from three winters (2005/2006, 2006/2007, and 2007/2008). Data from shielded ETI NOAH II precipitation gages could provide a useful index of snow accumulation in the study area each winter.

A LIDAR survey conducted on April 6, 2008, obtained a detailed map of snow depths for much of the study area following a winter with high snow accumulation. The LIDAR-derived snow depths were converted to SWE using a snow density model. The results from the LIDAR survey indicated that average SWE in the study area basins covered by the LIDAR survey ranged from 14.1 to 32.0 inches on April 6, 2008. The highest SWE was observed in NK119A, SK119A, and SK124A, mountainous basins with substantial east- to southeast-facing terrain.

Snow distribution in the study area, particularly in the mountains, is largely driven by wind and resultant redistribution of snow. Two distinct wind vectors cause snow transport from opposing directions, with the southeast wind vector usually dominant. Snow drifts are prominent on west- to north-facing slopes below mountain ridges. The drifts appear immediately adjacent to sharp ridges and are offset hundreds of feet or more from rounded mountaintops. Scoured areas with scant snow cover are evident on east- to south-facing slopes located on the opposite sides of ridges from drifts. Deep snow drifts are also common at slope breaks near valley bottoms. At finer scales, the snow distribution is extremely variable, with alternating patterns of shallower and deeper snow, especially in undulating terrain and in patchy tall shrubs. SWE increases with elevation except that ridges are often scoured.

In the study area, snow-free areas on April 1 (Figure 7.2D-17) are typically limited to the low elevations near the mouth of Upper Talarik Creek, hill crests in undulating terrain, and some south-facing slopes and ridges that are exposed to sun and wind. During April, most of the snow below approximately 800 feet elevation will typically melt, though drifts persist at cut banks, in depressions, and under some tall vegetation. On May 1, snow is typically patchy between 800 and 1,200 feet elevation and more continuous at higher elevations. By May 15, snow below 1,200 feet elevation is typically found only in drifts. At higher elevations, snow is patchy, though extensive snow fields persist around the highest peaks. By June 1, snow typically remains only near mountaintops and in drifts. Several large drifts typically persist well into July, and the deepest drifts do not melt every year.

This typical pattern usually repeats each year, with offsets of two weeks earlier or later common. Based on data from snowpack ablation surveys, MODIS satellite imagery, and stream discharge measurements, the snowmelt and the resulting spring runoff in the study area were very early in 2007, somewhat early in 2004 and 2005, and delayed in 2006 and 2008. The timing of snowmelt varied over a period of about a month during 2004 through 2008, with later snowmelts proceeding more rapidly after they initiated. MODIS imagery over the period 2000 through 2008 indicates that other years had a similar range of dates for snowmelt, except for 2003, when a very shallow snowpack melted several weeks earlier than the early 2007 snowmelt.

Snow transport was estimated in 2007 and 2008 based on drift profiles measured with depth probes, survey GPS, and the LIDAR survey. Mountain drift volumes imply snow transport rates exceeding 100 tons per linear foot while drifts in valleys indicate snow transport rates of 25 to 40 tons per linear foot. Modeling of snow transport processes by a computer model that incorporated topography, vegetation, and meteorological data did not satisfactorily simulate observed local-scale patterns, though regional patterns were better represented. Improvements in the modeling of complex wind fields and snowpack layers, as well as incorporation of detailed vegetation mapping and persistent drift and scour patterns, could improve results.

The snow model simulated snow accumulation and ablation in the study area for winters 2005/2006, 2006/2007, and 2007/2008, and good agreement was found between model outputs, MODIS-derived snow-covered area, and stream discharge measurements at basin and regional scales. The model represents the variation in the timing of snowmelt among different years. The model also captures the coincident pattern of snowmelt in valleys occurring while snow accumulation continues in the mountainous headwaters. Some limitations result from the complexity of precipitation patterns and the comparatively poor performance of the snow redistribution component of the model.

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10. GLOSSARY

Ablation—refers to all processes that remove snow or water from a snowpack.

Basal ice—a layer that occurs at the base of the snowpack when meltwater percolates through the snowpack and refreezes at the ground layer; occurs when the temperature of the substrate is below freezing.

Basal melting—melting that occurs at the base of the snowpack when the temperature of the substrate is above freezing.

Bounding box—a rectangular, two-dimensional array encompassing a geographic feature; used in geographic information systems and cell-based modeling.

Cloud mask—a map layer identifying portions of a satellite image where the ground is obscured by clouds.

Cubic convolution—an interpolation method for smoothly interpolating data points to a two dimensional regular grid.

Melt features—layers or columns in a snowpack that contain ice or liquid water that was generated from melting snow.

Normalized Difference Snow Index (NDSI)—a spectral index derived from visible and short-wave infrared reflectance; used in remote sensing to discriminate snow from other features.

Orographic—occurs when an air mass rises from a low elevation to a higher elevation as it moves over a mountain range.

Reflectance—the ratio of outgoing radiance to incoming radiance at a particular wavelength.

Reflectance, near-infrared—the ratio of outgoing radiance to incoming solar irradiance at wavelengths near 0.85 µm.

Reflectance, short-wave infrared—the ratio of outgoing radiance to incoming solar irradiance at wavelengths near 1.64 µm.

Reflectance, top-of-atmosphere–the ratio of outgoing radiance (as measured by a satellite) to incoming solar irradiance at a particular wavelength.

Reflectance, visible—the ratio of outgoing radiance to incoming solar irradiance at wavelengths near 0.55 µm.

Saltation—process of wind transport of snow particles by bouncing.

Sastrugi—ridges or grooves formed on a snow surface by wind erosion and deposition; they form parallel to the prevailing winds.

Snow water equivalent (SWE)—the amount of water contained within the snowpack.

Sublimation—removal of snow by conversion of snow directly to water vapor.

Suspension—process of wind transport of snow particles where turbulence holds particles aloft.

TABLES

TABLE 1
NRCS and Pebble Snow Survey Data Summary and Pebble 1 Winter Precipitation Summary, 2004–2008

Location	Elev. (feet)	Year	Date Sampled	SWE (inches) [a]	Percentage of Average [b]	Notes
Telaquana Lake (NRCS Snow Course)	1,550	2004	April 1	4.4	98	
		2005	April 12	6.4	142	
		2006	March 1	4.5	107 [c]	No April data
		2007	April 2	1.4	31	
		2008	April 1	5.8	129	
		Average [d]		4.5		17 year average
Upper Twin Lakes (NRCS Snow Course)	2,000	2004	April 1	5.8	88	
		2005	April 12	6.8	103	
		2006	March 1	5.8	97 [e]	No April data
		2007	April 2	4.0	61	
		2008	April 1	7.2	109	
		Average [d]		6.6		15 year average
Fishtrap Lake (NRCS Snow Course)	1,800	2004	April 1	8.6	84	
		2005	March 4	11.7	119 [f]	No April data
		2006				No April/March data
		2007	April 2	4.9	48	
		2008	March 7	9.5	97 [f]	No April data
		Average [d]		10.2		14 year average
Port Alsworth (NRCS Snow Course)	270	2004	April 3	5.1	146	
		2005	April 9	0.0	0.0	
		2006				No April/March data
		2007	April 3	1.9	54	
		2008	March 14	5.2	137 [g]	No April data
		Average [d]		3.5		16 year average
Brooks Camp (NRCS Snow Course)	150	2004				No April/March data
		2005				No April/March data
		2006	April 10	1.5	94	
		2007				No April/March data
		2008	April 3	0.8	50	
		Average [d]		1.6		6 year average
Three Forks (NRCS Snow Course)	900	2004				No April/March data
		2005				No April/March data
		2006	April 10	2.5	96	
		2007				No April/March data
		2008	April 3	3.0	115	
		Average [d]		2.6		4 year average
Pebble Snow Course 1 (Original)	2,000	2004	April 15	10.5	86	
		2005	April 12	15.5	127	
		2006	April 18	9.7	80	
		2007	April 8	5.8	48	
		2008	April 8	19.4	159	
		Average [d]		12.2		5 year average

Location	Elev. (feet)	Year	Date Sampled	SWE (inches) [a]	Percentage of Average [b]	Notes
Pebble Snow Course 1A (Plot ss1_c and ss1_h dropped)	2,000	2004	April 15	8.2	80	
		2005	April 12	13.8	134	
		2006	April 18	7.5	73	
		2007	April 8	5.3	51	
		2008	April 8	16.7	162	
		Average [d]		10.3		5 year average
Pebble Snow Course 2	1,200	2004	April 15	9.8	95	
		2005	April 11	12.0	116	
		2006	April 16, 23	8.1	78	
		2007	April 6	6.3	61	
		2008	April 7	15.6	151	
		Average [d]		10.4		5 year average
Pebble Repeated Plots [h]	Various	2004	April 13–18	11.9	83	
		2005	April 10–16	16.5	115	
		2006	April 16–23	14.1	98	
		2007	April 3–16	8.5	60	
		2008	April 5–10	20.4	143	
		Average [d]		14.3		5 year average
Pebble 1 Meteorological Station Winter Precipitation [i]	1,556	2006 [j]	Oct 21–Apr 19	13.3	98	
		2007 [j]	Oct 20–Apr 7	8.3	61	
		2008 [j]	Oct 6–Apr 6	19.2	142	
		Average [k]		13.6		3 year average

Notes:

a. Snow water equivalent in inches.

b. Percentage of long-term (1992-2009) average SWE of each station for early April (NRCS) or mid-April (Pebble), unless otherwise specified.

c. Percentage calculated based on long-term (1992-2009) average for early March at Telaquana Lake (4.2 inches, based on 16 years).

d. Long-term (for all data collected between 1992-2009) average SWE of each station for early April (NRCS) or mid-April (Pebble). The number of years of data used to calculate the average varies between sites and is provided in the notes column.

e. Percentage calculated based on long-term (1992-2009) average for early March at Upper Twin Lakes (6.0 inches, based on 14 years).

f. Percentage calculated based on long-term (1992-2009) average for early March at Fishtrap Lake (9.8 inches, based on 14 years).

g. Percentage calculated based on long-term (1992-2009) average for early March at Port Alsworth (3.8 inches, based on 15 years).

h. Includes plots sampled in all 5 years (2004-2008) of the Pebble Snow Distribution Surveys.

i. Total precipitation measured by shielded ETI Instruments NOAH II Weighing Precipitation Gage between the onset of predominantly freezing temperatures and the Pebble Snow Courses survey date midpoint (LIDAR acquisition date in 2008).

j. Winter ending in the specified year.

k. Average winter precipitation (winters ending 2006–2008). The number of years of data used to calculate the average is given in parentheses.

TABLE 2
Field Snow Survey Plot Data Summary, April Distribution Surveys, 2004–2008

	2004 Average			2005 Average			2006 Average			2007 Average			2008 Average		
Plot	**n [a]**	**Depth (in.)**	**SWE (in.)**	**n [a]**	**Depth (in.)**	**SWE (in.)**	**n [a]**	**Depth (in.)**	**SWE (in.)**	**n [a]**	**Depth (in.)**	**SWE (in.)**	**n [a]**	**Depth (in.)**	**SWE (in.)**
ss1_a	4	58.8	23.3	1	90.0	36.8	3	53.0	25.8	3	37.7	19.6	3	102.8	45.5
ss1_b	3	32.7	13.1	3	63.3	27.8	2	28.0	12.7	3	15.8	6.8	3	61.2	25.0
ss1_c	4	47.8	19.8	3	44.0	20.1	4	36.5	13.9	3	10.2	2.8	3	46.8	17.2
ss1_d	4	62.0	26.9	1	94.0	45.4	2	73.4	21.3	3	55.5	23.6	4	91.4	44.5
ss1_e	4	16.6	4.7	4	19.1	5.5	4	11.3	3.1	1	1.5	0.5	3	21.3	8.1
ss1_f	4	11.9	5.4	4	28.4	10.4	2	21.8	10.2	3	12.8	5.4	3	33.2	14.8
ss1_g	1	0.0	0.0	4	9.9	2.5	2	0.7	0.2	1	0.0	0.0	3	8.3	3.0
ss1_h	4	65.8	26.0	4	65.5	29.7	3	70.3	29.7	4	32.3	13.4	3	99.8	51.1
ss1_i	1	0.0	0.0	3	4.0	1.6	1	0.0	0.0	1	0.0	0.0	3	9.5	3.5
ss1_j	4	8.6	2.8	3	11.7	5.3	3	3.3	1.6	1	0.0	0.0	3	29.7	14.3
ss1_k	4	6.6	2.0	3	14.8	5.7	2	4.8	0.9	1	0.2	0.1	3	13.3	5.4
ss1_l	4	17.3	6.7	3	20.8	6.8	3	10.9	4.1	4	5.4	1.8	3	27.3	11.0
ss1_m	4	12.8	5.3	4	15.0	4.5	4	8.0	2.4	1	2.7	0.9	1	23.2	8.3
ss2_a	1	0.0	0.0	1	0.0	0.0	4	2.7	1.1	1	0.0	0.0	3	4.2	1.1
ss2_b	4	7.9	2.6	1	0.2	0.1	4	4.5	1.8	1	0.0	0.0	3	12.3	4.1
ss2_c	4	38.2	12.8	3	29.7	14.7	4	25.1	10.3	1	6.0	2.0	3	46.7	17.8
ss2_d	4	60.0	24.5	3	66.8	28.4	3	51.7	21.3	1	47.0	22.0	3	90.7	38.2
ss2_e	4	28.3	9.9	3	15.5	7.6	2	5.5	2.3	1	0.0	0.0	3	25.0	8.4
ss2_f	4	40.5	15.8	3	61.7	25.2	4	43.6	16.1	1	35.0	15.3	3	74.0	32.5
ss2_g	4	5.7	1.7	2	12.1	5.1	4	9.4	2.6	1	0.0	0.0	3	14.3	4.3
ss2_h	4	61.1	25.0	3	79.8	31.5	4	52.1	19.6	1	64.0	23.9	3	93.7	43.2
ss2_i	4	5.1	1.9	3	4.8	2.2	4	4.4	1.1	1	0.0	0.0	3	8.5	2.0
ss2_j	4	13.5	4.2	3	12.8	5.3	4	15.4	4.9	1	0.0	0.0	3	12.0	4.0
MET_1 [b]	4	2.8	1.1	3	11.7	4.5									
MET_2 [b]	1	0.0	0.0	3	3.7	1.8									

Plot	2004 Average			2005 Average			2006 Average			2007 Average			2008 Average		
	n [a]	Depth (in.)	SWE (in.)	n [a]	Depth (in.)	SWE (in.)	n [a]	Depth (in.)	SWE (in.)	n [a]	Depth (in.)	SWE (in.)	n [a]	Depth (in.)	SWE (in.)
Pebble_1 [c]										12	3.6	1.9			
Pebble_3 [c]										39	19.8	8.8			
Pebble_4 [c]										6	0.0	0.0			
2_2	4	13.6	5.4												
2_3	3	62.7	27.4												
2_4	4	5.3	2.4												
2_5	4	66.0	25.9												
3_1	4	1.3	0.2												
3_2	4	9.1	2.7												
3_3	4	19.0	6.0												
3_4	4	45.5	12.2												
3_5	3	18.5	4.9												
4_1	4	5.9	1.1							3	4.7	1.6	1	22.5	10.5
4_2	4	22.0	6.4							2	5.6	1.9	1	39.8	14.9
4_3	4	86.8	42.1							3	55.1	24.3	1	115.4	52.6
4_4	4	21.0	6.7							3	13.5	4.6	1	91.3	38.6
4_5	4	32.1	11.1							2	11.0	5.5	1	51.0	18.2
4_6	4	21.3	6.6							1	0.0	0.0	1	16.5	5.7
4_7	3	88.3	39.8							2	120.5	58.3	1	176.8	84.2
5_1	4	4.4	1.5				2	2.6	0.6	2	3.8	1.3	1	5.5	2.0
5_2	1	94.0	51.4				1	108.0	58.3	1	81.0	36.9	1	164.2	77.7
5_3	1	92.0	39.6				1	131.0	70.1	2	134.5	66.0	1	177.6	84.6
5_4	4	65.9	30.5				3	46.2	18.2	3	31.5	13.4	1	83.5	33.2
5_5	4	26.1	7.0				4	13.5	3.7	4	21.5	6.1	1	18.1	6.4
5_6	4	51.0	16.6				3	64.8	22.6	3	53.3	19.7	1	87.0	31.4
5_7	3	63.0	23.6				4	36.4	8.1	2	35.0	8.6	1	78.7	23.0
6_1	1	0.0	0.0	3	2.5	0.8	4	2.1	0.6				1	3.5	1.4

Plot	2004 Average			2005 Average			2006 Average			2007 Average			2008 Average		
	n [a]	Depth (in.)	SWE (in.)	n [a]	Depth (in.)	SWE (in.)	n [a]	Depth (in.)	SWE (in.)	n [a]	Depth (in.)	SWE (in.)	n [a]	Depth (in.)	SWE (in.)
6_1a				1	0.5	0.2	1	0.0	0.0	1	3.0	1.0	1	5.9	2.5
6_2	4	11.6	4.7	4	30.8	14.5	4	2.5	0.8				1	5.4	1.7
6_2a				4	46.0	19.0	4	56.0	22.1	3	27.2	6.5	1	59.1	23.2
6_3	4	50.0	21.1	3	78.3	36.6	2	80.0	32.7	2	59.8	23.6	1	82.7	33.7
6_4	4	22.0	6.7	4	13.2	5.1	3	21.5	5.5				1	21.3	6.2
6_4a				3	58.8	20.8	4	93.1	35.0				1	102.4	44.1
6_5	4	42.0	14.2	4	40.5	10.5	4	44.8	13.1				1	48.4	18.5
6_6	4	26.4	8.4	4	39.3	9.6	4	38.3	8.7				1	37.8	11.1
8_1	1	0.0	0.0	1	0.5	0.2	1	0.3	0.1				1	6.5	2.9
8_1a				1	0.0	0.0	1	0.0	0.0	1	0.1	0.0	1	2.3	0.8
8_2	4	11.1	3.8	1	33.0	14.3	3	7.3	2.7				1	39.0	12.4
8_2a				1	71.0	32.0	4	50.8	19.7	2	29.0	11.5	1	98.8	42.1
8_3	4	46.8	17.9	3	42.5	18.1	4	33.0	12.8	2	35.0	14.3	1	62.0	25.8
8_4	4	7.9	2.8	3	9.6	3.5	3	21.8	6.7	1	1.0	0.3	1	27.5	9.6
8_5	4	35.3	12.8	1	71.0	30.1	4	56.1	19.9	2	49.0	17.4	1	82.0	30.1
8_6	4	50.5	20.3	1	59.0	19.8	4	54.4	17.0	3	51.7	13.4	1	87.0	21.0
9_1	3	18.8	6.7							3	3.5	1.0	1	25.6	10.0
9_2	4	77.8	31.7							2	52.5	20.8	1	177.2	84.4
9_3	4	57.2	22.9							3	34.2	11.6	1	64.2	24.1
9_4	4	28.3	9.8							3	10.8	3.5	1	29.5	10.4
9_5	4	27.0	11.3							2	4.5	1.5	1	22.8	7.2
9_6	3	67.3	29.3							2	56.3	20.8	1	96.5	40.2
9_7	4	27.1	8.5							2	28.3	12.9	1	57.5	21.5
9_8	4	67.1	21.6							3	53.7	20.2	1	97.6	36.2
10_1	4	41.0	14.3												
10_2	4	35.5	15.5												
10_3	3	52.3	24.4												

Plot	2004 Average			2005 Average			2006 Average			2007 Average			2008 Average		
	n [a]	Depth (in.)	SWE (in.)	n [a]	Depth (in.)	SWE (in.)	n [a]	Depth (in.)	SWE (in.)	n [a]	Depth (in.)	SWE (in.)	n [a]	Depth (in.)	SWE (in.)
10_4	4	46.0	14.9												
10_5	4	58.0	20.2												
10_6	4	53.0	17.9												
10_7	2	74.0	27.2												
11_1	1	0.0	0.0	4	19.1	7.0	4	7.8	1.9	1	1.6	0.5	1	15.5	6.7
11_2	3	74.7	33.4	1	120.0	51.6	2	139.5	79.1	3	71.2	35.2	1	107.5	46.8
11_3	4	17.2	5.6	4	34.5	12.8	4	37.9	14.8	3	17.7	5.1	1	37.5	10.5
11_4	4	66.1	22.7	3	83.3	29.9	4	82.4	22.0	3	52.2	17.8	1	112.0	43.0
11_5	4	7.2	2.3	4	6.6	2.6				1	0.0	0.0	1	13.0	3.8
11_6	4	33.0	9.7	4	40.8	14.5	4	37.3	10.5	4	17.3	4.4	1	57.0	18.2
11_7	4	36.8	12.5	4	39.3	13.9	4	62.3	20.7	2	27.5	9.1	1	67.0	22.9
12_1	4	6.1	2.6	1	0.1	0.0	3	9.0	3.2				1	7.5	2.8
12_1a				4	20.6	4.5	3	23.7	8.1	1	0.0	0.0	1	33.0	13.4
12_2	4	17.5	6.1	4	9.1	4.4	4	47.6	19.0	2	9.9	5.1	1	37.0	10.5
12_3	4	55.8	23.0	1	58.0	30.6	3	34.3	10.9	2	33.3	17.9	2	78.0	32.9
12_4	4	63.3	26.7	3	73.5	29.6	3	72.8	34.3	3	58.8	21.0	2	90.1	36.8
12_5	3	12.7	4.3	4	6.4	1.9	3	15.0	4.9	1	0.0	0.0	2	13.9	6.1
12_6	3	75.7	33.0	4	41.5	13.6				1	0.0	0.0	2	21.0	8.7
12_7	4	43.5	13.6	4	45.8	20.7	3	55.0	21.8	2	40.3	14.8	2	51.9	19.1
12_8	4	9.6	3.9	3	8.3	4.1	3	19.1	6.3				5	20.7	9.1
13_1	4	1.6	0.4												
13_2	4	73.3	34.6												
13_3	4	4.7	1.7												
13_4	4	53.0	17.8												
13_5	4	54.5	23.5												
13_6	4	1.8	0.6												
14_1	2	5.1	1.5	1	9.6	0.8	3	5.4	1.6	2	4.2	1.4	1	7.1	2.1

Plot	2004 Average			2005 Average			2006 Average			2007 Average			2008 Average		
	n [a]	Depth (in.)	SWE (in.)	n [a]	Depth (in.)	SWE (in.)	n [a]	Depth (in.)	SWE (in.)	n [a]	Depth (in.)	SWE (in.)	n [a]	Depth (in.)	SWE (in.)
14_2	4	33.5	12.7	1	54.0	24.4	2	54.0	22.0	1	21.5	4.8	1	103.5	34.6
14_3	4	22.5	8.4	2	56.5	18.4	3	47.3	15.8	4	26.1	8.0	1	50.8	20.7
14_4	4	27.5	11.6	2	29.8	10.5	3	32.7	13.2	4	8.8	2.2	1	88.6	39.2
14_5	3	85.8	39.1				2	106.5	45.9	2	85.0	44.4	1	151.6	71.1
14_6	4	41.3	15.0	2	44.5	19.3	2	63.5	23.9	3	42.5	13.2	1	58.3	22.8
14_7	4	48.1	19.5	1	64.0	20.8	3	53.5	19.9	3	39.0	15.9	1	73.2	18.9
14_8	4	42.2	13.7	3	49.2	16.6	3	80.7	32.3				1	103.5	38.7
14_9	4	32.7	13.4				3	85.0	29.0				1	36.6	11.8
20_1				2	9.2	3.8	8	4.7	1.3	1	2.0	0.6			
20_2				4	50.4	21.1	3	31.2	12.3	1	21.5	5.3			
20_3				2	76.5	34.4	3	68.7	28.7	2	31.5	11.0			
20_4				3	48.7	17.9	4	26.6	10.5	3	17.2	6.3			
20_5				2	65.5	26.9	3	65.0	28.0	4	21.1	7.4			
20_6				2	72.0	28.3	4	41.4	14.2	3	12.2	3.5			
20_7				3	44.0	16.6	4	39.6	11.2	1	3.0	1.0			
20_8				1	84.0	15.8	3	54.5	18.3	3	48.8	15.3			
20_9				3	46.0	14.1	3	49.3	15.0	1	41.0	13.9			
21_1				4	31.6	12.5	3	14.7	4.6	1	6.5	2.2	1	33.0	13.4
21_2				4	41.9	17.6	4	34.6	13.0	1	20.5	7.3	1	69.5	27.7
21_3				4	51.6	22.6	4	9.6	3.6	1	25.0	9.1	1	37.0	19.1
21_4				1	124.0	53.3	2	93.5	36.3	1	53.0	19.1	2	130.2	50.8
21_5				4	47.8	15.5	4	40.8	7.9	1	29.0	7.6	1	72.0	22.9
21_6				4	40.6	16.4	3	19.5	5.7	1	4.5	1.5	1	49.0	14.3
21_8				2	33.0	14.8				3	15.0	5.9	1	48.0	15.3
22_1							3	5.1	1.7				1	20.5	7.3
22_2				3	29.0	13.0	3	7.6	4.1				1	27.2	9.9
22_3				4	54.5	24.8	4	20.5	8.0	1	25.5	10.5	1	69.3	27.8

Plot	2004 Average			2005 Average			2006 Average			2007 Average			2008 Average		
	n [a]	Depth (in.)	SWE (in.)	n [a]	Depth (in.)	SWE (in.)	n [a]	Depth (in.)	SWE (in.)	n [a]	Depth (in.)	SWE (in.)	n [a]	Depth (in.)	SWE (in.)
22_4				1	117.0	50.3	3	67.8	28.8	1	71.0	31.3	1	161.4	76.2
22_5				1	92.0	29.4	2	87.5	36.1				1	137.8	63.9
22_6				1	114.5	44.2	2	88.8	35.4	1	92.0	38.8	1	105.1	38.6
22_7				3	80.0	29.6	3	43.0	12.9	1	45.0	15.4	1	65.4	22.0
22_8				3	34.7	14.0	3	23.2	8.6				1	24.0	8.3
23_1				3	24.0	9.9	1	8.8	2.3	2	9.0	1.8	1	28.5	9.2
23_2				4	23.1	10.4	1	10.0	2.9	3	7.8	1.3	1	31.5	11.2
23_3				2	69.0	31.8	4	55.5	17.9	2	55.5	25.6	1	56.7	22.3
23_4				4	20.2	9.6	4	8.3	2.9	3	3.6	1.2	1	22.8	6.4
23_5				2	59.0	25.8	3	62.3	27.6	2	27.8	10.5	1	64.2	24.4
23_6				4	30.4	12.5	1	78.0	34.9	1	11.0	4.3	1	34.6	12.1
23_7				3	68.2	24.0	2	88.5	31.5	1	59.5	21.5	1	88.6	32.1
23_8				3	45.0	19.3	4	37.5	12.4	1	19.5	7.6	1	74.4	25.3
24_1				2	0.5	0.3	3	2.0	0.8	2	4.1	1.4	1	8.5	2.9
24_2				4	12.7	4.7	3	21.2	7.2	3	11.7	2.8	1	24.5	9.6
24_3				3	50.4	19.7	4	58.0	19.6	2	38.0	14.8	1	47.5	15.3
24_4				3	66.2	23.2	3	71.1	25.0	3	47.0	17.7	1	73.5	31.1
24_5				4	11.6	6.0	3	8.0	1.6	1	0.2	0.0	1	12.5	4.3
24_6				2	84.0	25.3	4	76.5	24.5	2	56.5	20.5	1	119.0	46.4
24_7				3	56.7	16.2	3	54.2	16.2	1	34.0	11.5	1	66.9	23.0
25_1				4	36.3	15.5	4	17.1	5.0	2	7.3	2.4			
25_2				4	54.9	22.2	4	34.8	12.7	2	16.3	8.0			
25_3				2	101.0	49.2	2	65.5	28.2	2	39.8	19.2			
25_4				4	28.5	10.3	3	10.6	2.9	1	13.3	4.6			
25_5				4	36.3	14.3	4	21.6	8.2	1	17.0	8.1			
25_6				3	74.3	33.0	2	53.8	24.8	3	27.7	11.1			
25_7				4	71.3	29.4	3	45.2	16.1	1	28.0	6.7			

	2004 Average			2005 Average			2006 Average			2007 Average			2008 Average		
Plot	n [a]	Depth (in.)	SWE (in.)	n [a]	Depth (in.)	SWE (in.)	n [a]	Depth (in.)	SWE (in.)	n [a]	Depth (in.)	SWE (in.)	n [a]	Depth (in.)	SWE (in.)
25_8				4	64.0	22.1	3	56.0	17.5	2	40.5	11.9			
25_9				2	62.0	26.5				2	87.5	40.4			
26_1				2	5.2	2.1				2	6.8	2.4			
26_10				3	15.6	5.4	4	30.9	8.5	4	14.4	4.1			
26_2				4	27.1	9.6				3	25.5	6.7			
26_3				4	9.1	3.8	4	41.0	14.8	3	17.8	6.5			
26_4				3	30.2	11.1	3	22.2	7.8	3	8.7	2.9			
26_5				3	3.7	1.9	4	5.4	1.7	3	7.2	1.8			
26_6				1	98.0	43.5	2	107.0	44.0	3	49.3	20.1			
26_7				4	60.8	27.9	3	61.2	21.5	4	54.1	23.3			
26_9				1	105.0	37.3	3	92.3	38.4	3	78.8	28.3			
27_1				4	12.7	4.7	4	14.9	5.4				1	5.0	0.9
27_2				4	13.1	6.2	3	27.3	11.2				1	45.5	22.9
27_3				4	10.4	3.5	4	25.4	9.2				1	37.0	18.2
27_4				4	10.3	4.2	3	29.3	8.8				1	35.0	15.3
27_6				2	12.0	4.7	4	28.4	10.6				1	35.0	16.2
27_7				4	9.1	3.8	3	29.7	11.0				1	38.0	15.3
27_8				3	9.5	4.0	3	26.7	10.5				1	22.0	11.9
30_1										2	23.8	9.6	1	35.4	11.8
30_10										2	90.5	42.8	2	207.7	100.4
30_2										2	21.5	4.8	1	63.0	23.1
30_3										1	28.0	8.6	1	42.5	14.4
30_4										2	22.0	5.7	1	55.5	17.1
30_5										3	60.3	22.3	1	128.0	58.0
30_6										1	13.5	2.4	1	61.0	21.3
30_7										2	22.8	7.2	1	33.5	10.2
30_8										1	61.0	19.1	1	100.4	41.7

Plot	2004 Average			2005 Average			2006 Average			2007 Average			2008 Average		
	n [a]	Depth (in.)	SWE (in.)	n [a]	Depth (in.)	SWE (in.)	n [a]	Depth (in.)	SWE (in.)	n [a]	Depth (in.)	SWE (in.)	n [a]	Depth (in.)	SWE (in.)
30_9										1	56.0	18.6	1	112.2	43.1
33_1										1	0.9	0.3	1	13.8	6.0
33_2										1	0.0	0.0	1	6.3	2.0
33_3										1	0.0	0.0	2	15.6	5.0
33_4										3	32.2	14.1	1	90.9	38.2
33_5										2	101.5	47.9	1	181.1	86.5
33_6										2	57.5	22.4	1	147.6	69.0
33_7										2	70.8	27.7	1	134.3	61.7
33_8										3	44.3	14.5			
34_1										3	22.5	7.3	1	5.5	1.6
34_10										2	10.6	3.6	1	43.3	14.4
34_11										2	22.5	8.2	1	72.8	27.7
34_12										2	118.5	57.2			
34_2													1	20.1	6.4
34_3										2	10.5	3.2	1	12.6	4.1
34_4										2	7.5	2.5	1	24.8	9.7
34_5										3	18.0	7.6	1	62.6	24.4
34_6										3	9.5	3.2	1	40.2	13.5
34_7										2	8.5	2.9	1	37.8	13.6
34_8										2	22.0	9.1	1	68.9	27.8
34_9										1	42.5	17.2	1	90.6	38.0
38_1										1	12.0	4.1	1	53.1	20.7
38_2										1	28.0	10.3	1	92.9	37.8
38_3										1	34.0	12.9	1	73.6	27.7
38_4										2	31.0	11.7	1	72.0	27.0
38_5										3	27.3	8.4	1	53.1	17.6
38_6										3	19.8	5.4	1	57.9	21.0

Plot	2004 Average			2005 Average			2006 Average			2007 Average			2008 Average		
	n [a]	Depth (in.)	SWE (in.)	n [a]	Depth (in.)	SWE (in.)	n [a]	Depth (in.)	SWE (in.)	n [a]	Depth (in.)	SWE (in.)	n [a]	Depth (in.)	SWE (in.)
38_7										4	10.3	3.4	1	46.1	16.0
38_8										3	21.3	8.3	1	72.8	28.9
41_001_P													1	15.5	8.6
41_006_P													1	20.0	7.1
41_011_P													1	4.3	1.5
41_031_P										1	0.0	0.0	2	11.4	4.0
41_040_P													1	29.0	10.5
41_053_P													1	39.0	11.5
41_058_P													1	0.0	0.0
41_063_P													1	13.5	5.7
41_068_P													1	24.0	9.1
41_073_P													1	14.0	6.2
41_079_P													1	20.1	7.2
41_084_P													1	40.6	15.2
41_089_P													1	13.4	4.7
43_001_P													1	7.1	1.5
43_006_P													1	8.3	1.7
43_011_P													1	15.0	5.7
43_016_P													1	21.7	8.0
43_021_P													4	20.4	6.7
43_028_P													2	16.9	5.5
43_033_P													1	14.6	4.3
43_038_P													1	20.5	5.7
43_042_P													1	14.6	5.1
43_048_P													1	26.4	8.1
43_053_P													1	5.9	0.8
43_058_P													2	27.3	8.6

	2004 Average			2005 Average			2006 Average			2007 Average			2008 Average		
Plot	n [a]	Depth (in.)	SWE (in.)	n [a]	Depth (in.)	SWE (in.)	n [a]	Depth (in.)	SWE (in.)	n [a]	Depth (in.)	SWE (in.)	n [a]	Depth (in.)	SWE (in.)
43_063_P													2	20.8	6.9
43_075_P													1	19.7	6.3
43_080_P													1	21.3	5.2
43_085_P													2	21.1	7.9
43_090_P													1	16.5	4.1
43_095_P													1	23.2	6.7
43_100_P													1	15.7	4.6
47_001_P													1	22.8	7.1
47_003_P													1	19.5	10.0
47_008_P													1	22.4	7.8
47_027_P													1	26.8	6.2
47_032_P													1	24.4	7.8
47_037_P													1	15.0	6.3
47_042_P													1	37.0	15.8
47_047_P													1	9.8	3.3
49_038_P													1	30.7	9.6
49_043_P													17	35.5	11.2
49_048_P													1	10.2	3.5
49_062_P													1	60.6	20.5
49_067_P													1	14.6	4.6
49_072_P													1	70.1	27.2
49_077_P													1	11.8	4.5
49_082_P													1	34.6	11.2
49_087_P													1	62.2	20.6
49_092_P													1	26.8	7.2
49_097_P													2	48.4	12.3
49_102_P													1	41.3	8.5

Plot	2004 Average			2005 Average			2006 Average			2007 Average			2008 Average		
	n [a]	Depth (in.)	SWE (in.)	n [a]	Depth (in.)	SWE (in.)	n [a]	Depth (in.)	SWE (in.)	n [a]	Depth (in.)	SWE (in.)	n [a]	Depth (in.)	SWE (in.)
49_107_P													1	70.9	24.6
50_001_P													2	18.9	7.6
50_006_P													1	5.7	1.2
50_012_P													2	19.2	5.8
50_017_P													2	25.4	10.1
50_022_P													1	4.5	1.5
50_027_P													2	17.8	6.6
50_032_P													1	0.8	0.3
51_001_P													1	56.3	19.1
51_006_P													1	45.7	17.3
51_011_P													1	39.4	14.7
51_016_P													1	42.5	16.0
51_021_P													1	26.0	9.4
51_026_P													1	24.8	7.1
51_031_P													1	20.5	7.1
51_036_P													1	57.1	16.8
51_041_P													1	28.0	7.4
51_047_P													1	22.0	8.3
51_051_P													1	45.3	15.4
51_056_P													2	39.4	13.2
51_061_P													1	67.7	22.6
51_066_P													1	73.6	23.1
51_071_P													1	124.0	55.8
R02C14										11	24.5	10.0			
R05C05										9	11.4	3.5			
R05C06										25	22.0	8.1			
R05C14										25	25.1	10.2			

Plot	2004 Average			2005 Average			2006 Average			2007 Average			2008 Average		
	n [a]	Depth (in.)	SWE (in.)	n [a]	Depth (in.)	SWE (in.)	n [a]	Depth (in.)	SWE (in.)	n [a]	Depth (in.)	SWE (in.)	n [a]	Depth (in.)	SWE (in.)
R06C12										8	61.3	26.6			
R07C01										14	6.6	2.0	14	20.8	6.6
R07C04										9	1.8	0.6			
R07C05										25	30.2	10.4			
R07C06										16	2.5	0.8			
R07C11										24	23.8	5.6			
R07C12										31	21.9	8.1			
R07C13										19	21.3	7.7			
R08C01										9	4.7	1.5			
R08C05										8	21.8	6.8			
R08C10										14	30.2	8.6			
R08C11										24	4.3	1.2			
R08C13										10	2.2	0.7			
R09C10										7	26.5	8.1			
R09C11										22	22.7	6.2			
R10C10										23	0.5	0.2			

Notes:

a. n is the number of samples at each plot.

b. Plots at proposed meteorological station locations. The stations were established at other locations.

c. Plots at actual meteorological station locations.

TABLE 3
Field Ablation Rates and Spring Precipitation, Pebble Snow Courses, 2004–2008

	Pebble Snow Course 1				Pebble Snow Course 1A				Pebble Snow Course 2			
Season	Dates	Precip (in.)	SWE (in.)	Ablation Rate (in/day)	Dates	Precip (in.)	SWE (in.)	Ablation Rate (in./day)	Dates	Precip (in.)	SWE (in.)	Ablation Rate (in./day)
WINTER 2003/2004												
Distribution Snow Survey	April 15	n/a	10.5		April 15	n/a	8.2		April 15	n/a	9.8	
(between snow surveys)	April 16–May 1	n/a		-0.09	April 16–May 1	n/a		0.00	April 16–May 2	n/a		0.20
Ablation 1 Snow Survey	May 2	n/a	12.0		May 2	n/a	8.2		May 3	n/a	6.2	
(between snow surveys)	May 3–May 15	n/a		0.58	May 3– May 15	n/a		0.36	May 4–14	n/a		0.46
Ablation 2 Snow Survey	May 16	n/a	3.9		May 16	n/a	3.1		May 15	n/a	0.7	
WINTER 2004/2005 [a]												
Distribution Snow Survey	April 12	0.00	15.5		April 12	0.00	13.8		April 11	0.10	12.0	
(between snow surveys)	April 13–28	2.64		0.38	April 13–28	2.64		0.34	April 12–28	1.32		0.33
Ablation 1 Snow Survey	April 29	0.28	11.9		April 29	0.28	10.9		April 29	0.14	7.5	
(between snow surveys)	April 30–May 12	0.54		0.49	April 30–May 12	0.54		0.38	April 30–May 12	0.27		0.51
Ablation 2 Snow Survey	May 13	0.32	5.8		May 13	0.32	6.4		May 13	0.16	0.8	
WINTER 2005/2006 [b]												
Distribution Snow Survey	April 18	0.00	9.7		April 18	0.00	7.5		April 16 & 23 (20[c])	0.01	8.1	
(between snow surveys)	April 19–May 12	1.78		0.04	April 19–May 12	1.78		0.10	April 21–May 12	1.28		0.20
Ablation 1 Snow Survey	May 13	0.00	10.5		May 13	0.00	6.8		May 13	0.00	4.8	
(between snow surveys)	May 14–21	0.34		0.39	May 14–21	0.34		0.20	May 14–22	0.31		0.29
Ablation 2 Snow Survey	May 22	0.00	7.3		May 22	0.00	5.4		May 23	0.00	2.3	

Season	Pebble Snow Course 1				Pebble Snow Course 1A				Pebble Snow Course 2			
	Dates	Precip (in.)	SWE (in.)	Ablation Rate (in/day)	Dates	Precip (in.)	SWE (in.)	Ablation Rate (in./day)	Dates	Precip (in.)	SWE (in.)	Ablation Rate (in./day)
WINTER 2006/2007 [b]												
Distribution Snow Survey	April 8	0.08	5.8		April 8	0.08	5.3		April 6	0.12	6.3	
(between snow surveys)	April 9–April 22	1.87		0.13	April 9–April 22	1.87		0.15	April 7–April 23	2.22		0.22
Ablation 1 Snow Survey	April 23	0.00	5.7		April 23	0.00	5.0		April 24	0.02	4.6	
(between snow surveys)	April 24–May 6	0.28		0.17	April 24–May 6	0.28		0.13	April 25–May 7	0.23		0.15
Ablation 2 Snow Survey	May 7	0.00	3.6		May 7	0.00	3.4		May 8	0.00	2.7	
(between snow surveys)	May 8–May 18	0.78		0.20	May 8–May 18	0.78		0.16	May 9–May 20	0.30		0.23
Ablation 3 Snow Survey	May 19	0.00	2.0		May 19	0.00	2.2		May 21	0.00	0.0	
WINTER 2007/2008 [b]												
Distribution Snow Survey	April 8	0.05	19.4		April 8	0.05	16.7		April 7	0.03	15.6	
(between snow surveys)	April 9–April 21	1.08		0.04	April 9–April 21	1.08		0.10	April 8–April 22	0.97		0.09
Ablation 1 Snow Survey	April 22	0.03	20.0		April 22	0.03	16.5		April 23	0.01	15.2	
(between snow surveys)	April 23–May 5	0.60		0.15	April 23–May 5	0.60		0.12	April 24–May 6	0.51		0.27
Ablation 2 Snow Survey	May 6	0.01	18.5		May 6	0.01	15.3		May 7	0.06	12.0	
(between snow surveys)	May 7–May 20	2.11		0.44	May 7–May 20	2.11		0.38	May 8–May 21	1.87		0.46
Ablation 3 Snow Survey	May 21	0.01	14.1		May 21	0.01	11.8		May 22	0.02	7.1	

Notes:

a. Precipitation data from Pebble Meteorological Station 2.

b. Precipitation data from snow model output.

c. Snow course survey conducted on two dates; the median date of April 20, 2006, was used for this analysis.

TABLE 4
Parameters for Snow Density Model, by Snow Survey, 2004–2008

Year	Survey ID	Survey Name	Survey Start Date	Survey End Date	Intercept [a]	Slope [a]	Shrub Offset [b]	Deep Drift Asymptote [c]	Deep Drift Cutpoint [d]
2004	200401	Distribution 2004	4/13/2004	4/18/2004	0.31377	0.0216	-0.05524	550	6.5
2005	200501	Distribution 2005	4/10/2005	4/16/2005	0.40109	0.0025	-0.05524	522	6
	200502	Ablation 1 2005	4/29/2005	4/30/2005	0.406	0.005	0	550	5.5
2006	200601	Distribution 2006	4/16/2006	4/23/2006	0.30624	0.0172	-0.05524	522	7.5
2007	200701	Distribution 2007	4/3/2007	4/16/2007	0.32096	0.0203	-0.05524	550	6.5
	200702	Ablation 1 2007	4/23/2007	4/25/2007	0.409	-0.001	0	550	4
	200703	Ablation 2 2007	5/7/2007	5/9/2007	0.434	-0.002	0	550	5
	200704	Ablation 3 2007	5/19/2007	5/21/2007	0.405	0.019	0	550	4
2008	200800	Recon 2008	3/1/2008	3/2/2008	0.33824	0.0108	-0.05524	522	11.5
	200801	Distribution 2008, Valley Transects	3/15/2008	3/20/2008	0.33824	0.0108	-0.05524	522	11.5
	200802	Distribution 2008, Mountain Transects	4/5/2008	4/10/2008	0.33824	0.0108	-0.05524	522	11.5
	200803	Ablation 1 2008	4/22/2008	4/23/2008	0.401	0.002	0	550	4
	200804	Ablation 2 2008	5/6/2008	5/7/2008	0.358	0.014	0	550	5
	200805	Ablation 3 2008	5/21/2008	5/22/2008	0.383	0.019	0	550	10

Notes:

a. Modeled Density = Intercept + (Snow Depth (feet) * Slope).

b. For plots located in tall shrub, the Intercept and Shrub Offset are added.

c. The deep drift asymptote is the value of the asymptote parameter in the exponential density function.

d. At snow depths exceeding the deep drift cutpoint (in feet), the exponential density function is applied instead of the linear fit.

TABLE 5
Mean Snow Water Equivalent by Basin (Model and LIDAR), April 2006–2008

	Mean Snow Water Equivalent (inches)			
Basin	SnowModel 4/19/2006	SnowModel 4/9/2007	SnowModel 4/6/2008	LIDAR 4/6/2008
KC100A	13.0	0.2	9.3	
NK100A	21.5	6.1	23.8	
NK100A1	22.3	6.6	25.1	
NK100B	22.8	6.6	25.8	
NK100C	22.6	6.3	26.3	
NK119A	23.8	7.5	24.8	29.4
NK119B	22.3	6.4	25.1	24.8
SK100A	19.5	4.5	19.3	
SK100B	21.3	5.7	21.7	
SK100B1	21.5	5.8	22.0	
SK100C	21.2	5.5	22.2	
SK100F	21.8	6.3	23.7	23.7
SK100G	21.4	5.9	23.9	21.9
SK119A	23.3	6.9	22.6	30.9
SK124A	22.3	6.5	22.7	32.0
UT100APC1	18.9	4.2	18.9	
UT100APC2	18.4	3.9	18.0	
UT100APC3	17.6	3.4	16.4	
UT100B	19.2	4.4	19.6	
UT100C	19.9	5.0	20.9	
UT100C1	20.3	5.3	21.3	
UT100C2	20.6	5.6	21.9	
UT100D	20.5	5.8	22.6	15.2
UT100E	21.4	6.3	25.1	14.1
UT119A	18.1	2.0	17.2	
UT135A	19.9	4.8	21.5	
LIDAR Survey Area	22.0	6.3	23.5	24.4
Mine Study Area	21.9	6.1	23.5	
Extended Mine Study Area	19.0	4.3	18.9	

TABLE 6
Landsat Satellite Imagery Used to Estimate Typical Snow-Free Date

Date	Sensor	Date	Sensor
2/9/1993	Landsat 4	4/23/2002	Landsat 7
2/21/2009	Landsat 7	4/23/2008	Landsat 7
2/23/2007	Landsat 7	5/3/2000	Landsat 7
3/1/2006	Landsat 7	5/3/2003	Landsat 7
3/4/2007	Landsat 7	5/3/2009	Landsat 7
3/6/2002	Landsat 7	5/11/2009	Landsat 5
3/9/2003	Landsat 7	5/13/2001	Landsat 7
3/11/2007	Landsat 7	5/25/2002	Landsat 7
3/16/2009	Landsat 7	5/26/2000	Landsat 7
3/19/2001	Landsat 7	6/4/2000	Landsat 7
3/22/2002	Landsat 7	6/6/2004	Landsat 7
3/27/2004	Landsat 7	6/17/2002	Landsat 7
3/27/2007	Landsat 7	7/6/2009	Landsat 7
4/1/2000	Landsat 7	7/15/2003	Landsat 7
4/7/2002	Landsat 7	8/2/2004	Landsat 7
4/7/2008	Landsat 7	8/12/2005	Landsat 7
4/12/2004	Landsat 7	8/28/1999	Landsat 7
4/15/2005	Landsat 7	8/30/1991	Landsat 5

TABLE 7
Terra MODIS Satellite Images Used to Estimate Fractional Snow-Covered Area, 2000–2008

Date	Time (UTC)	Date	Time (UTC)	Date	Time (UTC)	Date	Time (UTC)	Date	Time (UTC)
3/11/2000	2140	5/19/2001	2120	6/17/2002	2150	3/20/2005	2105	3/14/2007	2220
3/12/2000	2220	5/27/2001	2210	3/5/2003	2205	4/3/2005	2115	3/15/2007	2125
3/14/2000	2210	5/28/2001	2115	3/7/2003	2155	4/10/2005	2125	3/16/2007	2205
3/17/2000	2240	5/30/2001	2240	3/9/2003	2140	4/11/2005	2205	3/18/2007	2155
3/18/2000	2145	5/31/2001	2145	3/11/2003	2130	4/12/2005	2110	3/19/2007	2235
3/27/2000	2140	6/1/2001	2225	3/12/2003	2215	4/13/2005	2155	3/30/2007	2220
3/31/2000	2250	6/2/2001	2130	3/19/2003	2220	4/15/2005	2140	4/1/2007	2205
4/1/2000	2155	6/11/2001	2125	3/23/2003	2155	4/24/2005	2135	4/11/2007	2105
4/6/2000	2215	3/4/2002	2155	3/27/2003	2130	4/28/2005	2110	4/12/2007	2142
4/15/2000	2210	3/6/2002	2145	3/28/2003	2215	4/29/2005	2155	4/14/2007	2135
4/22/2000	2215	3/9/2002	2215	4/3/2003	2135	4/30/2005	2100	4/16/2007	2125
4/29/2000	2220	3/11/2002	2200	4/6/2003	2205	5/2/2005	2225	4/26/2007	2200
5/1/2000	2210	3/29/2002	2150	4/19/2003	2135	5/8/2005	2145	4/30/2007	2135
5/5/2000	2145	3/31/2002	2135	4/23/2003	2110	5/9/2005	2230	5/3/2007	2205
5/7/2000	2135	4/2/2002	2125	4/29/2003	2210	5/10/2005	2135	5/11/2007	2115
5/10/2000	2205	4/4/2002	2110	4/30/2003	2115	5/11/2005	2220	5/21/2007	2155
5/12/2000	2150	4/5/2002	2155	5/3/2003	2150	3/27/2006	2220	6/6/2007	2155
5/26/2000	2205	4/7/2002	2145	5/16/2003	2115	4/6/2006	2115	6/10/2007	2130
6/5/2000	2240	4/10/2002	2215	5/20/2003	2230	4/15/2006	2110	3/18/2008	2205
3/17/2001	2205	4/11/2002	2120	5/23/2003	2125	4/27/2006	2135	3/19/2008	2110
3/19/2001	2150	4/12/2002	2200	5/24/2003	2205	4/29/2006	2125	3/23/2008	2225
3/21/2001	2140	4/23/2002	2145	5/25/2003	2110	5/12/2006	2230	3/25/2008	2210
3/22/2001	2225	4/24/2002	2225	6/13/2003	2140	5/17/2006	2110	3/26/2008	2115
3/31/2001	2215	4/29/2002	2105	4/1/2004	2200	5/23/2006	2210	3/28/2008	2105
4/4/2001	2150	5/10/2002	2225	4/12/2004	2140	5/29/2006	2135	4/5/2008	2155
4/5/2001	2235	5/11/2002	2130	4/25/2004	2110	6/3/2006	2155	4/7/2008	2140
4/14/2001	2230	5/12/2002	2215	5/4/2004	2105	2/20/2007	2115	4/9/2008	2130
4/17/2001	2120	5/13/2002	2120	5/6/2004	2230	2/21/2007	2200	4/10/2008	2210
4/18/2001	2205	5/14/2002	2200	5/7/2004	2135	2/23/2007	2150	4/11/2008	2115
4/24/2001	2125	5/16/2002	2150	5/14/2004	2140	2/28/2007	2205	4/12/2008	2200
4/27/2001	2200	5/18/2002	2135	5/20/2004	2105	3/1/2007	2110	4/18/2008	2125
4/29/2001	2145	5/19/2002	2220	5/22/2004	2230	3/2/2007	2155	4/23/2008	2140
5/4/2001	2205	5/20/2002	2125	6/6/2004	2150	3/4/2007	2140	4/25/2008	2130
5/8/2001	2140	5/24/2002	2240	6/26/2004	2125	3/6/2007	2130	5/17/2008	2055
5/11/2001	2210	5/25/2002	2145	2/27/2005	2225	3/9/2007	2200	5/20/2008	2125
5/13/2001	2155	6/7/2002	2115	2/28/2005	2130	3/11/2007	2150	5/21/2008	2205
5/14/2001	2240	6/14/2002	2120	3/18/2005	2115	3/12/2007	2230	5/27/2008	2130
5/18/2001	2215	6/15/2002	2200	3/19/2005	2200	3/13/2007	2135		

Note:

UTC = Universal Coordinated Time.

FIGURES

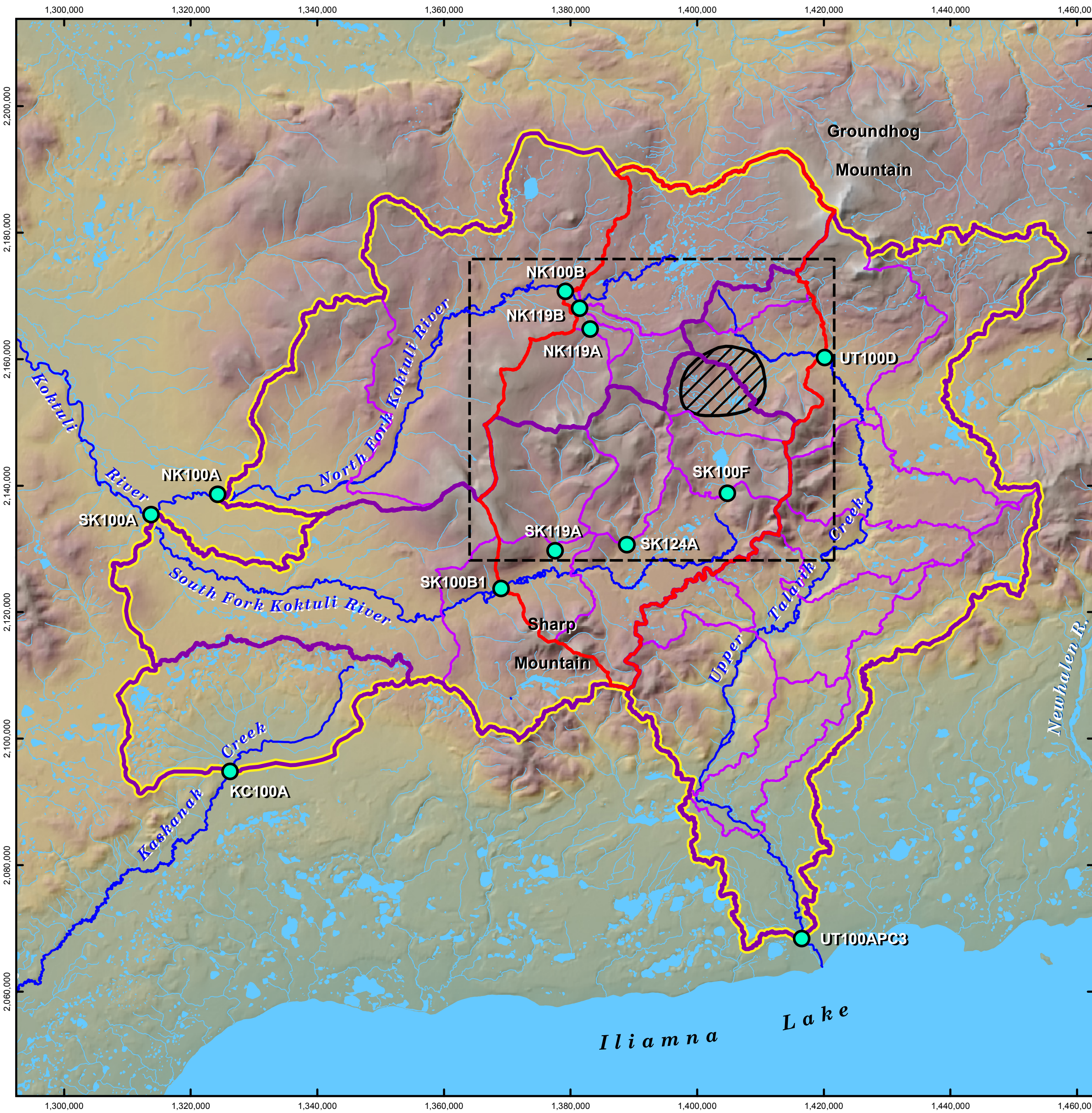

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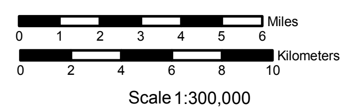
Figure 7.2D-1
Snow Survey Study Areas, 2004–2008

Legend

- Mine Study Area
- Extended Mine Study Area
- Basin Boundary
- Monitored Sub-basin Boundary
- Lidar Survey Area
- Stream Discharge Gaging Station
- General Deposit Location



Scale 1:300,000

Alaska State Plane Zone 5 (units feet)
1983 North American Datum

File: 7-2D-01_SnowSA_2004-08_PLP_EBD_v01.mxd	Date: Jan. 18, 2011
Version: 1	Author: ABR-AZC

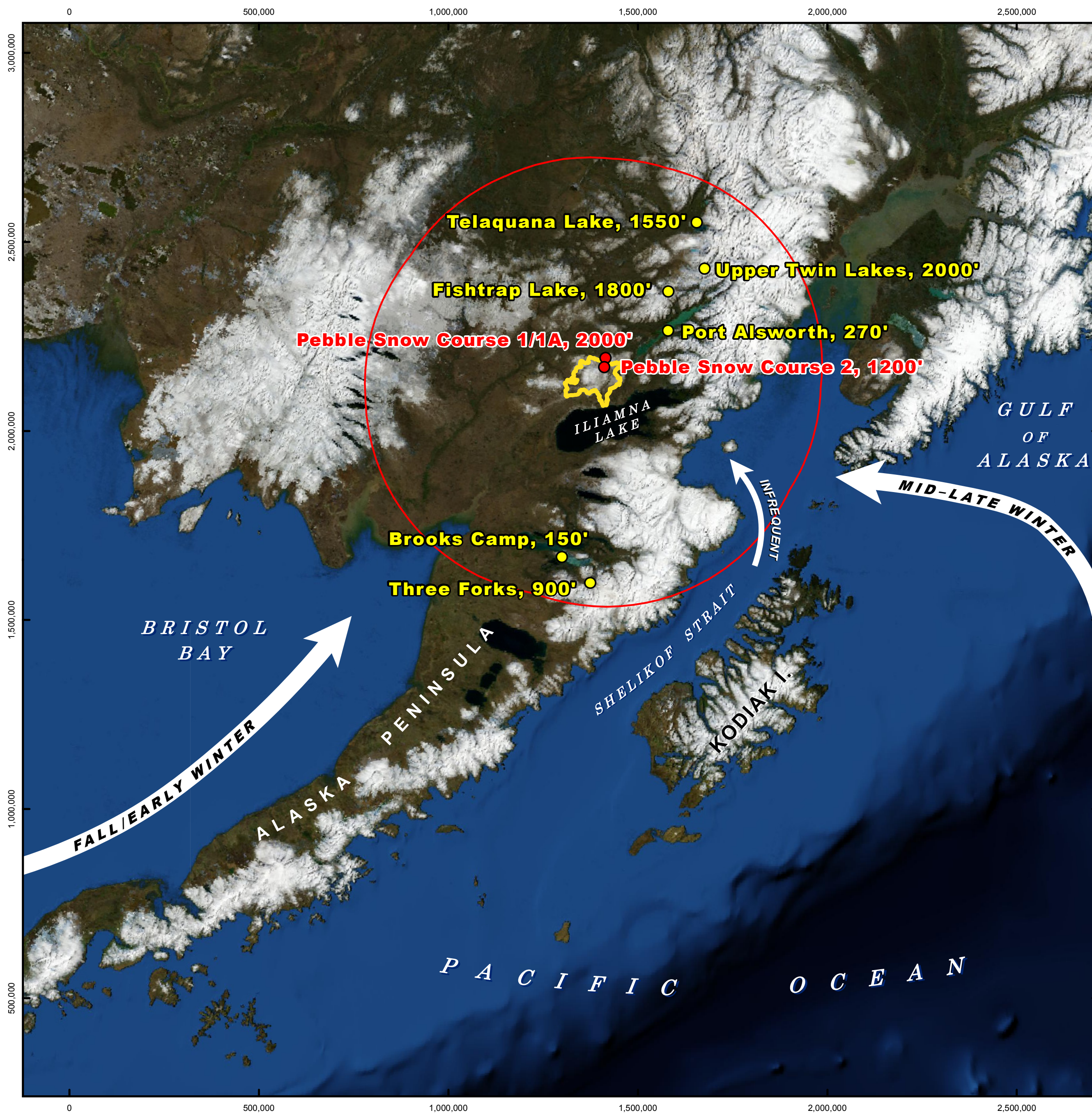


Figure 7.2D-2
Regional NRCS and Pebble Snow Course Locations

Legend

- Pebble Snow Course
- NRCS Snow Course
- 100-mile Distance from Major Drainages
- Extended Mine Study Area
- Dominant Flow Pattern

Background image:
Blue Marble Next Generation
acquired May 2004.

Miles: 0, 25, 50, 75, 100
Kilometers: 0, 50, 100, 150

N

Scale 1:5,000,000

Alaska State Plane Zone 5 (units feet)
1983 North American Datum

File: 7-2D-02_NRCSRegSnowCourse_PLP_EBD_v01.mxd	Date: Jan. 18, 2011
Version: 1	Author: ABR-AZC

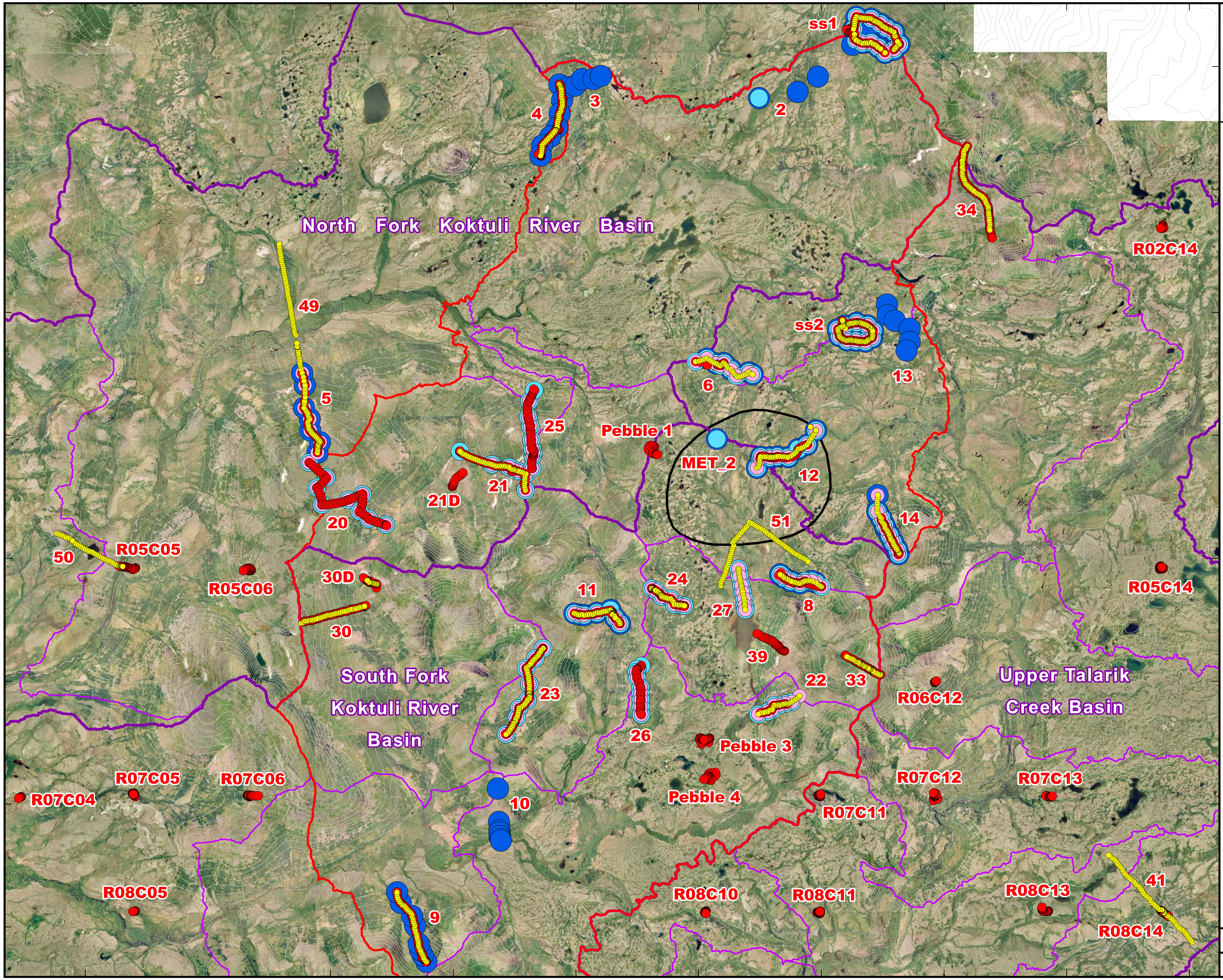


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Figure 7.2D-3 Mine Study Area Field Snow Survey Plots, 2004–2008

Legend

- 2008 Field Survey Plot
- 2007 Field Survey Plot
- 2006 Field Survey Plot
- 2005 Field Survey Plot
- 2004 Field Survey Plot
- Mine Study Area
- Basin Boundary
- Monitored Sub-basin Boundary
- 100-foot Contour
- General Deposit Location

Color orthophotography based on July 2004 1:20,000 scale photography; pixel size is 1.5 feet. Imagery by Kodiak Mapping Inc., Eagle Mapping Ltd., and Resource Data, Inc.

0 0.5 1 1.5 2 2.5 3 Miles

0 1 2 3 4 5 Kilometers

N

Scale 1:98,000

Alaska State Plane Zone 5 (units feet)
1983 North American Datum

File: 7-2D-03_MineSnowFieldPlots_04-08_PLP_EBD_v01.mxd	Date: Jan. 18, 2011
Version: 1	Author: ABR-AZC

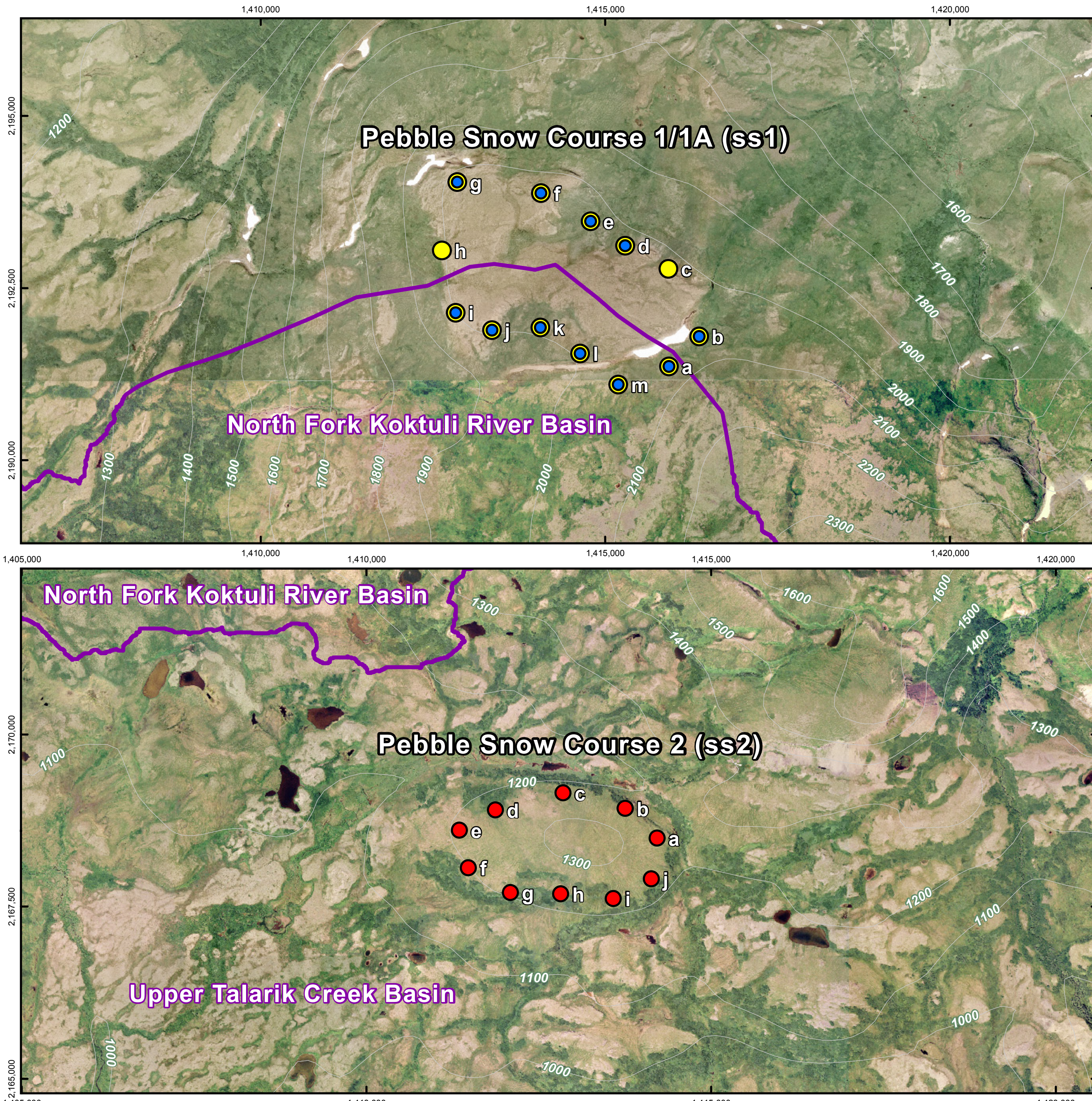

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Figure 7.2D-4
Pebble Snow Course Field Plots, 2004–2008

Legend

- Snow Course 1 Plot
- Snow Course 1A Plot
- Snow Course 2 Plot
- Basin Boundary
- 100-foot Contour

Color orthophotography based on July 2004 1:20,000 scale photography; pixel size is 1.5 feet. Imagery by Kodiak Mapping Inc., Eagle Mapping Ltd., and Resource Data, Inc.

Feet: 0, 1,000, 2,000, 3,000
Meters: 0, 200, 400, 600, 800, 1,000

N

Scale 1:27,500

Alaska State Plane Zone 5 (units feet)
1983 North American Datum

File: 7-2D-04_SnowCoursePlots_Mine_PLP_EBD_v01.mxd	Date: Jan. 18, 2011
Version: 1	Author: ABR-AZC

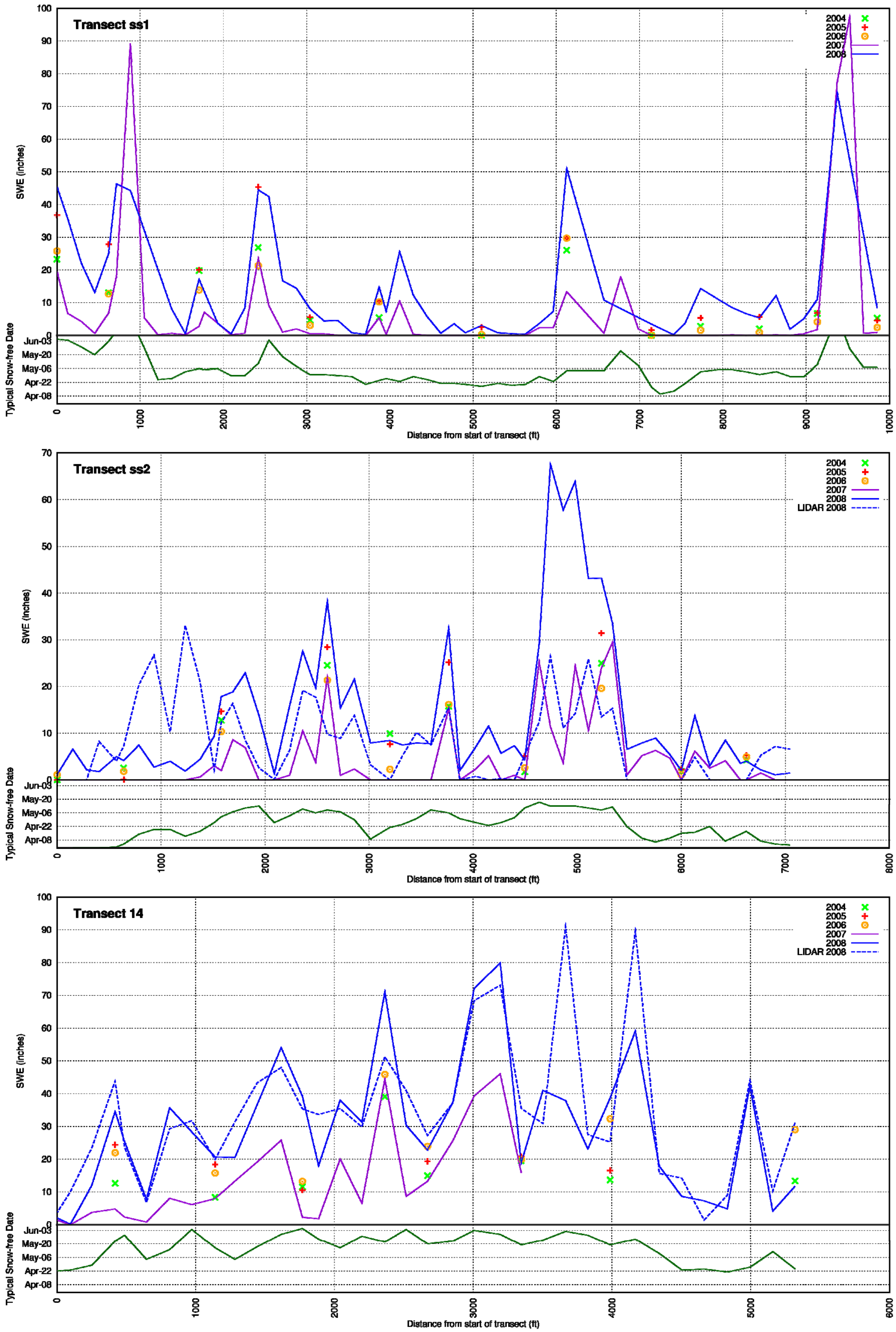

Figure 7.2D-5, Snow Distribution Survey Results (2004–2008), LIDAR Survey Results (2008), and Typical Snow-Free Date from Landsat for Pebble Snow Course 1, Pebble Snow Course 2, and Transect 14

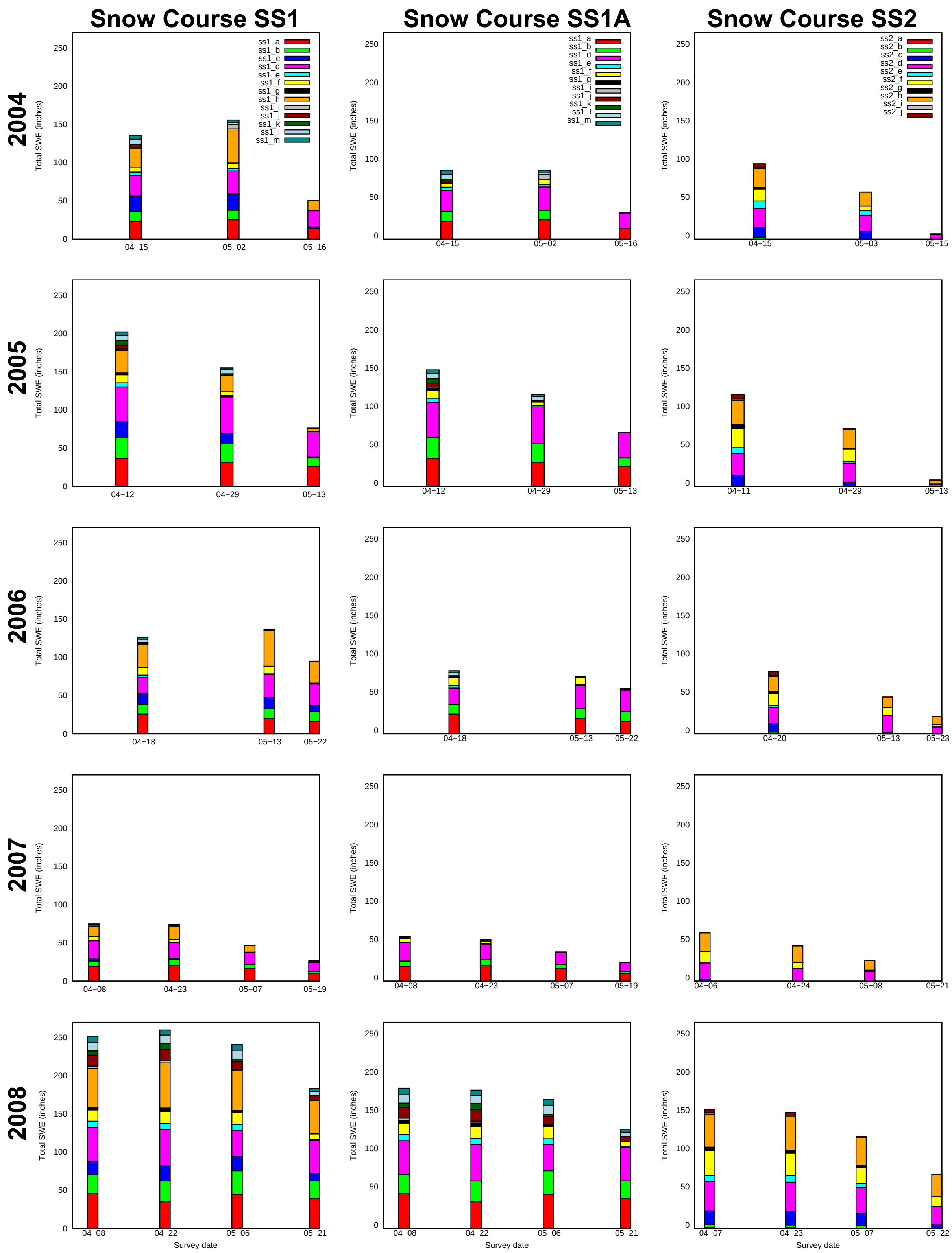

Figure 7.2D-6, Field Ablation Results, Pebble Snow Courses, 2004−2008

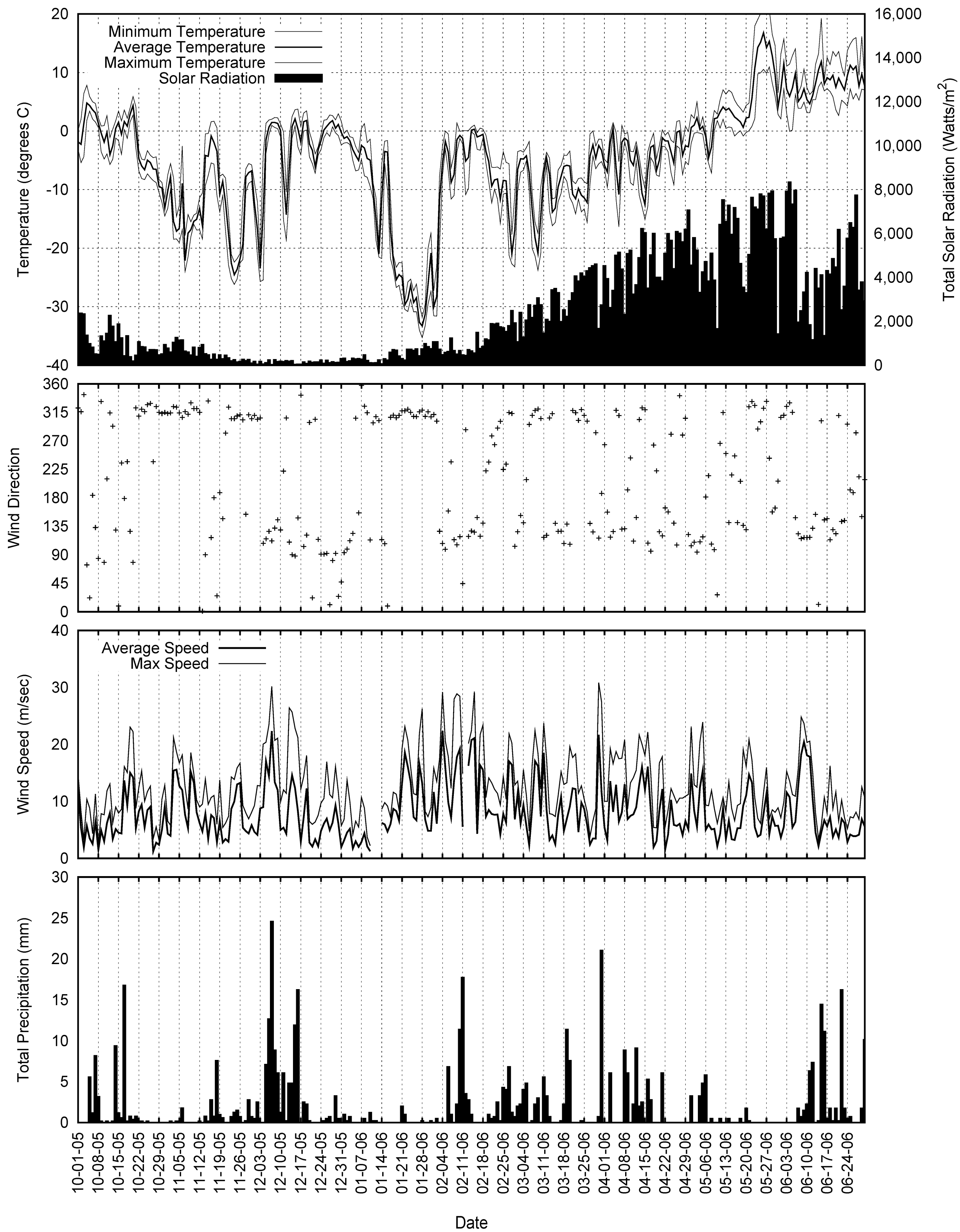

Figure 7.2D-7. Winter Weather at Pebble 1 Meteorological Station, Winter 2005/2006

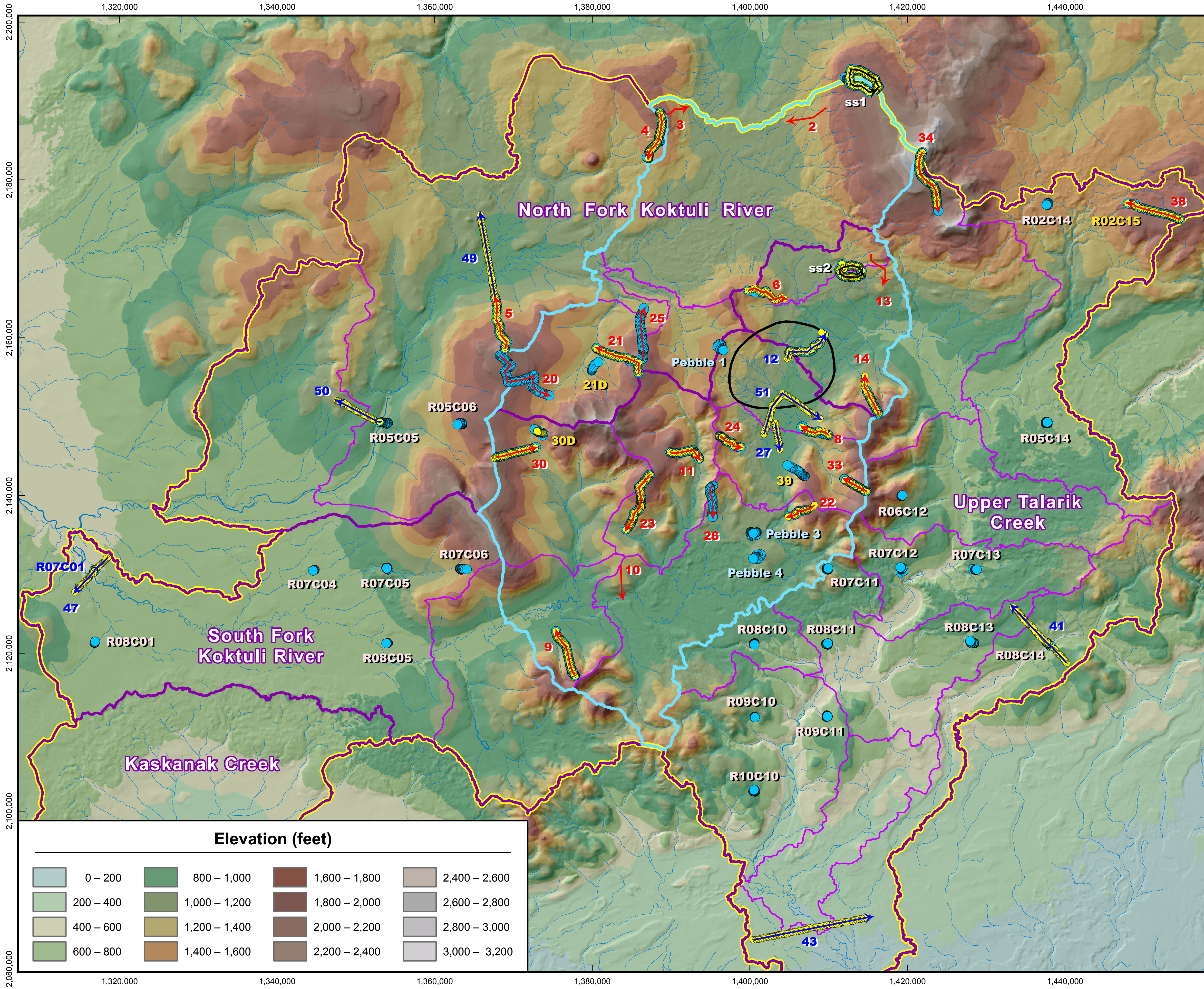

Figure 7.2D-8
Extended Mine Study Area Field Snow Survey Plots, 2004–2008

File: 7-2D-08_ExtMineSnowFldPlots04-08_PLP_EBD_v01.mxd | Date: July 23, 2010
Version: 1 | Author: ABR-AZC

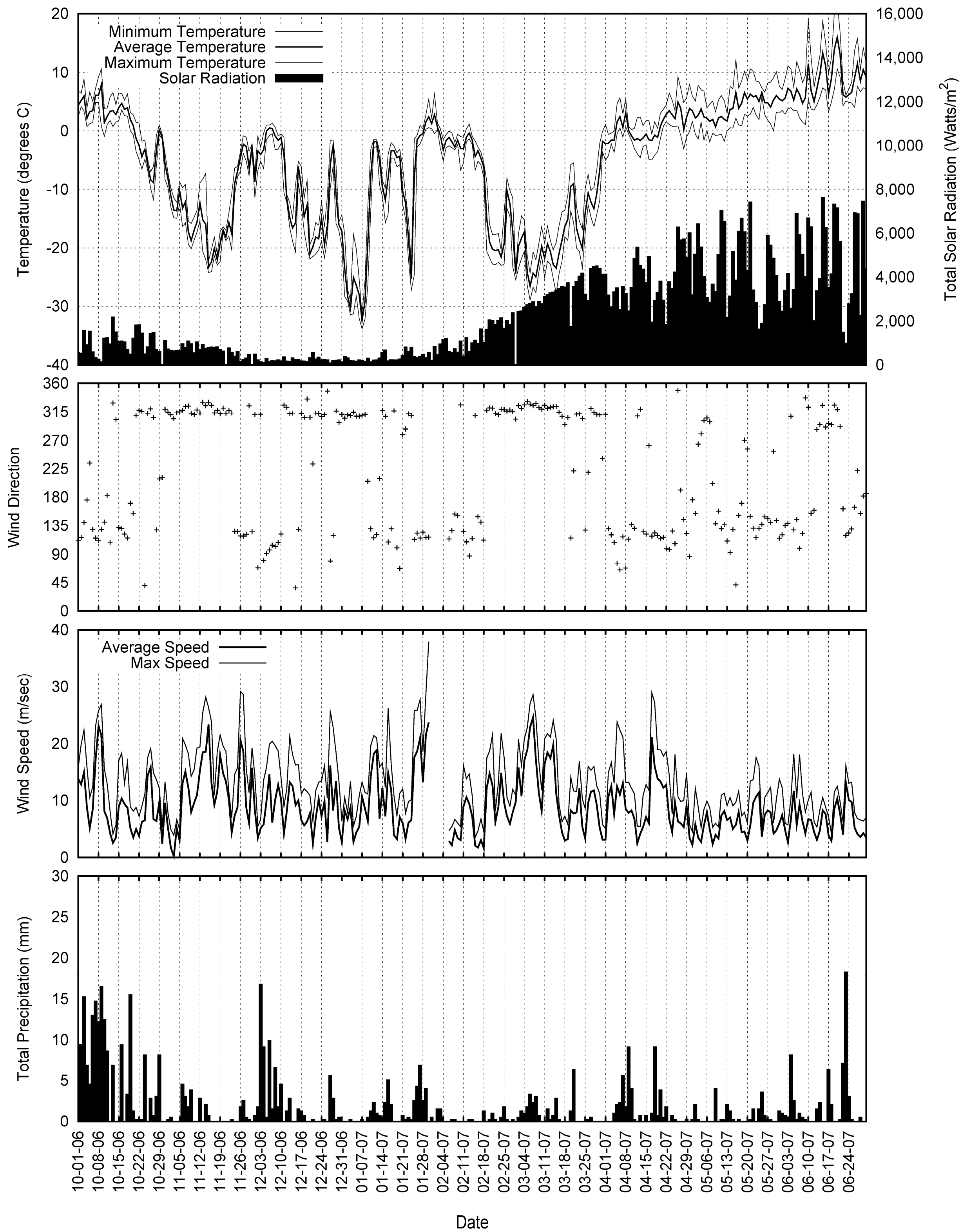

Figure 7.2D-9. Winter Weather at Pebble 1 Meteorological Station, Winter 2006/2007

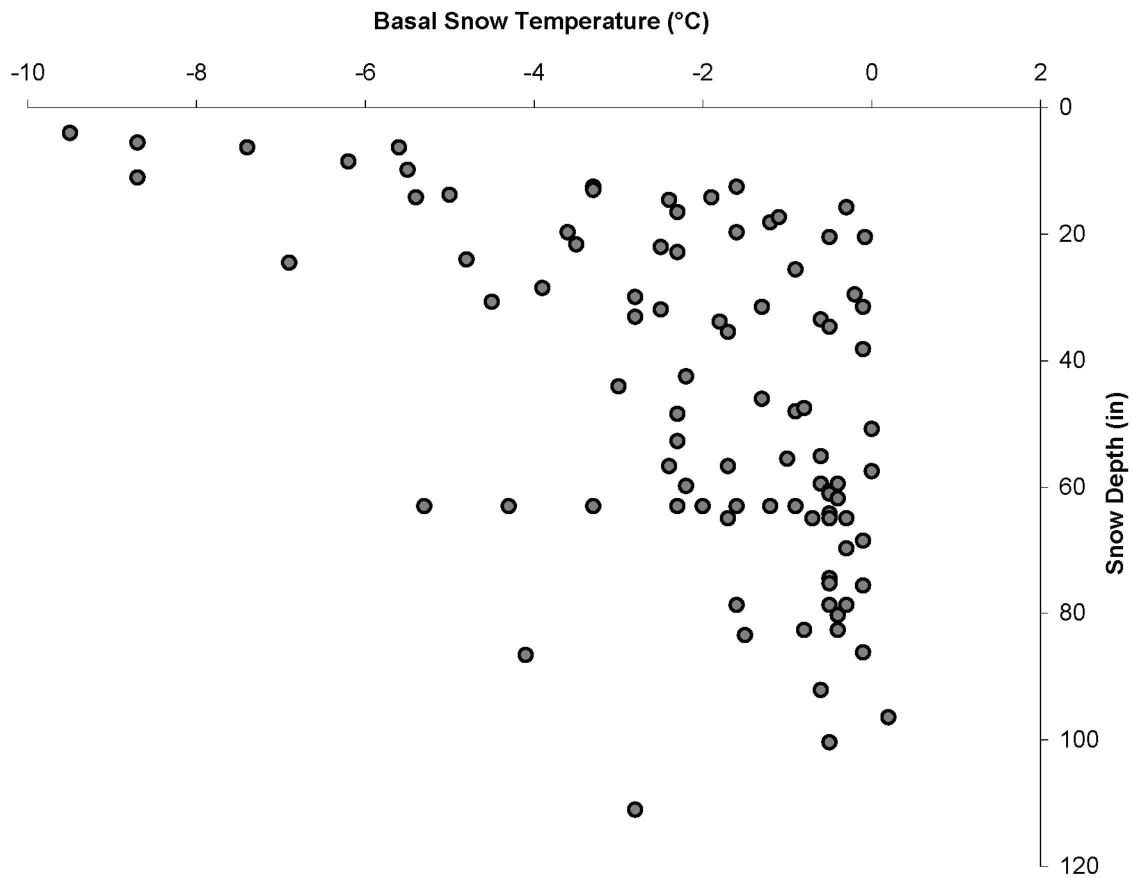

Figure 7.2D-10. Depth and Temperature at Base of Snow Pack at Pebble Snow Plots during the Mountain Distribution Survey, April 5–10, 2008

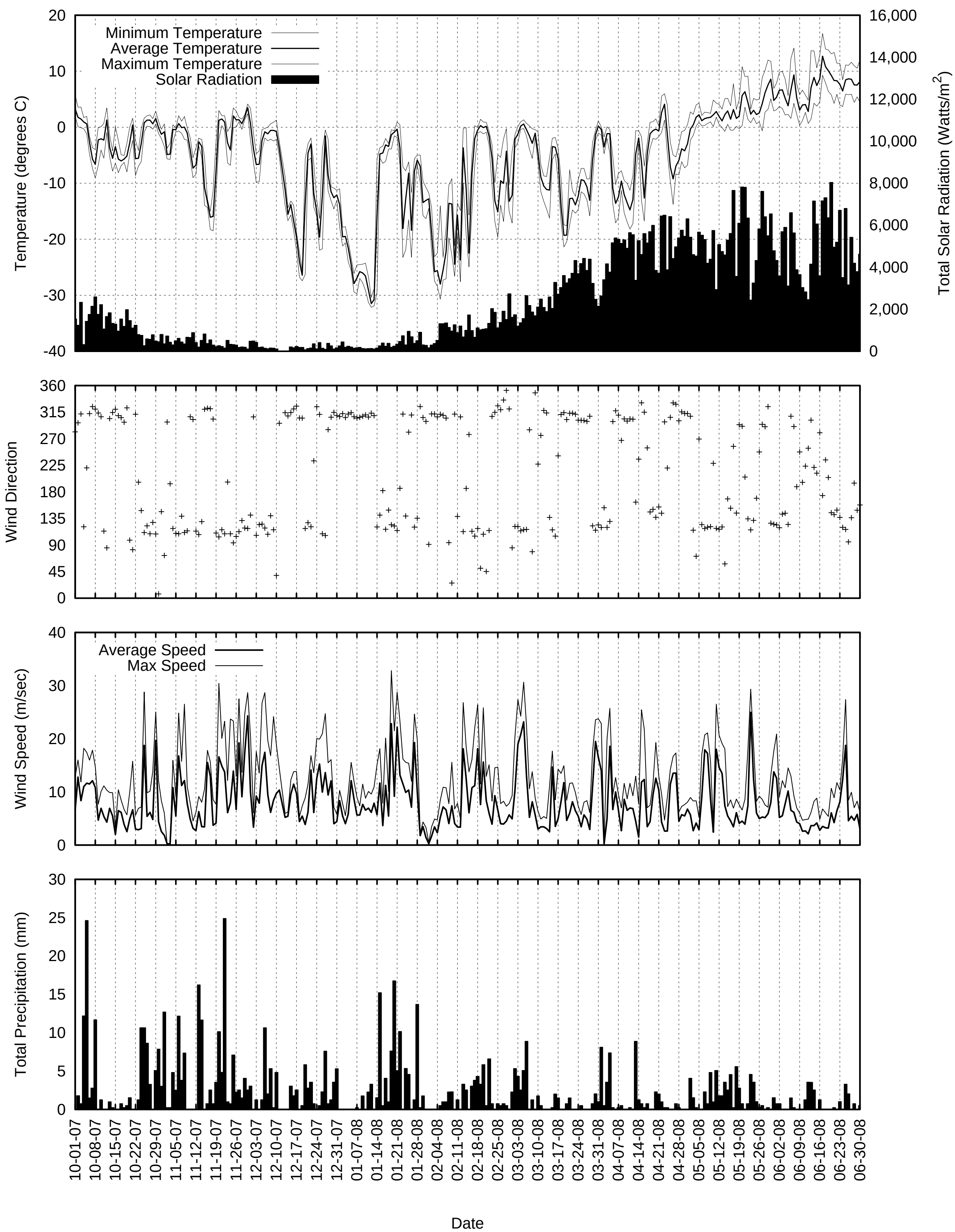

Figure 7.2D-11. Winter Weather at Pebble 1 Meteorological Station, Winter 2007/2008

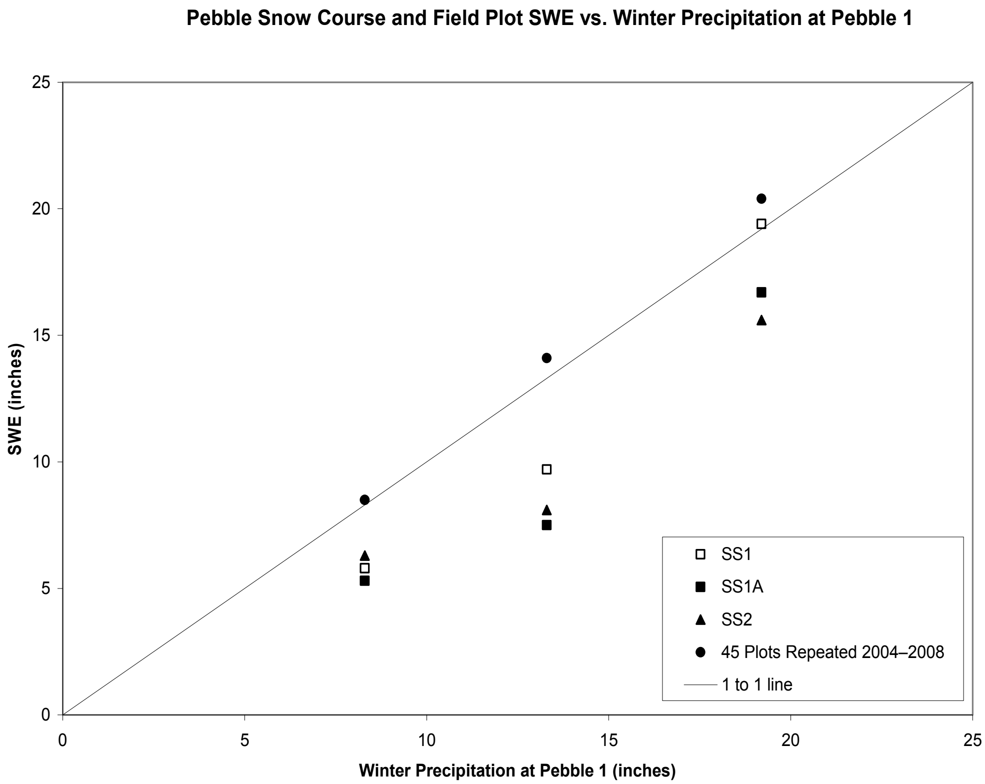

Figure 7.2D-12. Comparison of Pebble Snow Course and Field Plot SWE with Winter Precipitation at Pebble 1 Meteorological Station, Winters 2005/2006, 2006/2007, and 2007/2008

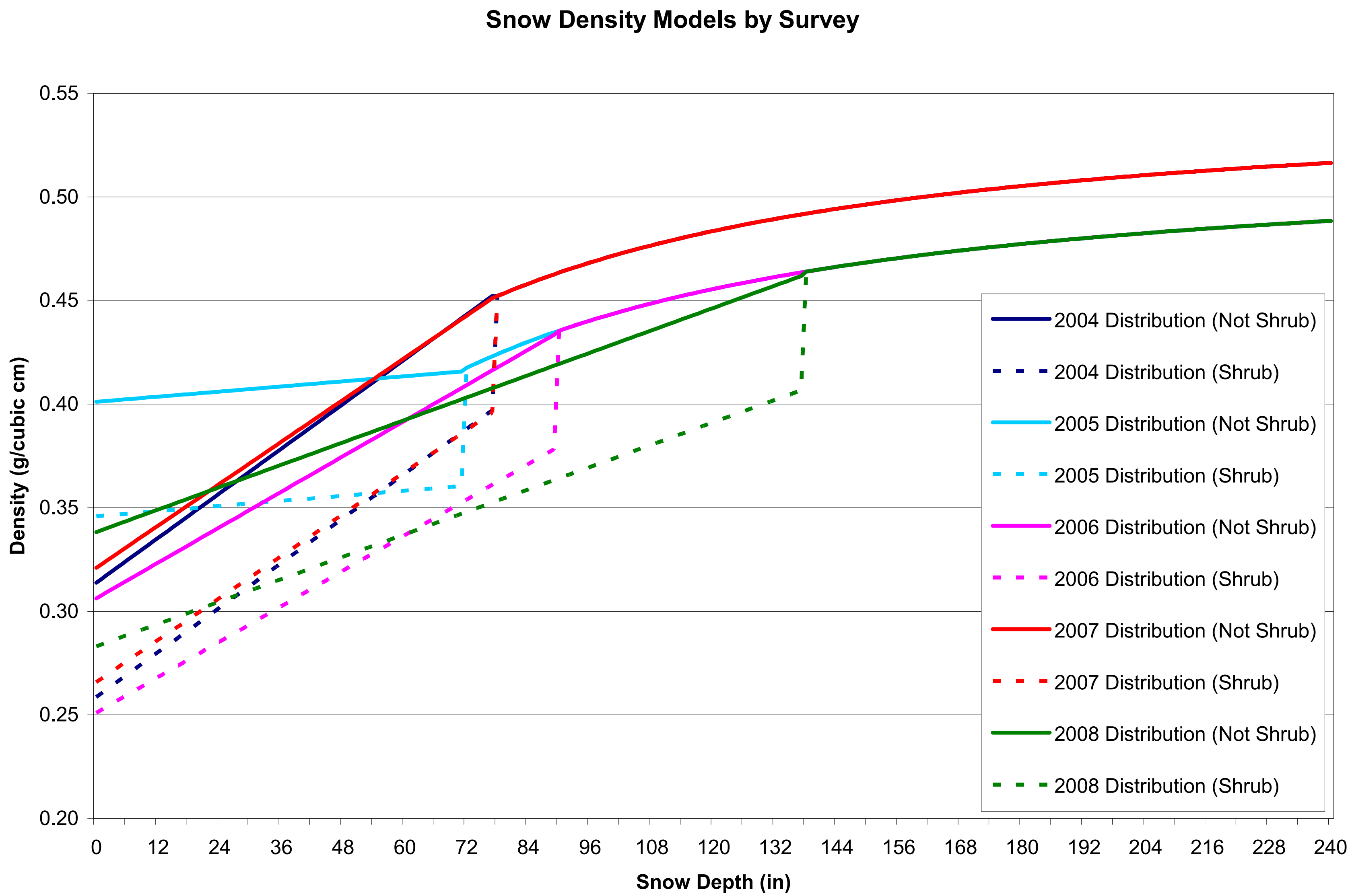

Figure 7.2D-13. Snow Density Models, Snow Distribution Surveys, 2004 through 2008

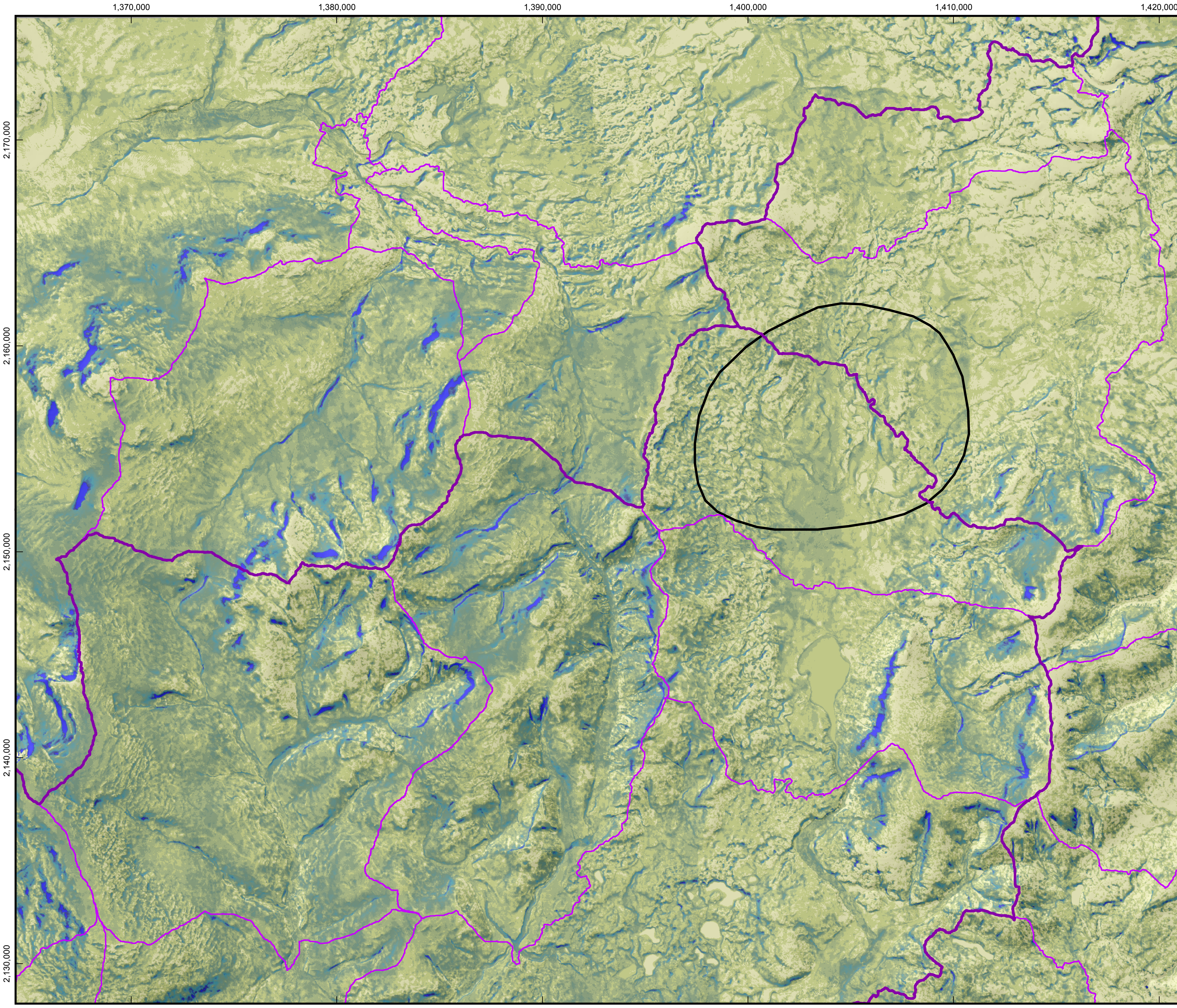

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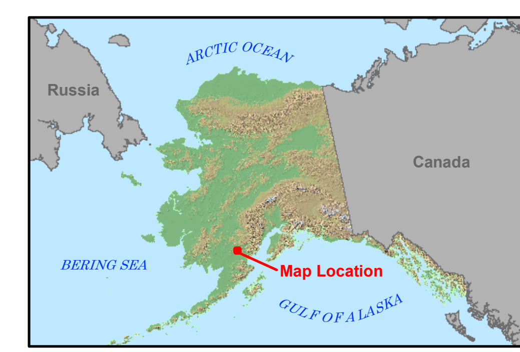
Figure 7.2D-14
Snow Depth Estimated from Lidar, April 6, 2008

Legend

Snow Depth (Feet)

- 0 – 2.00
- 2.01 – 4.00
- 4.01 – 6.00
- 6.01 – 8.00
- 8.01 – 10.00
- 10.01 – 12.00
- 12.01 – 14.00
- 14.01 – 16.00
- 16.01 – 18.00
- 18.01 – 20.00
- 20.01 – 22.00
- 22.01 – 24.00
- >24

- Basin Boundary
- Monitored Sub-basin Boundary
- General Deposit Location



0 0.5 1 1.5 2 Miles

0 0.5 1 1.5 2 2.5 3 Kilometers

N

Scale 1:59,000

Alaska State Plane Zone 5 (units feet)
1983 North American Datum

File: 7-2D-14_Lidar_Depth_Est_2008_PLP_EBD_v01.mxd	Date: Jan. 19, 2011
Version: 1	Author: ABR-AZC

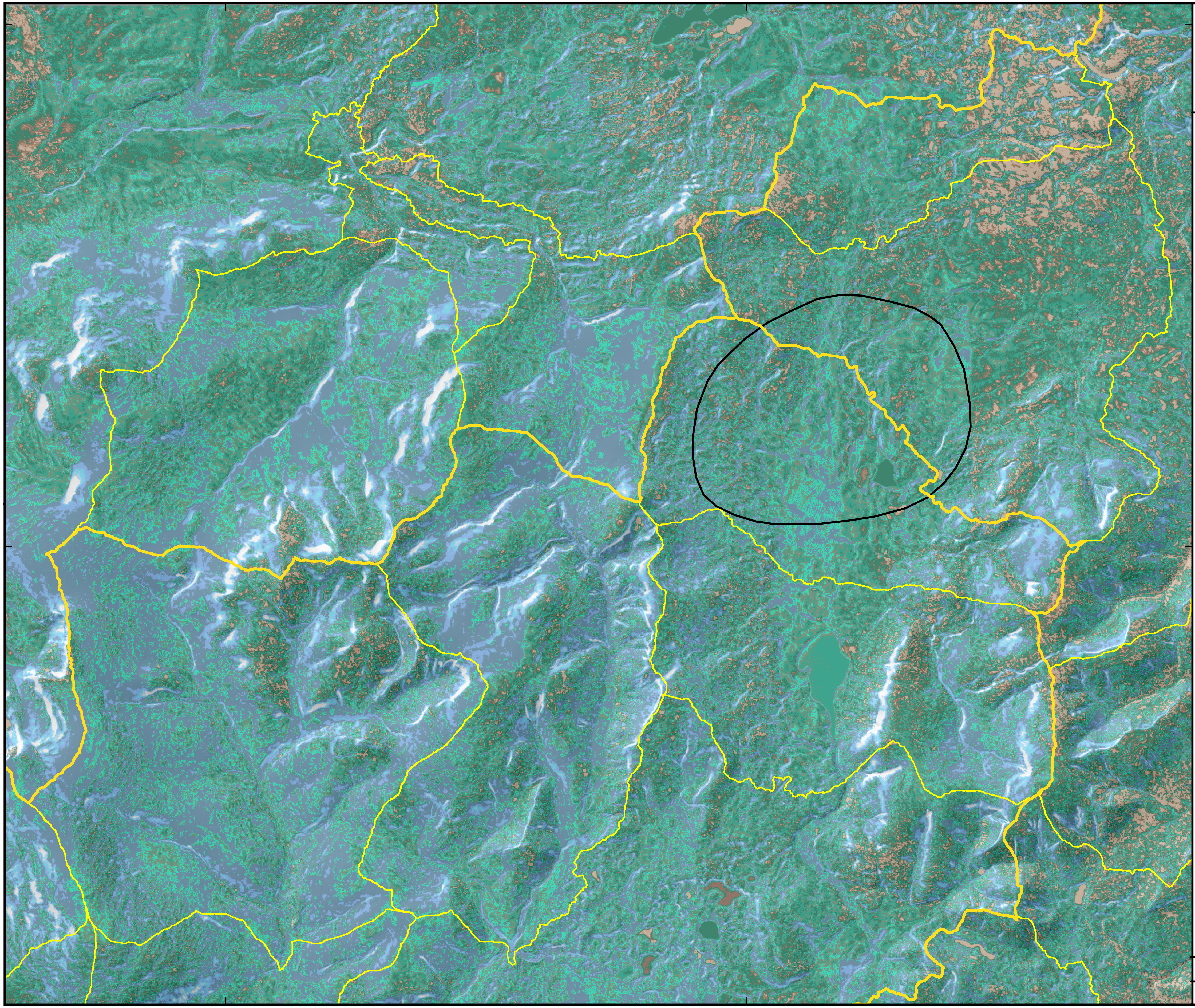


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Figure 7.2D-15
SWE Estimated from Lidar, April 6, 2008

Legend

SWE (Inches)

0 – 1.00
1.01 – 3.00
3.01 – 5.00
5.01 – 10.00
10.01 – 15.00
15.01 – 20.00
20.01 – 25.00
25.01 – 50.00
50.01 – 75.00
75.01 – 100.00
100.01 – 125.00
125.01 – 523.00

Basin Boundary
Monitored Sub-basin Boundary
General Deposit Location

0 0.5 1 1.5 2 Miles
0 0.5 1 1.5 2 2.5 3 Kilometers
N

Scale 1:59,000
Alaska State Plane Zone 5 (units feet)
1983 North American Datum

File: 7-2D-15_SWE_Est_Lidar_2008_PLP_EBD_v01.mxd	Date: Jan. 19, 2011
Version: 1	Author: ABR-AZC

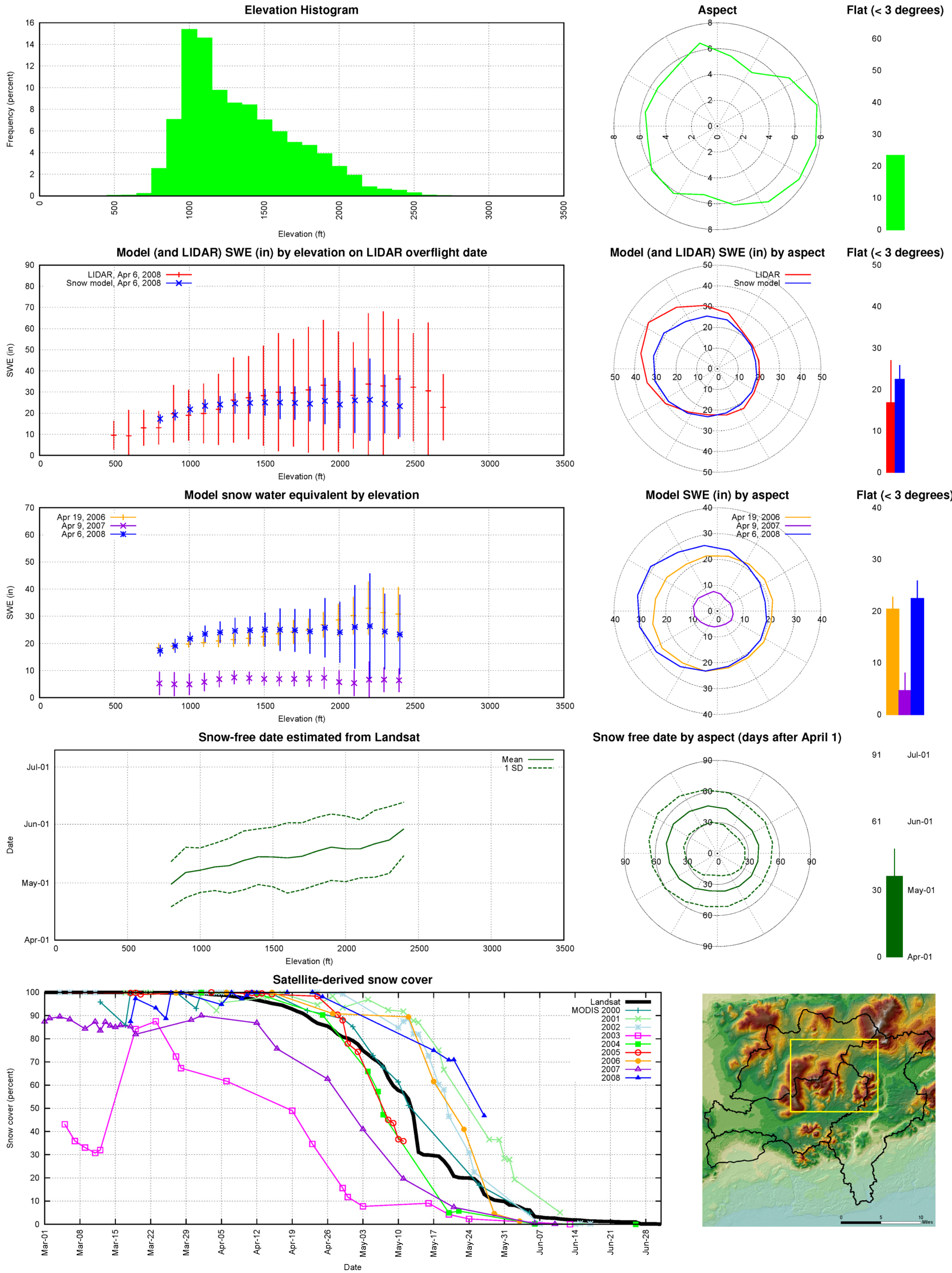

Figure 7.2D-16, Summary of Basin Characteristics, LIDAR Survey Area

Figure 7.2D-17
Typical Snow-Free Date from Landsat

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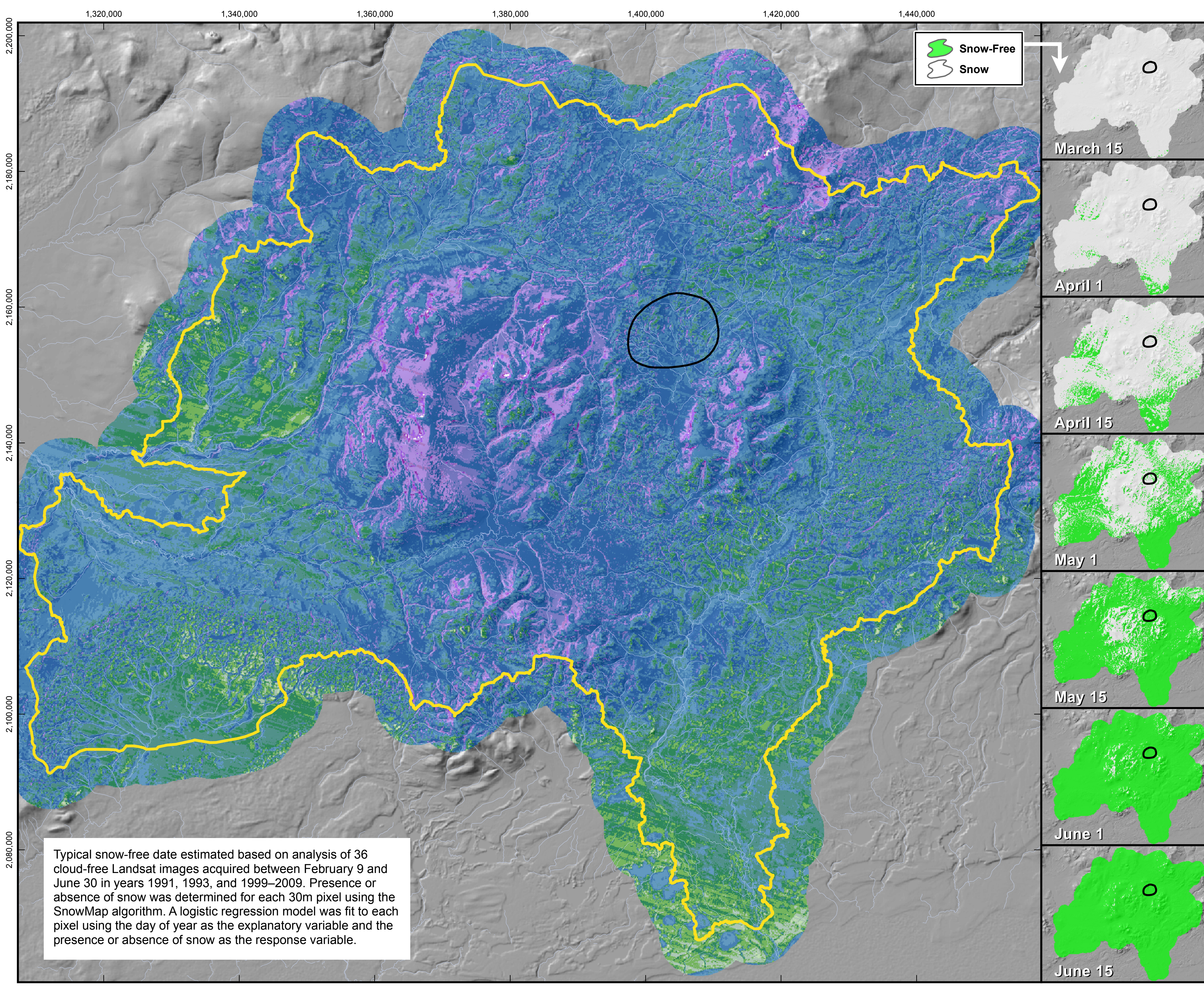


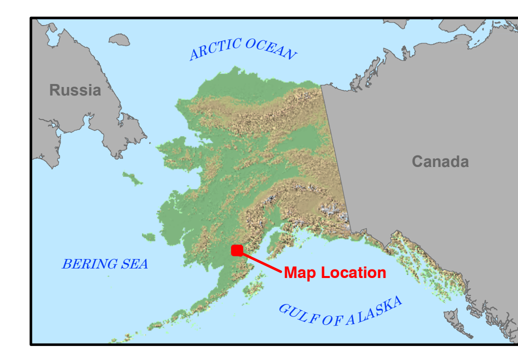
Typical snow-free date estimated based on analysis of 36 cloud-free Landsat images acquired between February 9 and June 30 in years 1991, 1993, and 1999–2009. Presence or absence of snow was determined for each 30m pixel using the SnowMap algorithm. A logistic regression model was fit to each pixel using the day of year as the explanatory variable and the presence or absence of snow as the response variable.

Legend

Snow-Free Date

- February 28 or earlier
- March 1–10
- March 11–20
- March 21–31
- April 1–10
- April 11–20
- April 21–30
- May 1–10
- May 11–20
- May 21–31
- June 1–10
- June 11–20
- June 21–30
- July 1–11
- July 12 or later

- Extended Mine Study Area
- General Deposit Location



Miles: 0 1 2 3 4 5 6
Kilometers: 0 2 4 6 8 10
N

Scale 1:175,000

Alaska State Plane Zone 5 (units feet)
1983 North American Datum

File: 7-2D-17_Typ_Snow_Free_Date_PLP_EBD_v01.mxd	Date: Jan. 19, 2011
Version: 1	Author: ABR-AZC

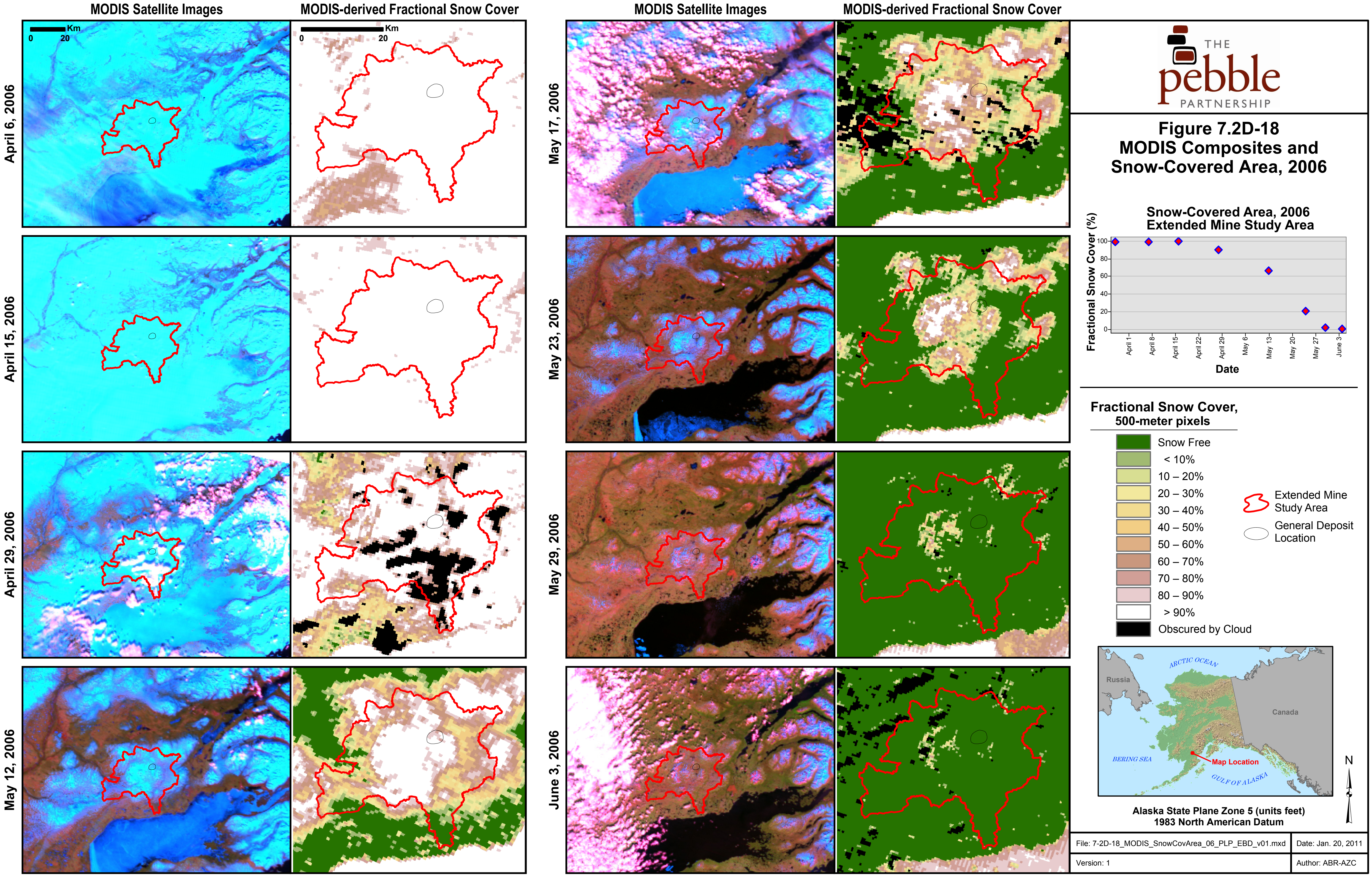


Figure 7.2D-18
MODIS Composites and Snow-Covered Area, 2006

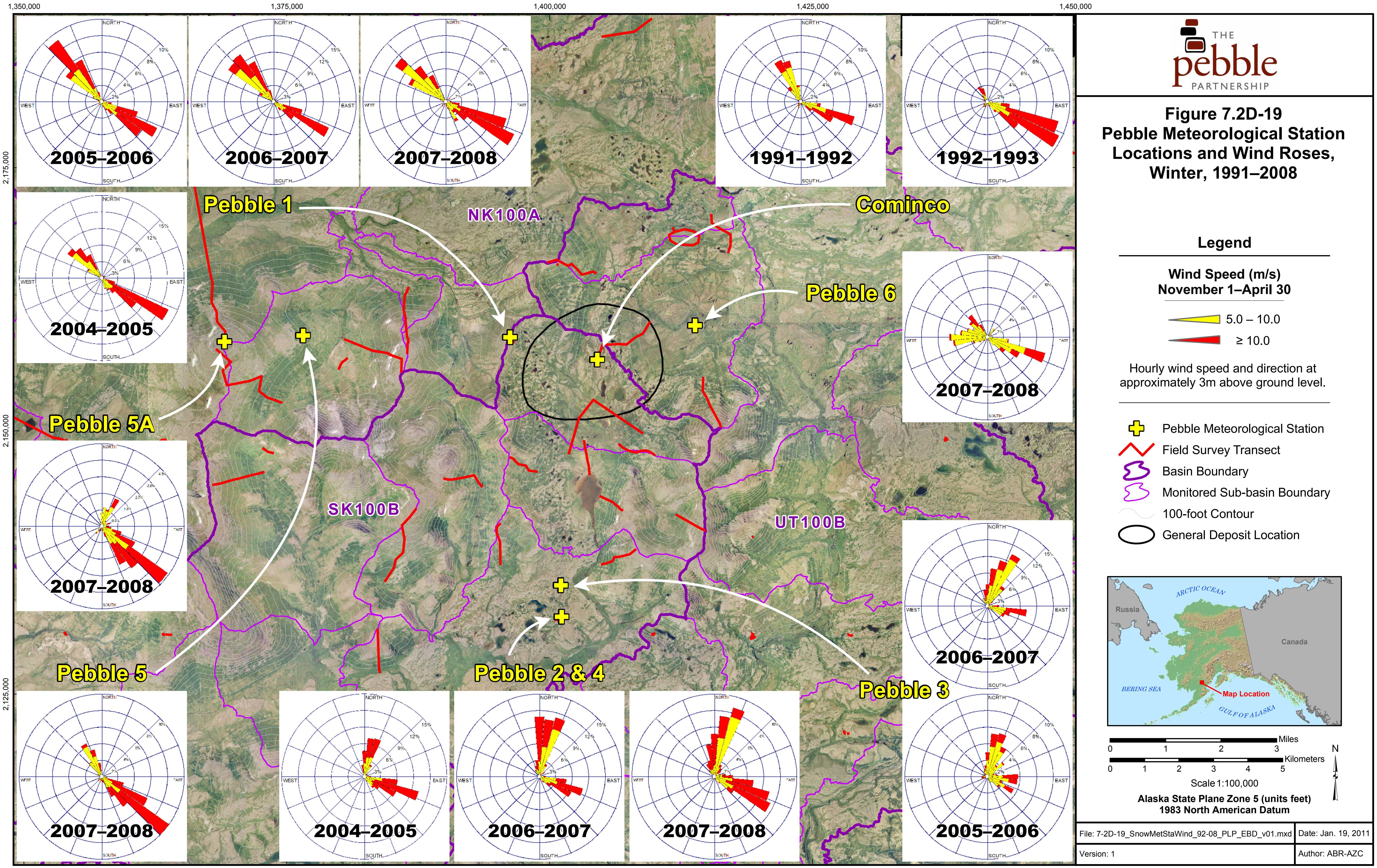


Figure 7.2D-19
Pebble Meteorological Station Locations and Wind Roses, Winter, 1991–2008

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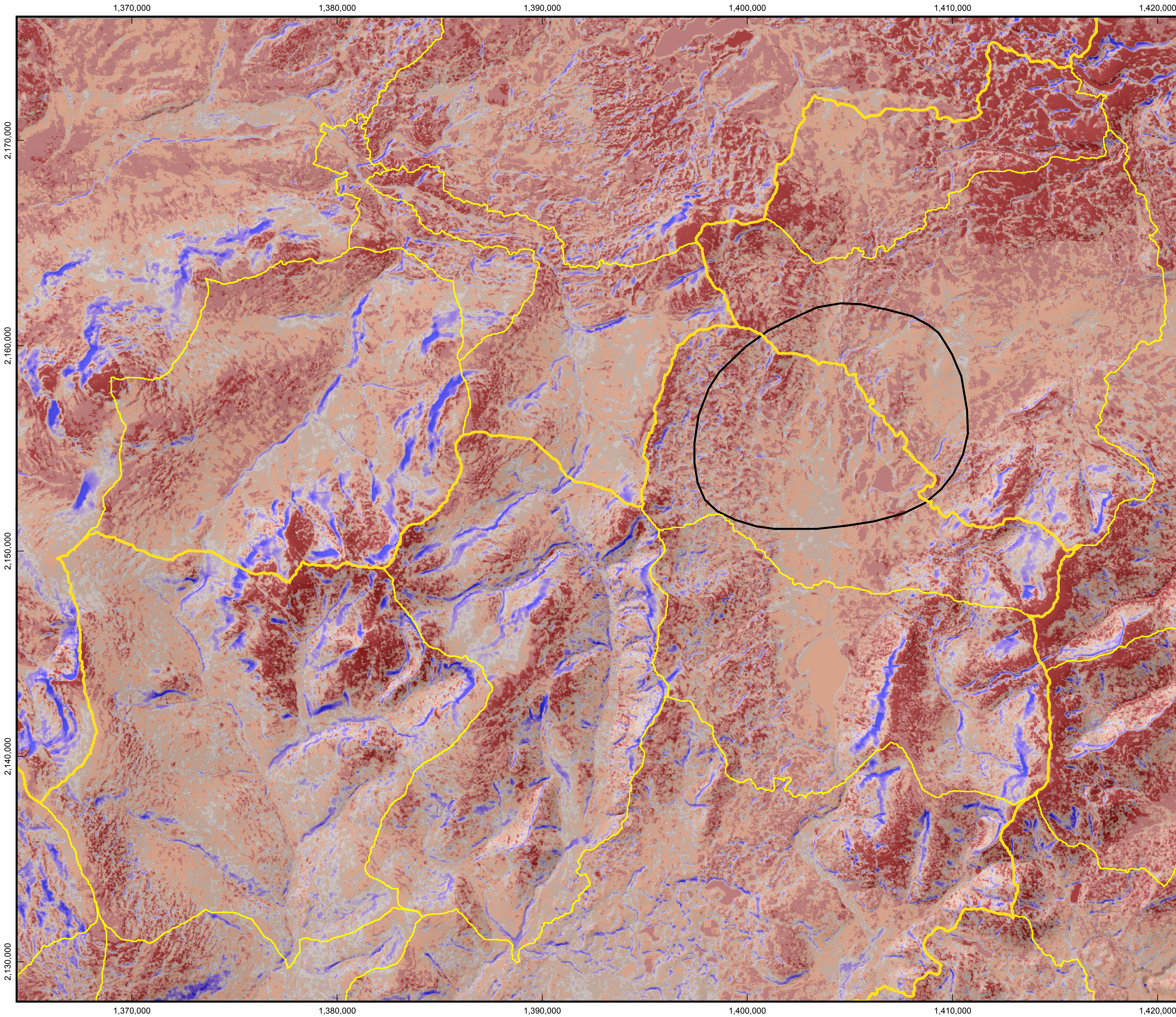
Figure 7.2D-20
Net Snow Transport Estimated from Lidar Snow Depth, April 6, 2008



Legend

SWE (Inches)

- -46.9 – -30.0
- -29.9 – -20.0
- -19.9 – -10.0
- -9.9 – 0.0
- 0.1 – 10.00
- 10.1 – 20.00
- 20.1 – 30.00
- 30.1 – 50.00
- 50.1 – 75.00
- 75.1 – 100.00
- 100.1 – 500.00

Erosion ↑
Deposition ↓

- Basin Boundary
- Monitored Sub-basin Boundary
- General Deposit Location

Miles: 0, 0.5, 1, 1.5, 2
Kilometers: 0, 0.5, 1, 1.5, 2, 2.5, 3
N

Scale 1:59,000

Alaska State Plane Zone 5 (units feet)
1983 North American Datum

File: 7-2D-20_SnowTransport_Lidar_2008_PLP_EBD_v01.mxd	Date: Jan. 19, 2011
Version: 1	Author: ABR-AZC

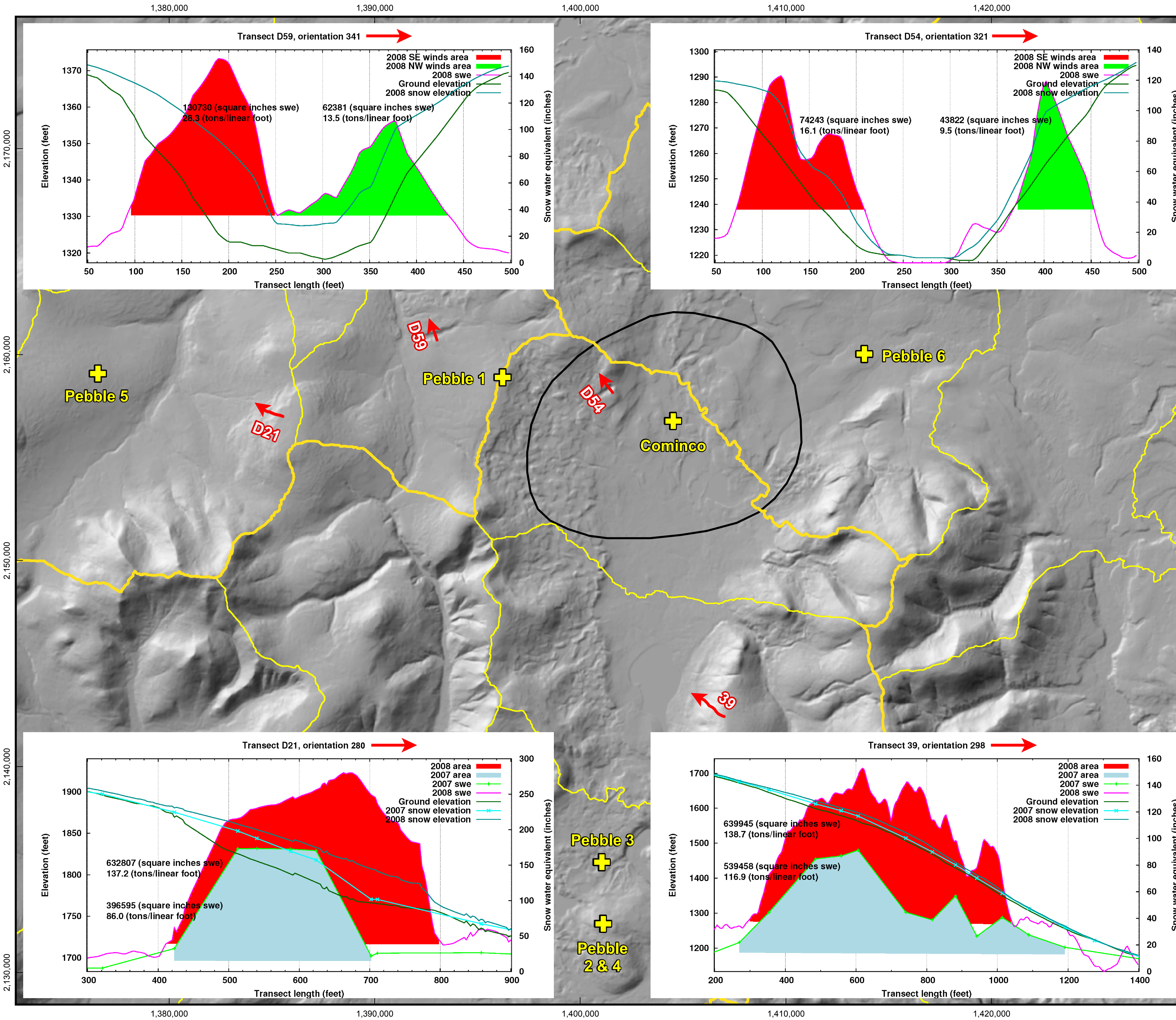
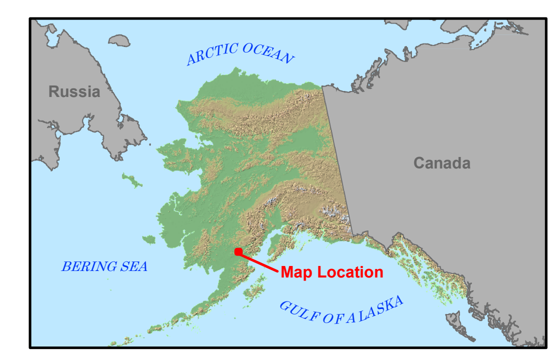


Figure 7.2D-21 Snow Drift Profiles and Snow Transport, 2007–2008

Legend

- Snow Transport Transect
- Pebble Meteorological Station
- Basin Boundary
- Monitored Sub-basin Boundary
- General Deposit Location

Drift cross-sectional area estimated from field measurements of snow depth, and snow surface elevation measurements by survey GPS and airborne lidar. Snow transport calculated as snow water volume in excess of winter precipitation for each transect.



0 0.5 1 1.5 2 Miles

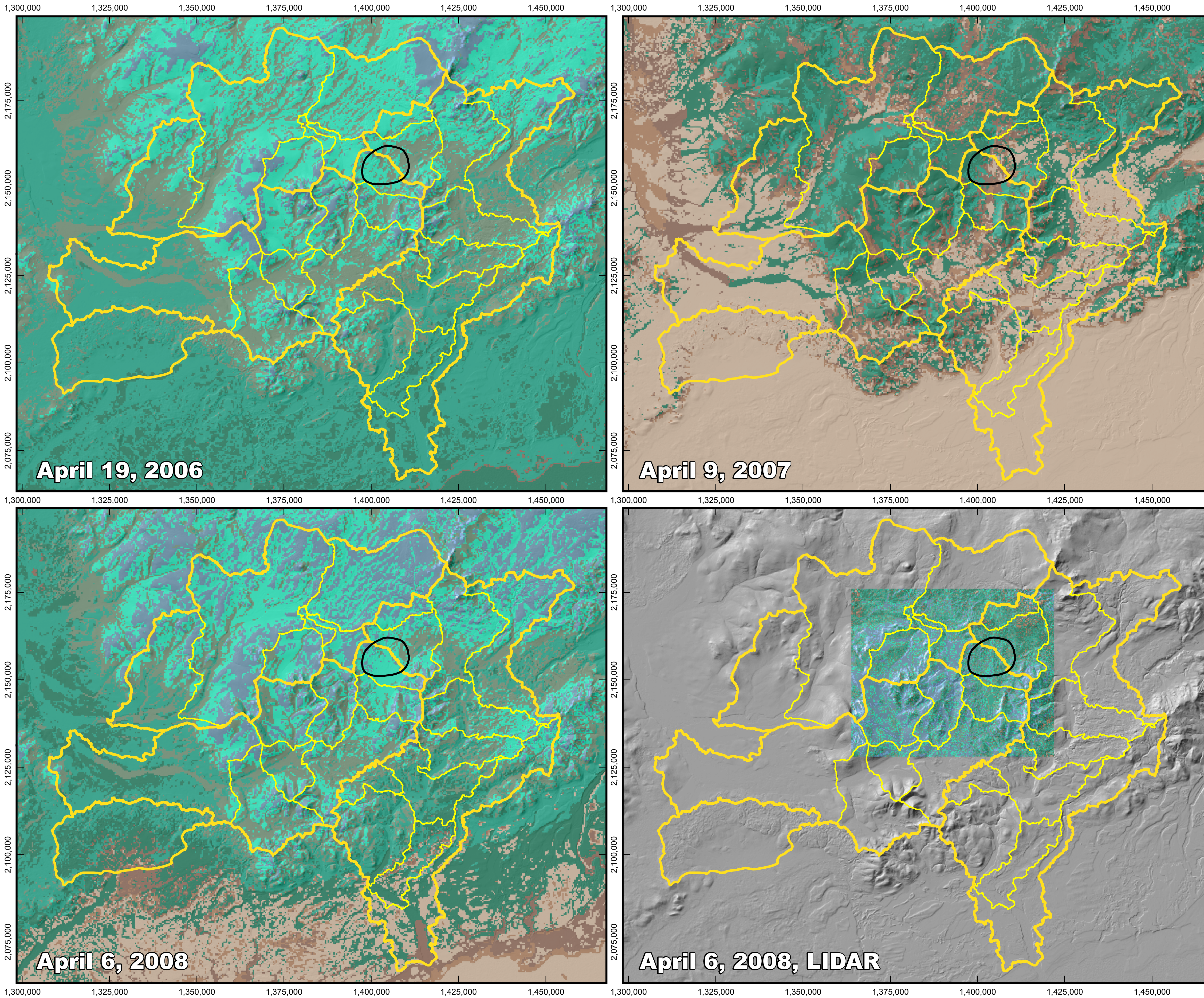
0 0.5 1 1.5 2 2.5 3 Kilometers

N

Scale 1:59,000

Alaska State Plane Zone 5 (units feet)
1983 North American Datum

File: 7-2D-21_DriftProfiles_Transport_0708_PLP_EBD_v01.mxd	Date: Jan. 19, 2011
Version: 1	Author: ABR-AZC



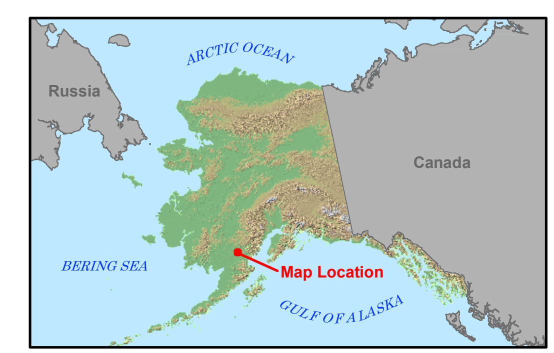
THE pebble PARTNERSHIP

Figure 7.2D-22 Snow Model Output (SWE), April, 2006–2008

Legend

SWE (Inches)
0 – 1.00
1.01 – 3.00
3.01 – 5.00
5.01 – 10.00
10.01 – 15.00
15.01 – 20.00
20.01 – 25.00
25.01 – 50.00
50.01 – 75.00
75.01 – 100.00
100.01 – 125.00
125.01 – 523.00

Basin Boundary
Monitored Sub-basin Boundary
General Deposit Location



Miles 0 2 4 6 8 10
Kilometers 0 5 10 15
N
Scale 1:340,000

Alaska State Plane Zone 5 (units feet)
1983 North American Datum

File: 7-2D-22_SnowDistModels_06-08_PLP_EBD_v01.mxd	Date: Jan. 19, 2011
Version: 1	Author: ABR-AZC

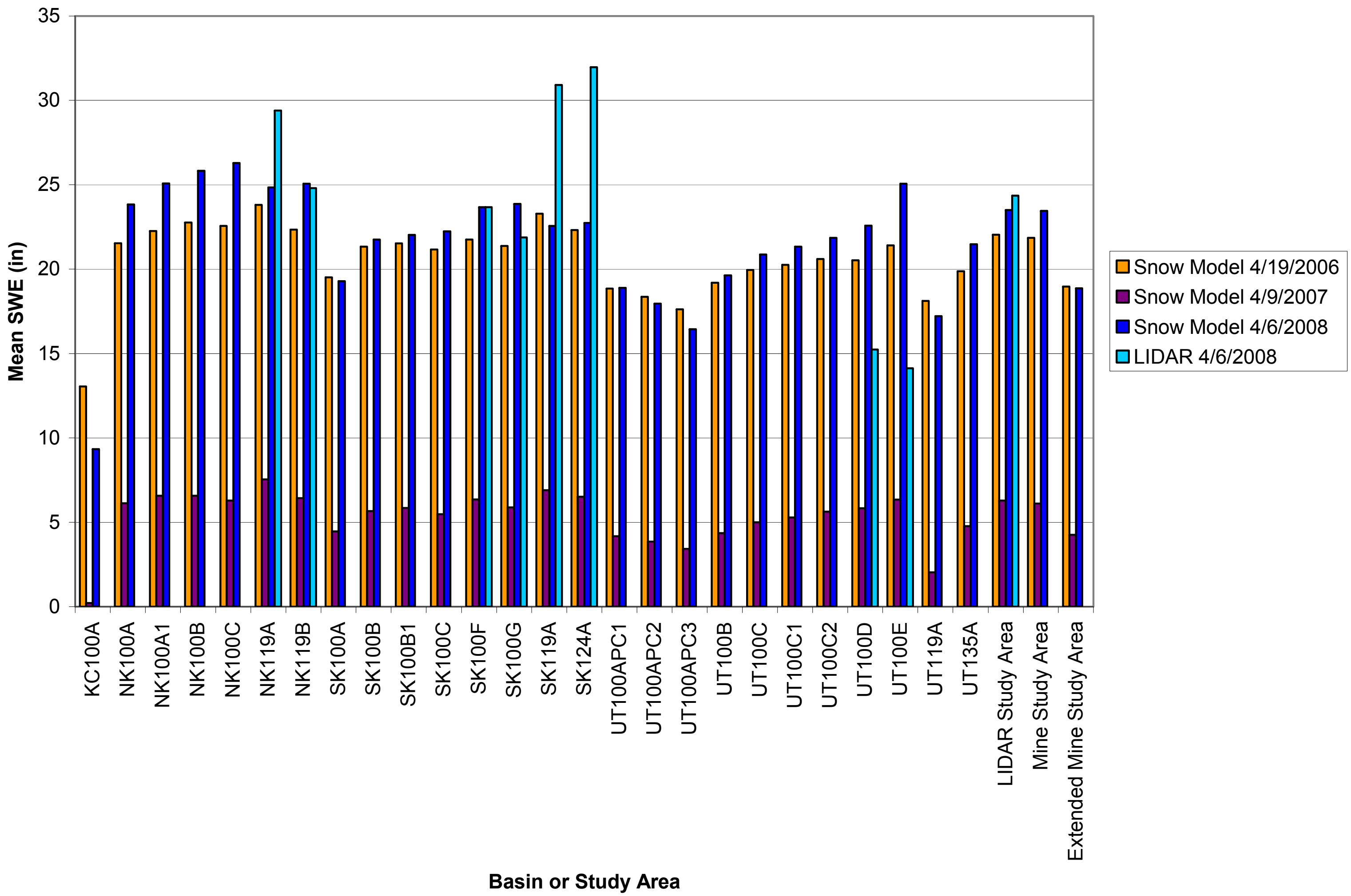


Figure 7.2D-23, Mean SWE by Basin, 2006–2008

SnowModel Output Summary: 384-foot cells, hourly timestep, precipitation factor 2.0
Basin nk119a, 2005-2006

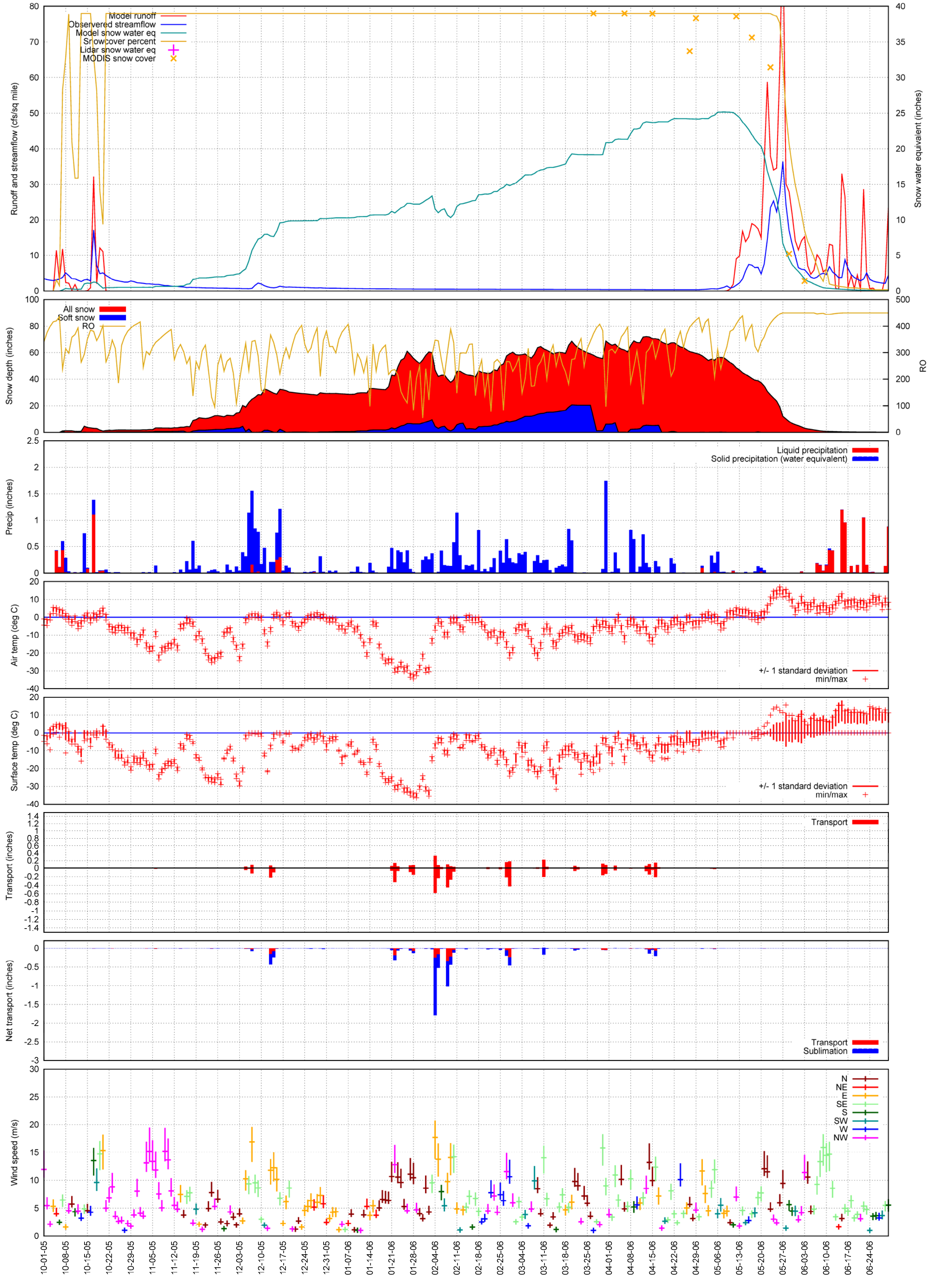


Figure 7.2D-24, Snow Model Output Summary and Comparison to Stream Discharge and MODIS Snow-Covered Area, Basin NK119A, Winter 2005/2006

SnowModel Output Summary: 384-foot cells, hourly timestep, precipitation factor 2.0
Basin nk119a, 2006-2007

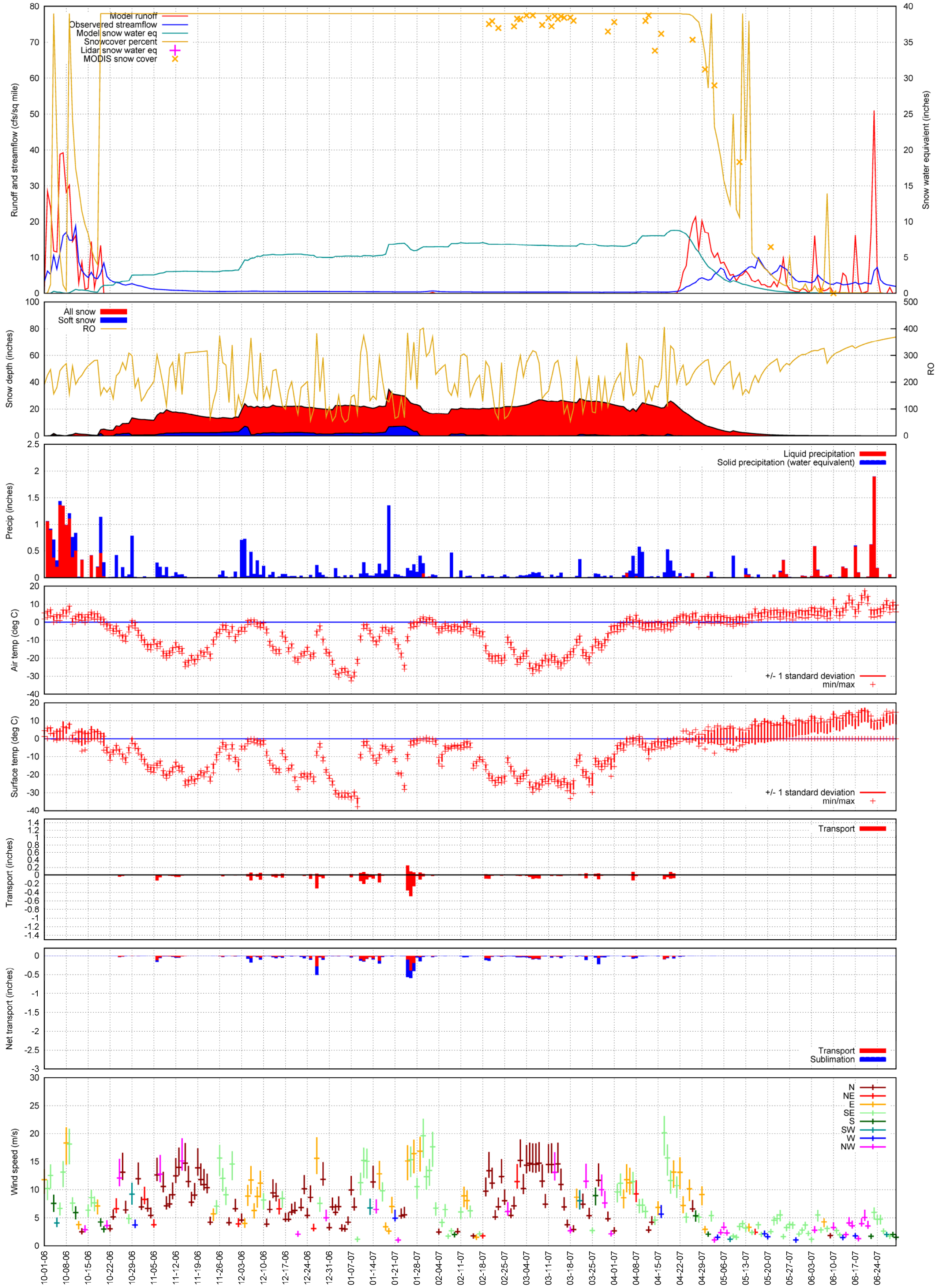


Figure 7.2D-25, Snow Model Output Summary and Comparison to Stream Discharge and MODIS Snow-Covered Area, Basin NK119A, Winter 2006/2007

SnowModel Output Summary: 384-foot cells, hourly timestep, precipitation factor 2.0
Basin nk119a, 2007-2008

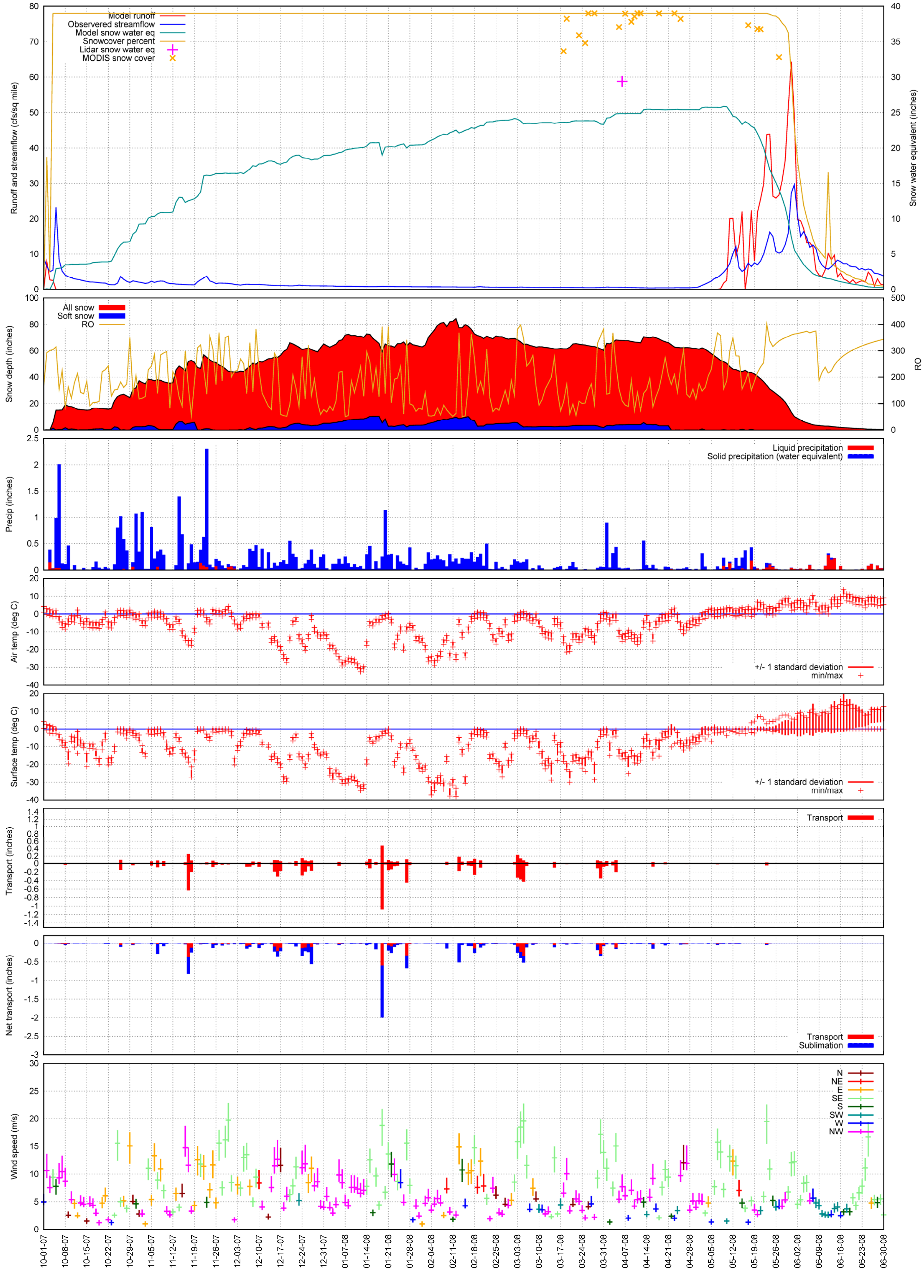


Figure 7.2D-26, Snow Model Output Summary and Comparison to Stream Discharge, LIDAR, and MODIS Snow-Covered Area, Basin NK119A, Winter 2007/2008

SnowModel Output Summary: 384-foot cells, hourly timestep, precipitation factor 2.0
Basin nk119a, Water Balance Summary, 2005-2008

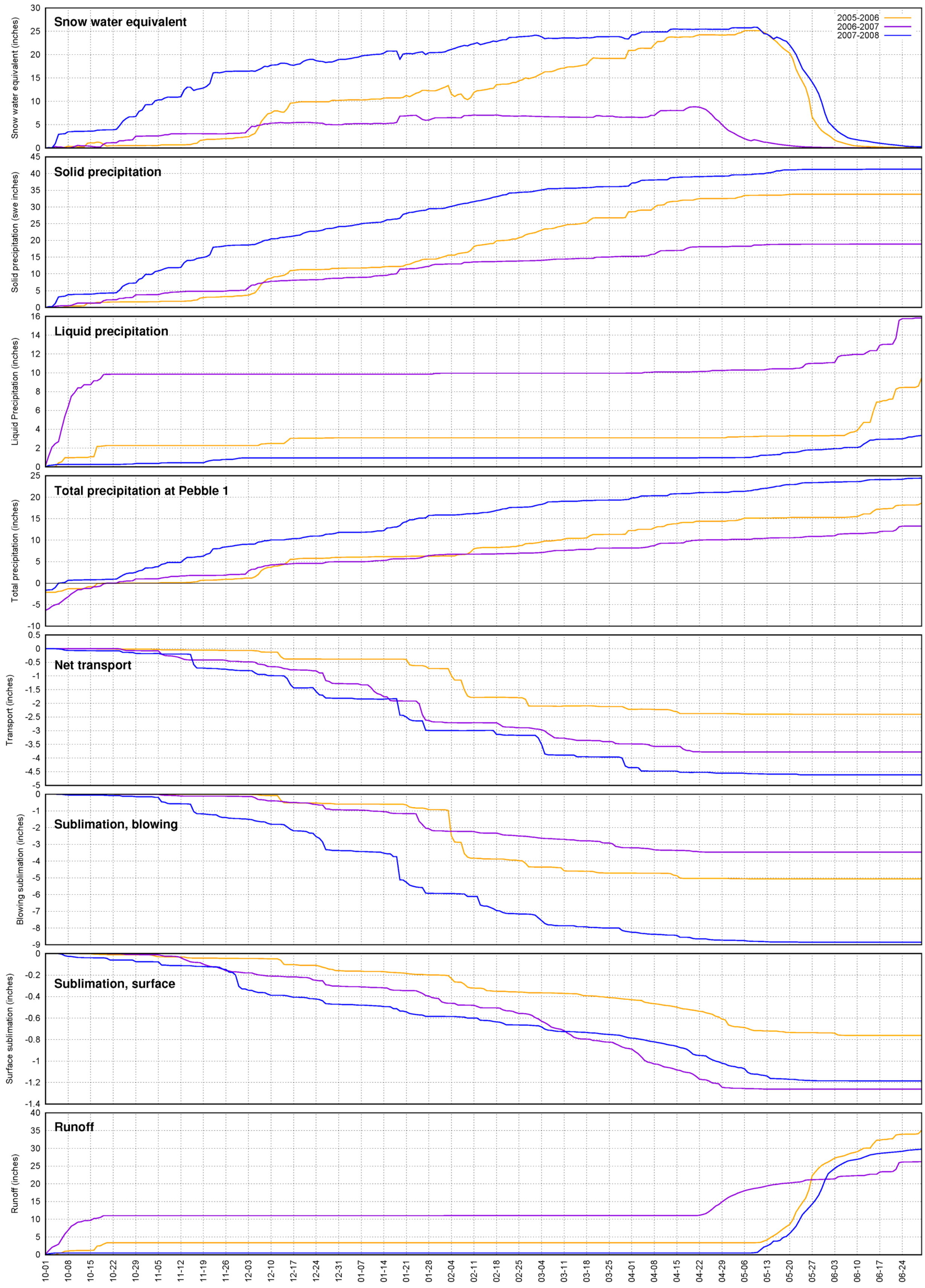


Figure 7.2D-27, Snow Model output Water Balance Summary, Basin NK119A, 2005–2008

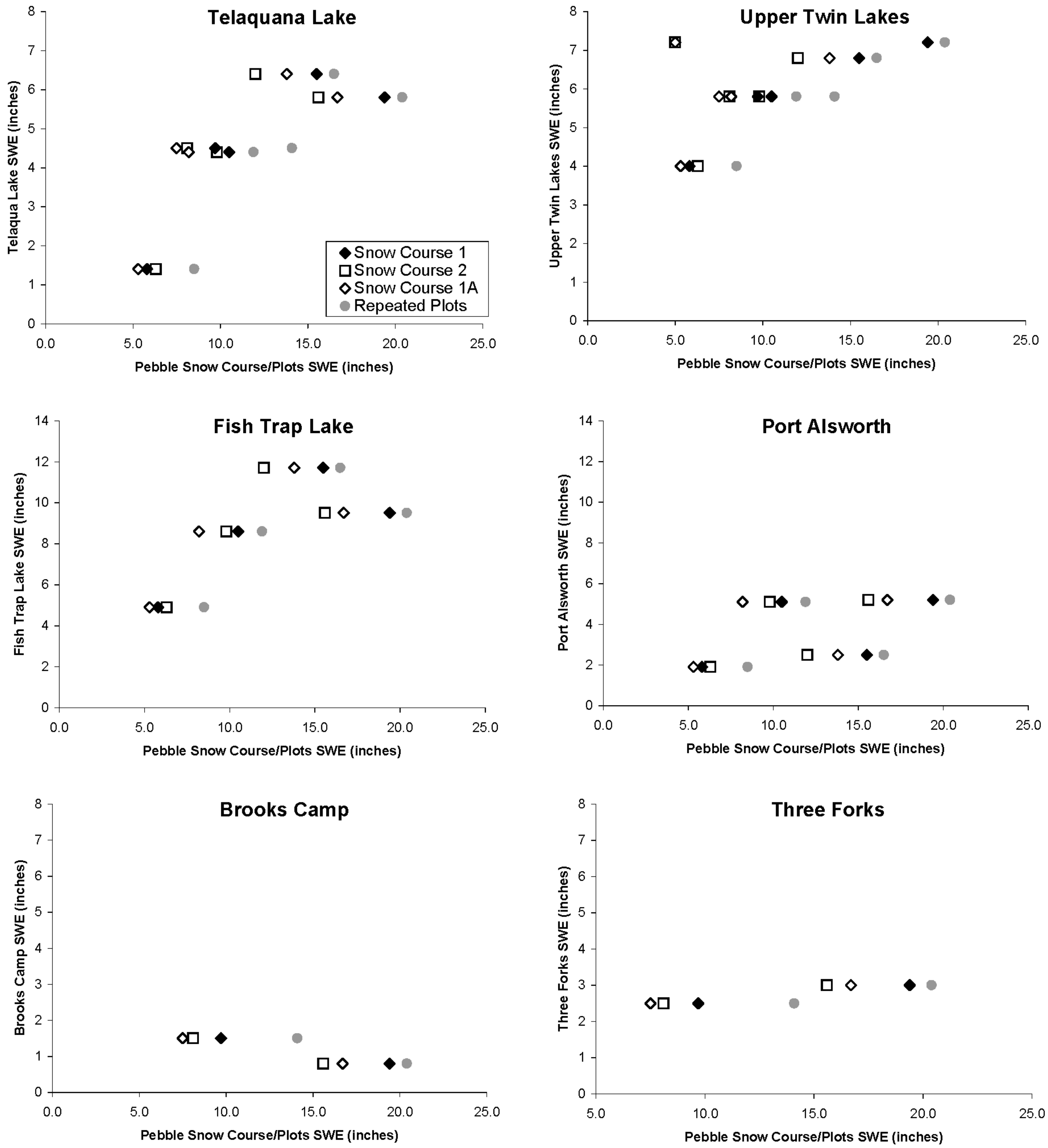


Figure 7.2D-28. Comparison of Regional NRCS Snow Courses with Pebble Snow Courses, 2004–2008

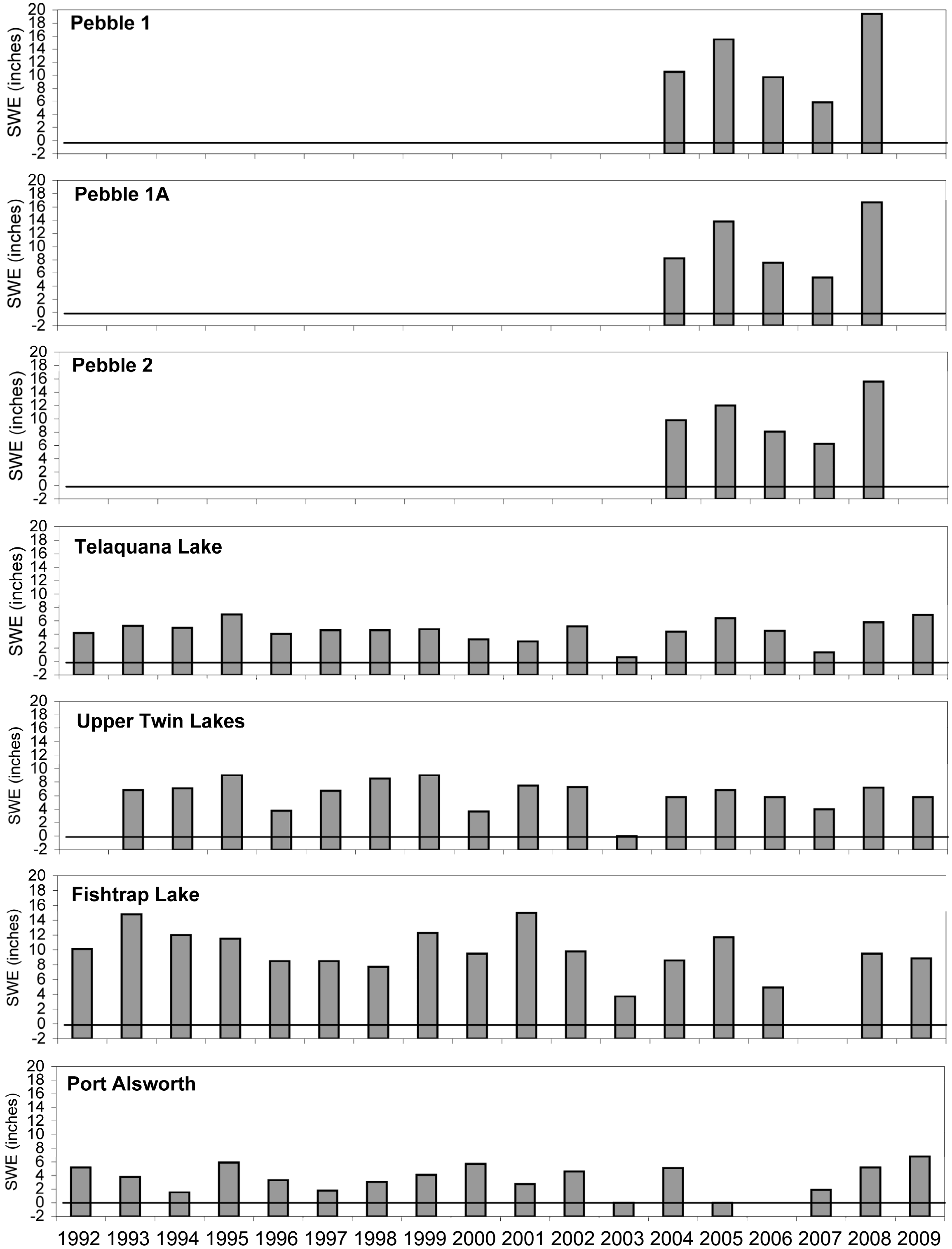
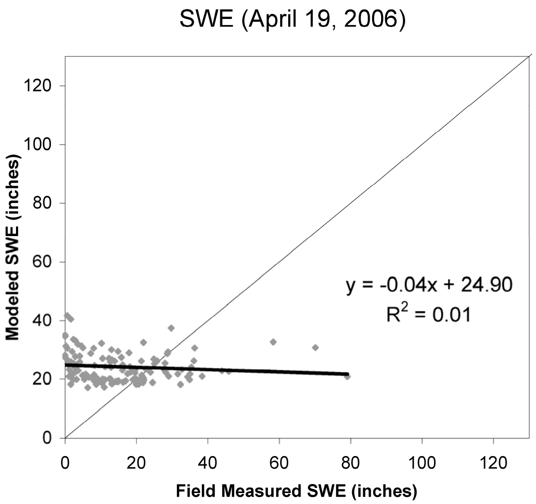
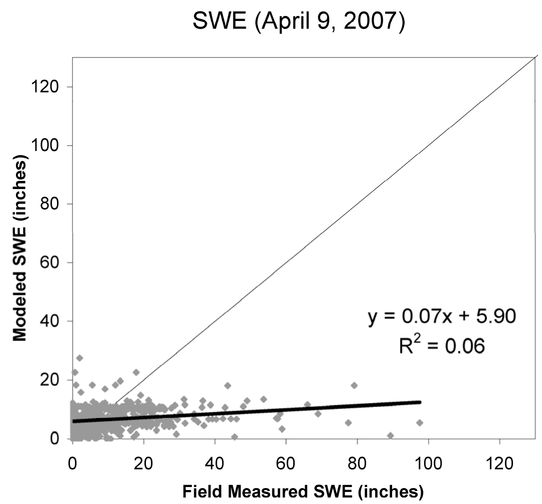
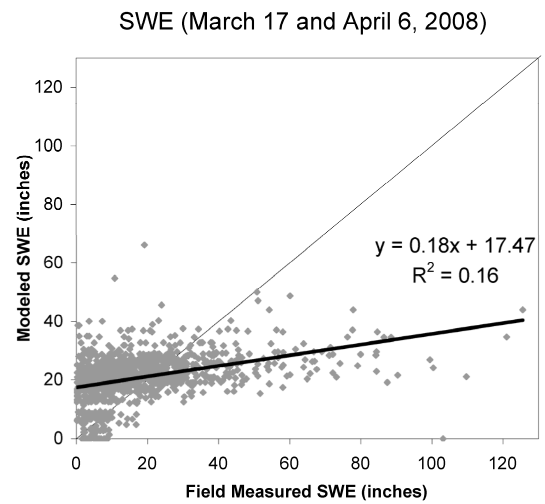


Figure 7.2D-29, Late-Winter SWE at Pebble and NRCS Snow Courses, 1992–2009

Field Measured vs. Modeled SWE:







LIDAR vs. Modeled SWE (LIDAR aggregated to 384 foot cells):

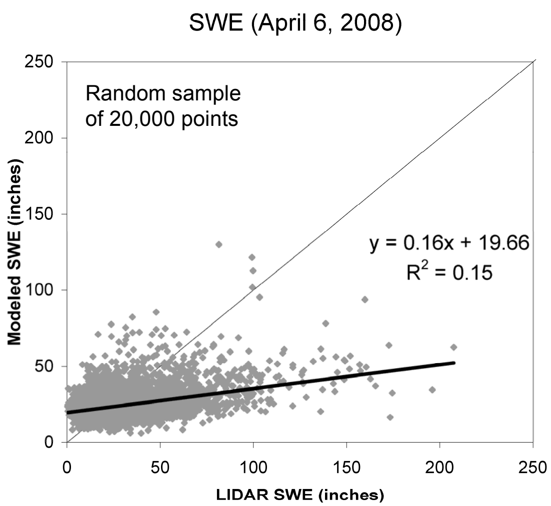


Figure 7.2D-30, Field and LIDAR SWE compared to Model SWE, 2006–2008

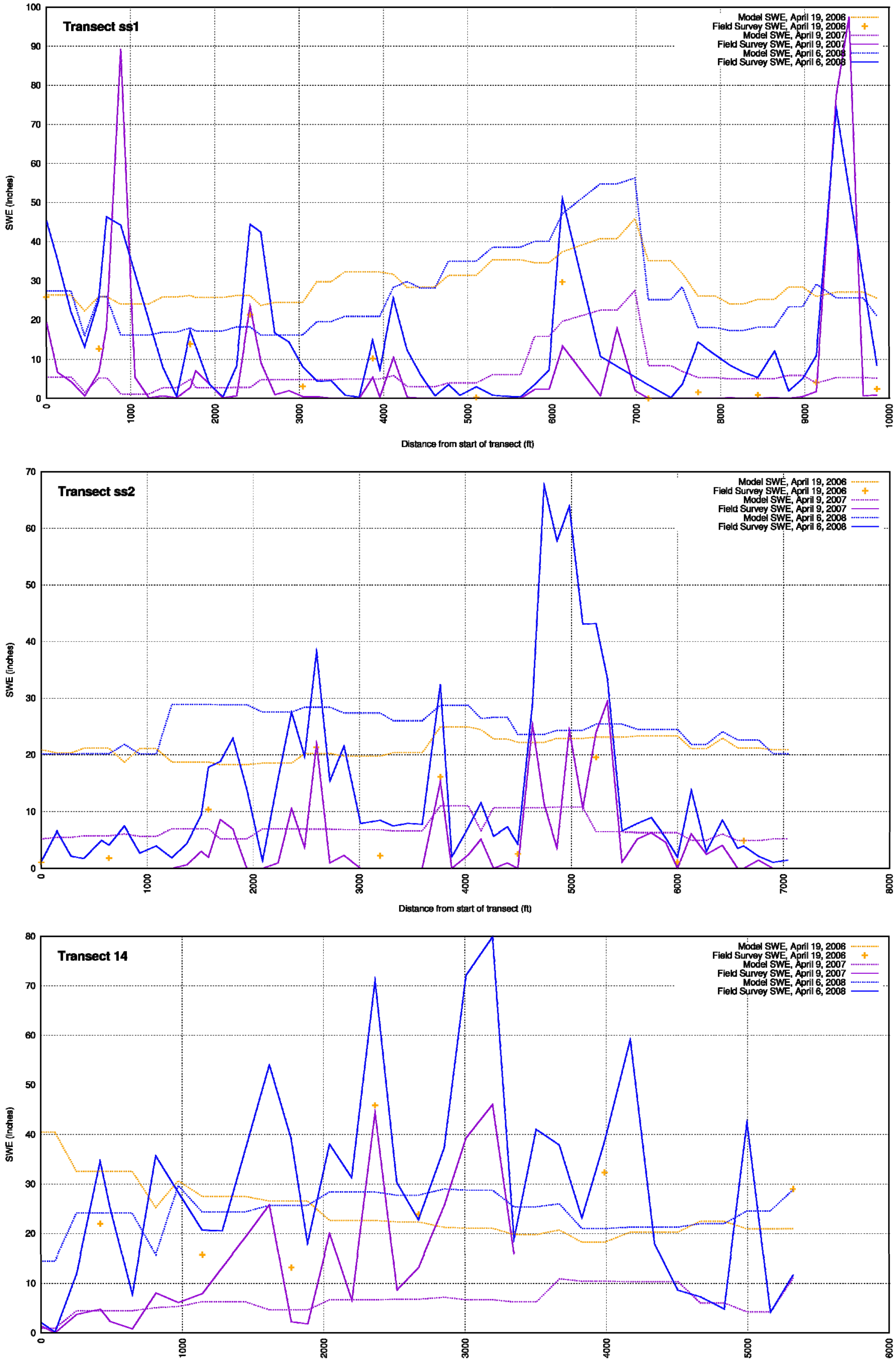


Figure 7.2D-31, Comparison of Field and Model SWE (inches) by Plot at Pebble Snow Courses 1 and 2 and Transect 14, 2006–2008

ATTACHMENTS

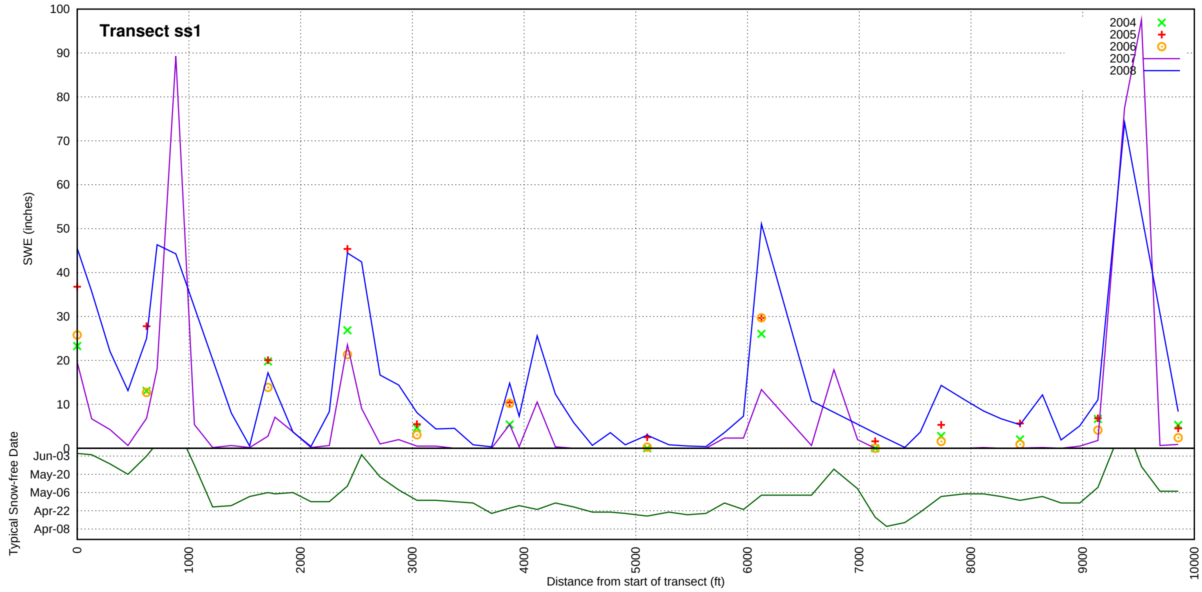
ATTACHMENT 1

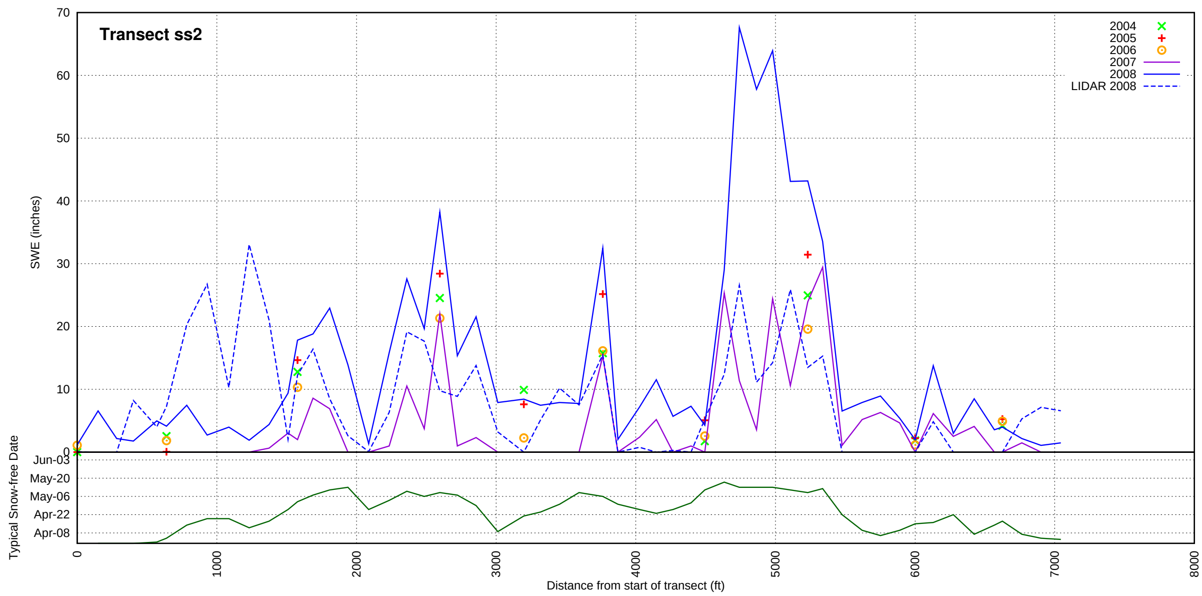
Snow Distribution Survey Results (2004–2008), LIDAR Survey Results (2008), and Typical Snow-Free Date from Landsat for Selected Transects, 2004–2008

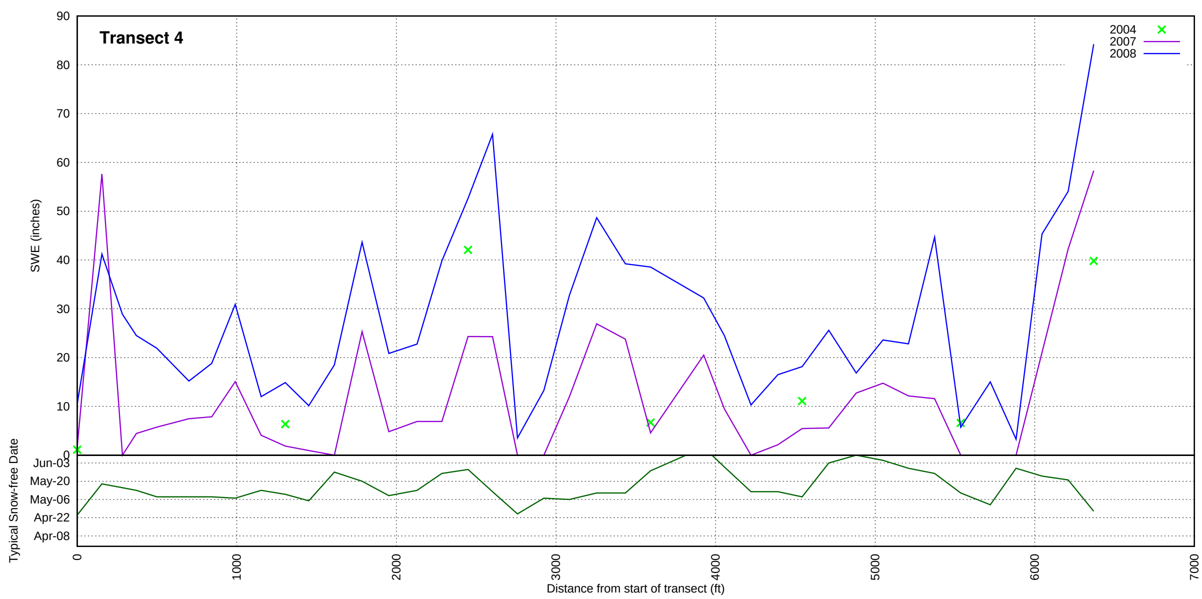
Attachment 1, Snow Distribution Survey Results (2004–2008), LIDAR Survey Results (2008), and Typical Snow-Free Date from Landsat for Selected Transects, 2004–2008.

The field SWE measurements for each primary and supplemental plot are presented for each transect. In 2004, 2005 and 2006 only primary plots were measured and these are displayed as dots. In 2007 and 2008 more frequent depth-only measurements were obtained between the primary plots. To reflect the higher spatial frequency, the 2007 and 2008 data are presented as lines. The results from the LIDAR survey are also displayed for transects within the LIDAR survey area. Finally, the narrow plot below the field measurements displays the typical snow-free date for each plot based on analysis of 36 Landsat scenes.

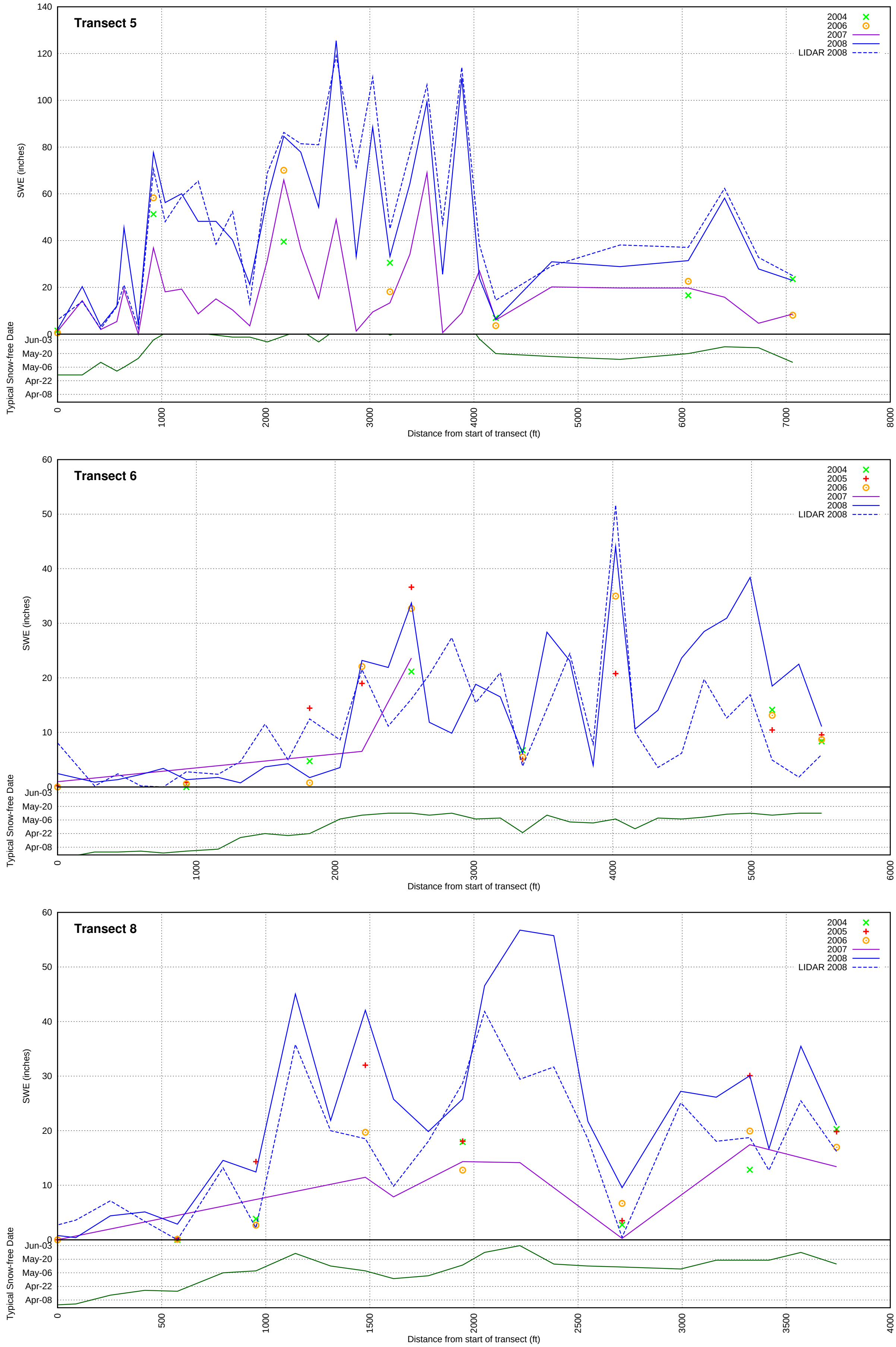
Measured SWE (inches) at Plots during Snow Distribution Surveys and Typical Snow-Free Date from Landsat



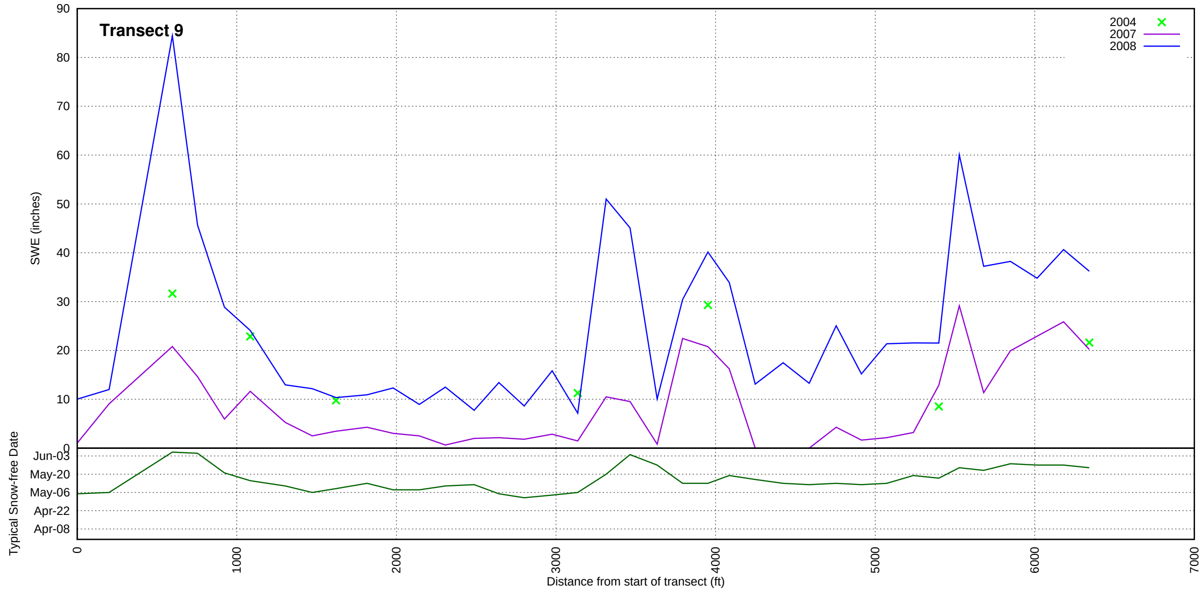


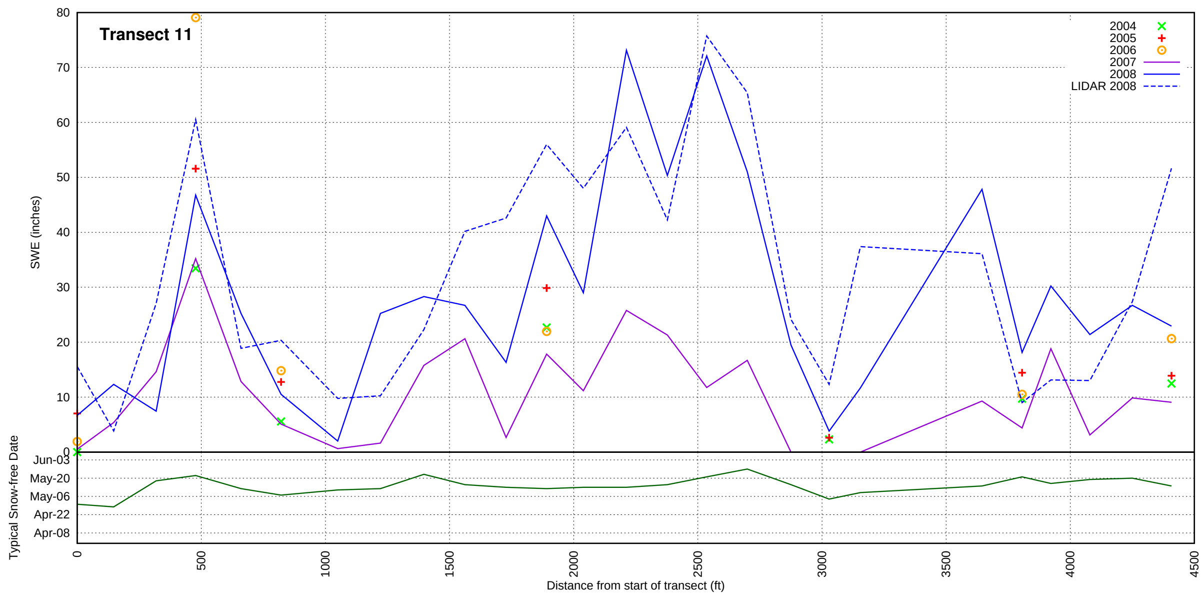


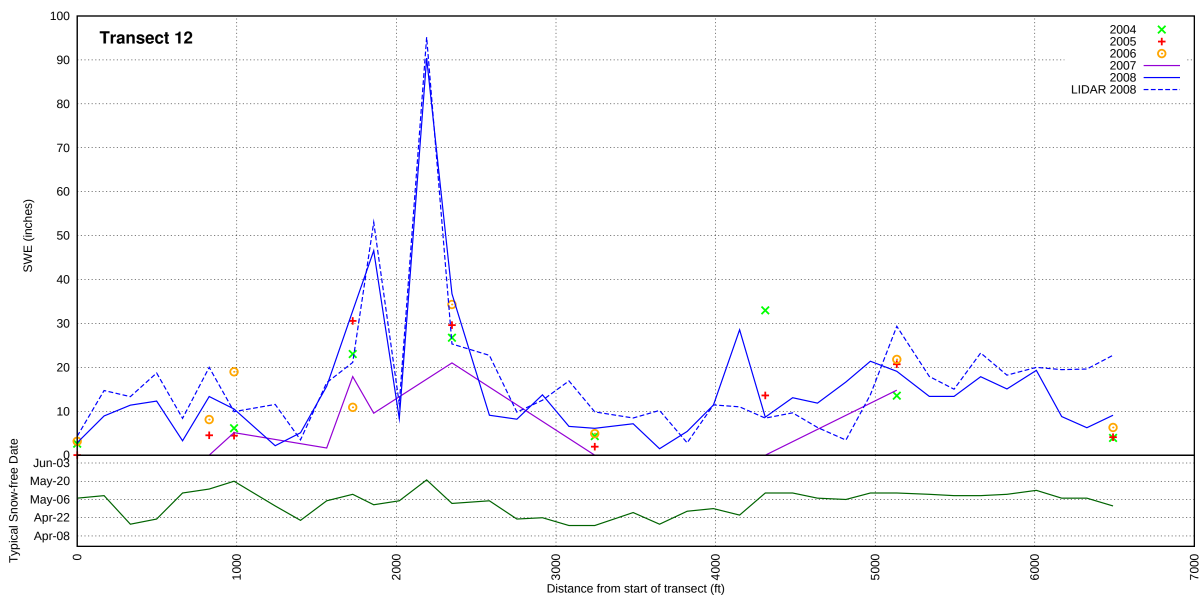
Measured SWE (inches) at Plots during Snow Distribution Surveys and Typical Snow-Free Date from Landsat



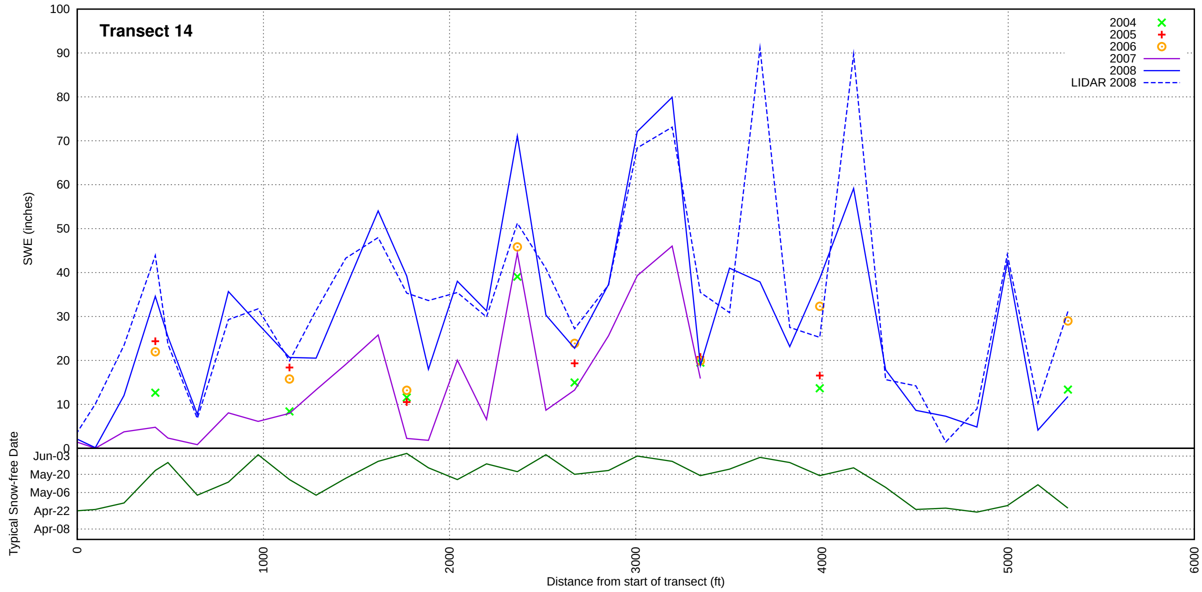
Measured SWE (inches) at Plots during Snow Distribution Surveys and Typical Snow-Free Date from Landsat

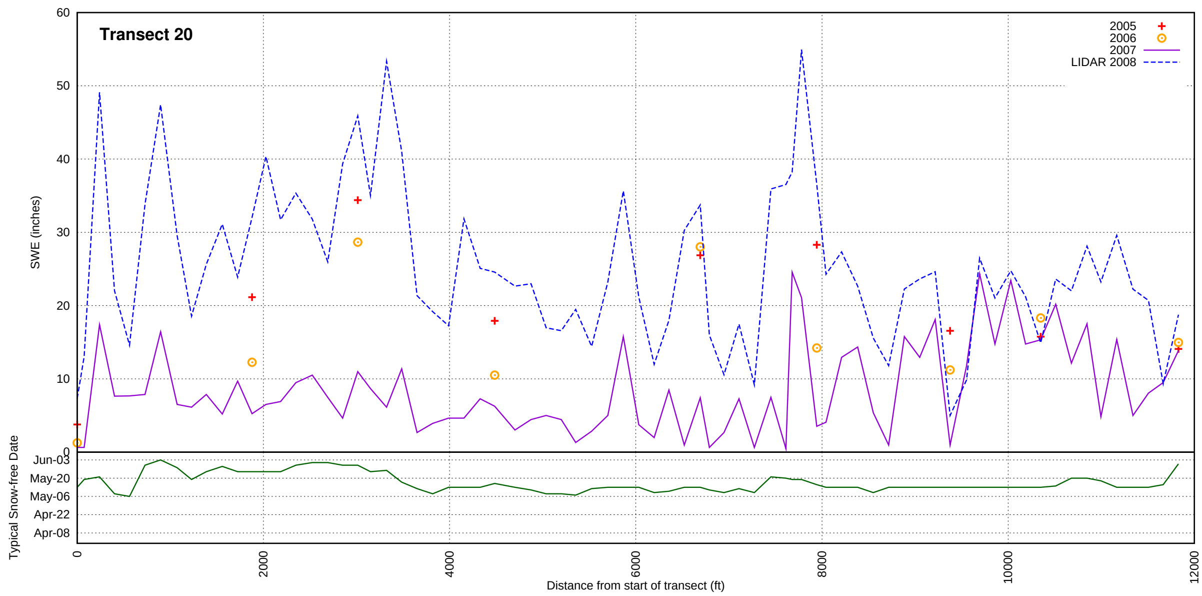


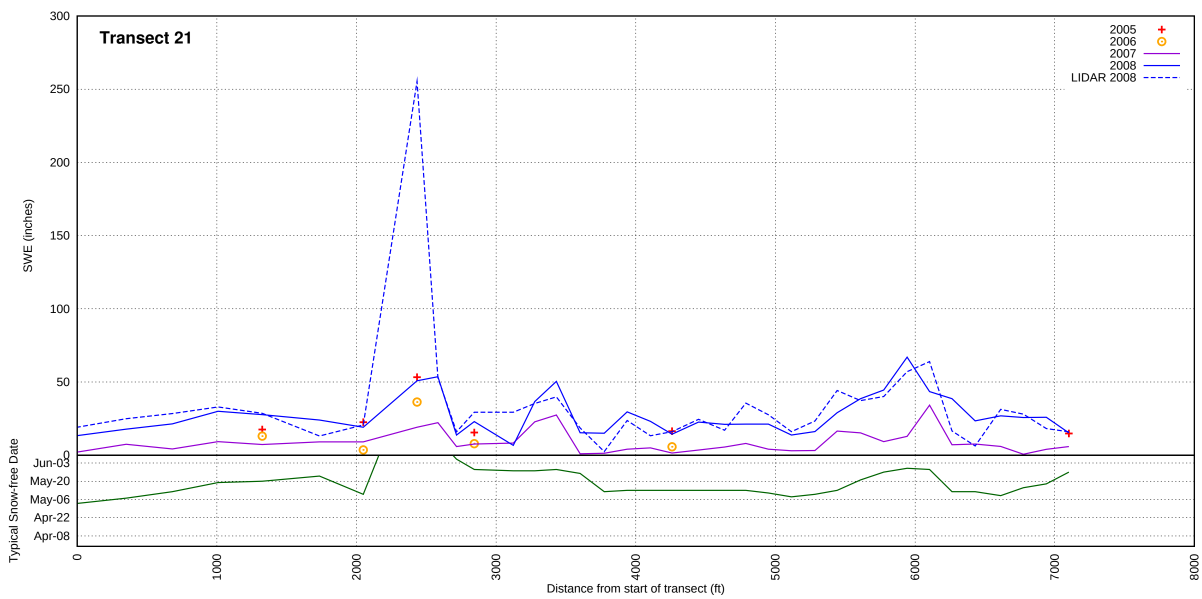




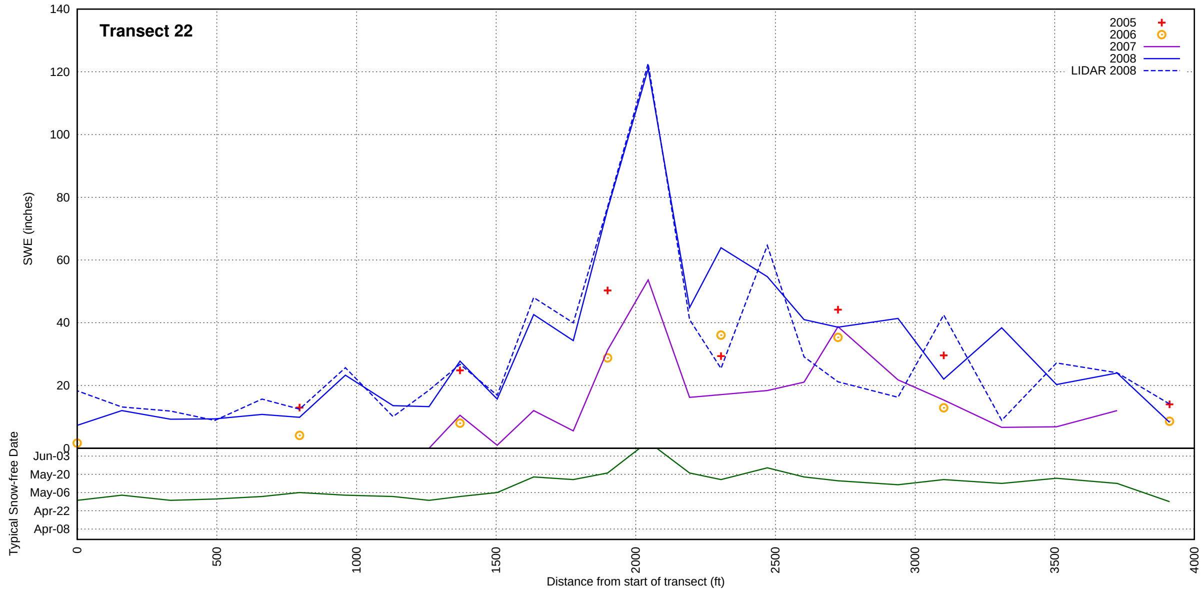
Measured SWE (inches) at Plots during Snow Distribution Surveys and Typical Snow-Free Date from Landsat

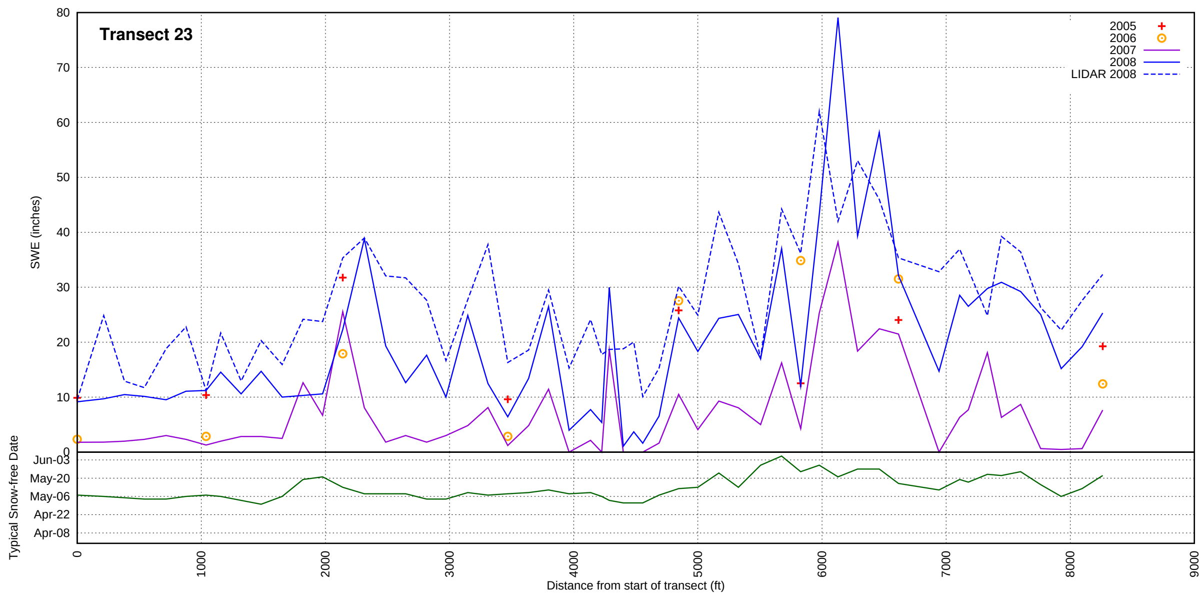


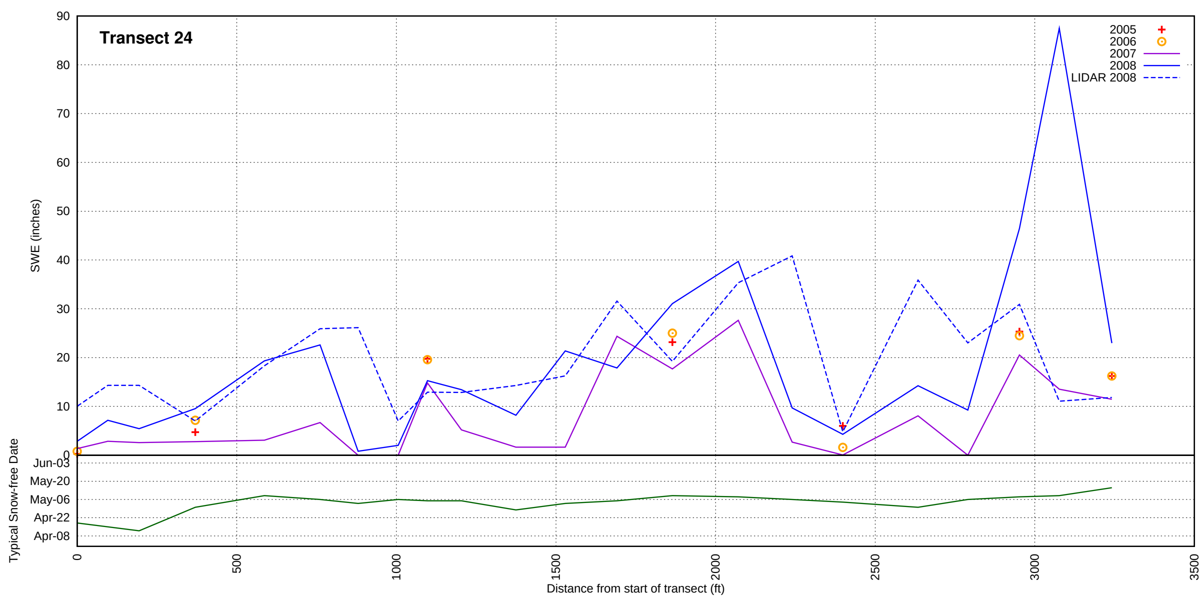




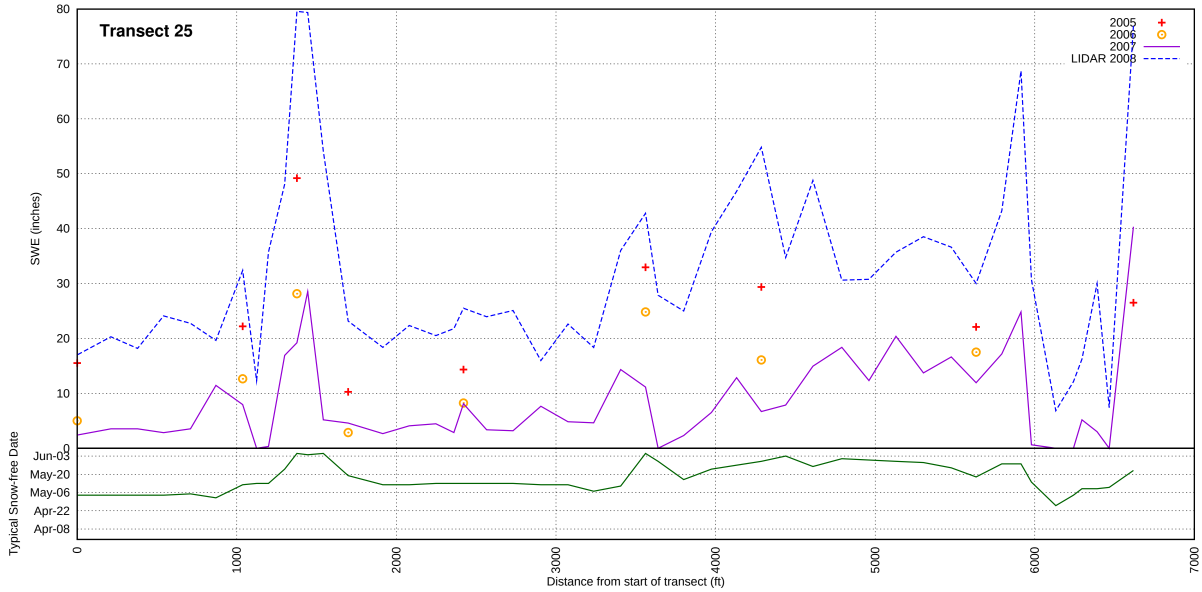
Measured SWE (inches) at Plots during Snow Distribution Surveys and Typical Snow-Free Date from Landsat

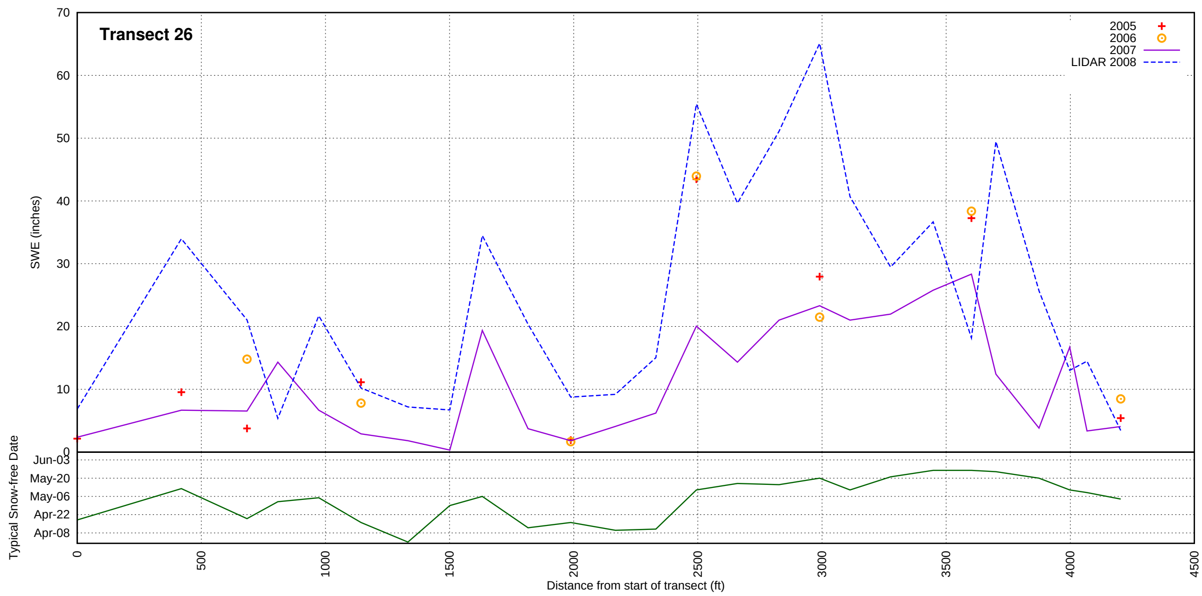


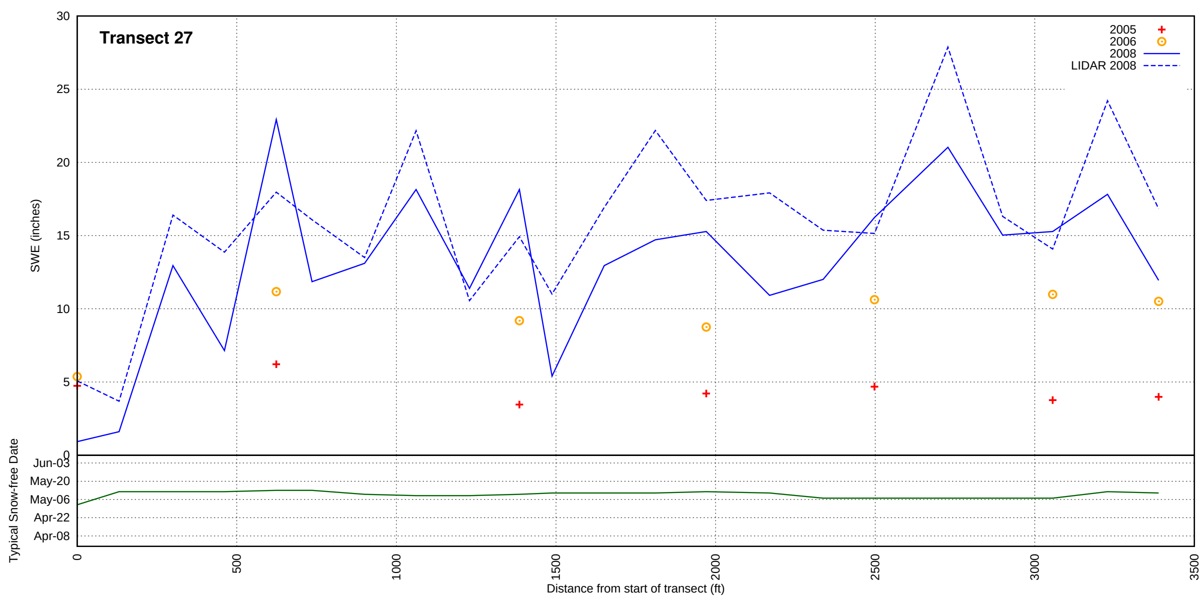




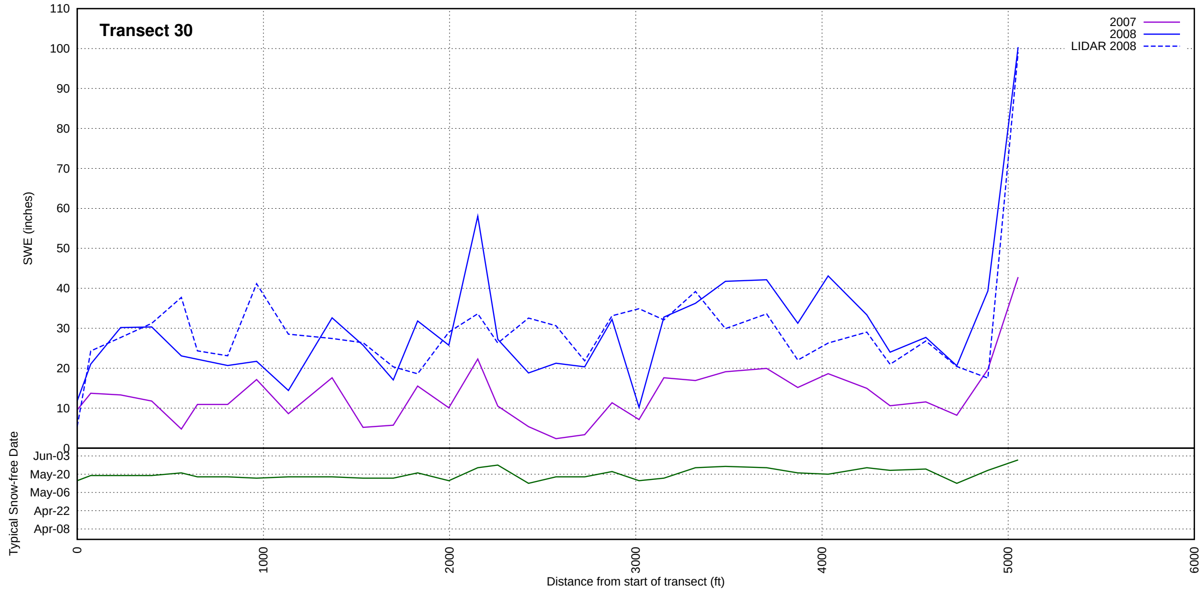
Measured SWE (inches) at Plots during Snow Distribution Surveys and Typical Snow-Free Date from Landsat

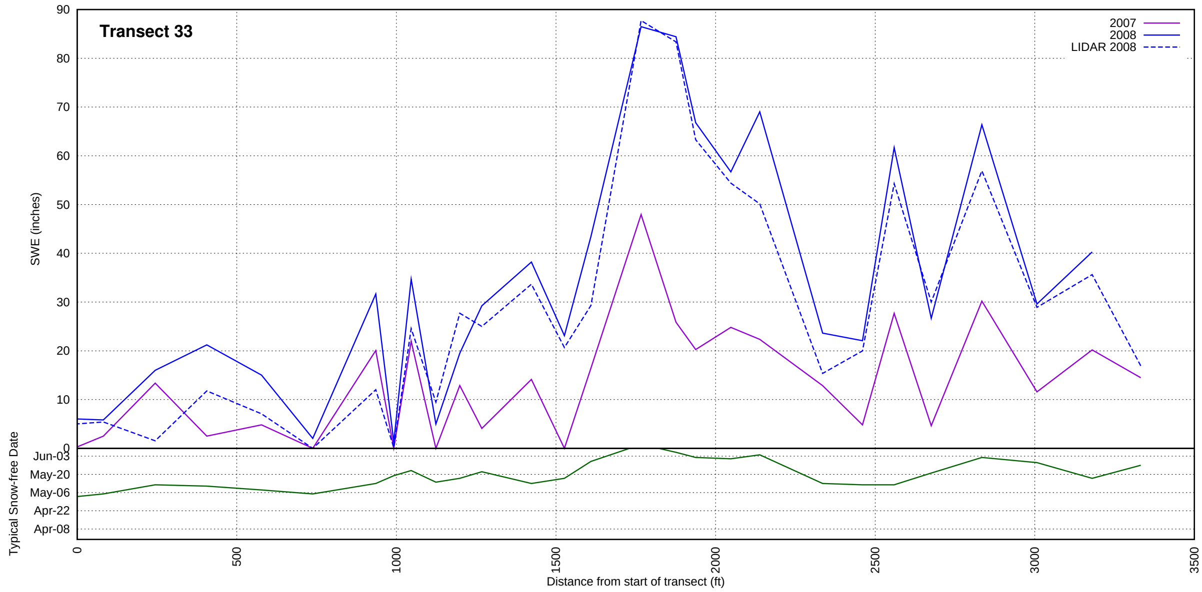


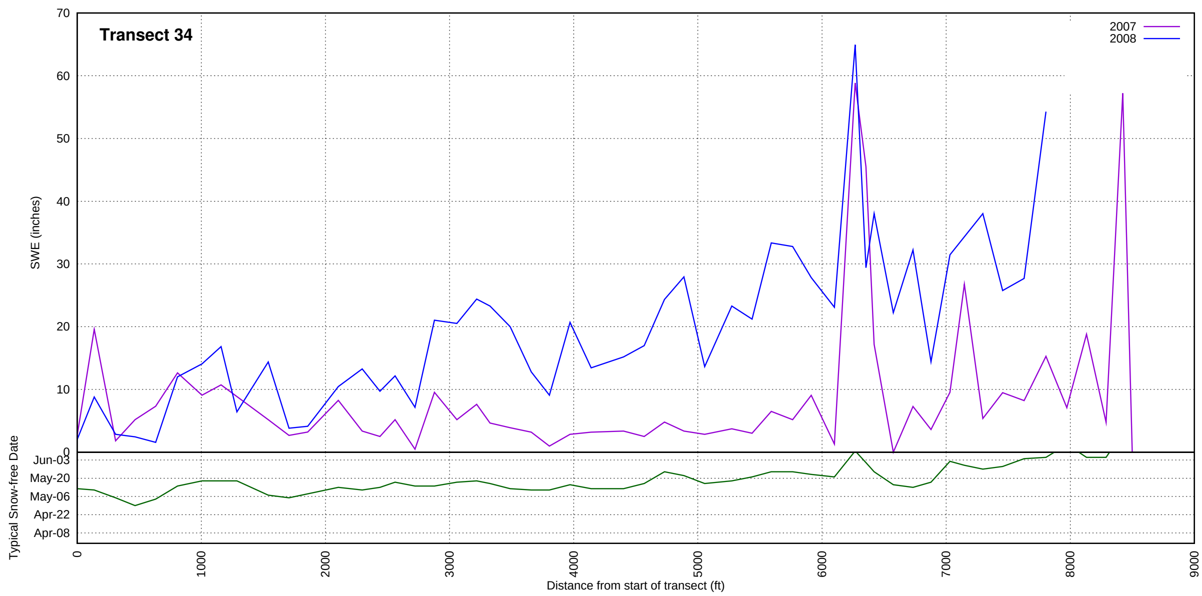




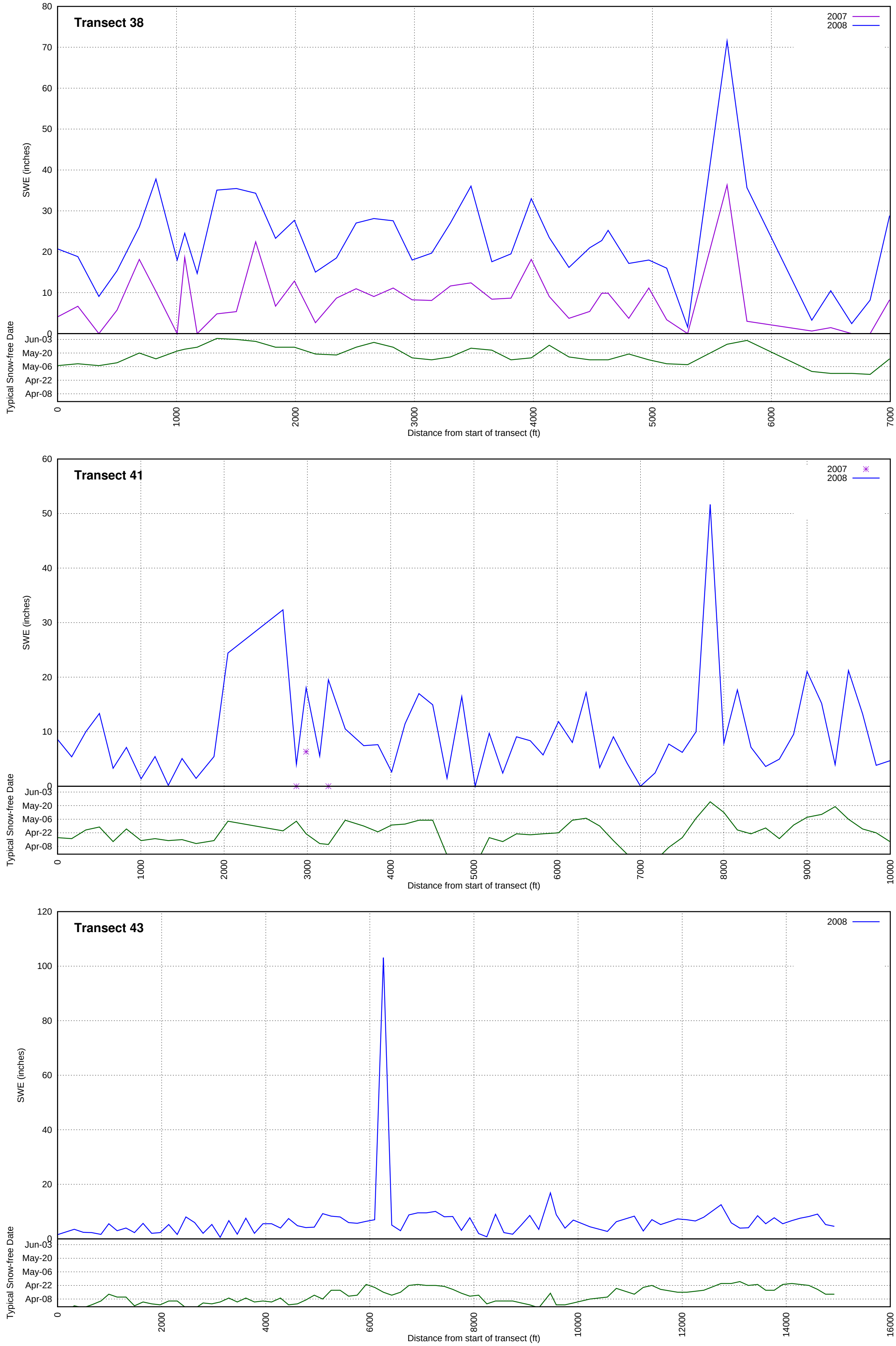
Measured SWE (inches) at Plots during Snow Distribution Surveys and Typical Snow-Free Date from Landsat



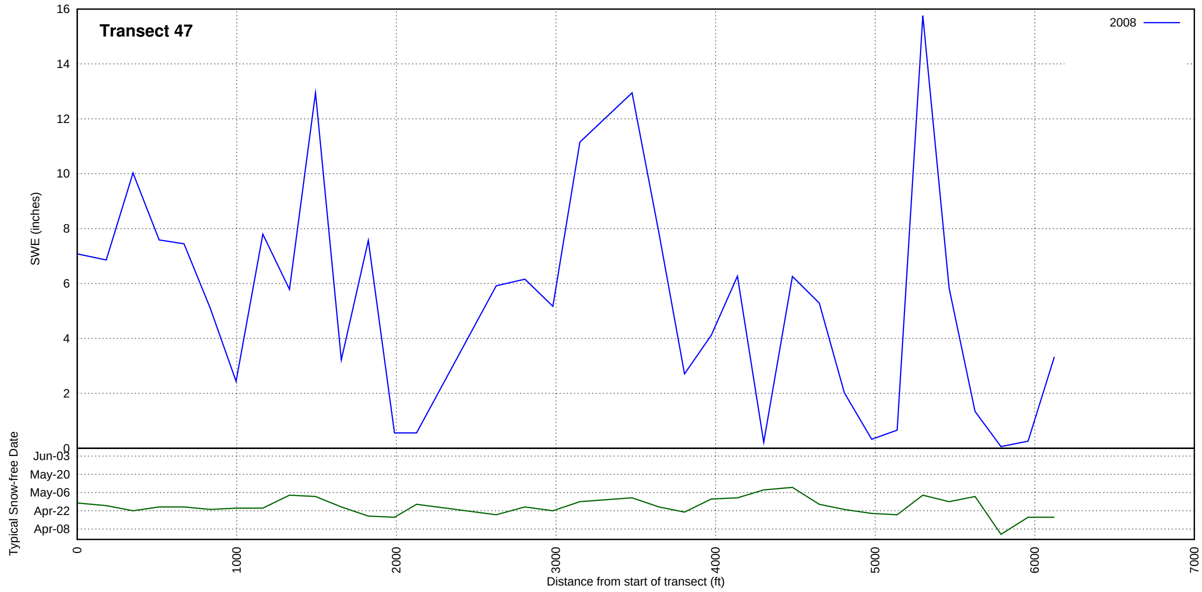


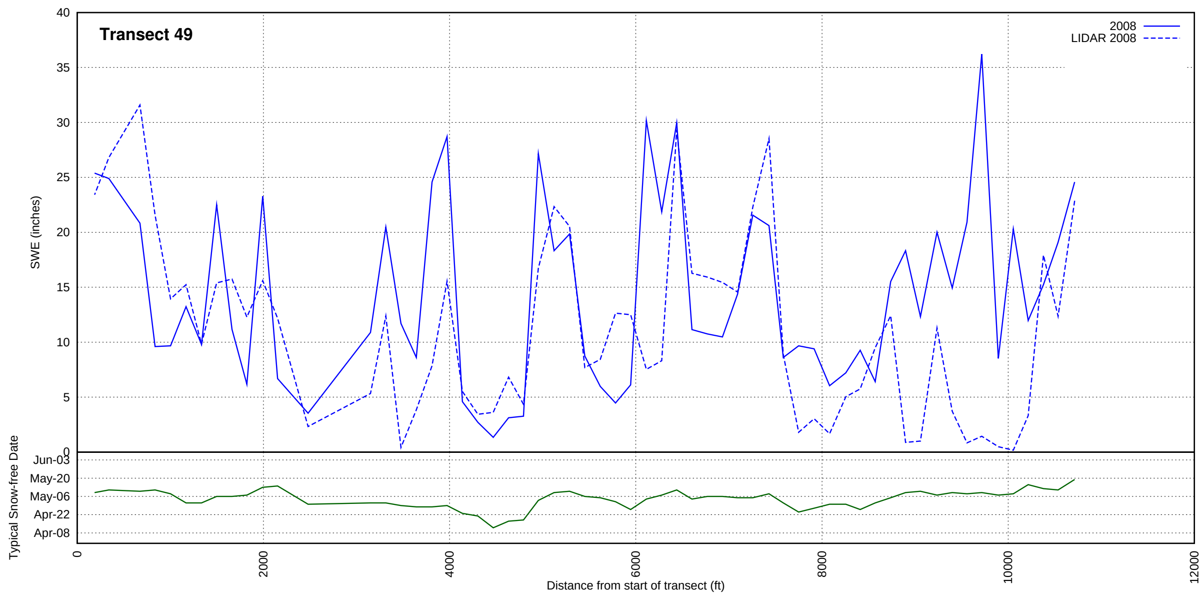


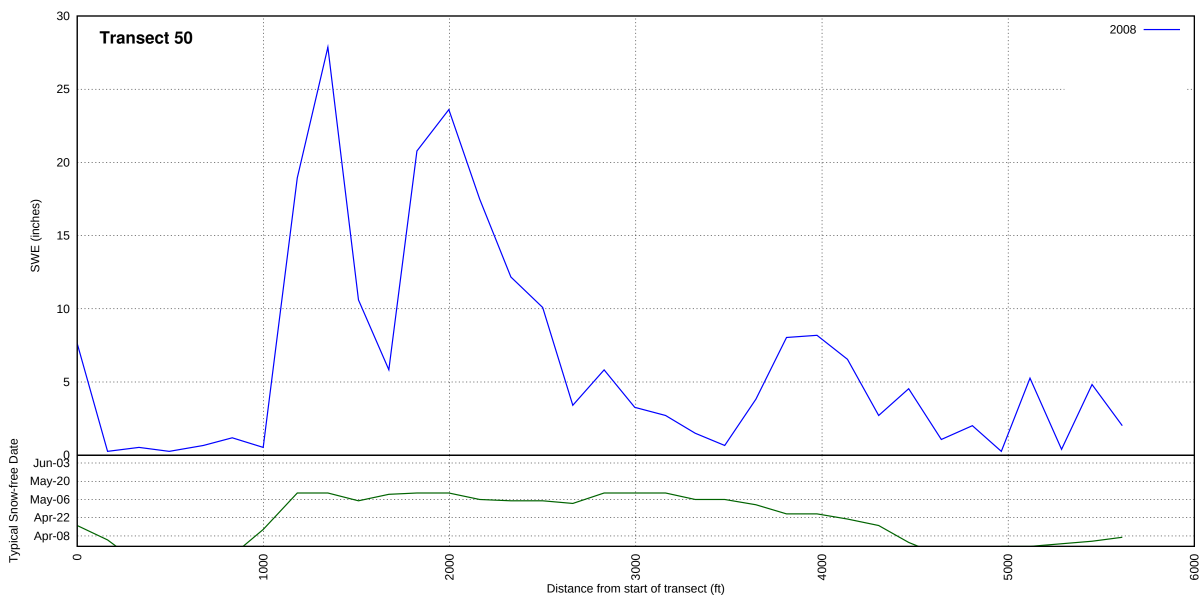
Measured SWE (inches) at Plots during Snow Distribution Surveys and Typical Snow-Free Date from Landsat



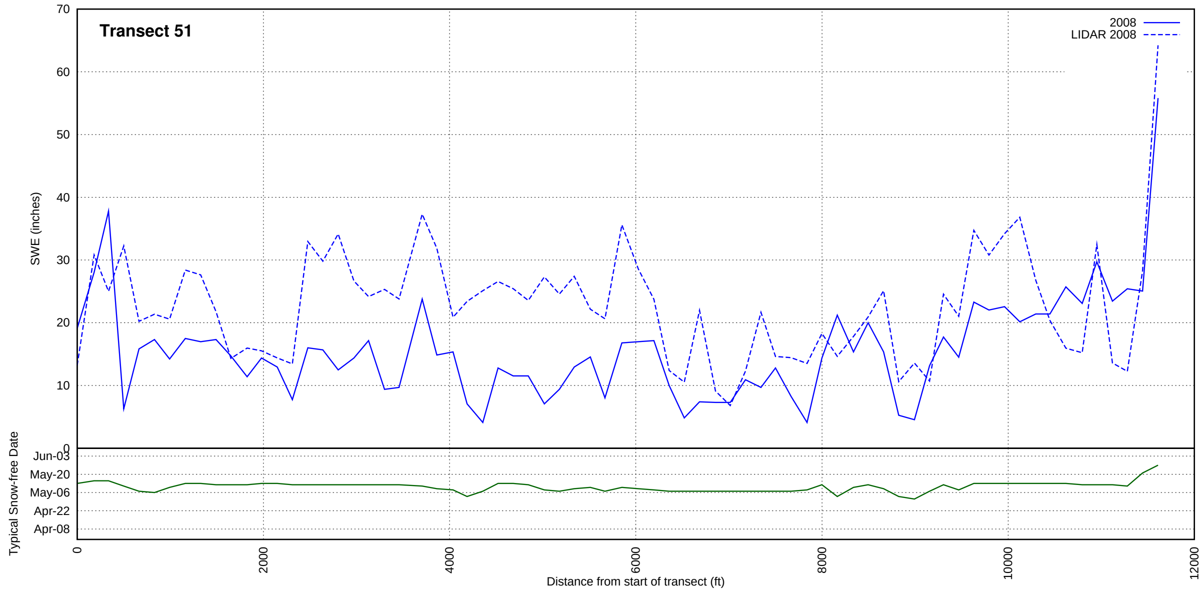
Measured SWE (inches) at Plots during Snow Distribution Surveys and Typical Snow-Free Date from Landsat







Measured SWE (inches) at Plots during Snow Distribution Surveys and Typical Snow-Free Date from Landsat



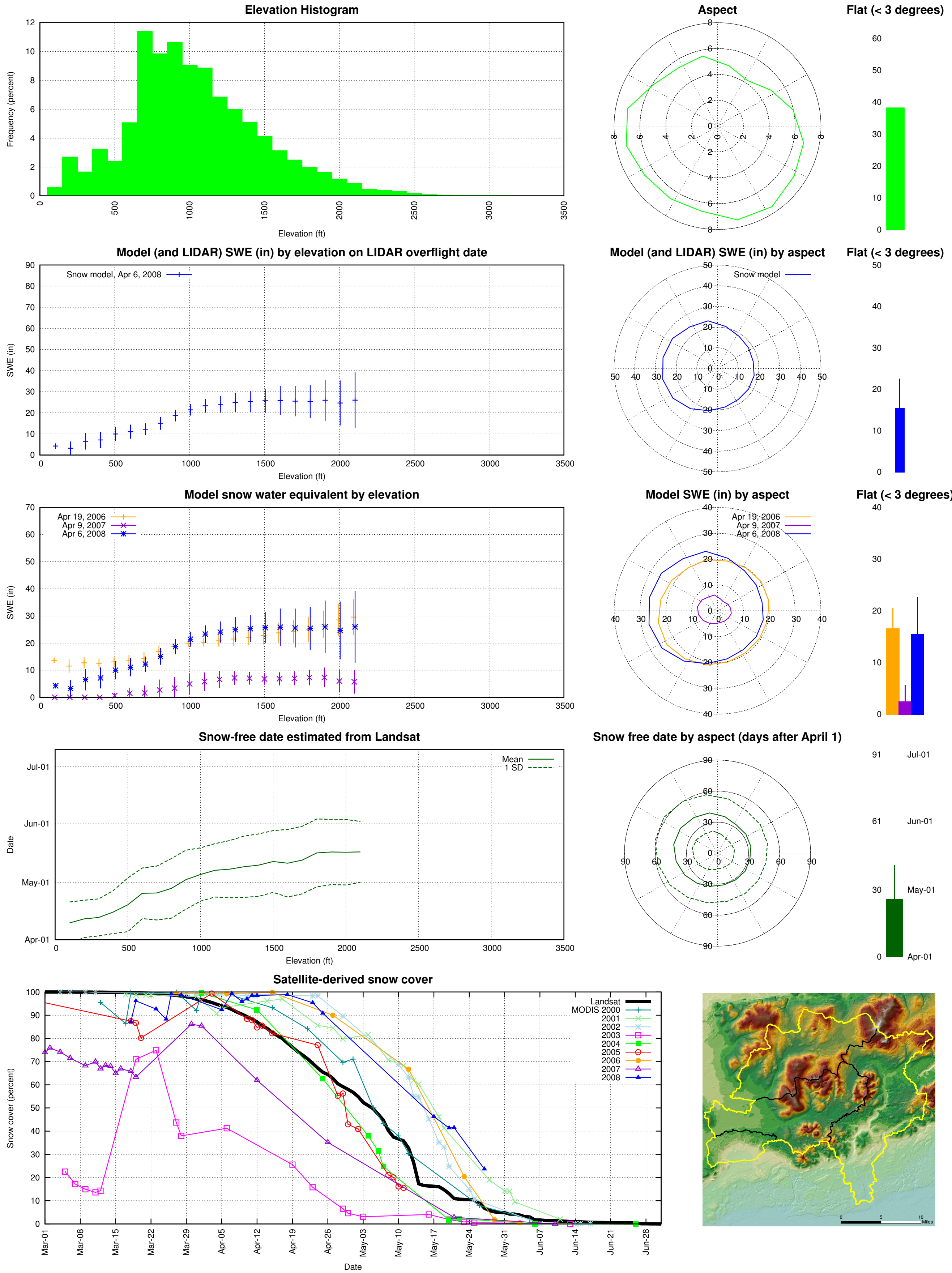
ATTACHMENT 2

Summary of Basin Characteristics

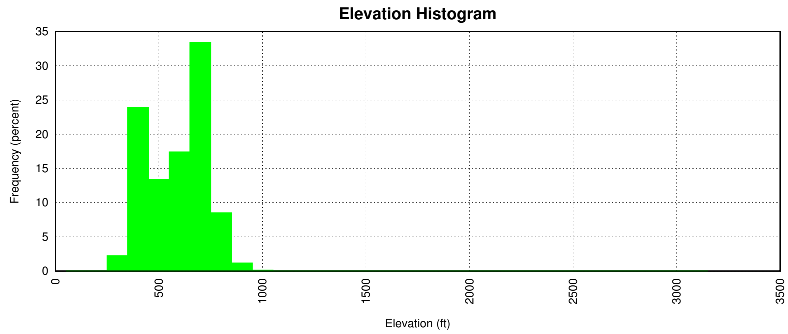
Attachment 2, Summary of Basin Characteristics.

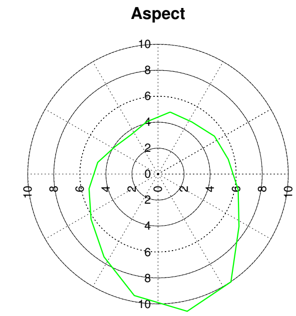
These plots summarize many attributes of each basin (or other extent). The top plots with the green bars summarize the distribution of different elevation bands and aspect categories. The snow model results and (if available) LIDAR results summarize SWE by elevation and aspect categories next. The horizontal line marks the mean SWE, while the vertical extent of the line indicates the range of plus and minus one standard deviation. The third row of plots is a comparison of snow model SWE from three winters, by elevation and aspect. The fourth row of plots depicts the typical snow-free date based on Landsat, summarized by elevation and aspect. In this case the solid line represents the mean and the dotted lines represent plus or minus one standard deviation. The bottom plot presents the snow-covered area depletion curves for 2000 through 2008 based on MODIS imagery, and also the typical snow cover at each date based on the Landsat typical snow-free date. The extent of the basin or area being summarized is in the bottom right corner.

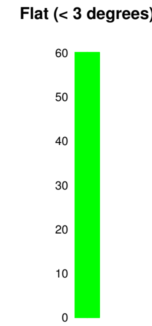
Extended Study Area Description

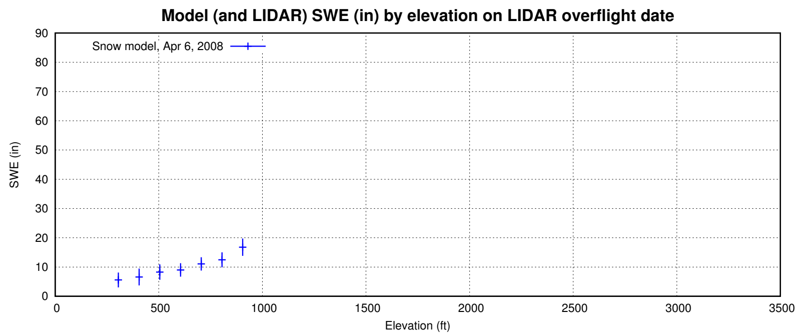


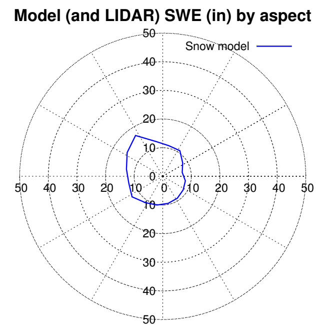
Basin KC100A Description

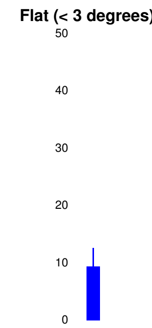


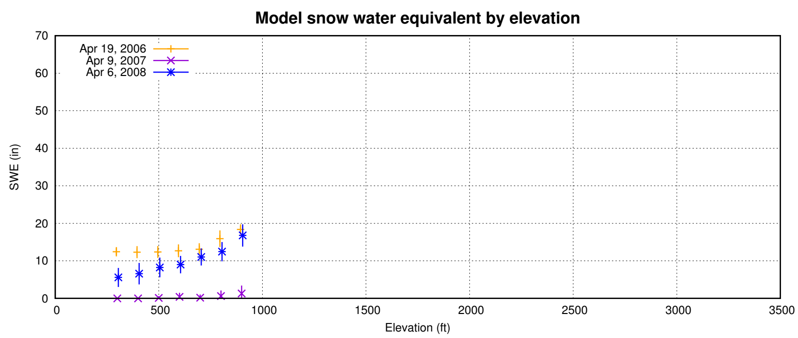


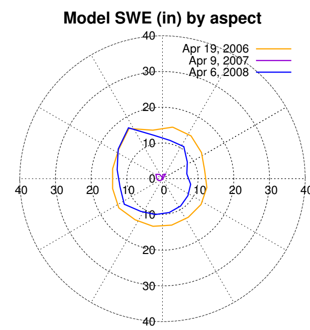


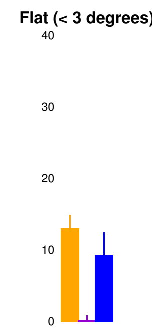


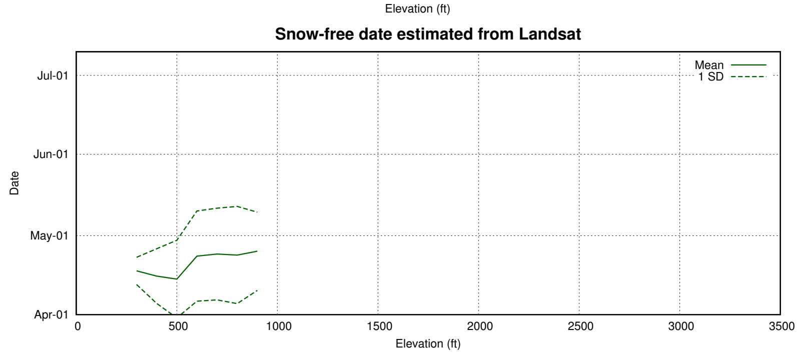


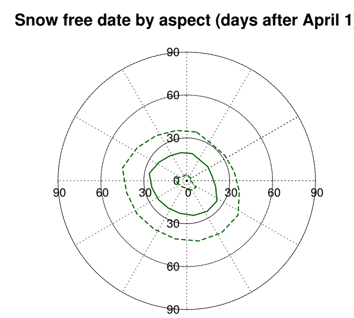


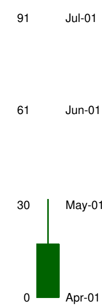


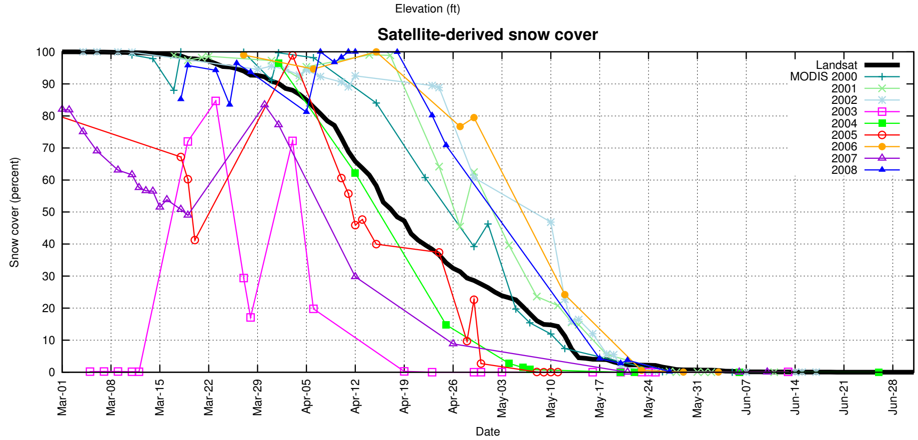


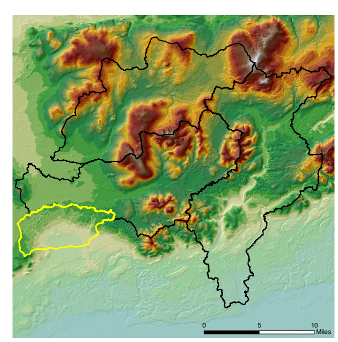






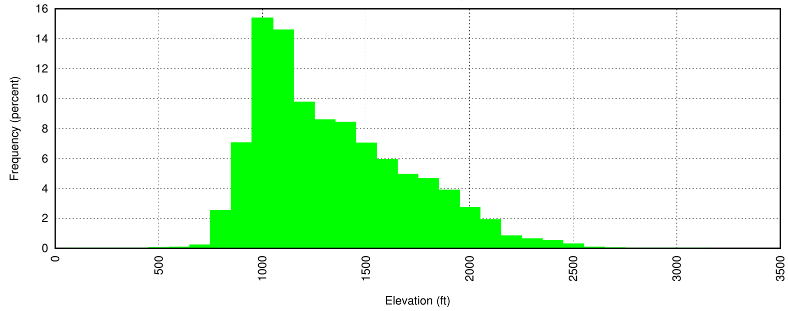




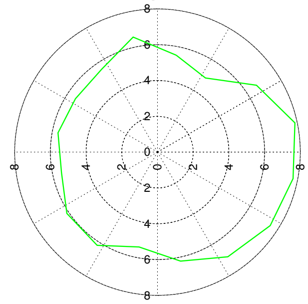


Lidar Survey Area Description

Elevation Histogram

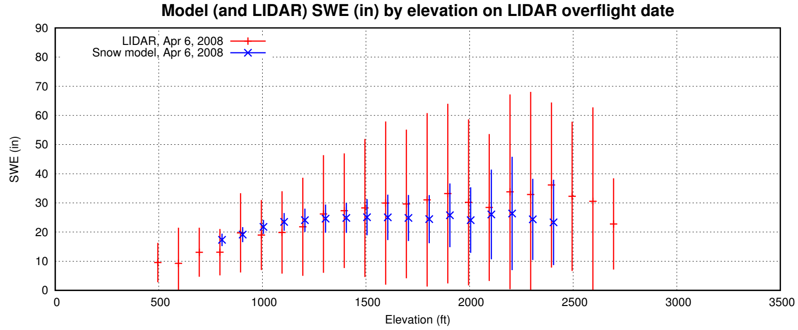


Aspect

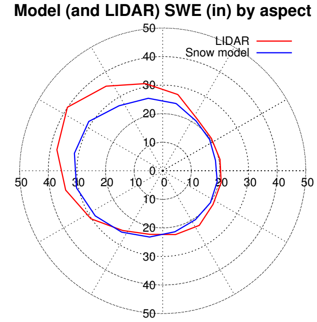


Flat (< 3 degrees)

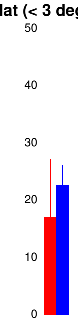
Model (and LIDAR) SWE (in) by elevation on LIDAR overflight date



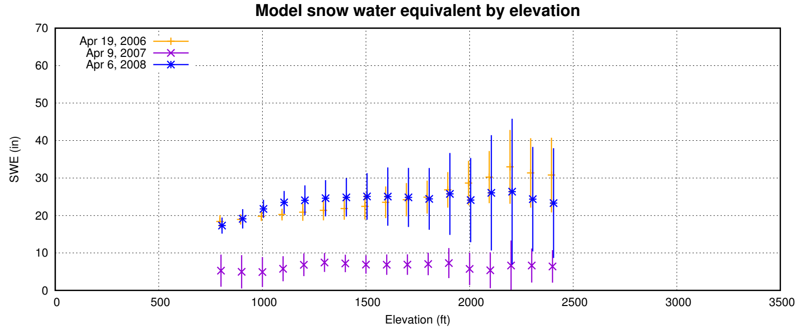
Model (and LIDAR) SWE (in) by aspect



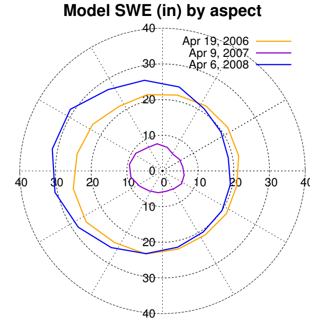
Flat (< 3 degrees)



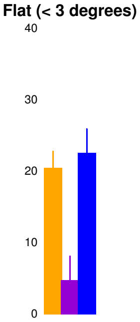
Model snow water equivalent by elevation



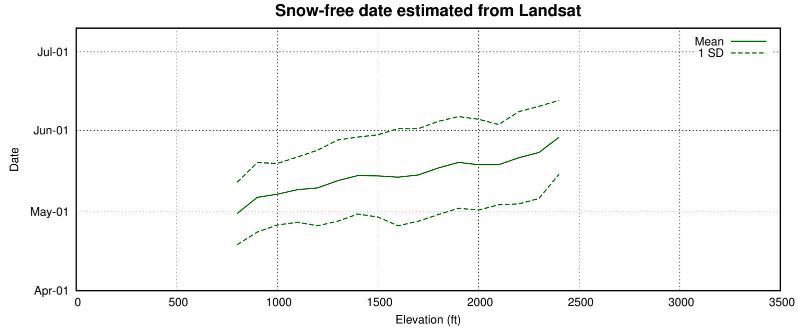
Model SWE (in) by aspect



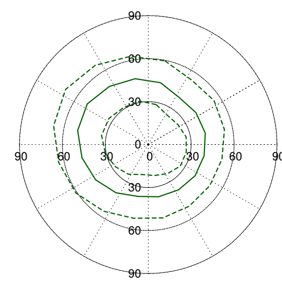
Flat (< 3 degrees)

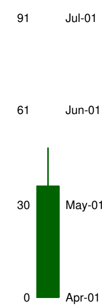


Snow-free date estimated from Landsat

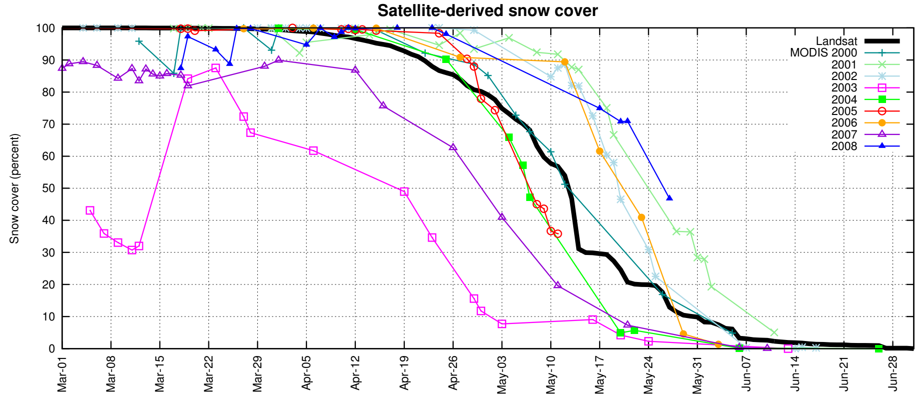


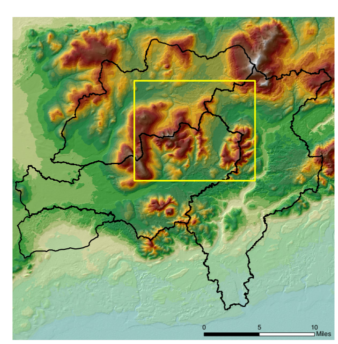
Snow free date by aspect (days after April 1)



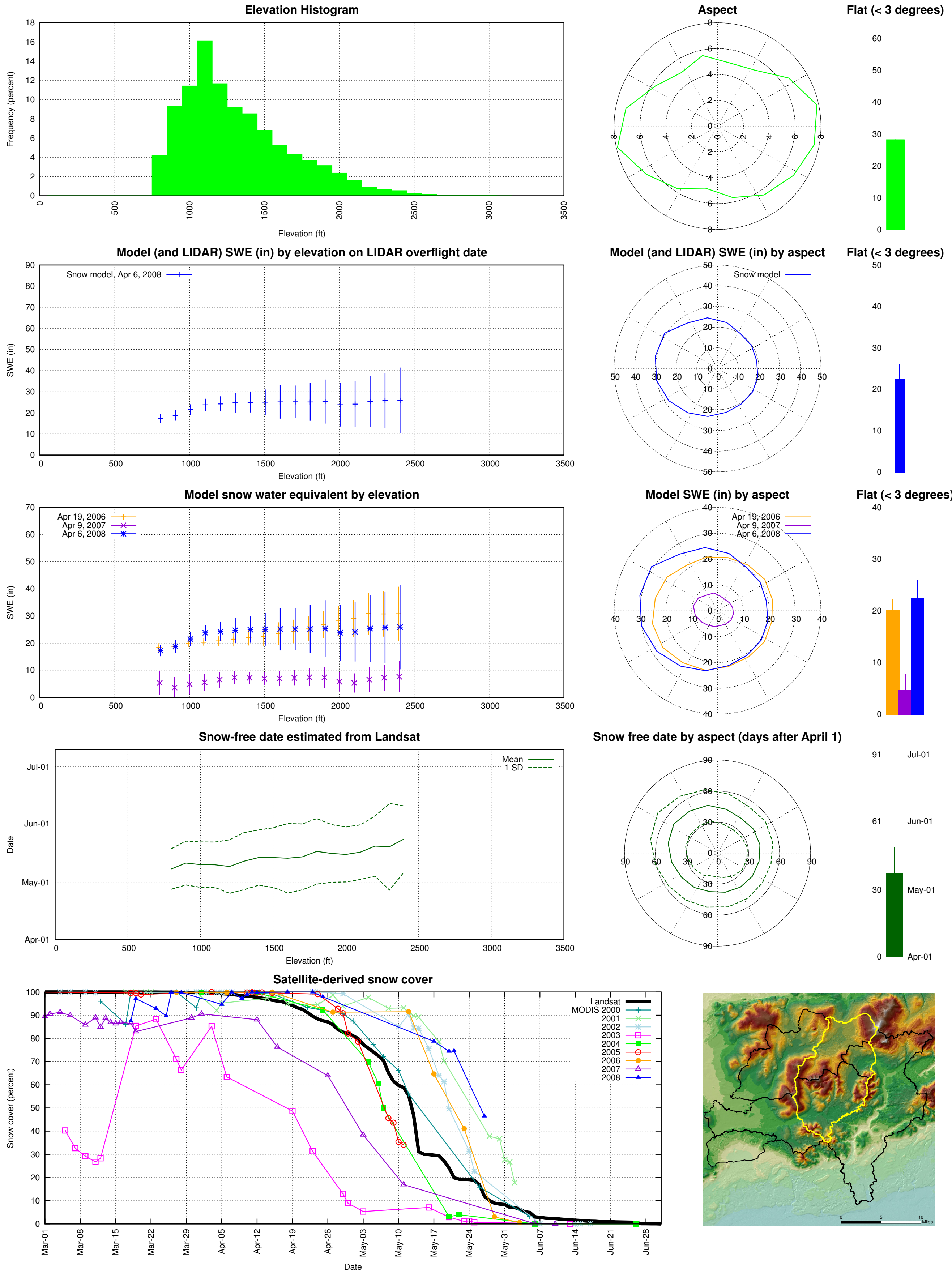


Satellite-derived snow cover



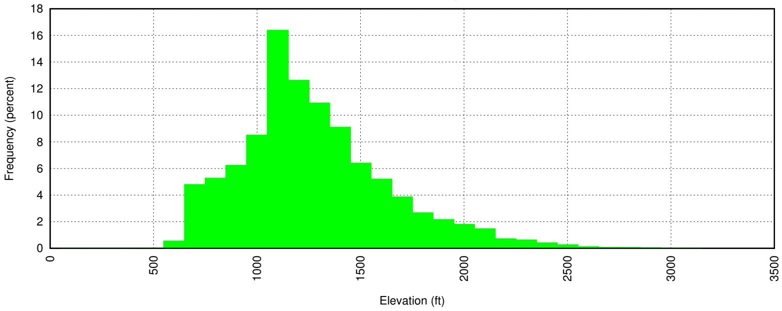


Mine Study Area Description

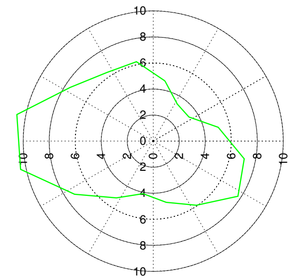


Basin NK100A Description

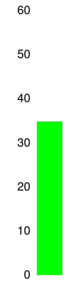
Elevation Histogram



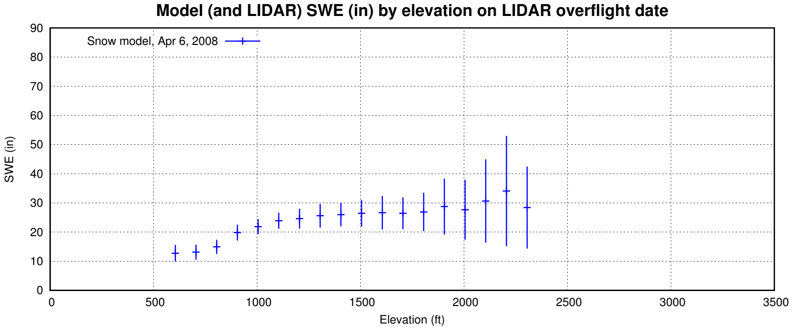
Aspect



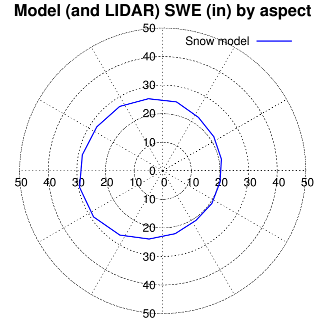
Flat (< 3 degrees)



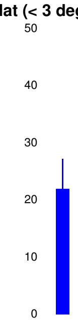
Model (and LIDAR) SWE (in) by elevation on LIDAR overflight date



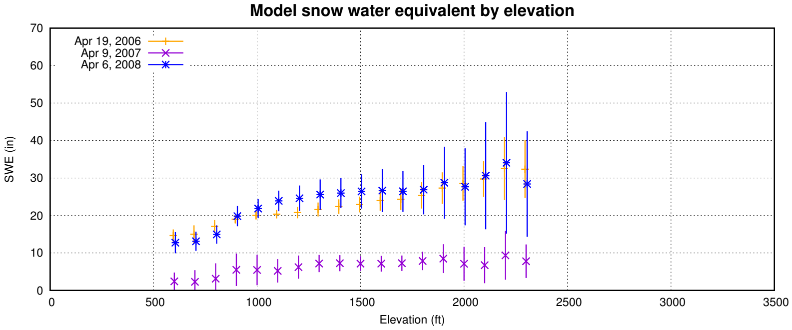
Model (and LIDAR) SWE (in) by aspect



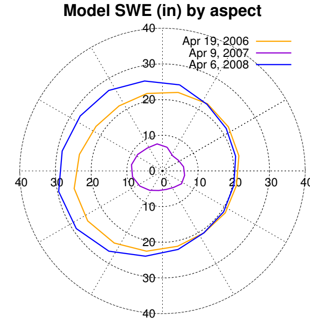
Flat (< 3 degrees)



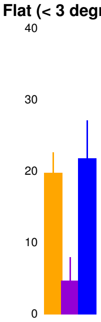
Model snow water equivalent by elevation



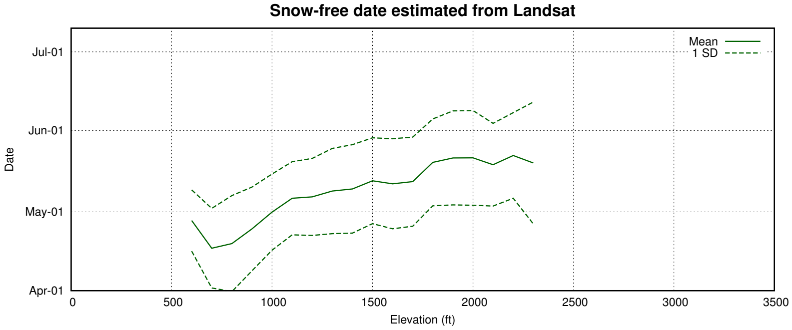
Model SWE (in) by aspect



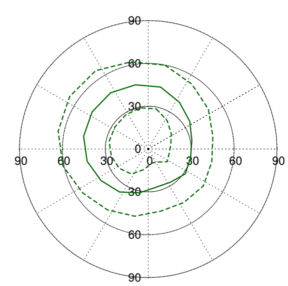
Flat (< 3 degrees)

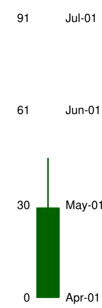


Snow-free date estimated from Landsat

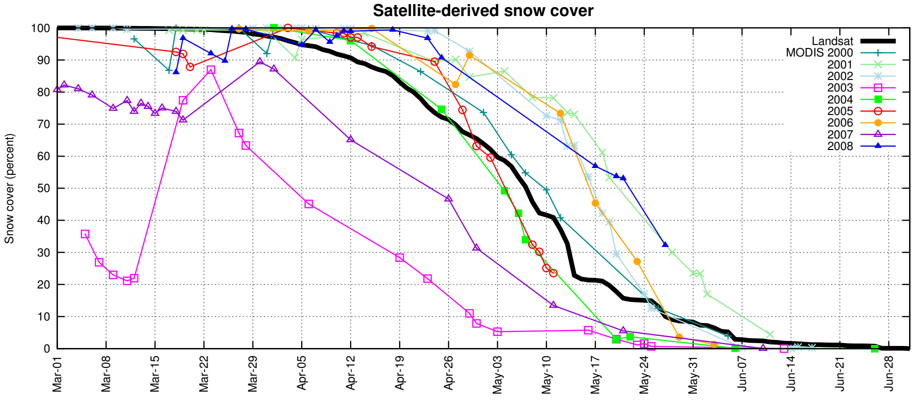


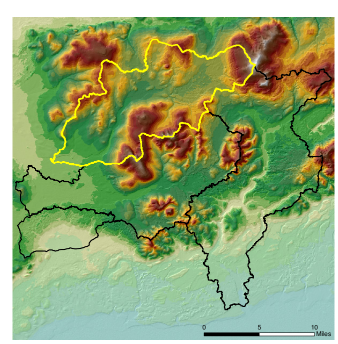
Snow free date by aspect (days after April 1)



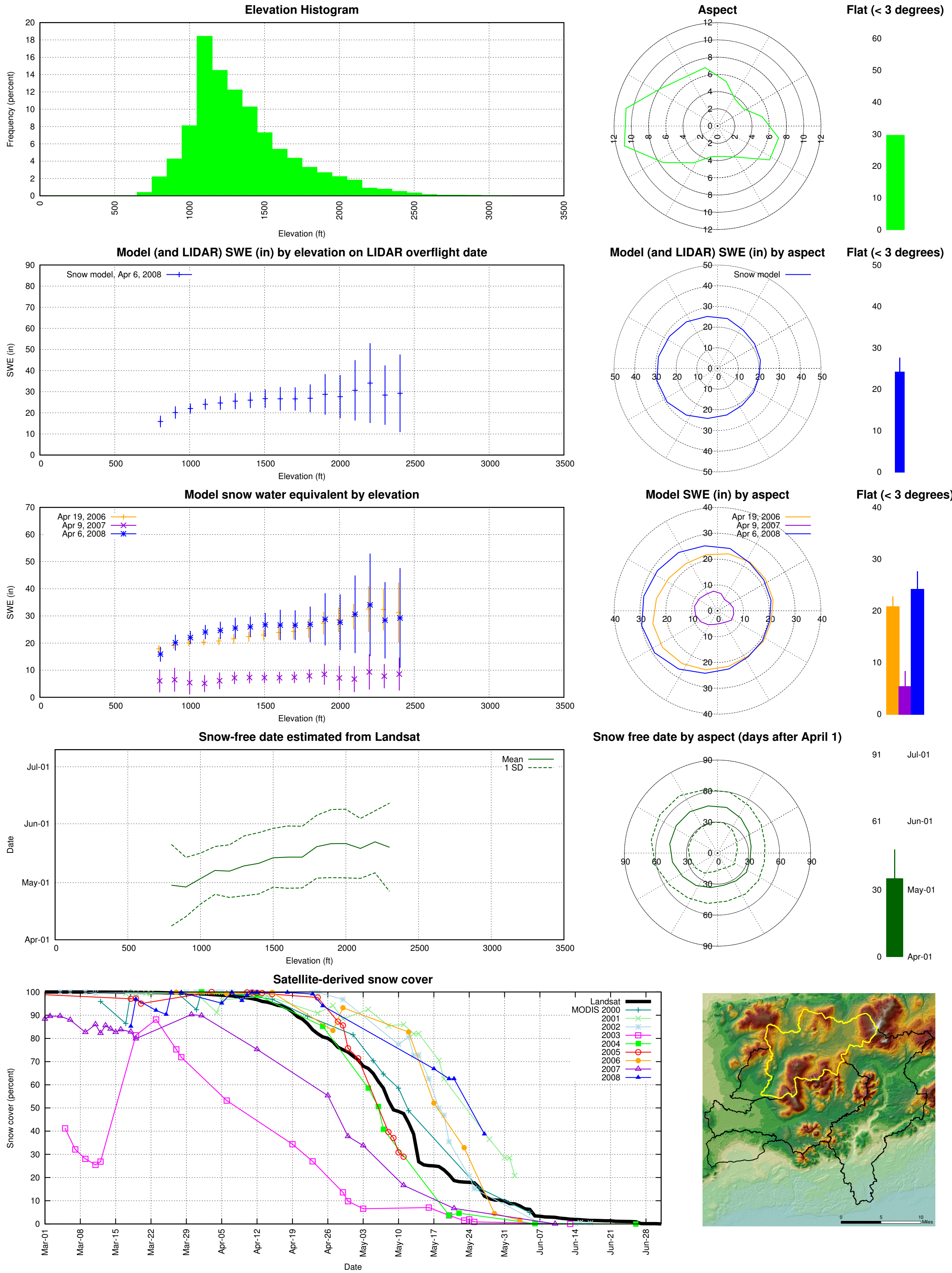


Satellite-derived snow cover

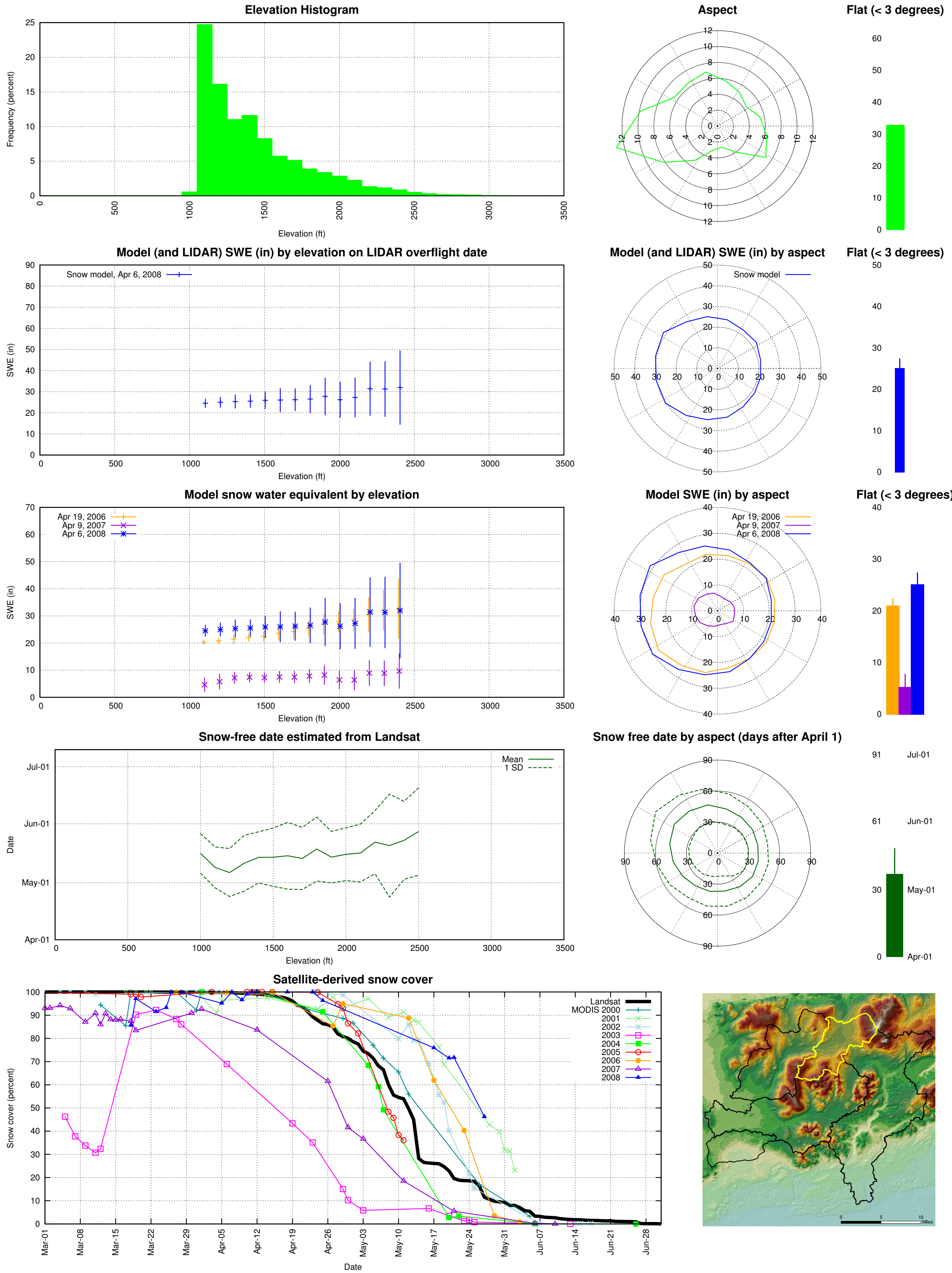




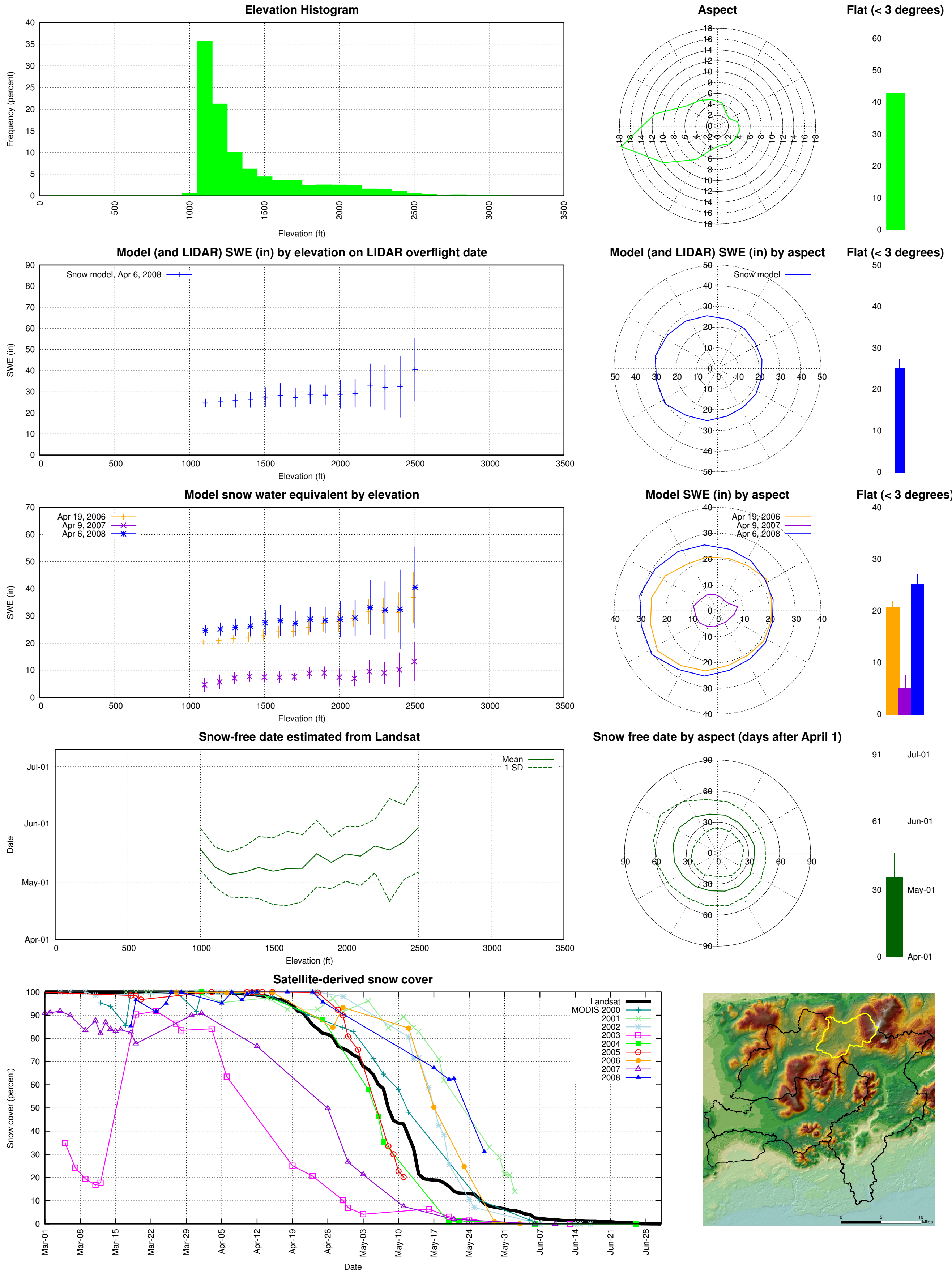
Basin NK100A1 Description



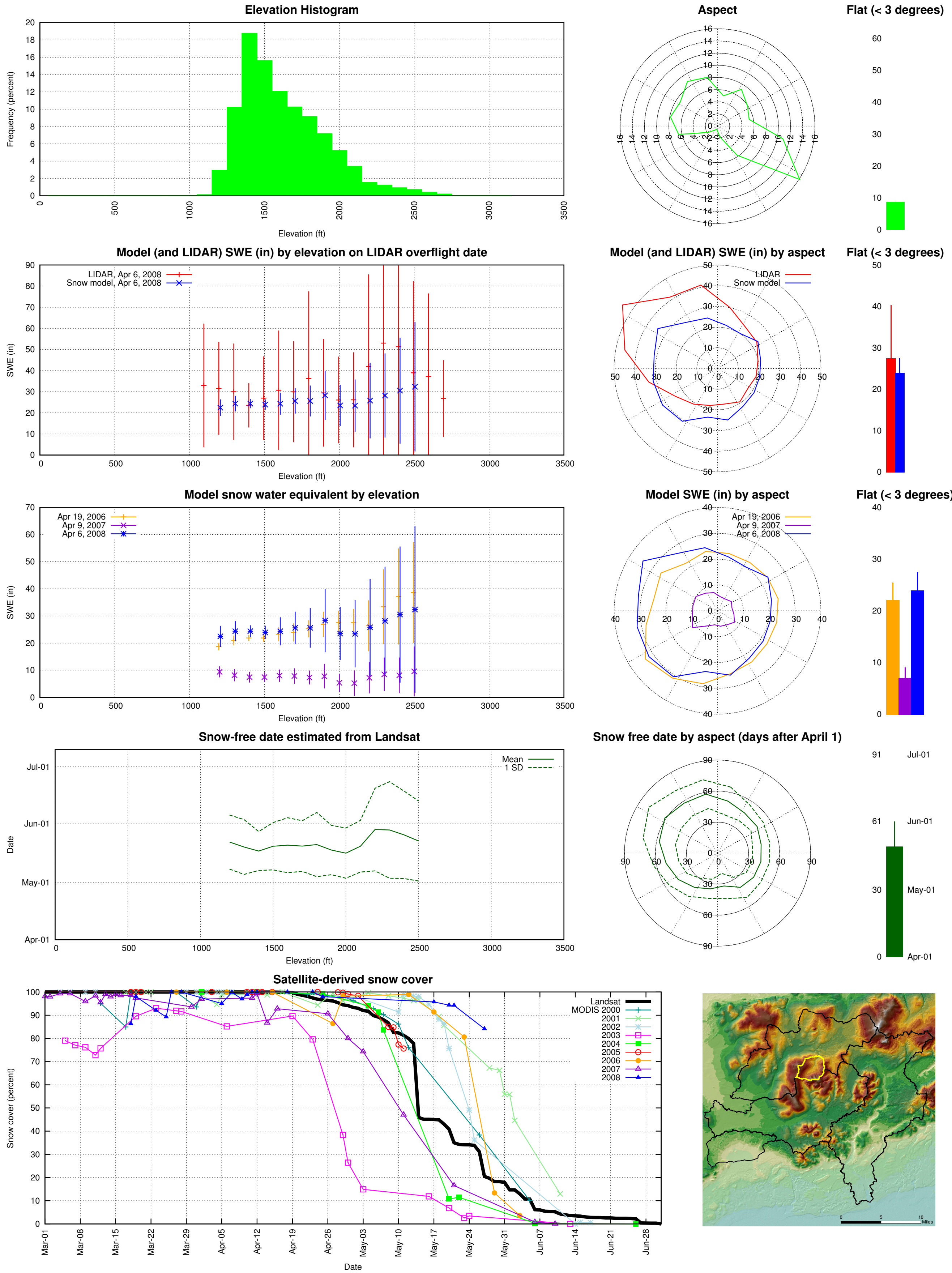
Basin NK100B Description



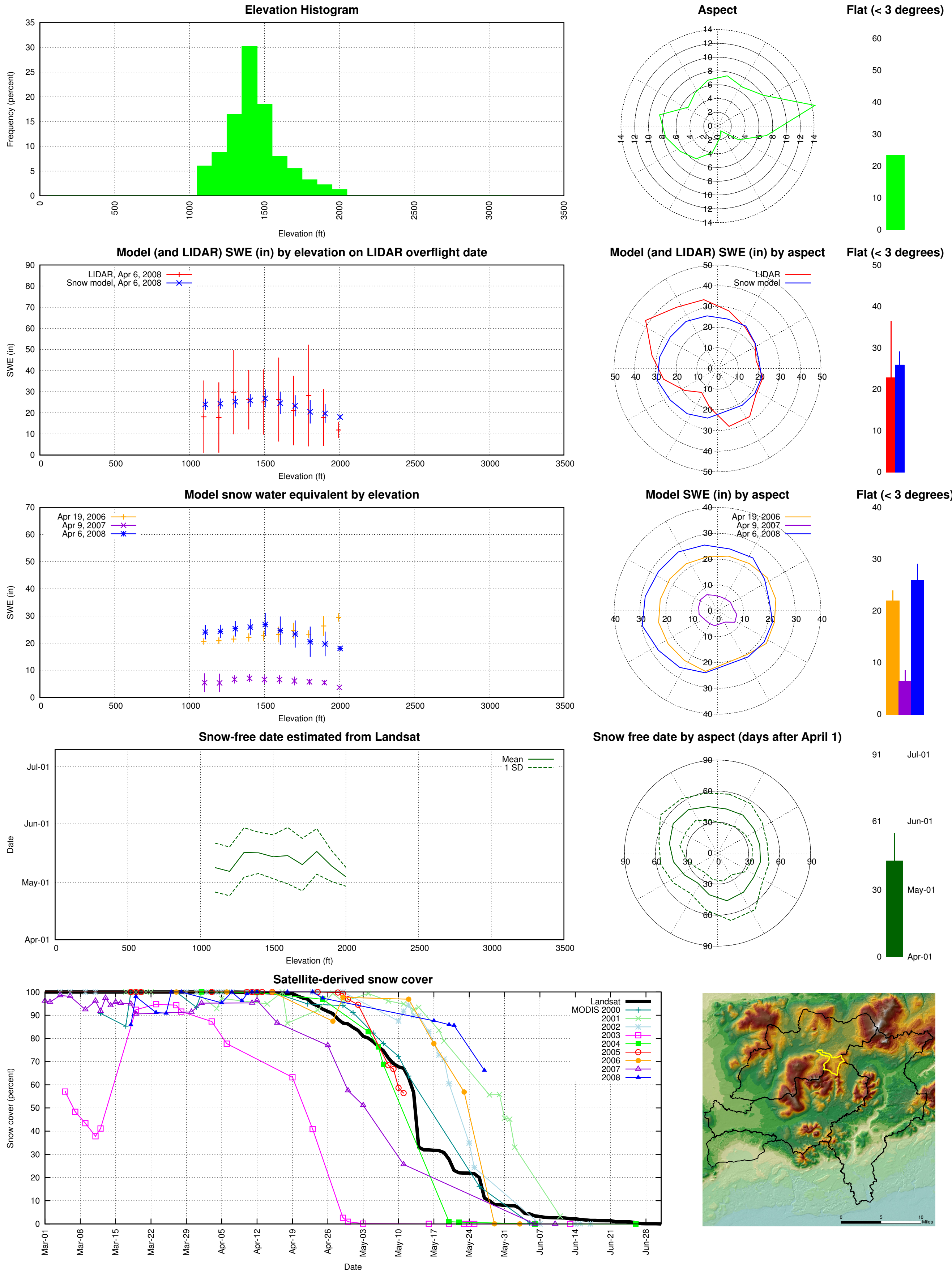
Basin NK100C Description



Basin NK119A Description

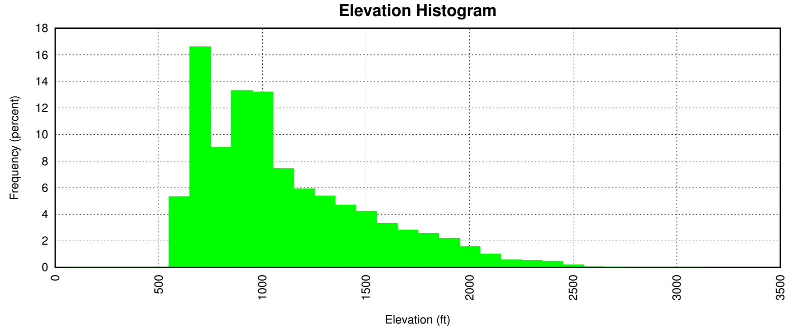


Basin NK119B Description

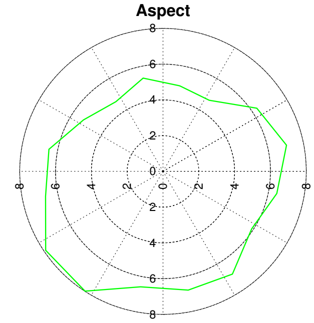


Basin SK100A Description

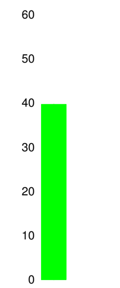
Elevation Histogram



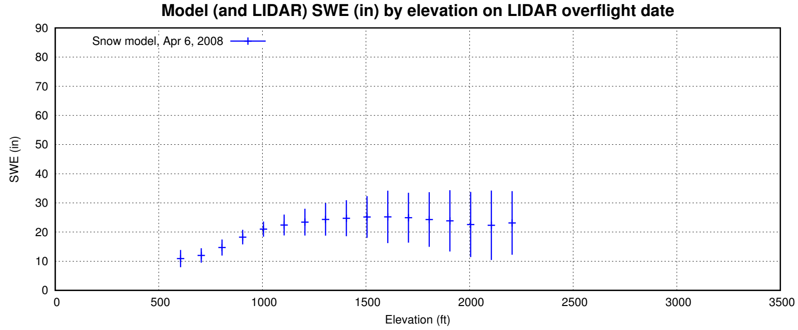
Aspect



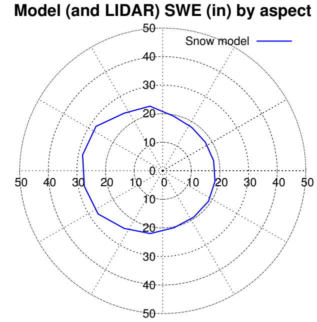
Flat (< 3 degrees)



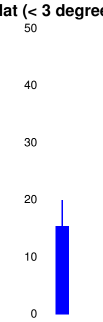
Model (and LIDAR) SWE (in) by elevation on LIDAR overflight date



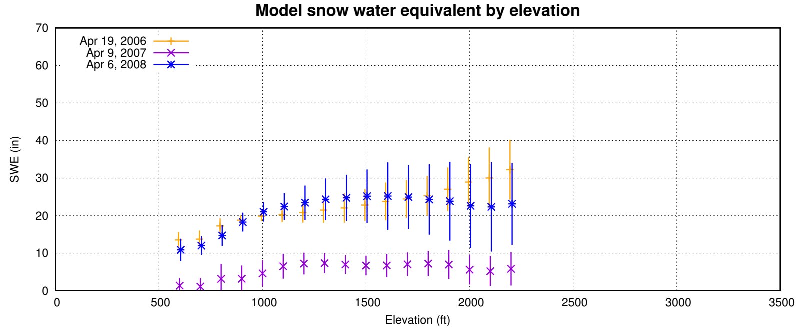
Model (and LIDAR) SWE (in) by aspect



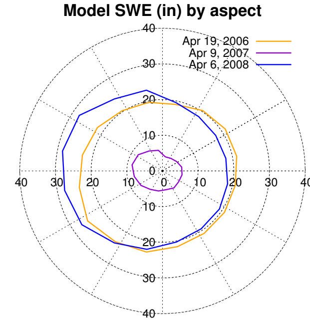
Flat (< 3 degrees)



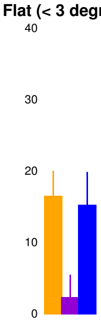
Model snow water equivalent by elevation



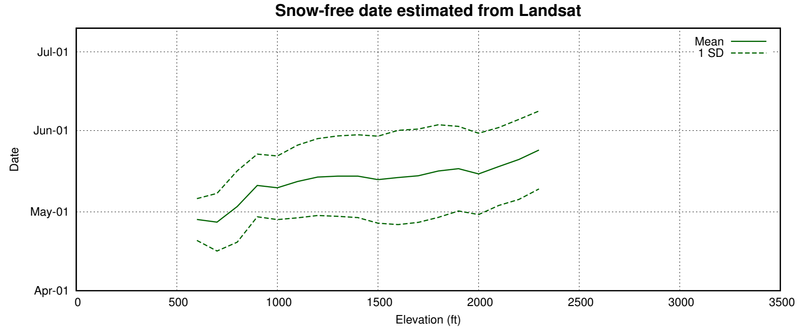
Model SWE (in) by aspect



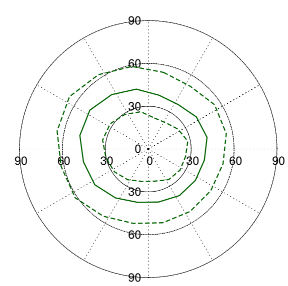
Flat (< 3 degrees)

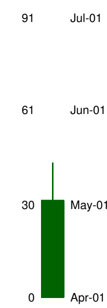


Snow-free date estimated from Landsat

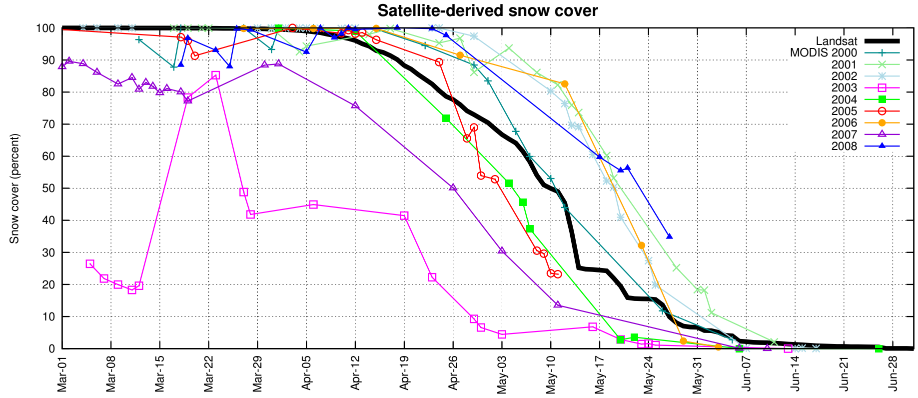


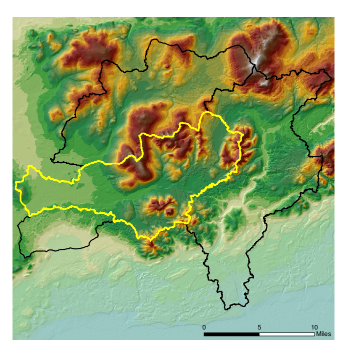
Snow free date by aspect (days after April 1)



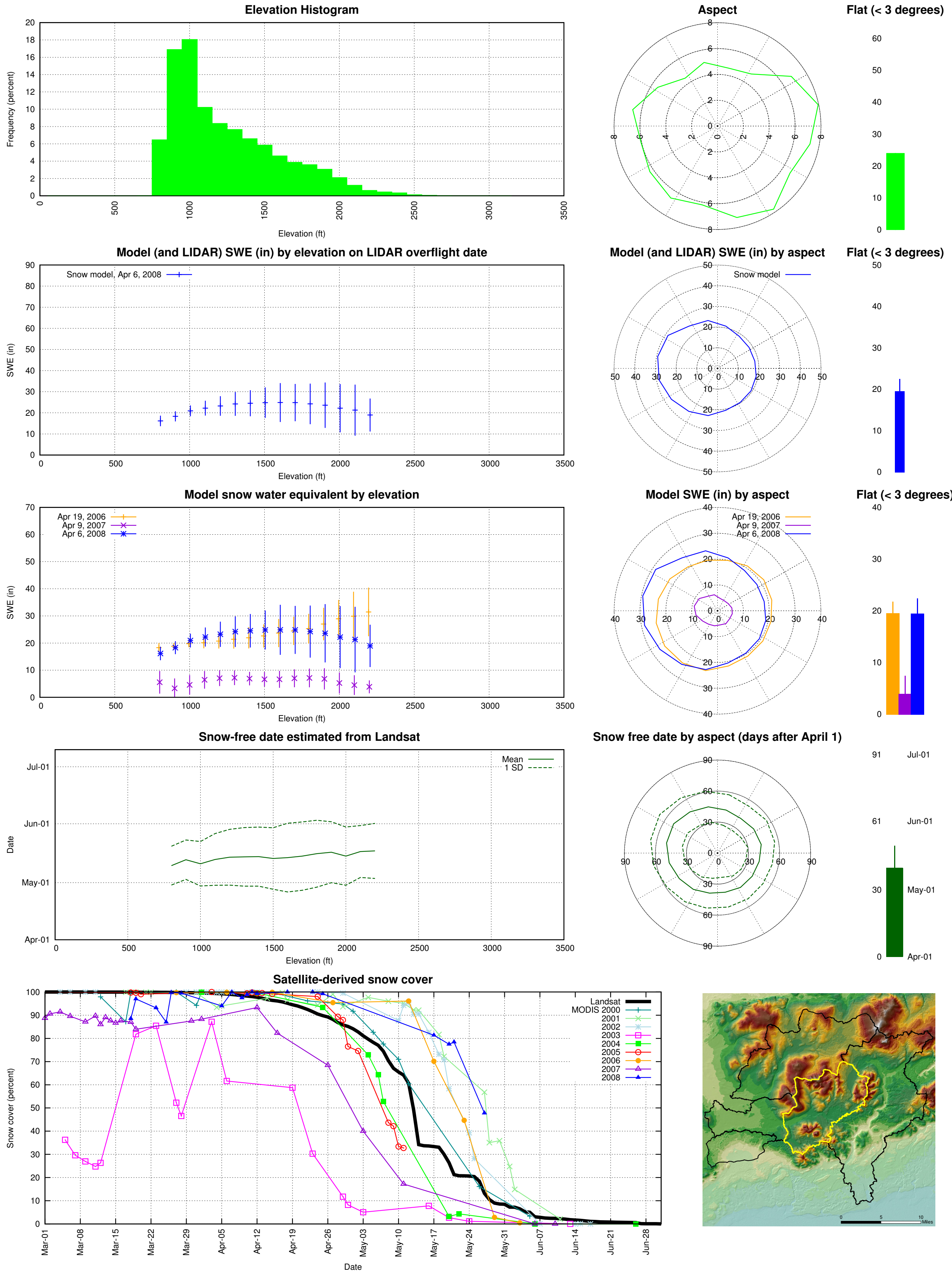


Satellite-derived snow cover

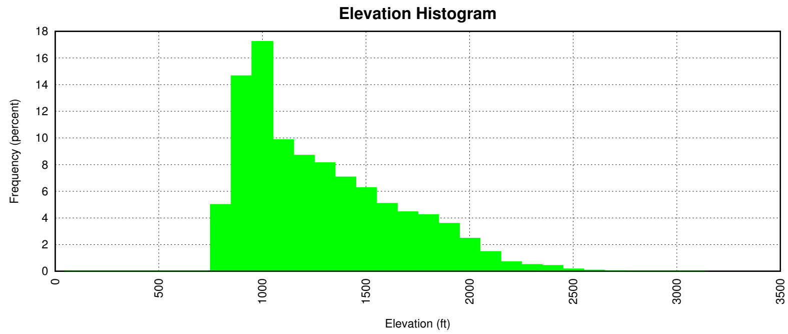


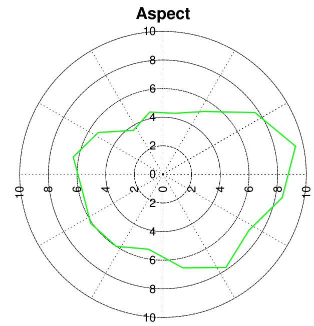


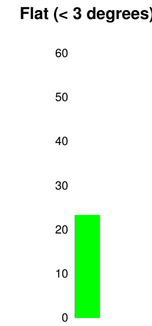
Basin SK100B Description

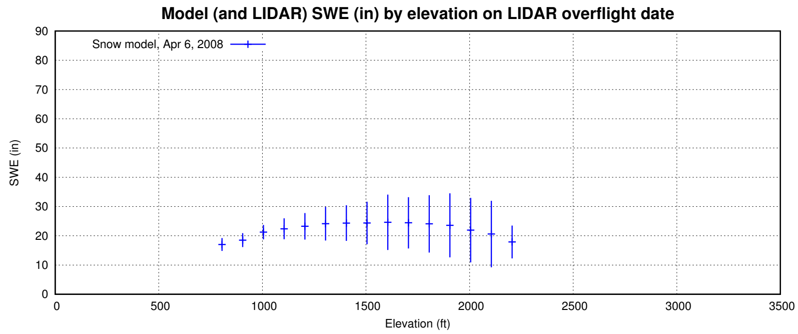


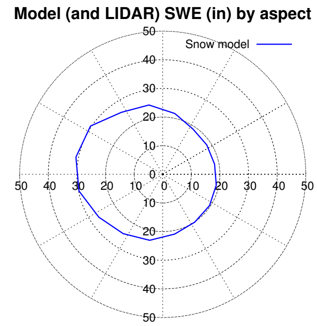
Basin SK100B1 Description

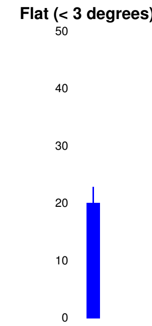


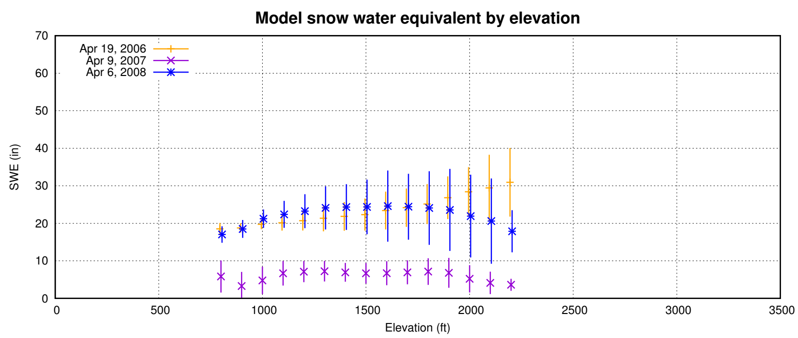


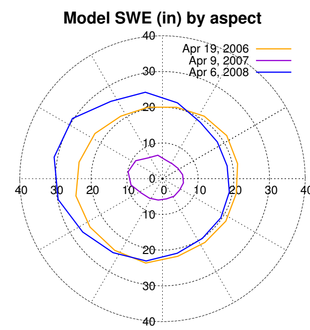


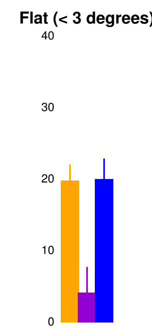


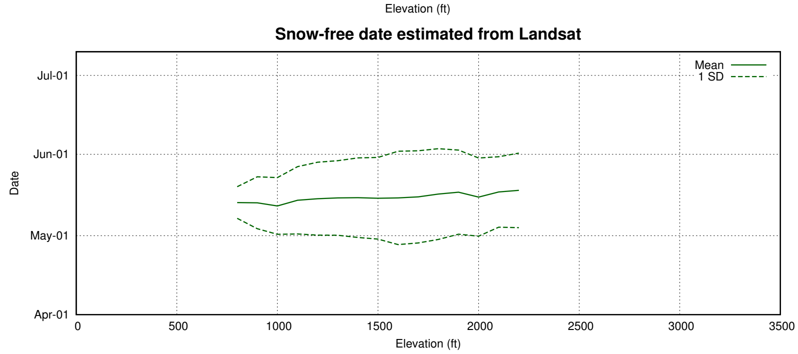


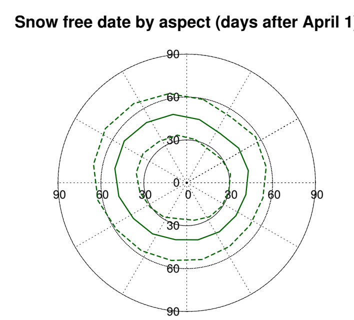


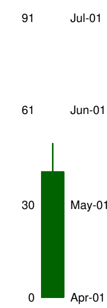


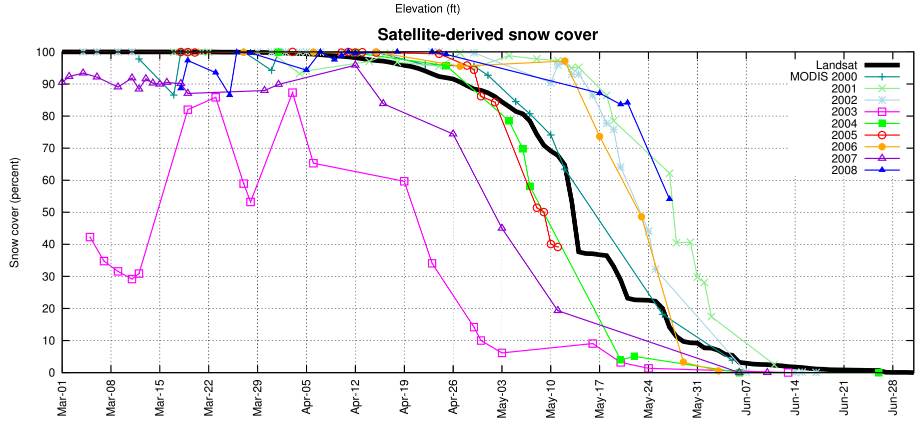


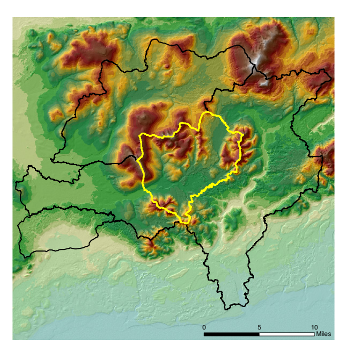




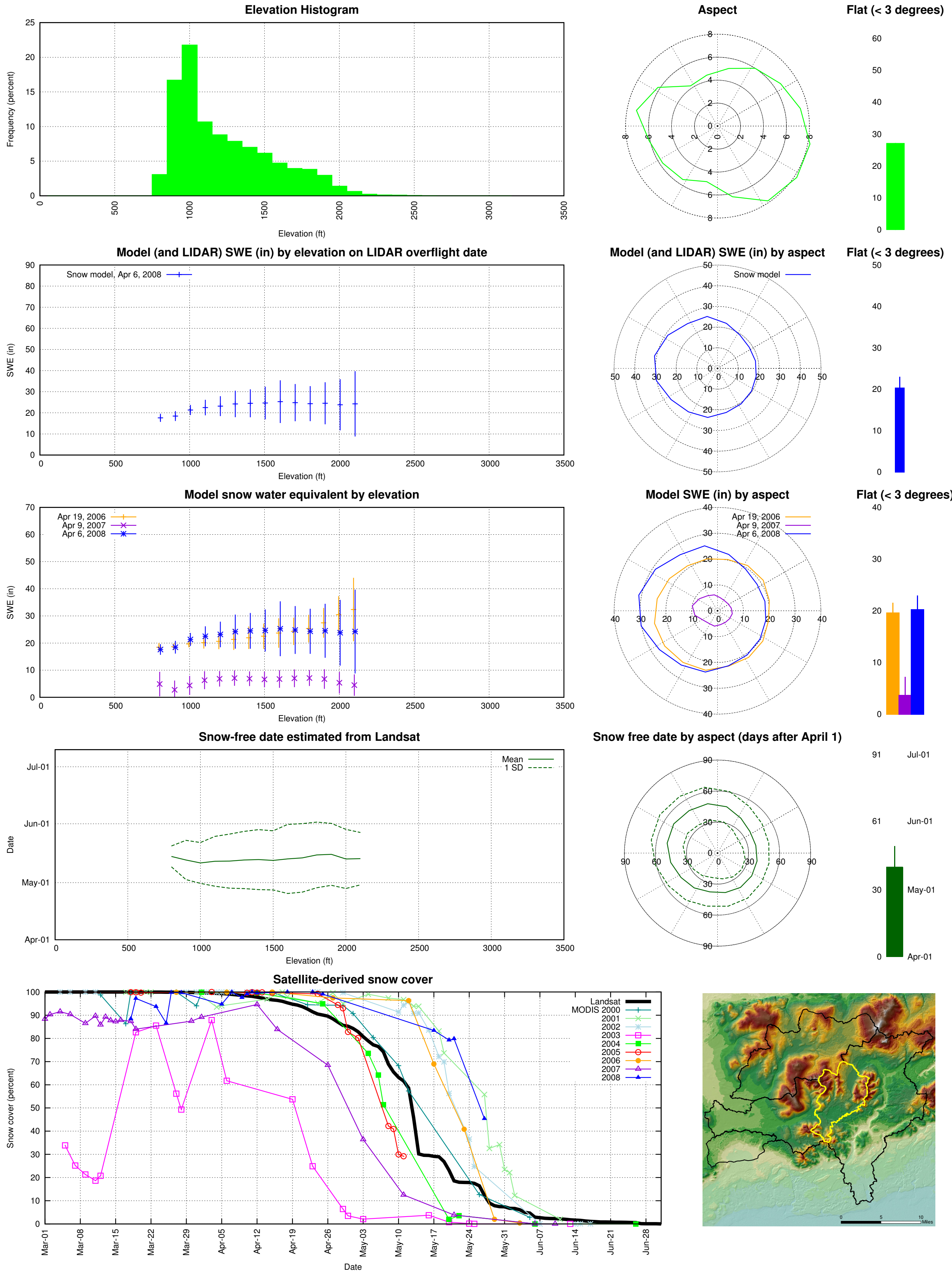




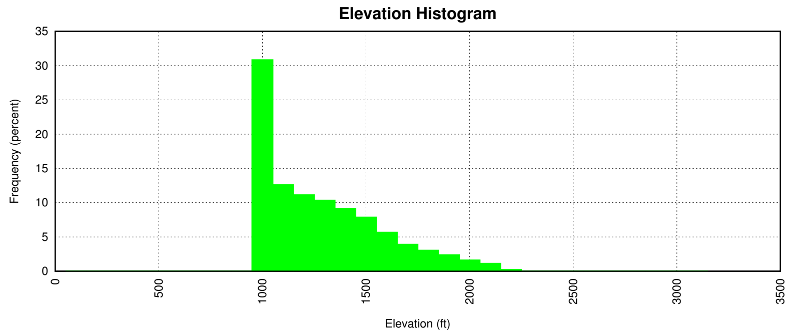


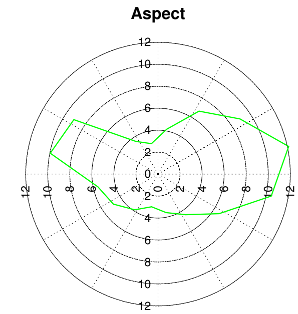


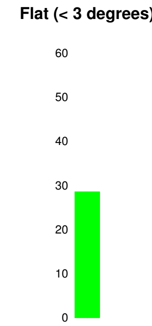
Basin SK100C Description

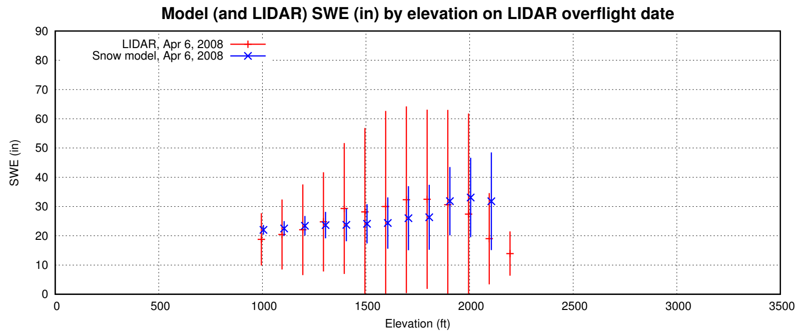


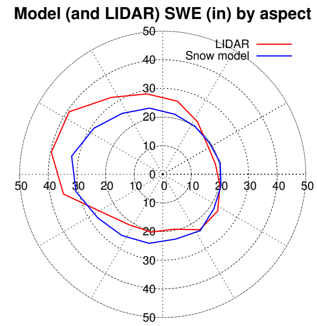
Basin SK100F Description

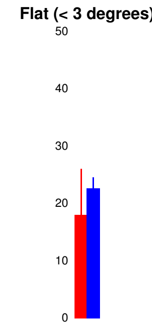


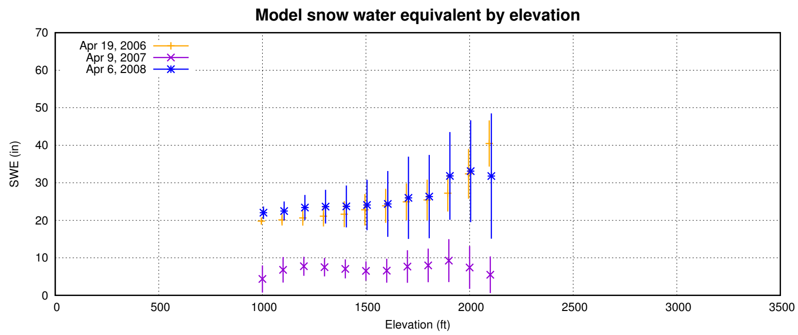


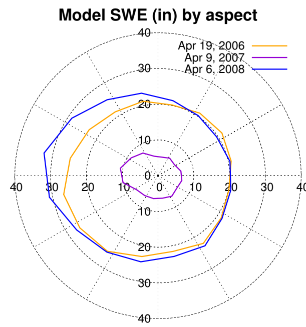


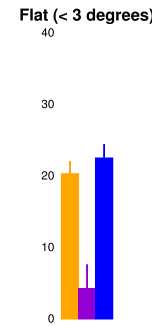


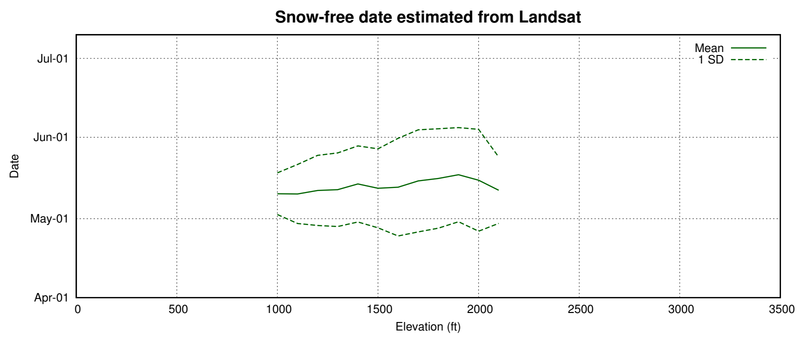


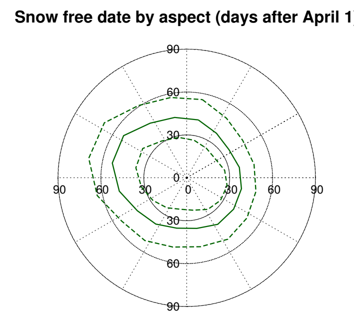


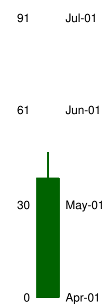


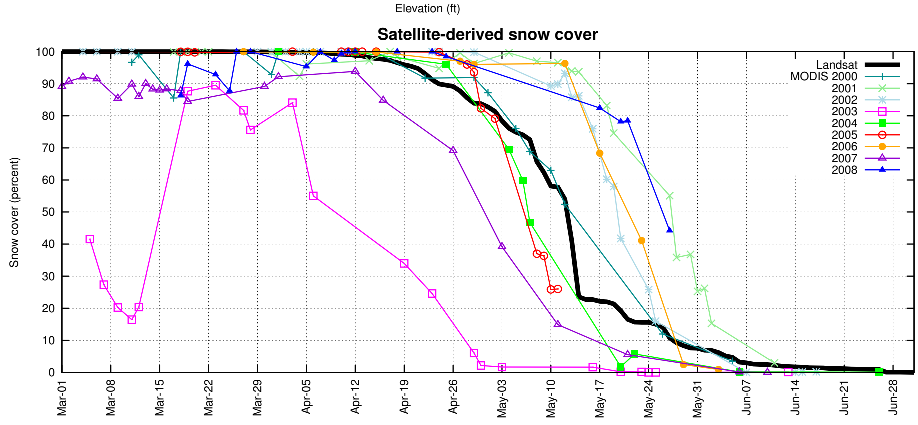


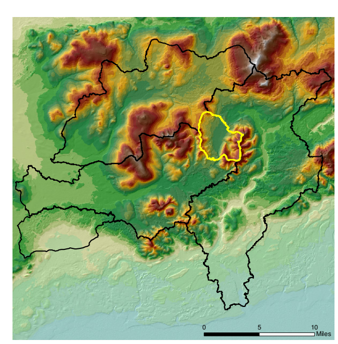






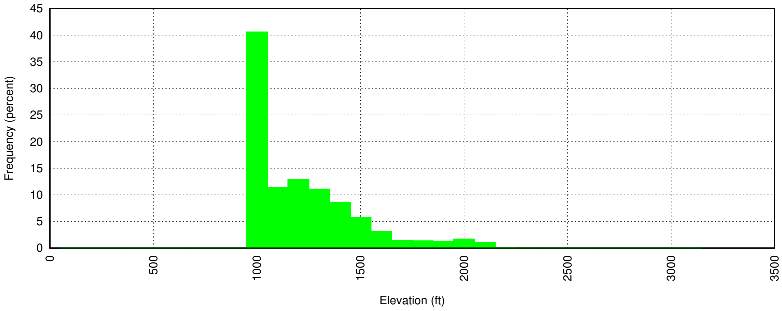




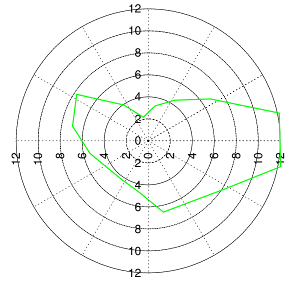


Basin SK100G Description

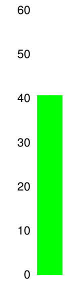
Elevation Histogram



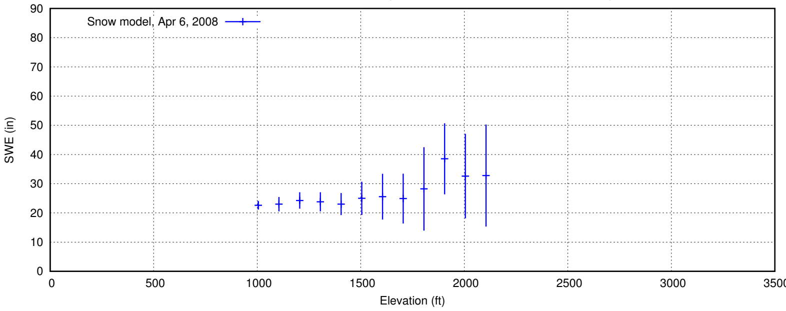
Aspect



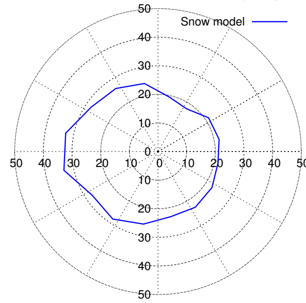
Flat (< 3 degrees)



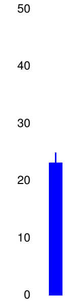
Model (and LIDAR) SWE (in) by elevation on LIDAR overflight date



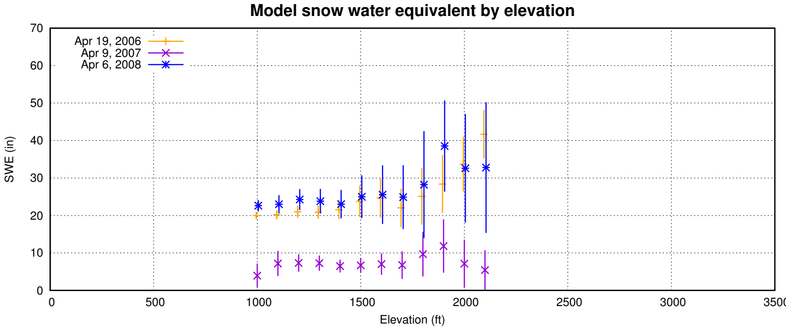
Model (and LIDAR) SWE (in) by aspect



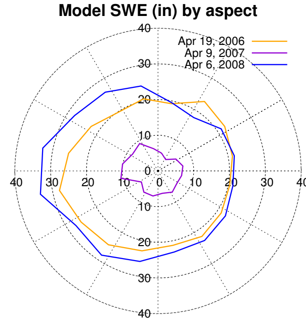
Flat (< 3 degrees)



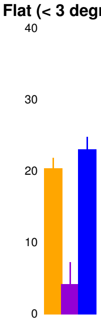
Model snow water equivalent by elevation



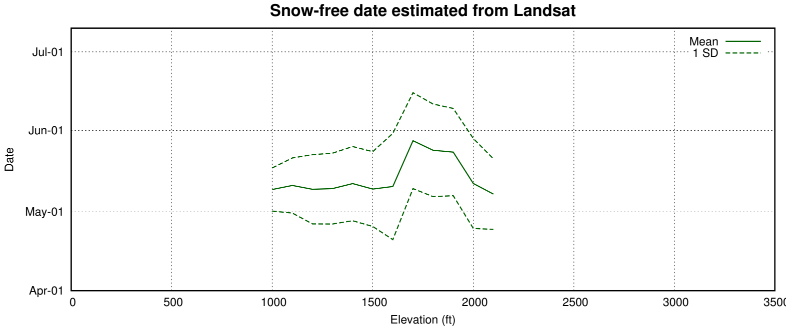
Model SWE (in) by aspect



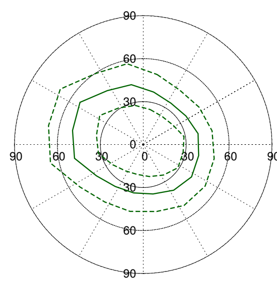
Flat (< 3 degrees)

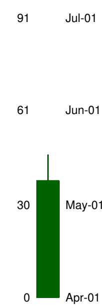


Snow-free date estimated from Landsat

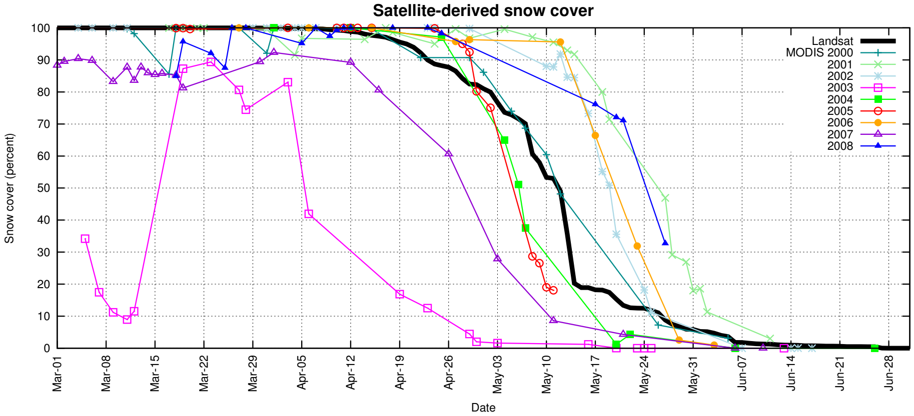


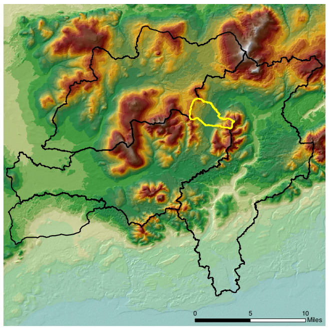
Snow free date by aspect (days after April 1)





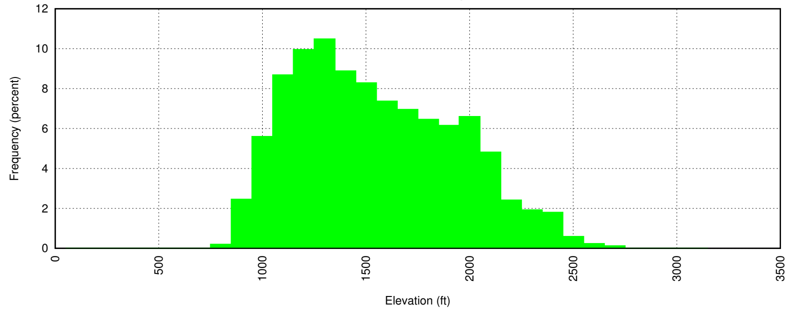
Satellite-derived snow cover



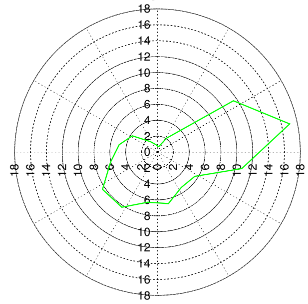


Basin SK119A Description

Elevation Histogram

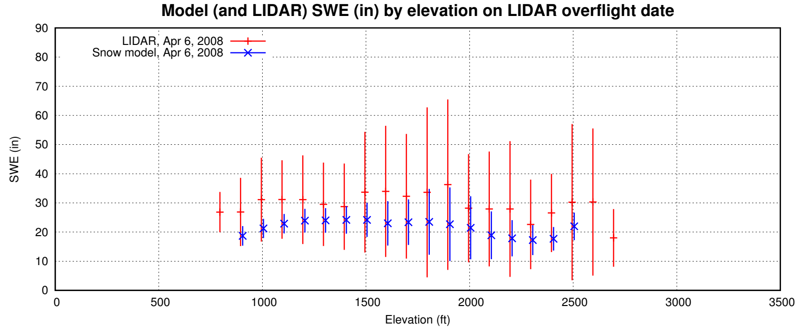


Aspect

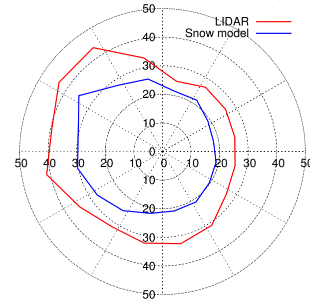


Flat (< 3 degrees)

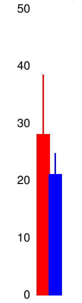
Model (and LIDAR) SWE (in) by elevation on LIDAR overflight date



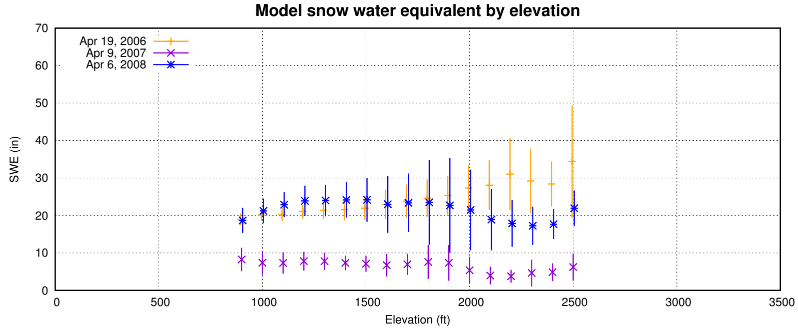
Model (and LIDAR) SWE (in) by aspect



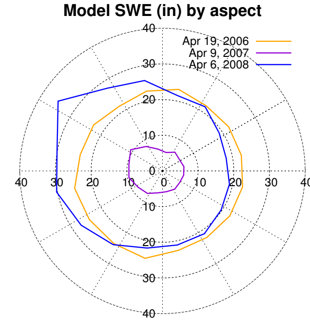
Flat (< 3 degrees)



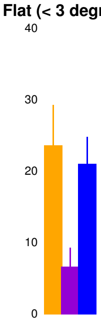
Model snow water equivalent by elevation



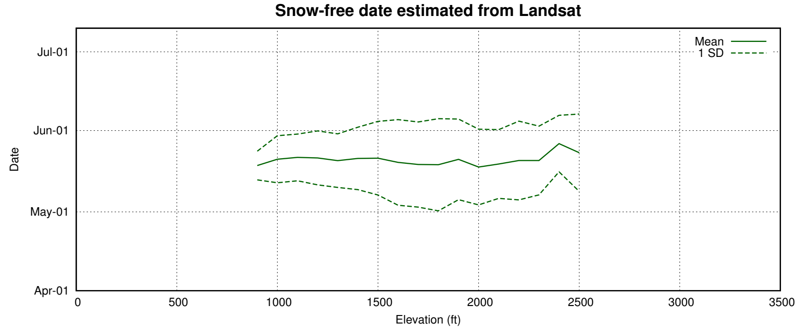
Model SWE (in) by aspect



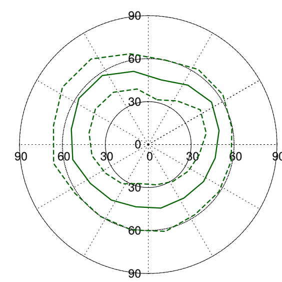
Flat (< 3 degrees)

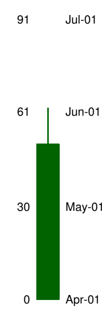


Snow-free date estimated from Landsat

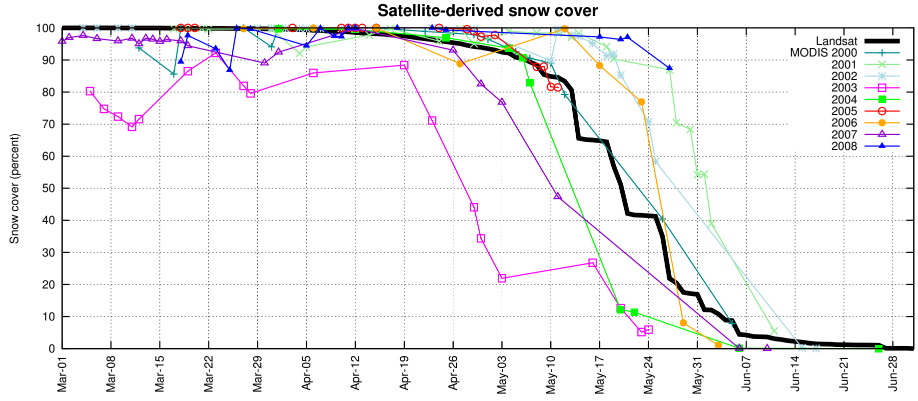


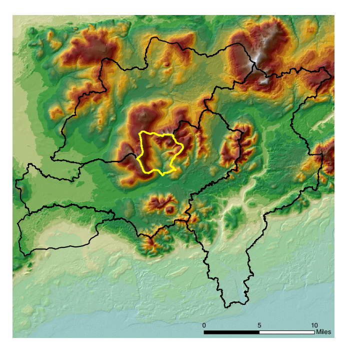
Snow free date by aspect (days after April 1)



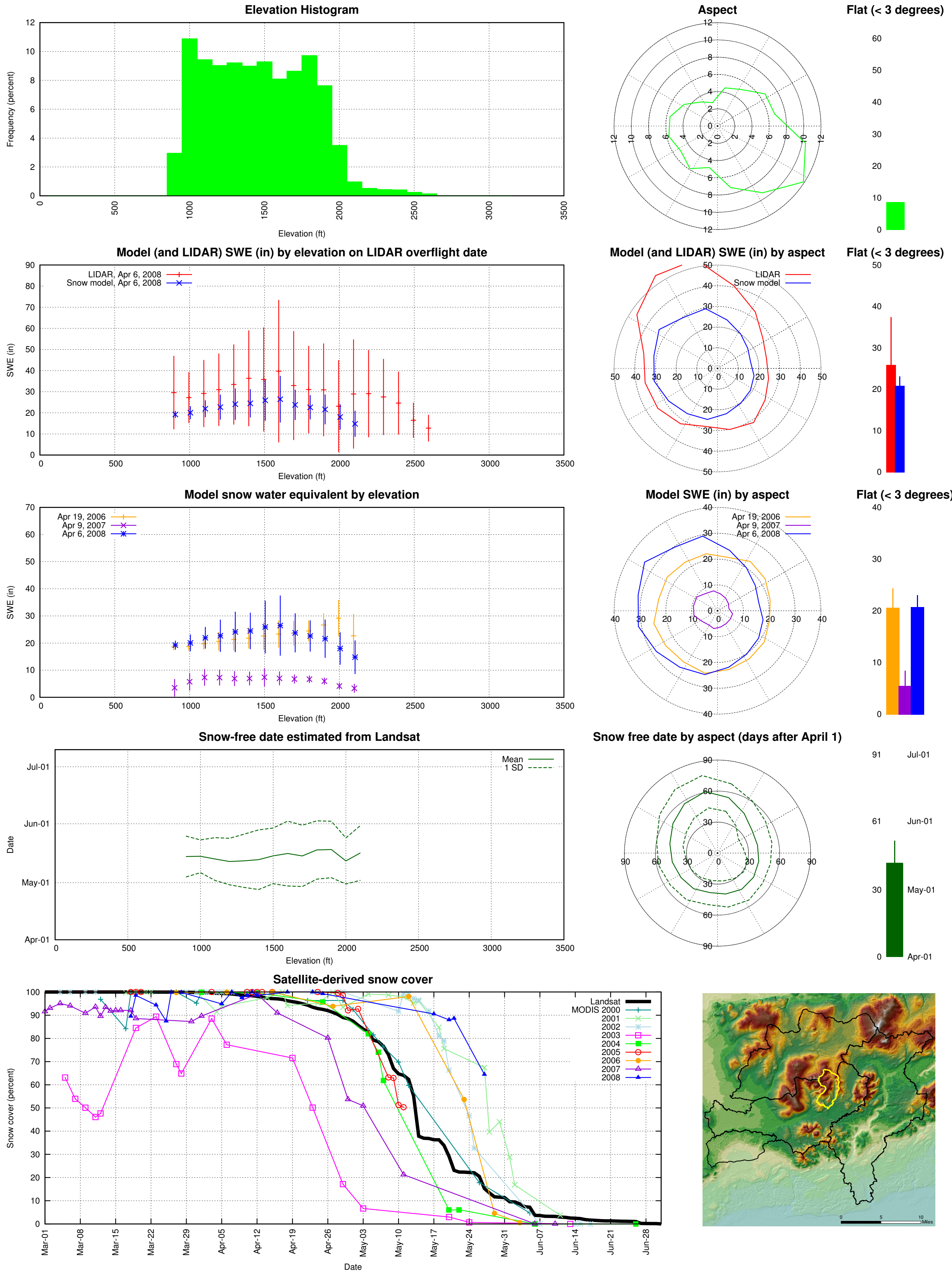


Satellite-derived snow cover

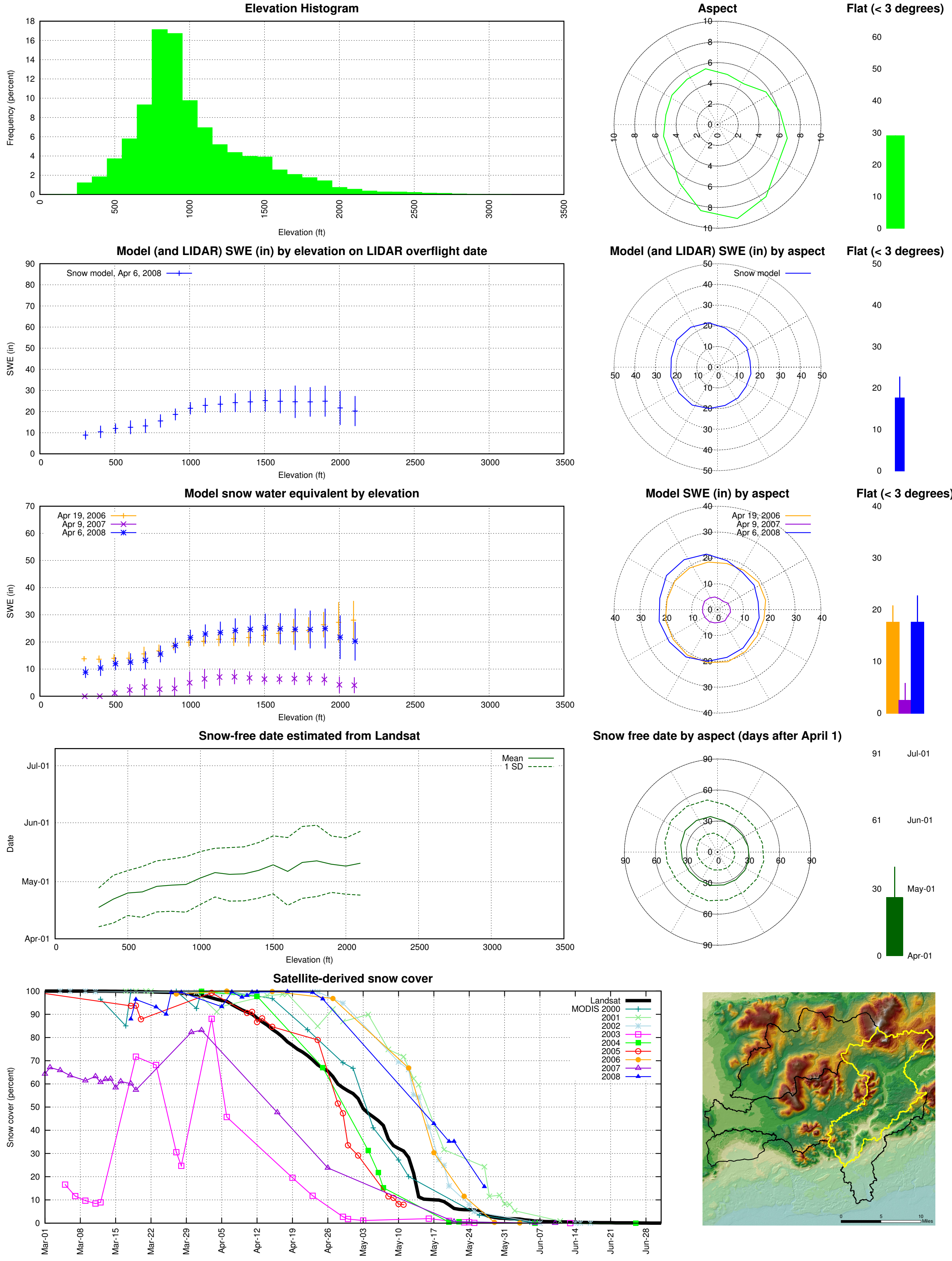




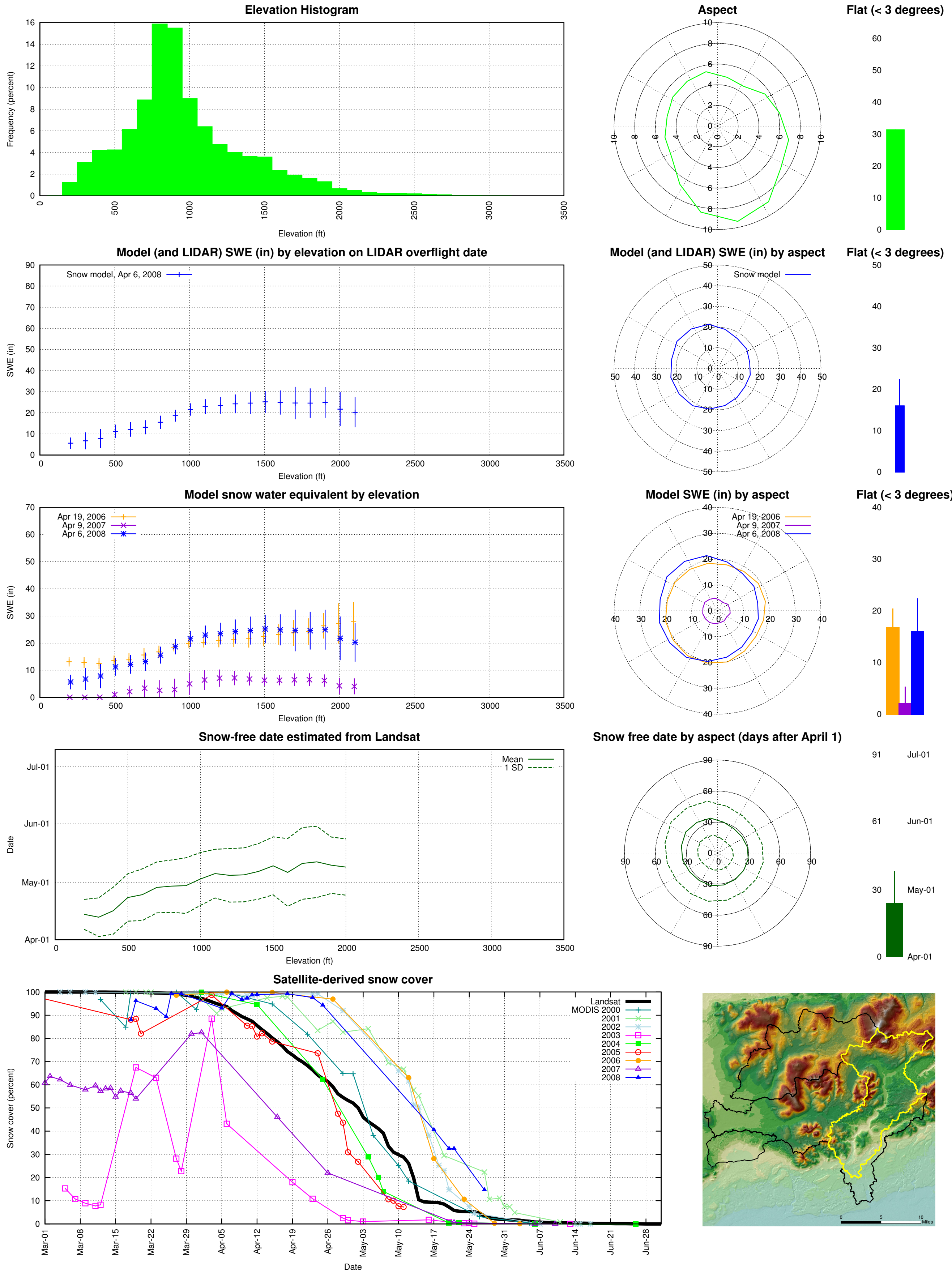
Basin SK124A Description



Basin UT100APC1 Description

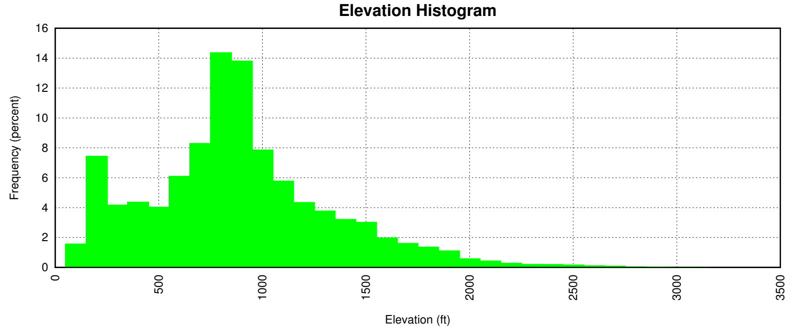


Basin UT100APC2 Description

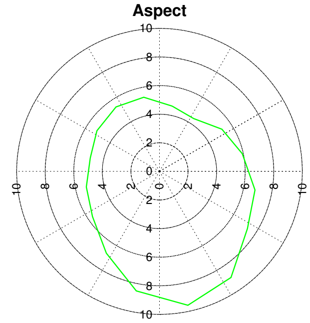


Basin UT100APC3 Description

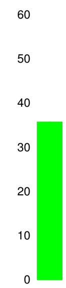
Elevation Histogram



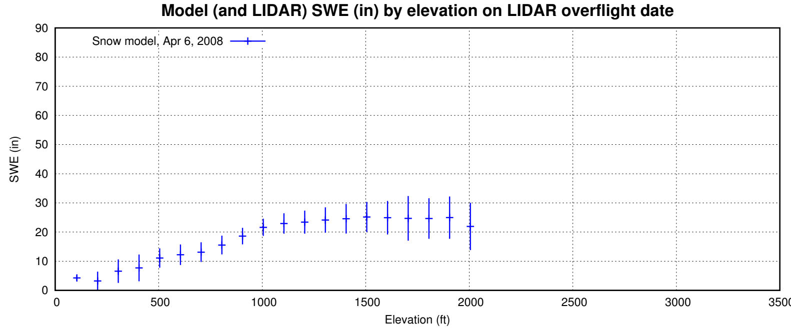
Aspect



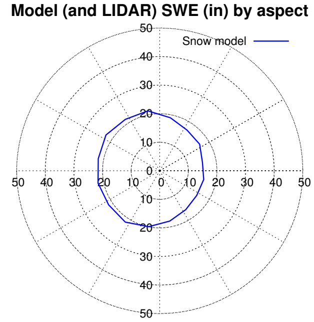
Flat (< 3 degrees)



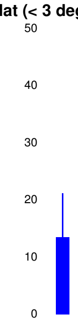
Model (and LIDAR) SWE (in) by elevation on LIDAR overflight date



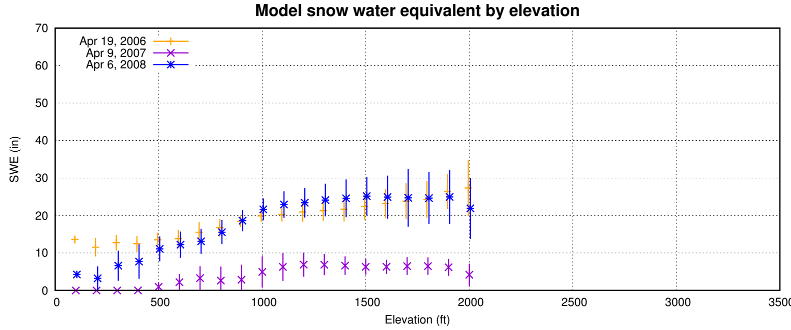
Model (and LIDAR) SWE (in) by aspect



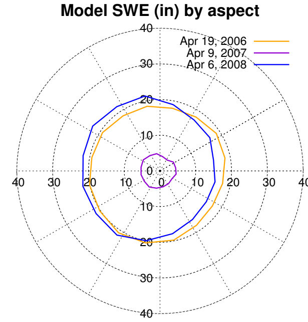
Flat (< 3 degrees)



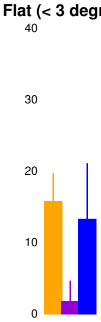
Model snow water equivalent by elevation



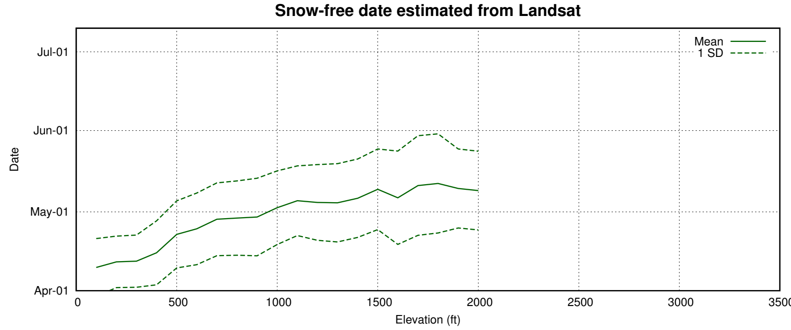
Model SWE (in) by aspect



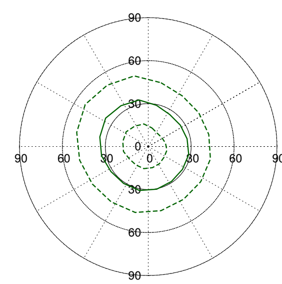
Flat (< 3 degrees)

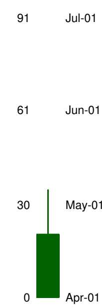


Snow-free date estimated from Landsat

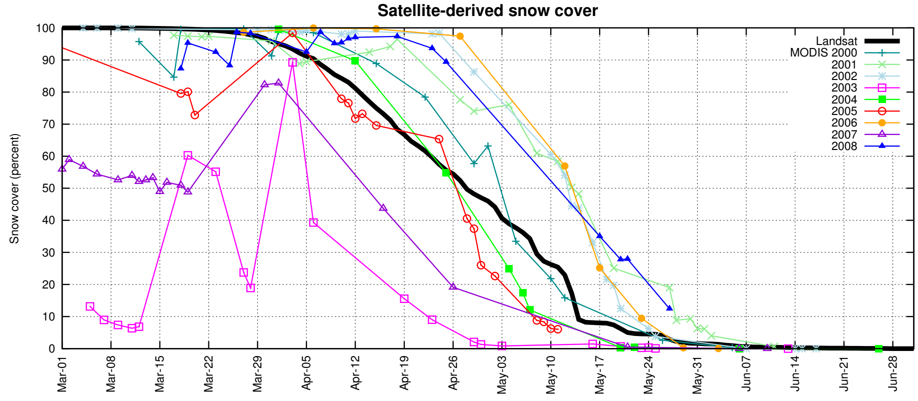


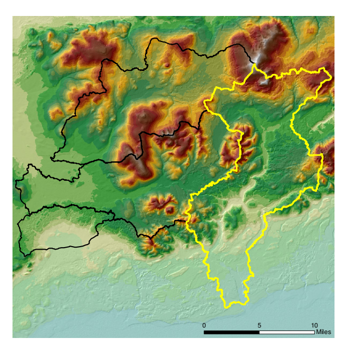
Snow free date by aspect (days after April 1)





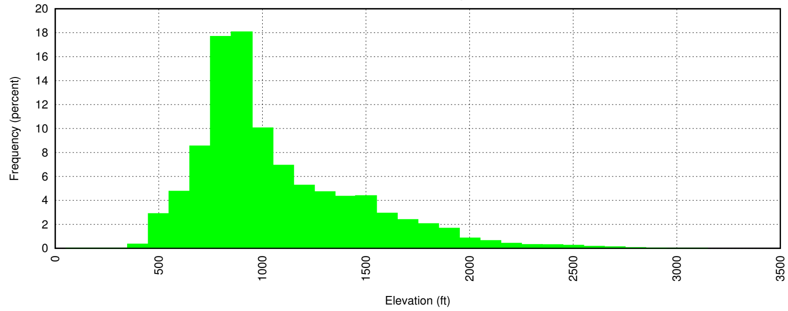
Satellite-derived snow cover



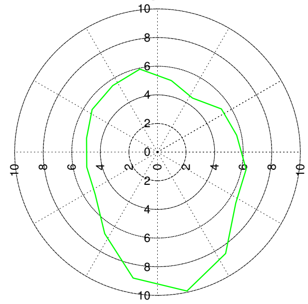


Basin UT100B Description

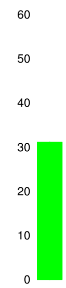
Elevation Histogram



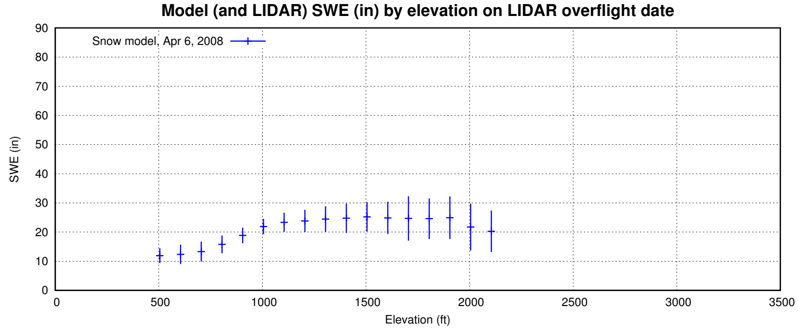
Aspect



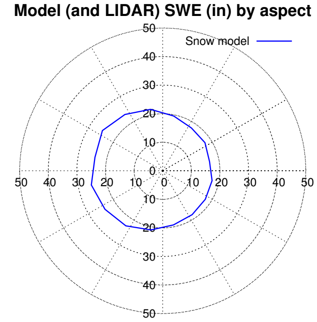
Flat (< 3 degrees)



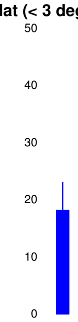
Model (and LIDAR) SWE (in) by elevation on LIDAR overflight date



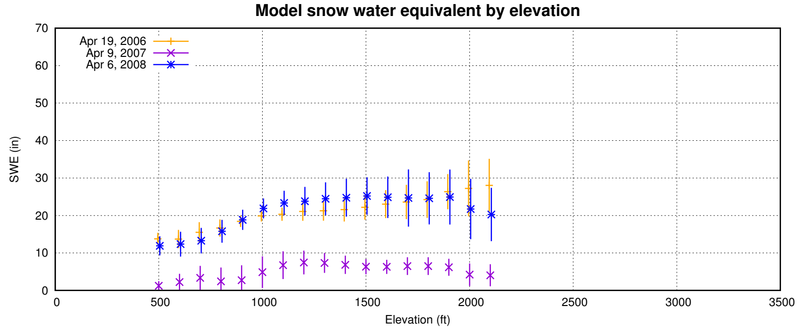
Model (and LIDAR) SWE (in) by aspect



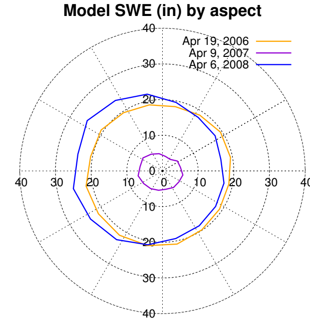
Flat (< 3 degrees)



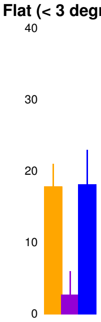
Model snow water equivalent by elevation



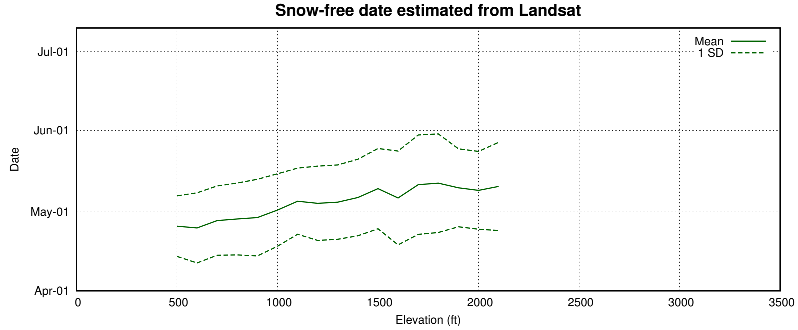
Model SWE (in) by aspect



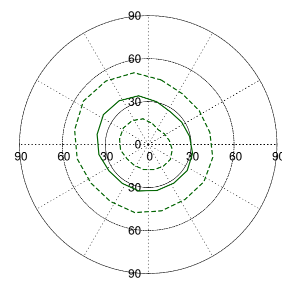
Flat (< 3 degrees)

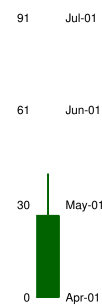


Snow-free date estimated from Landsat

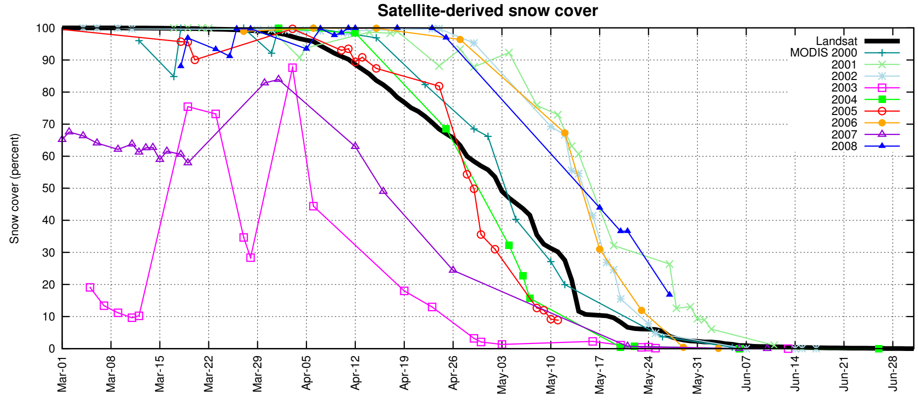


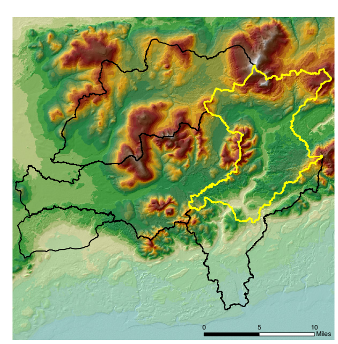
Snow free date by aspect (days after April 1)



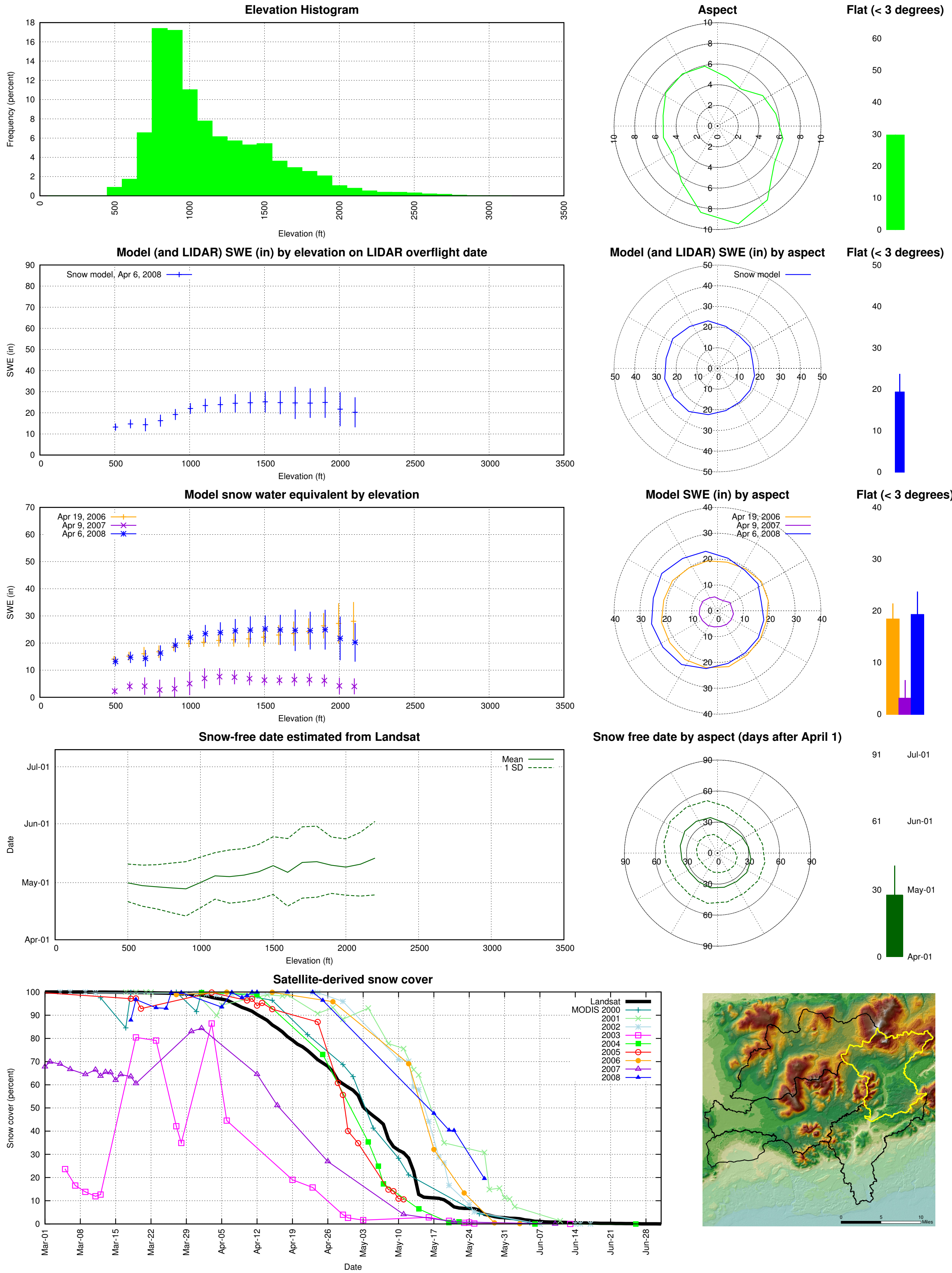


Satellite-derived snow cover

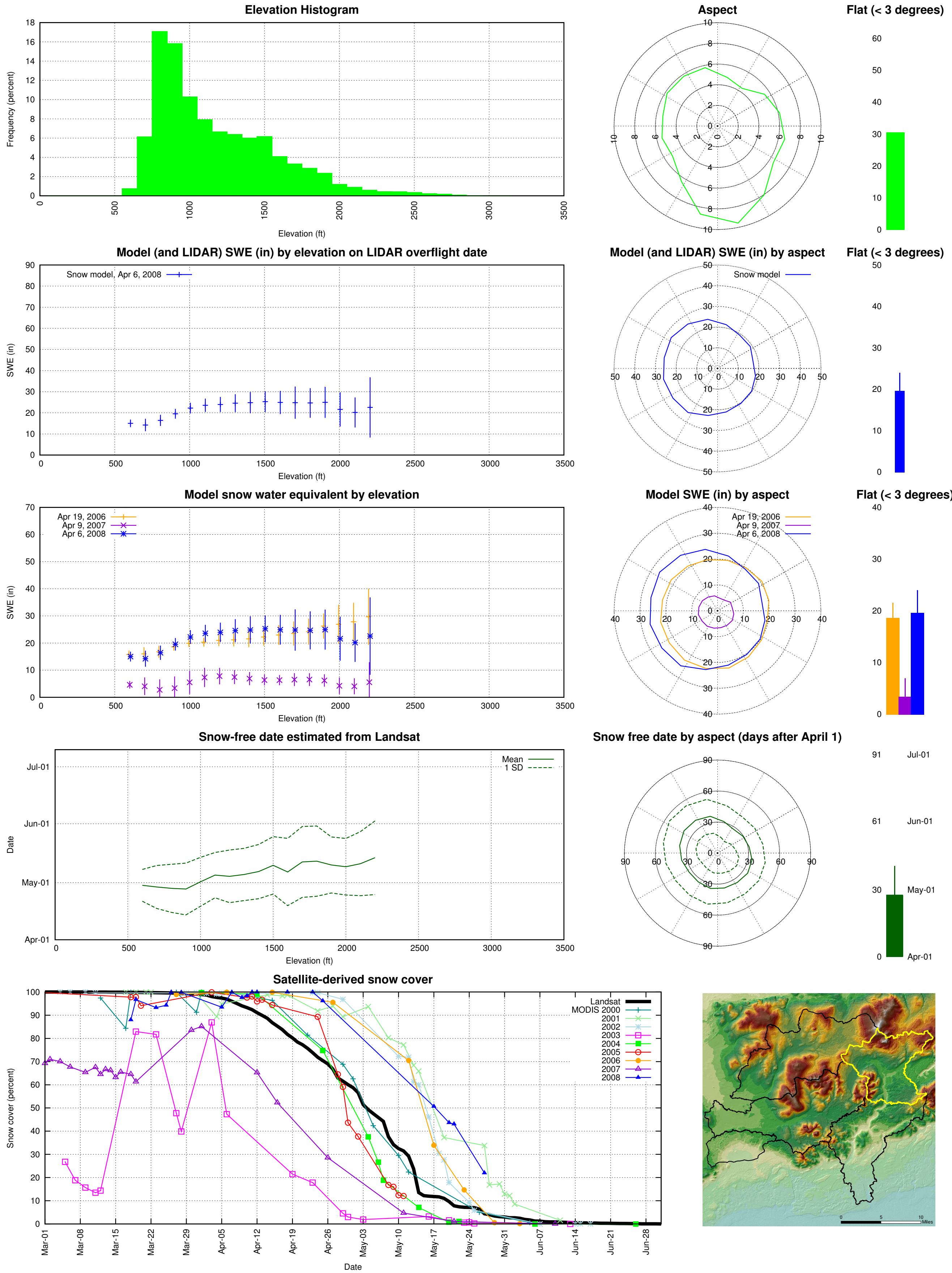




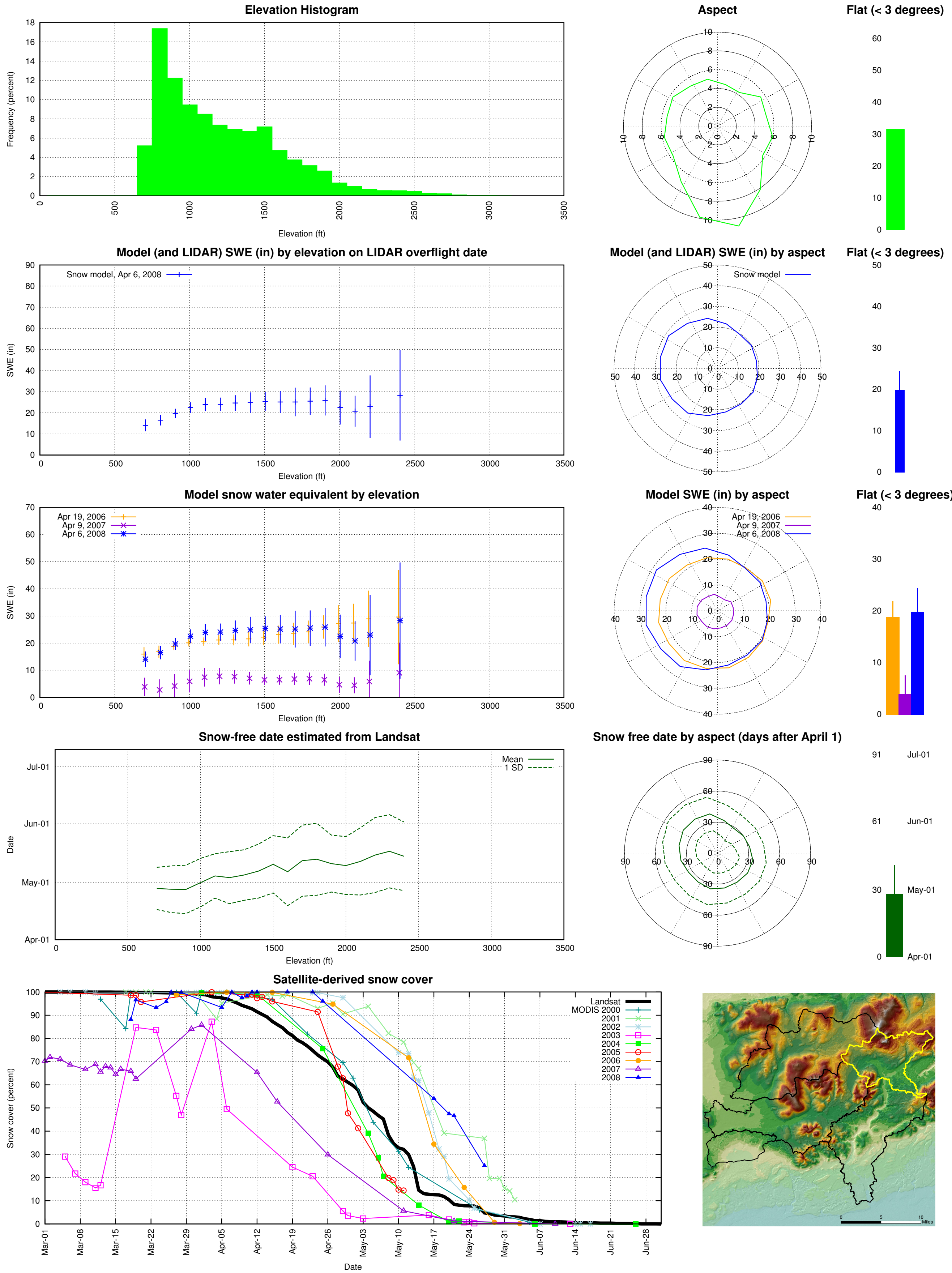
Basin UT100C Description



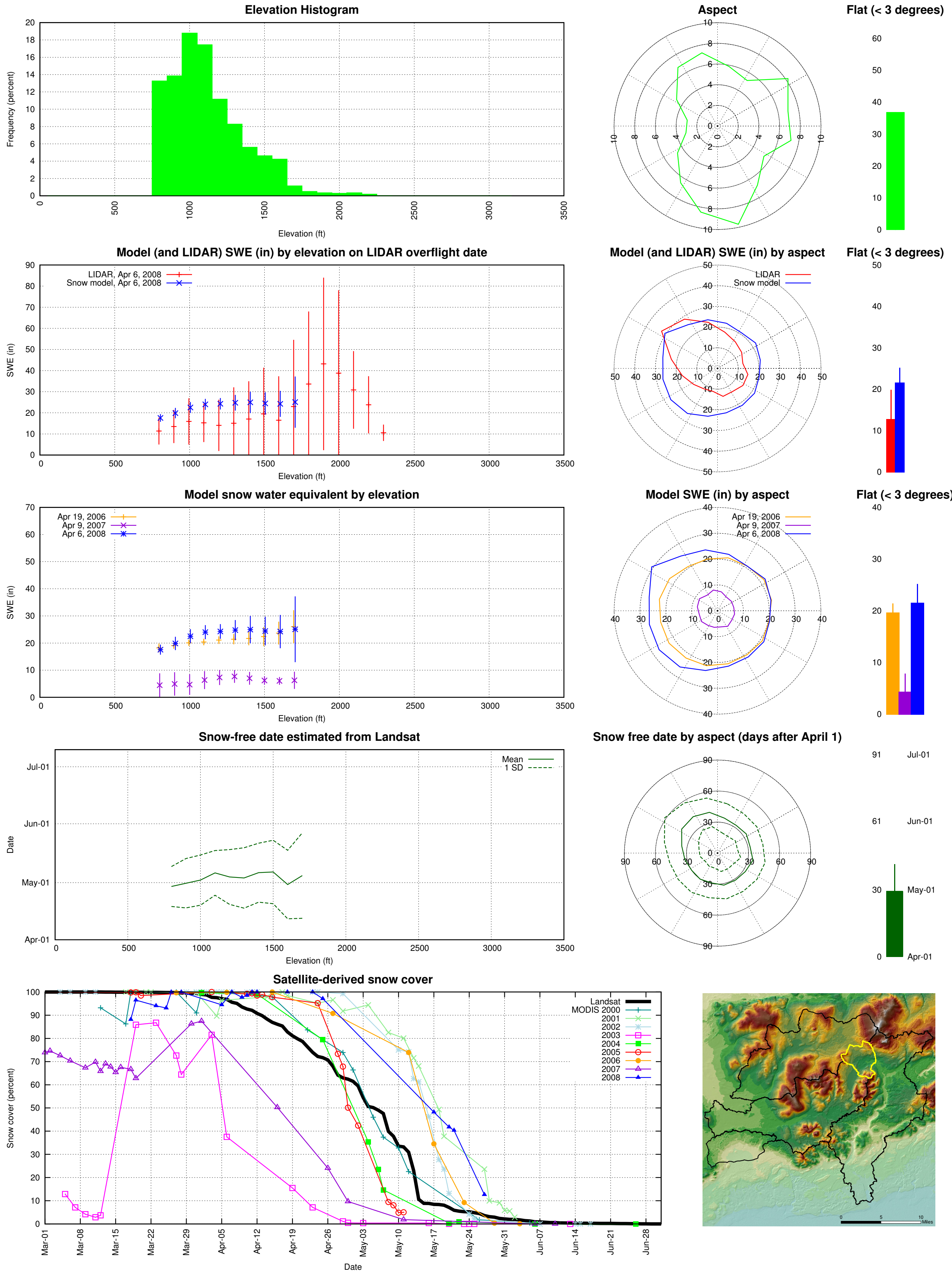
Basin UT100C1 Description



Basin UT100C2 Description

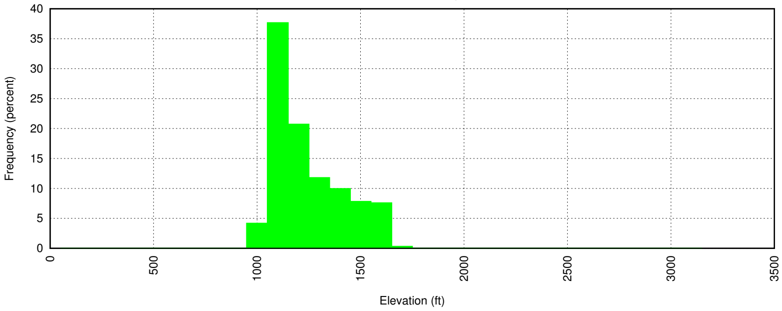


Basin UT100D Description

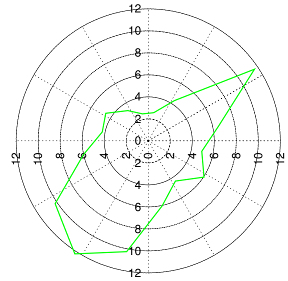


Basin UT100E Description

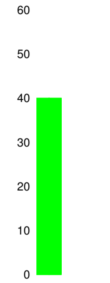
Elevation Histogram



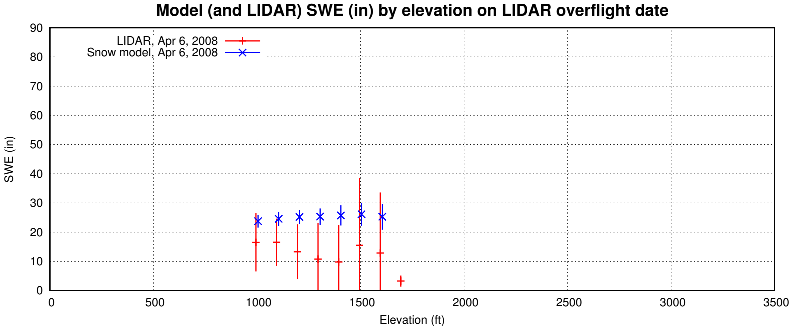
Aspect



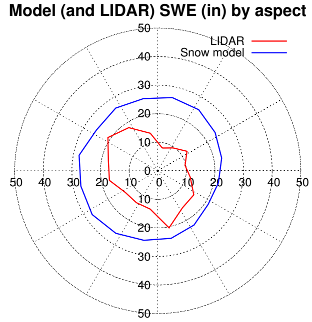
Flat (< 3 degrees)



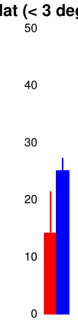
Model (and LIDAR) SWE (in) by elevation on LIDAR overflight date



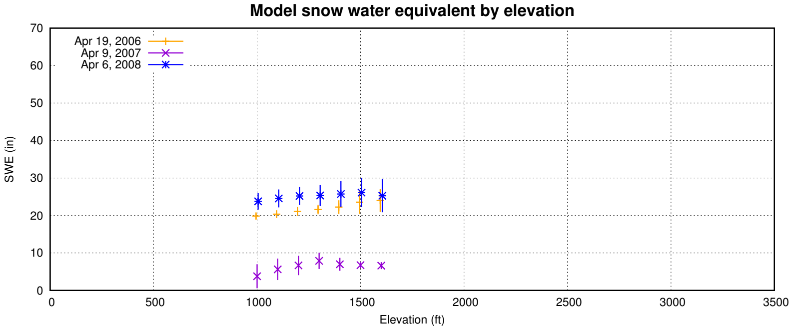
Model (and LIDAR) SWE (in) by aspect



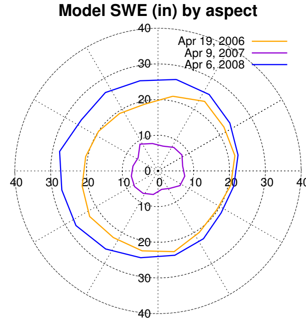
Flat (< 3 degrees)



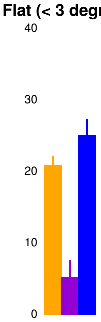
Model snow water equivalent by elevation



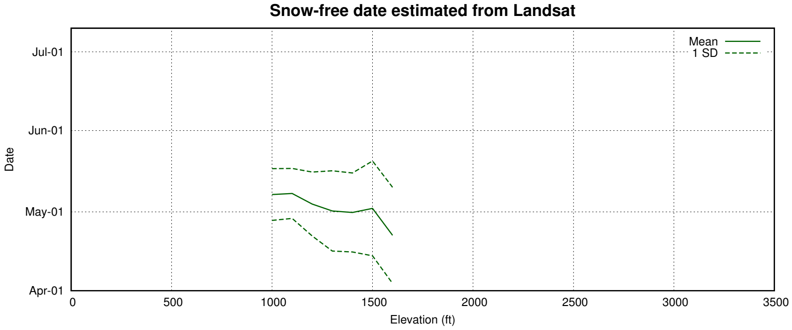
Model SWE (in) by aspect



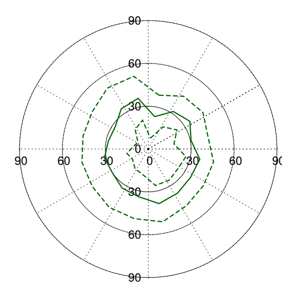
Flat (< 3 degrees)

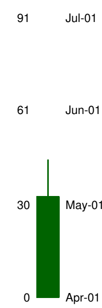


Snow-free date estimated from Landsat

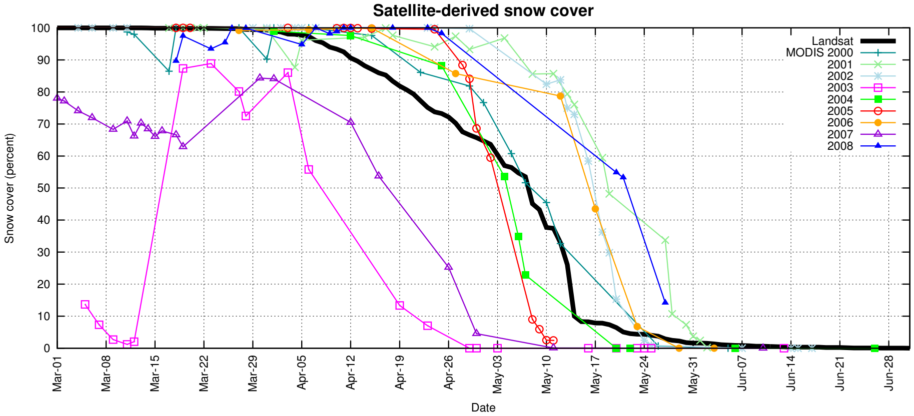


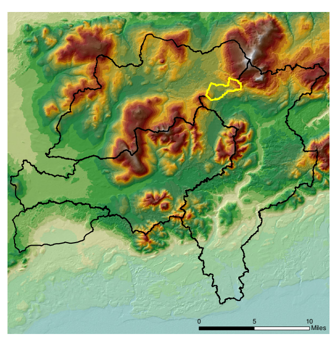
Snow free date by aspect (days after April 1)



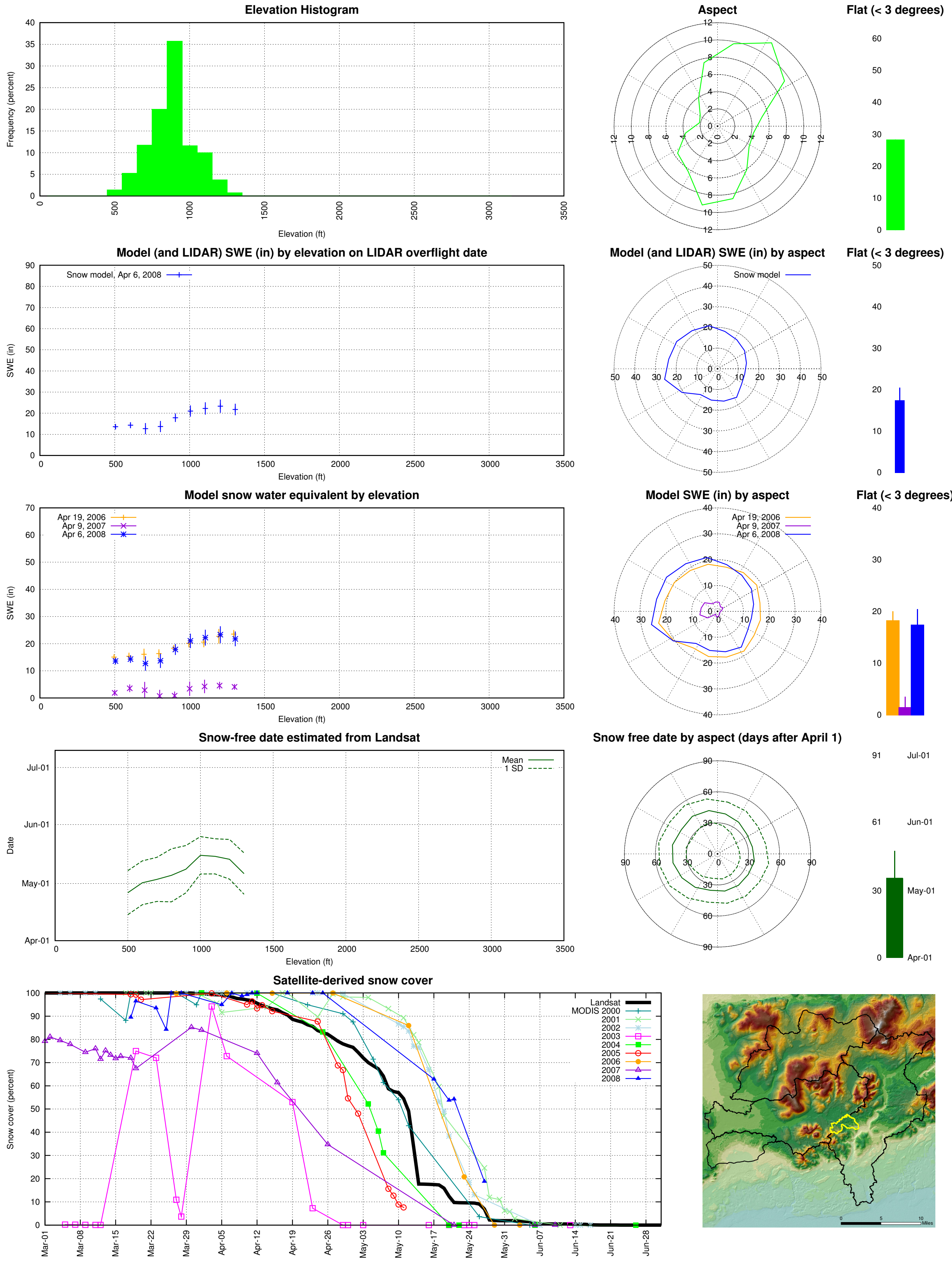


Satellite-derived snow cover

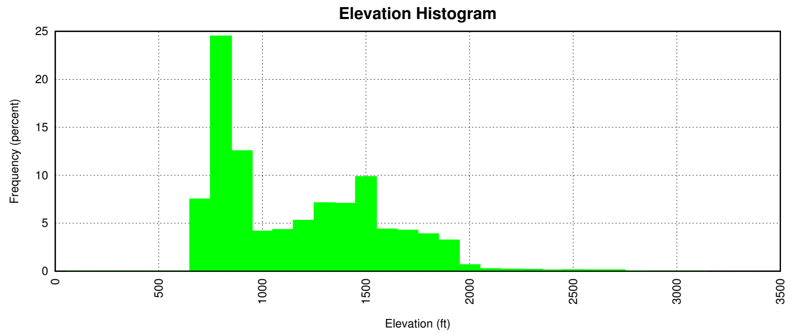


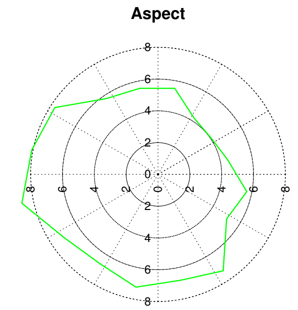


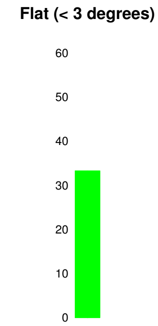
Basin UT119A Description

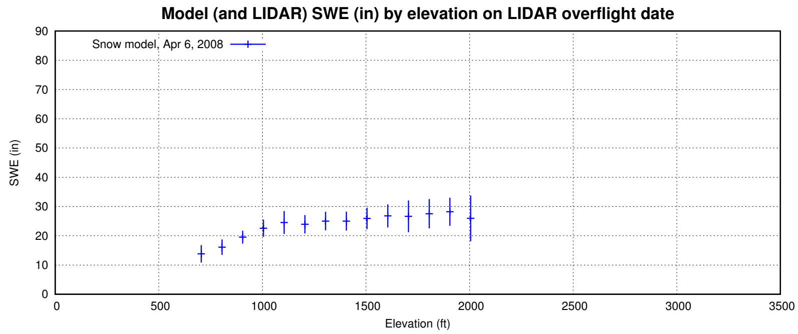


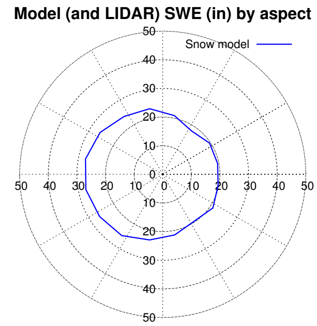
Basin UT135A Description

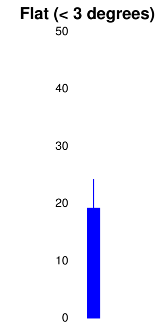


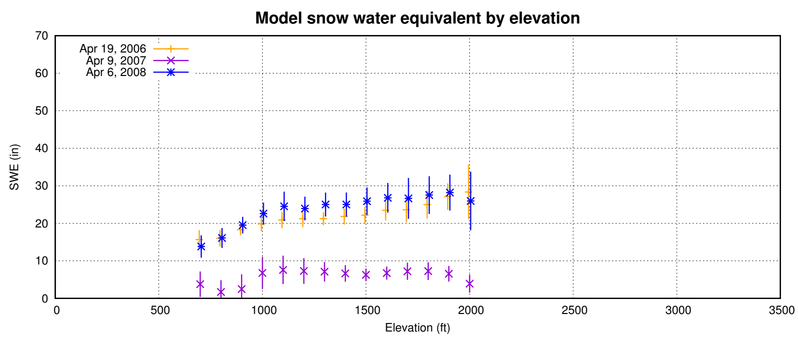


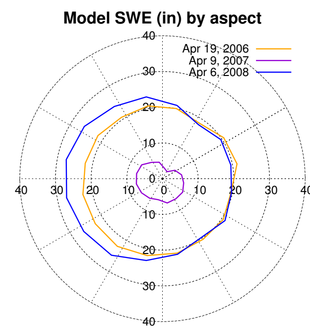


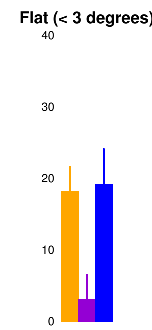


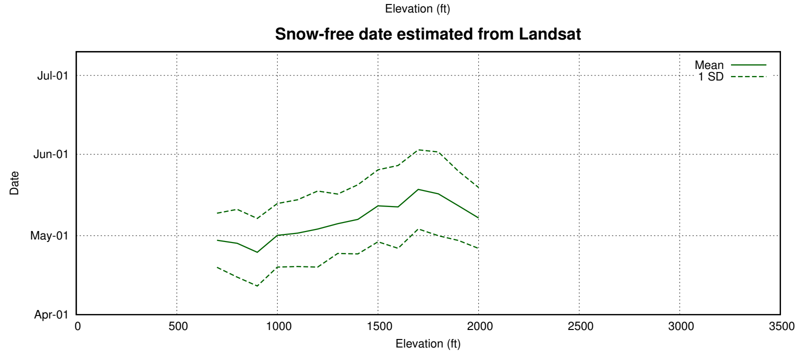


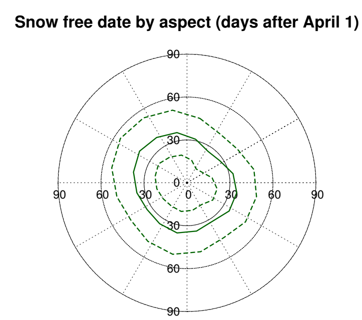


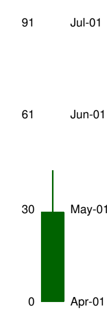


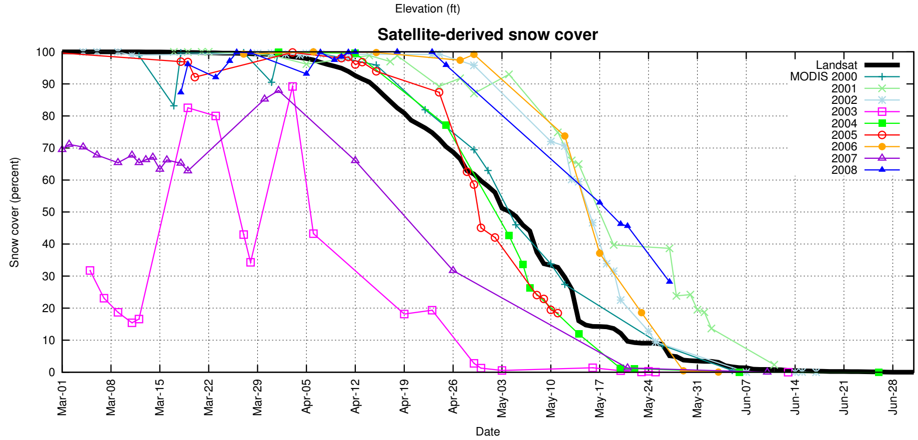


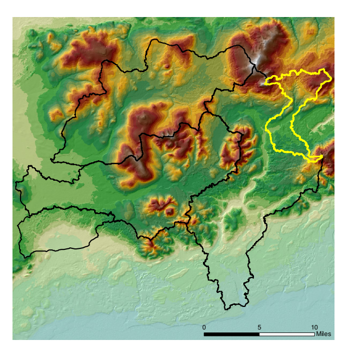












ATTACHMENT 3

Snow Model Output Summary by Basin, 2006–2008

Attachment 3, Snow Model Output Summary by Basin, 2006–2008.

This series of plots summarizes the snow model output for each basin and other extent. There are three annual plots for each basin, one for each winter modeled: 2005/2006, 2006/2007, and 2007/2008. The fourth page for each basin compares the water balance variables from the three winters based primarily on the snow model outputs.

Annual Plots

The top panel summarizes unit runoff (modeled and measured, where available) on the left axis, modeled SWE on the right axis, and modeled and MODIS-derived snow-covered area (no axis); the top of the plot represents 100 percent snow cover. For 2008 basins in the LIDAR survey area, the SWE estimated from the LIDAR survey is plotted on April 6, 2008.

The second panel presents snow depth (total and soft layer) on the left axis. The soft layer is where newly fallen snow accumulates. Soft snow is available for wind transport if wind speeds are high enough; once snow is no longer in the soft layer, it will never become available for transport. Modeled snow density (RO) is presented on the left axis. Snow density is the primary variable controlling the threshold wind speed required to initiate transport.

The third panel presents the total liquid and solid precipitation for each model time step. Precipitation that occurs when air temperatures are 2º C or colder is categorized as solid precipitation by the model.

The fourth and fifth plots represent air and snow surface temperatures, respectively. The vertical red line represents the range of values +/- one standard deviation. The horizontal lines represent the minimum and maximum values in the spatial domain for the time step.

The sixth panel presents the summed transport (positive and negative) at each time step. Positive transport occurs when more snow blows into a cell than blows out; negative transport indicates more snow blowing out of a model cell than is blowing in. The summed transport is an indicator of how much snow the model is blowing at a time step.

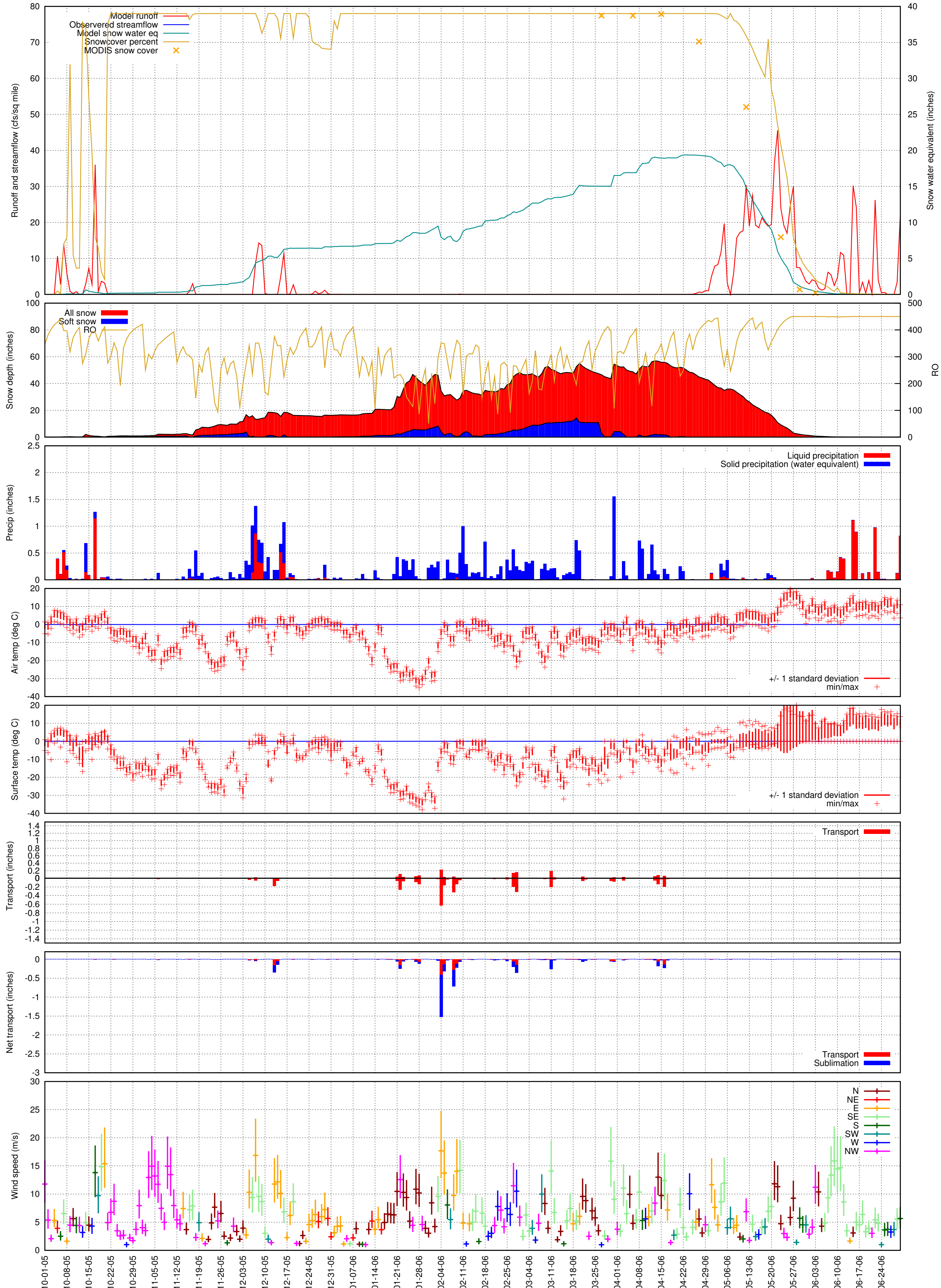
The seventh panel presents net transport (positive and negative values combined). The modeled blowing snow sublimation is also plotted. In many snow transport events the model indicates that more snow is lost to sublimation than to snow blowing out of the domain.

The bottom panel presents the modeled wind field summary for each time step. The color indicates the wind direction; the horizontal line indicates the mean wind speed; and the vertical line depicts the range, +/- one standard deviation.

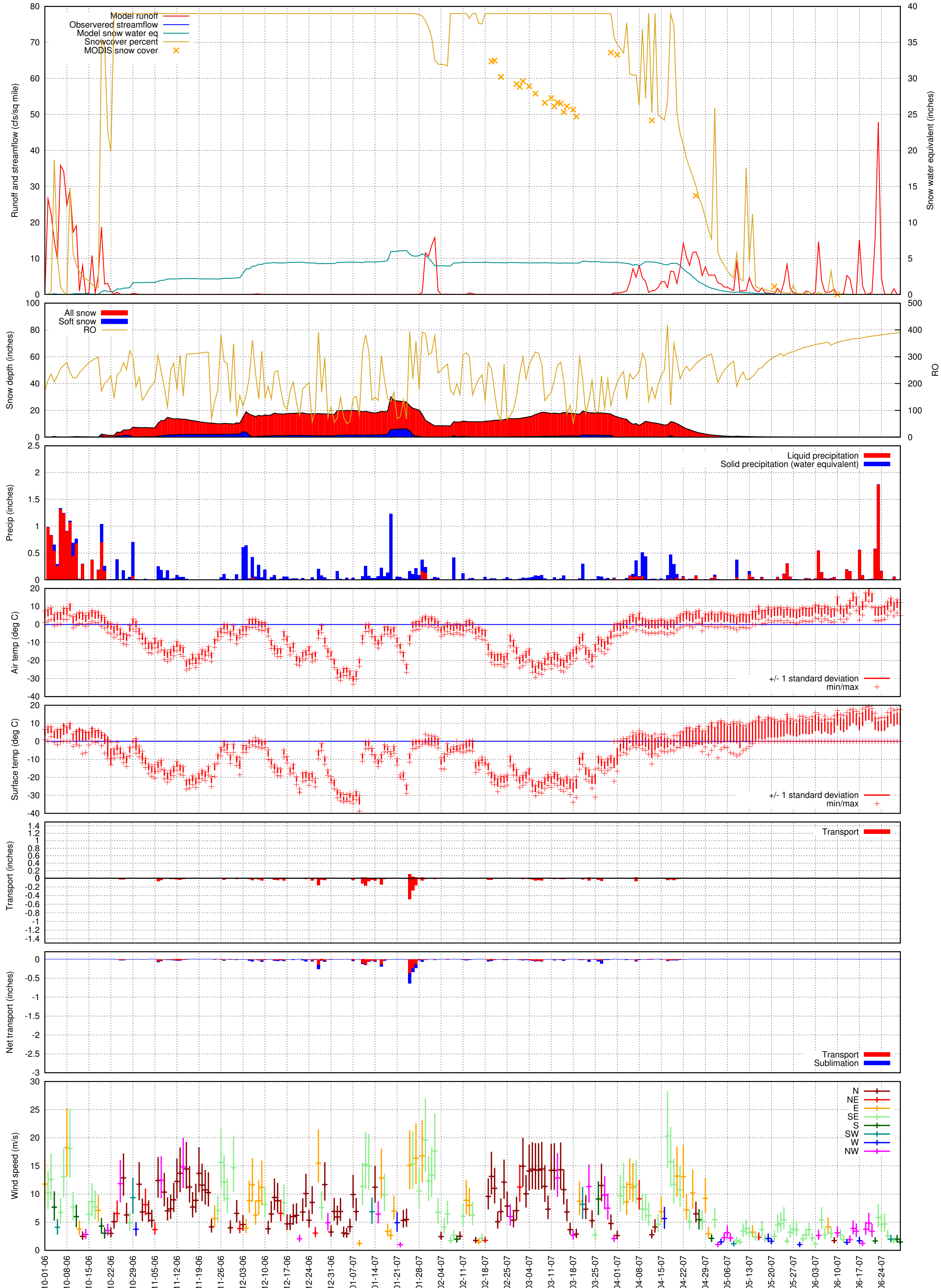
Water Balance Plots

The panels in the water balance plot represent the modeled SWE over time, and the summed solid precipitation, liquid precipitation, winter precipitation at the Pebble 1 meteorological station, net snow transport, blowing snow sublimation, surface snow sublimation, and runoff.

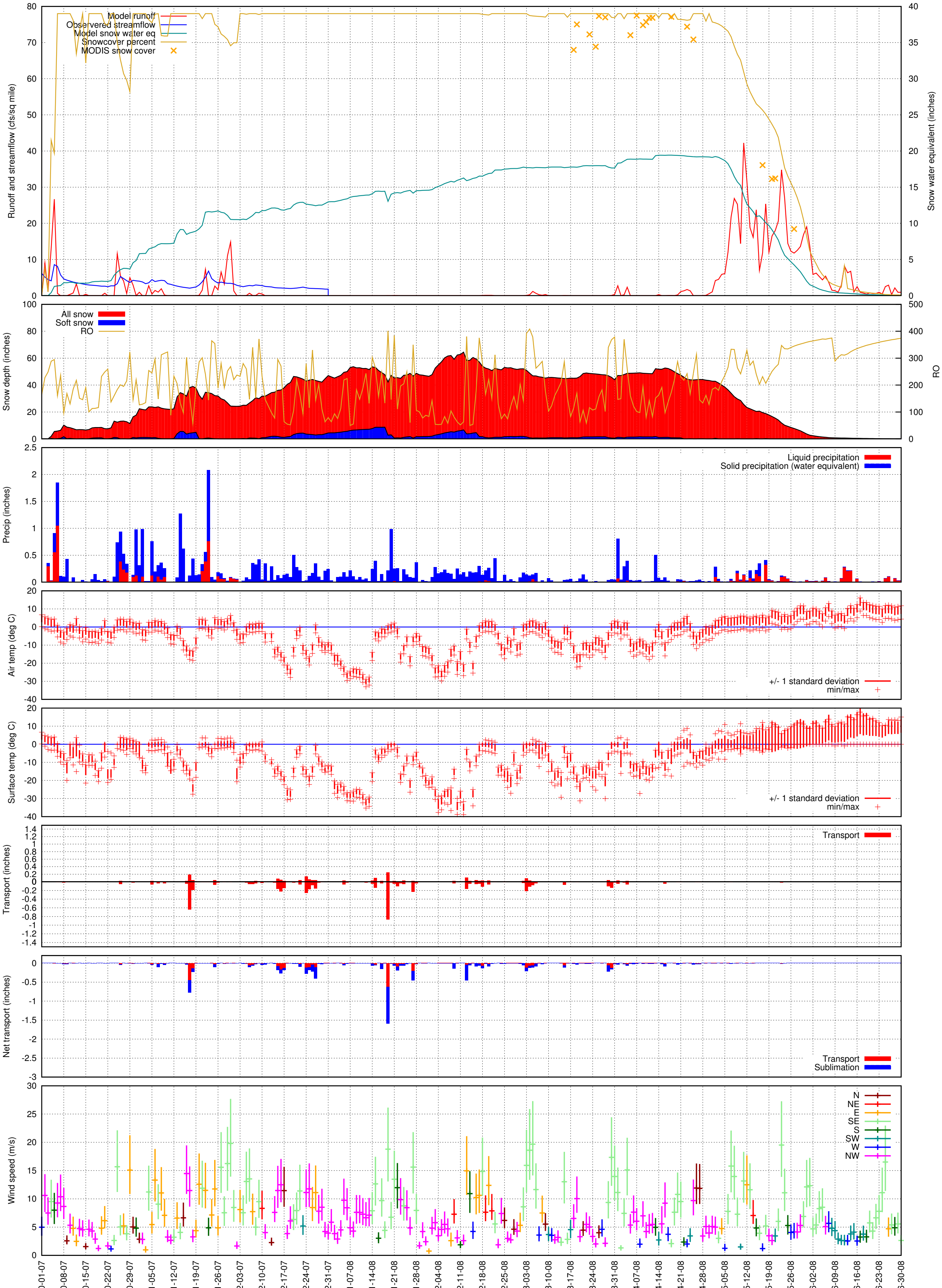
SnowModel Output Summary: 384-foot cells, hourly timestep, precipitation factor 2.0
Extended Study Area, 2005-2006



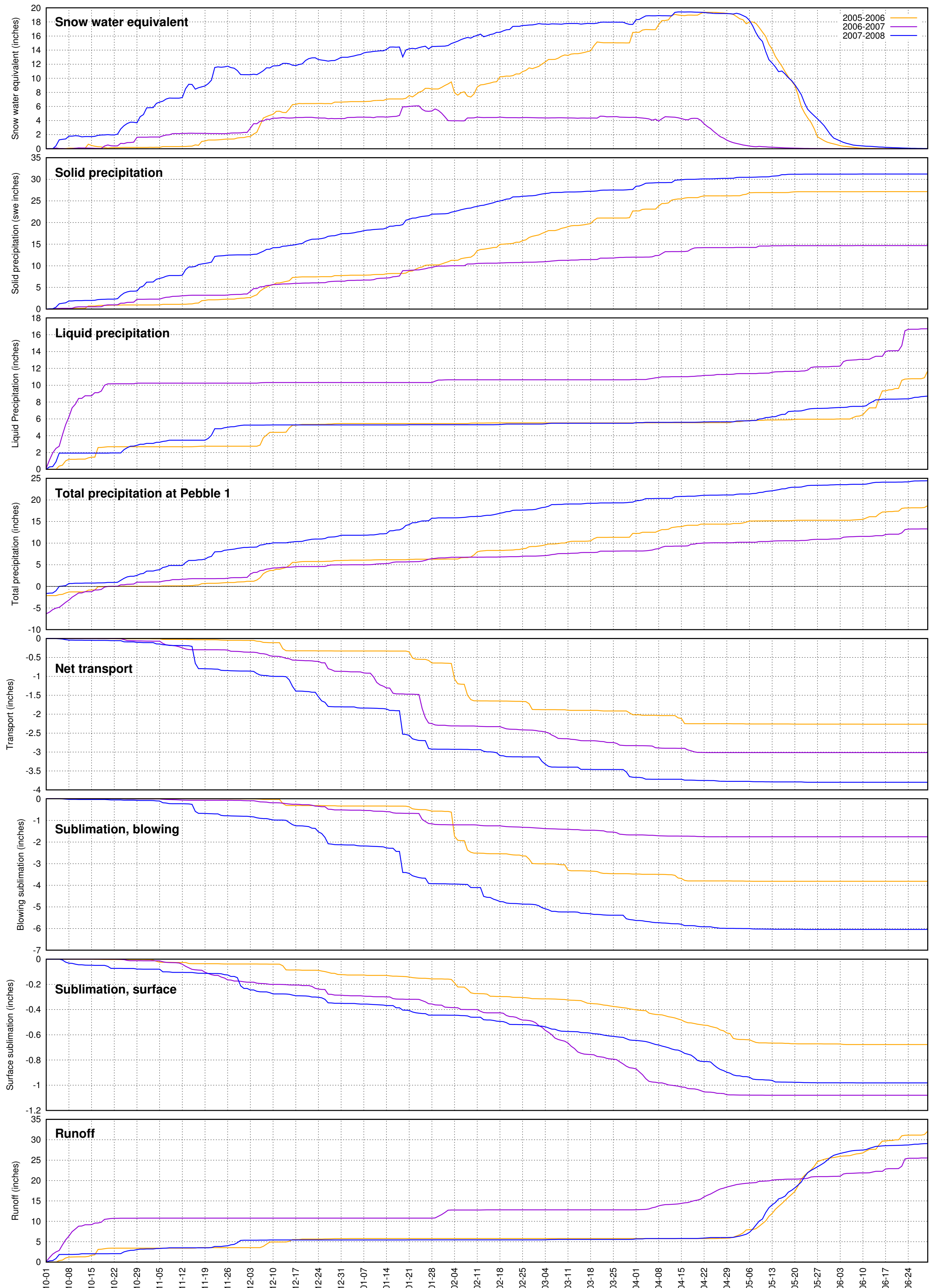
SnowModel Output Summary: 384-foot cells, hourly timestep, precipitation factor 2.0
Extended Study Area, 2006-2007



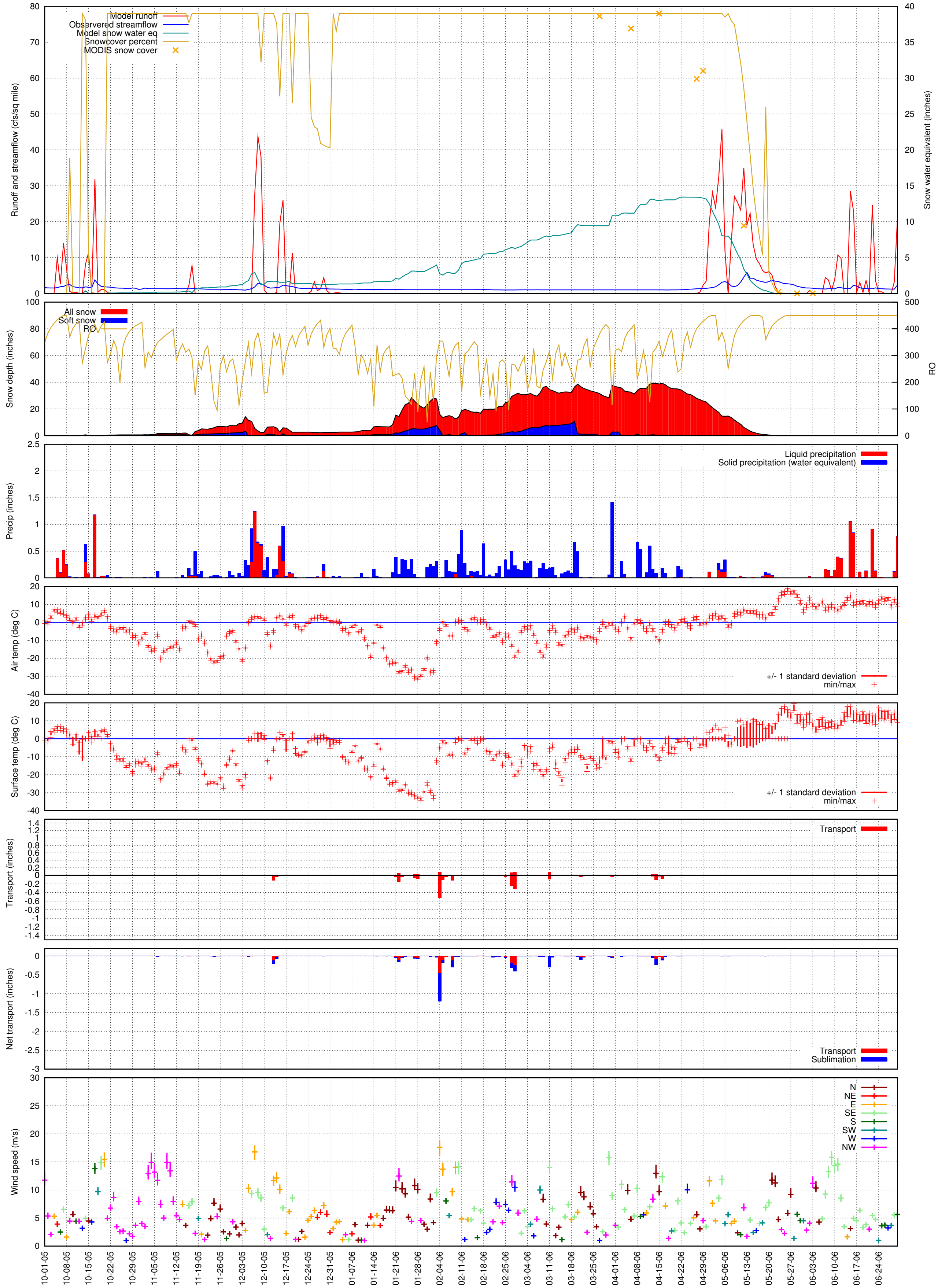
SnowModel Output Summary: 384-foot cells, hourly timestep, precipitation factor 2.0
Extended Study Area, 2007-2008



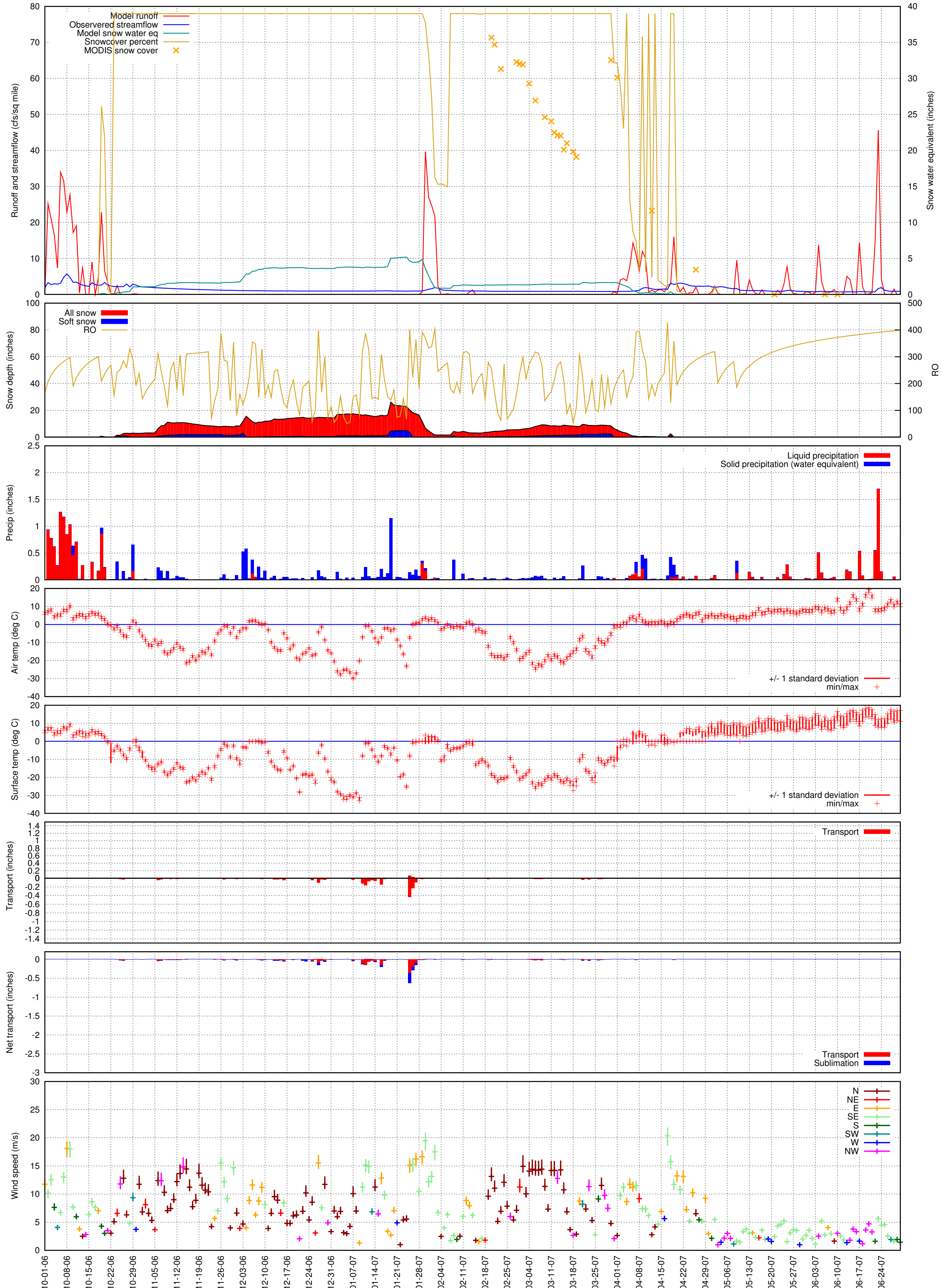
SnowModel Output Summary: 384-foot cells, hourly timestep, precipitation factor 2.0
Extended Study Area, Water Balance Summary, 2005-2008



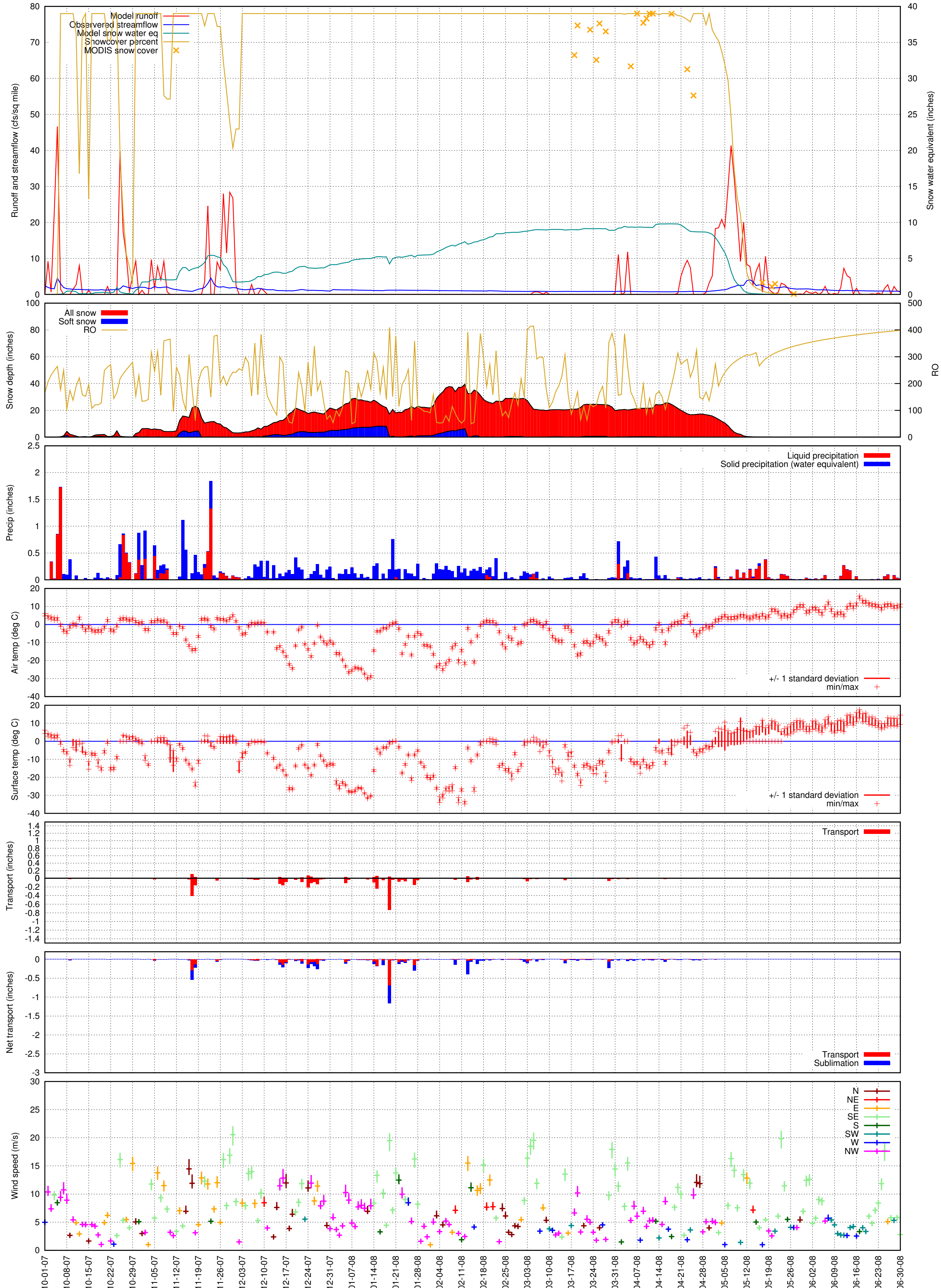
SnowModel Output Summary: 384-foot cells, hourly timestep, precipitation factor 2.0
Basin KC100A, 2005-2006



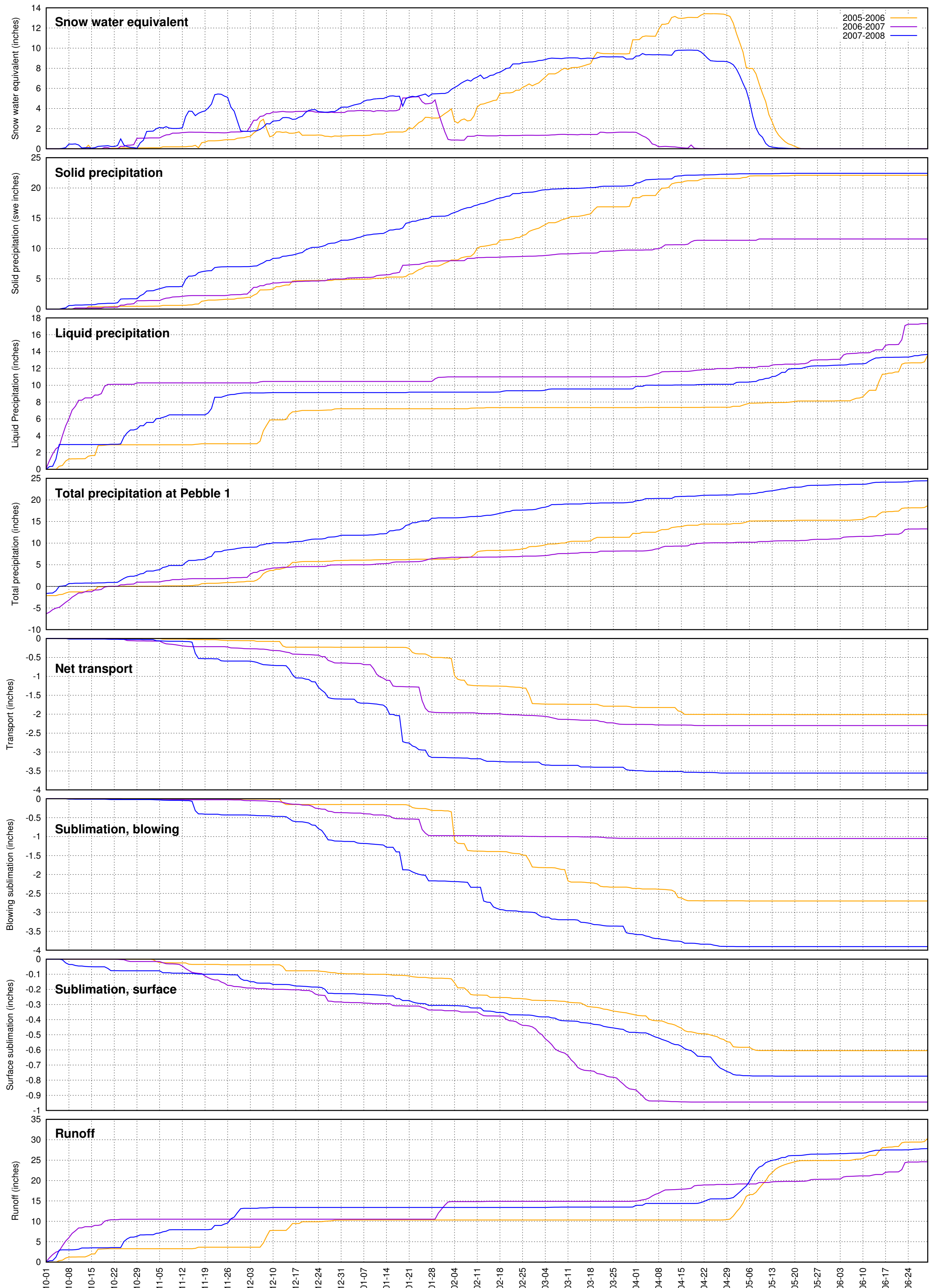
SnowModel Output Summary: 384-foot cells, hourly timestep, precipitation factor 2.0
Basin KC100A, 2006-2007



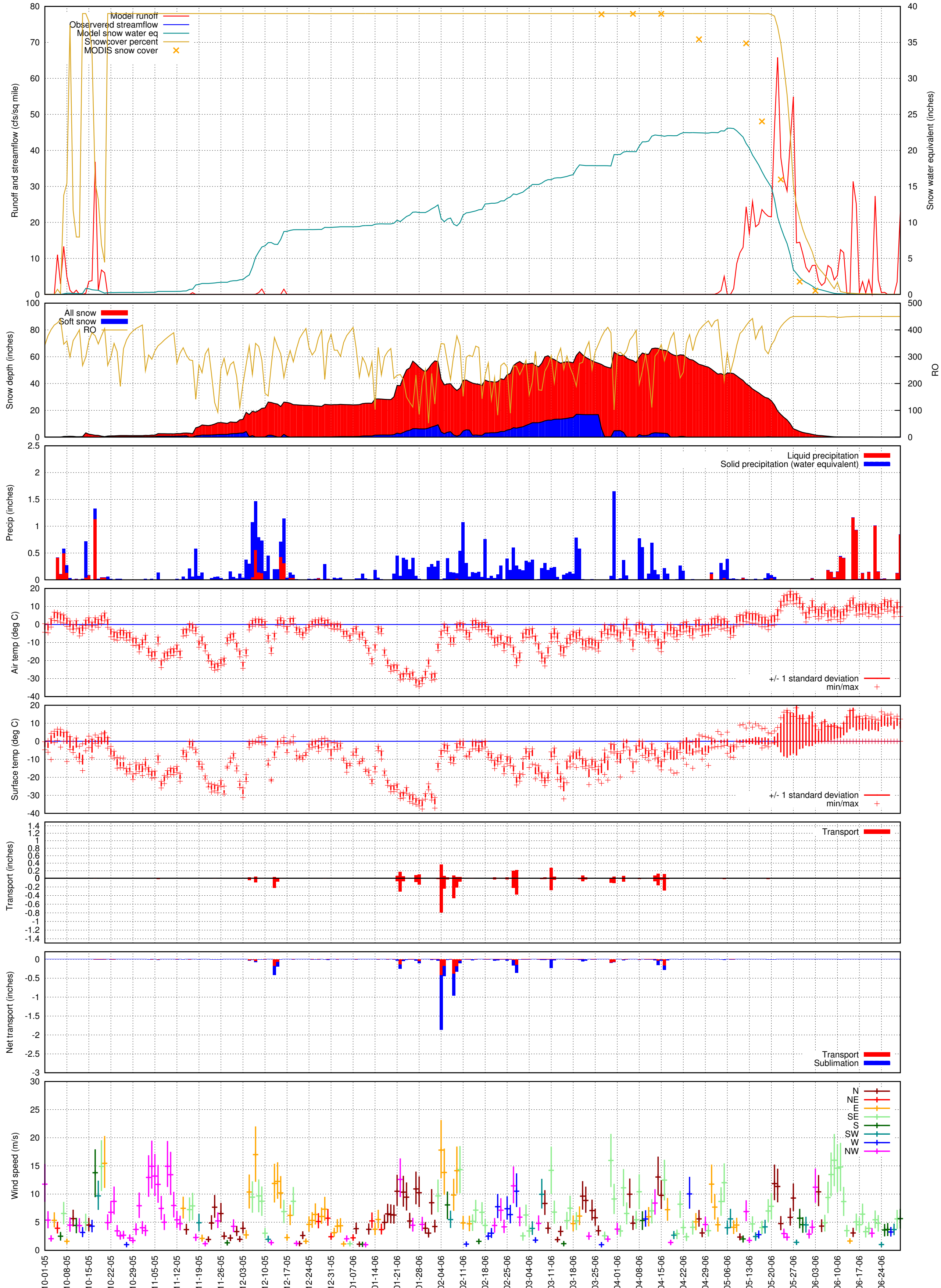
SnowModel Output Summary: 384-foot cells, hourly timestep, precipitation factor 2.0
Basin KC100A, 2007-2008



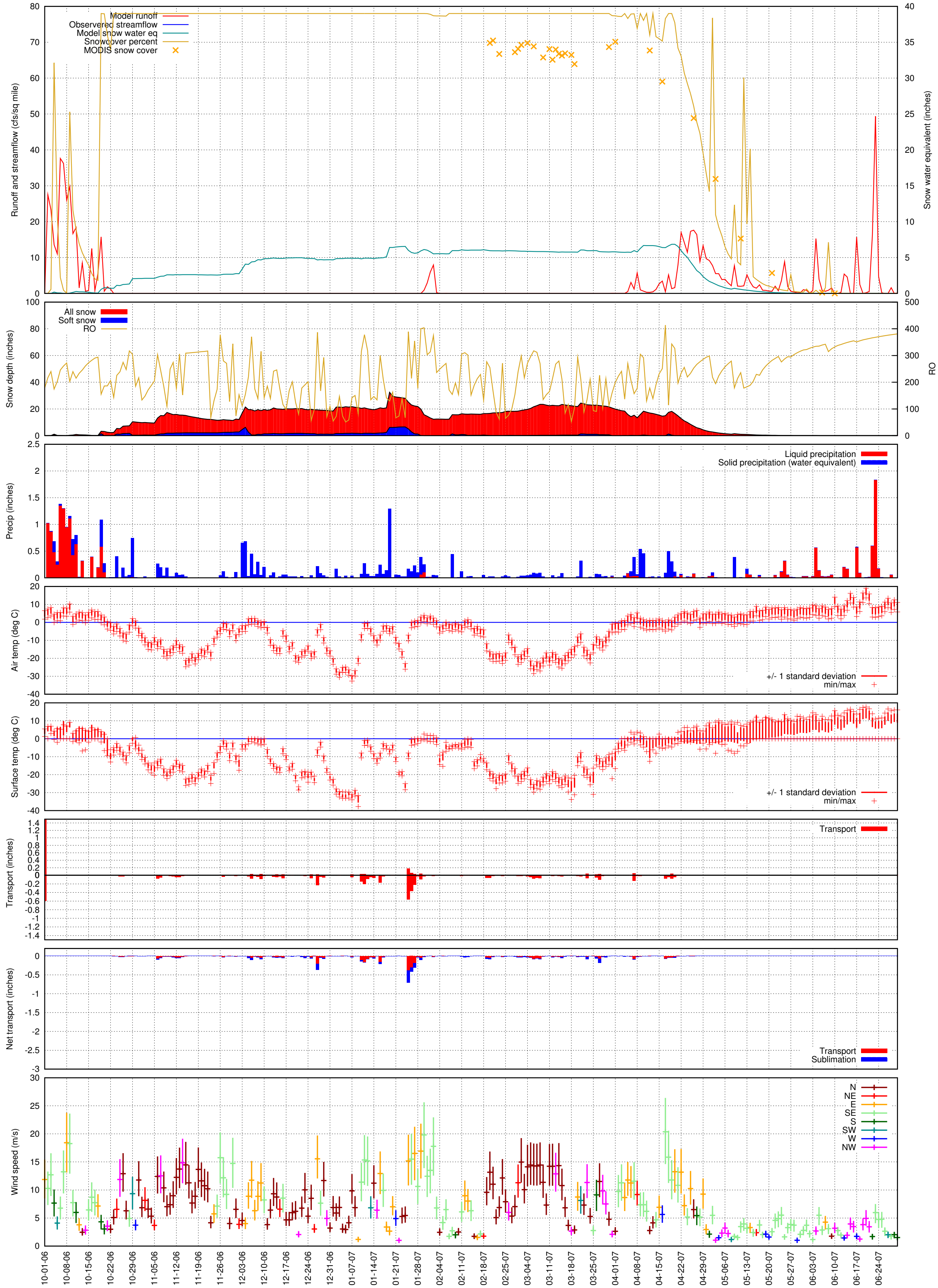
SnowModel Output Summary: 384-foot cells, hourly timestep, precipitation factor 2.0
Basin KC100A, Water Balance Summary, 2005-2008



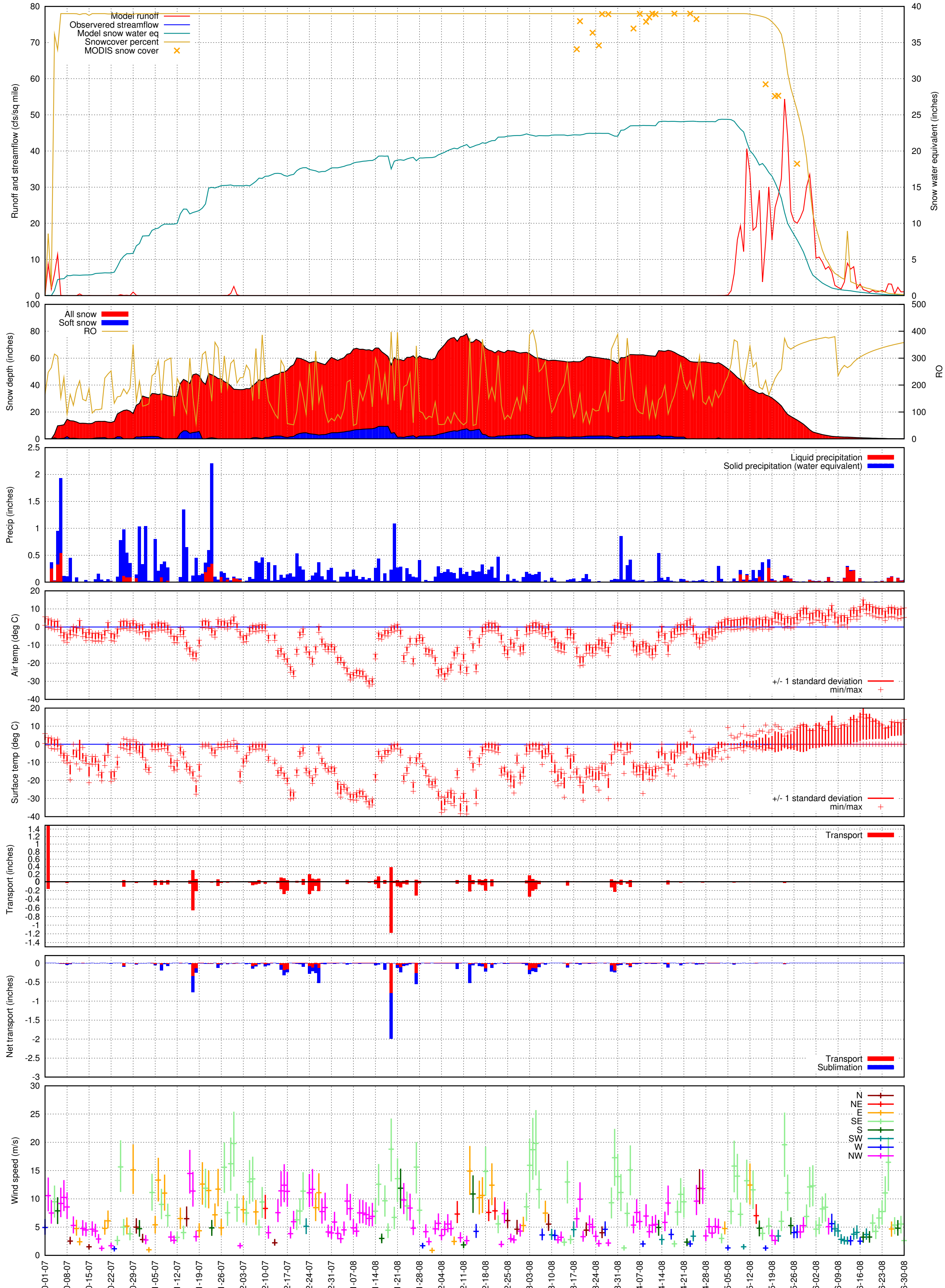
SnowModel Output Summary: 384-foot cells, hourly timestep, precipitation factor 2.0
Lidar Survey Area, 2005-2006



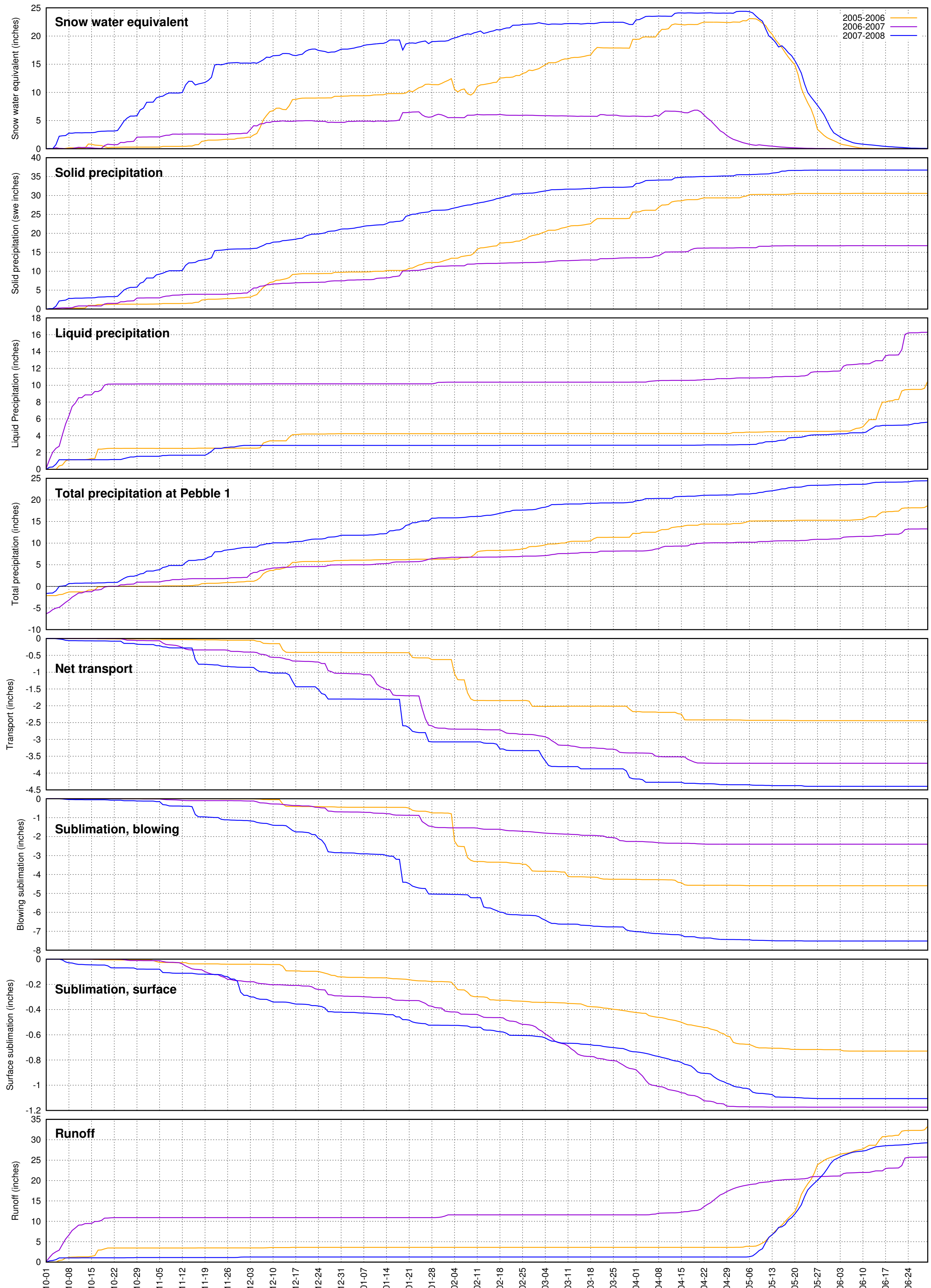
SnowModel Output Summary: 384-foot cells, hourly timestep, precipitation factor 2.0
Lidar Survey Area, 2006-2007



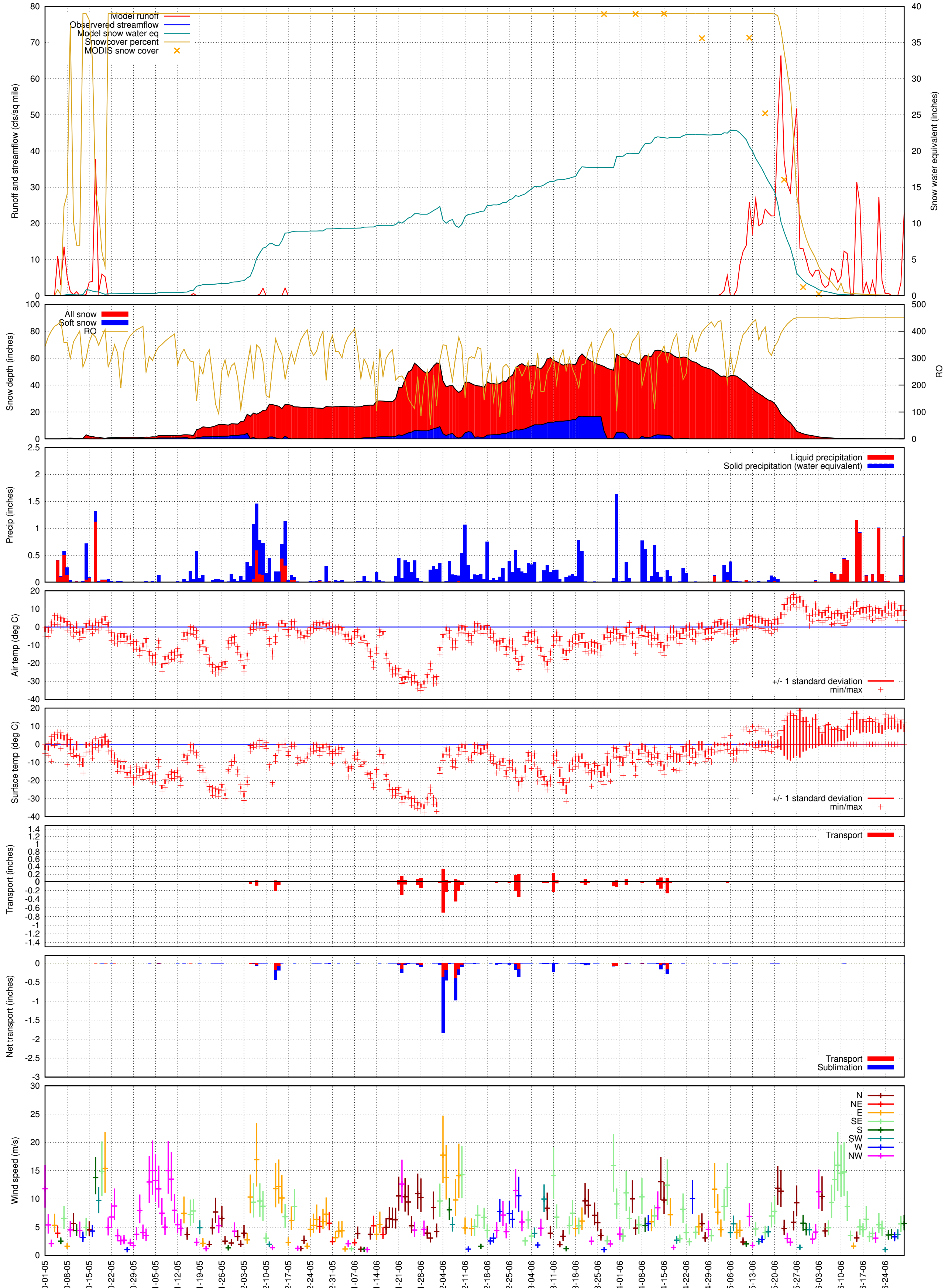
SnowModel Output Summary: 384-foot cells, hourly timestep, precipitation factor 2.0
Lidar Survey Area, 2007-2008



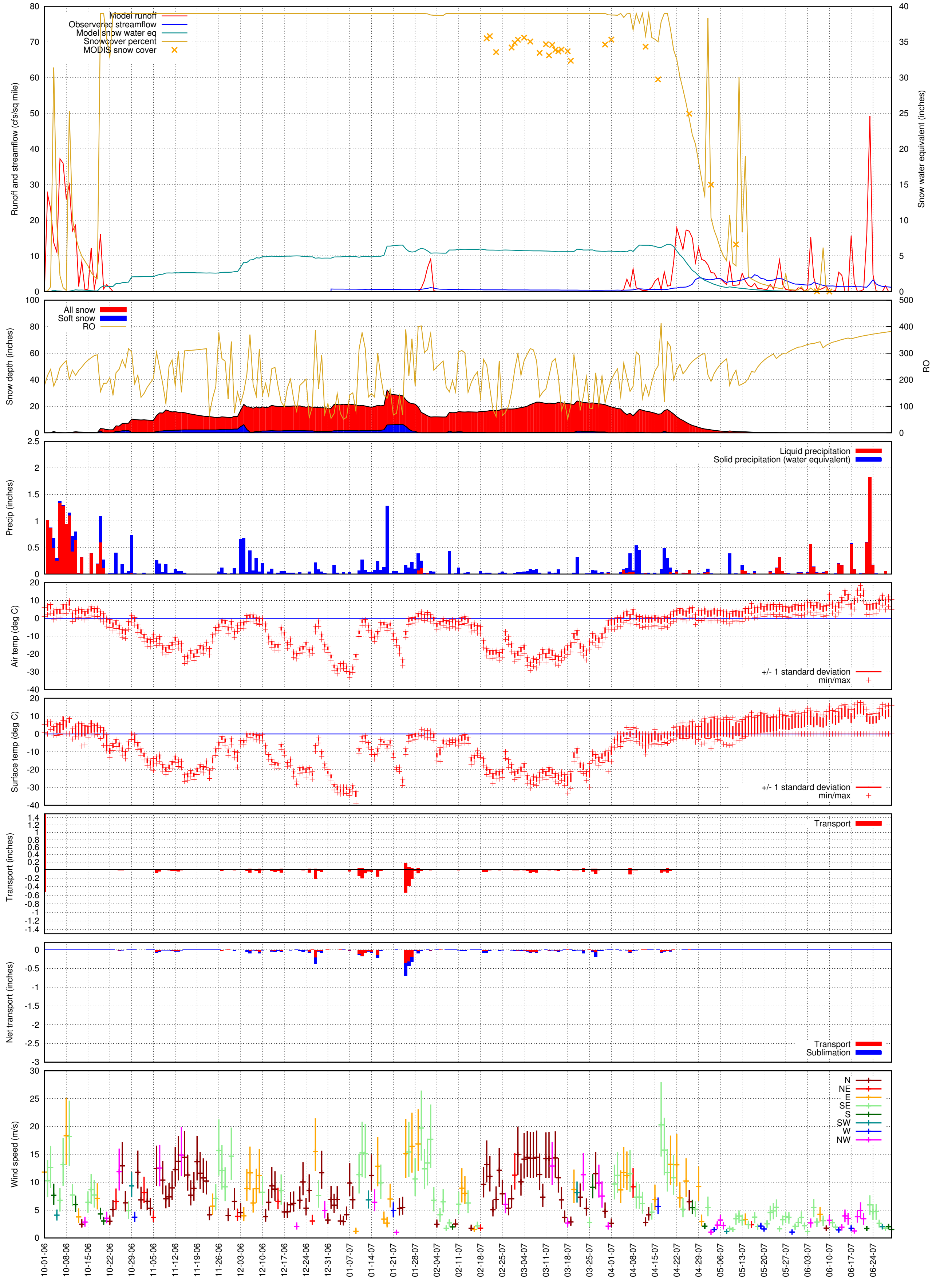
SnowModel Output Summary: 384-foot cells, hourly timestep, precipitation factor 2.0
Lidar Survey Area, Water Balance Summary, 2005-2008



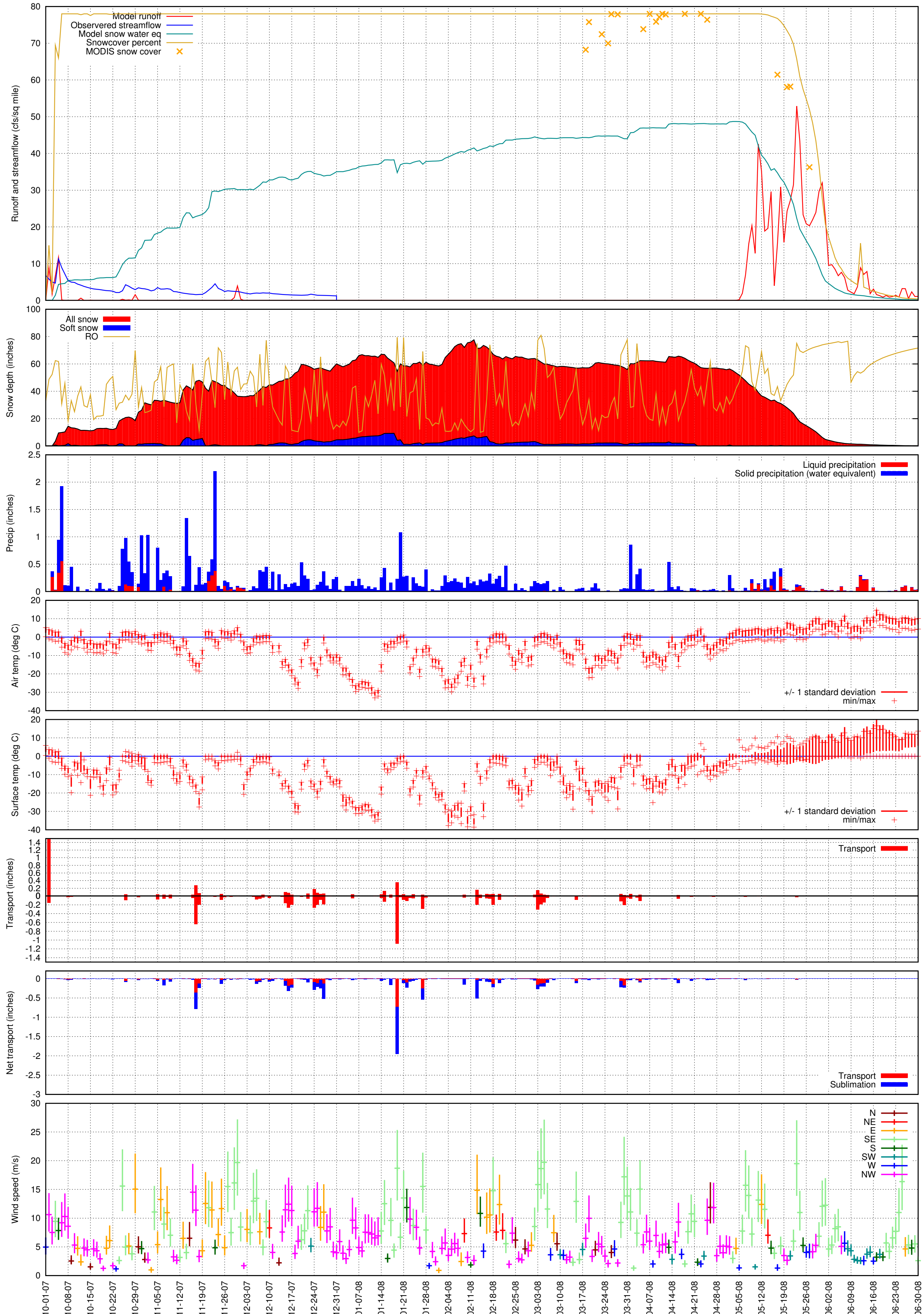
SnowModel Output Summary: 384-foot cells, hourly timestep, precipitation factor 2.0
Mine Study Area, 2005-2006



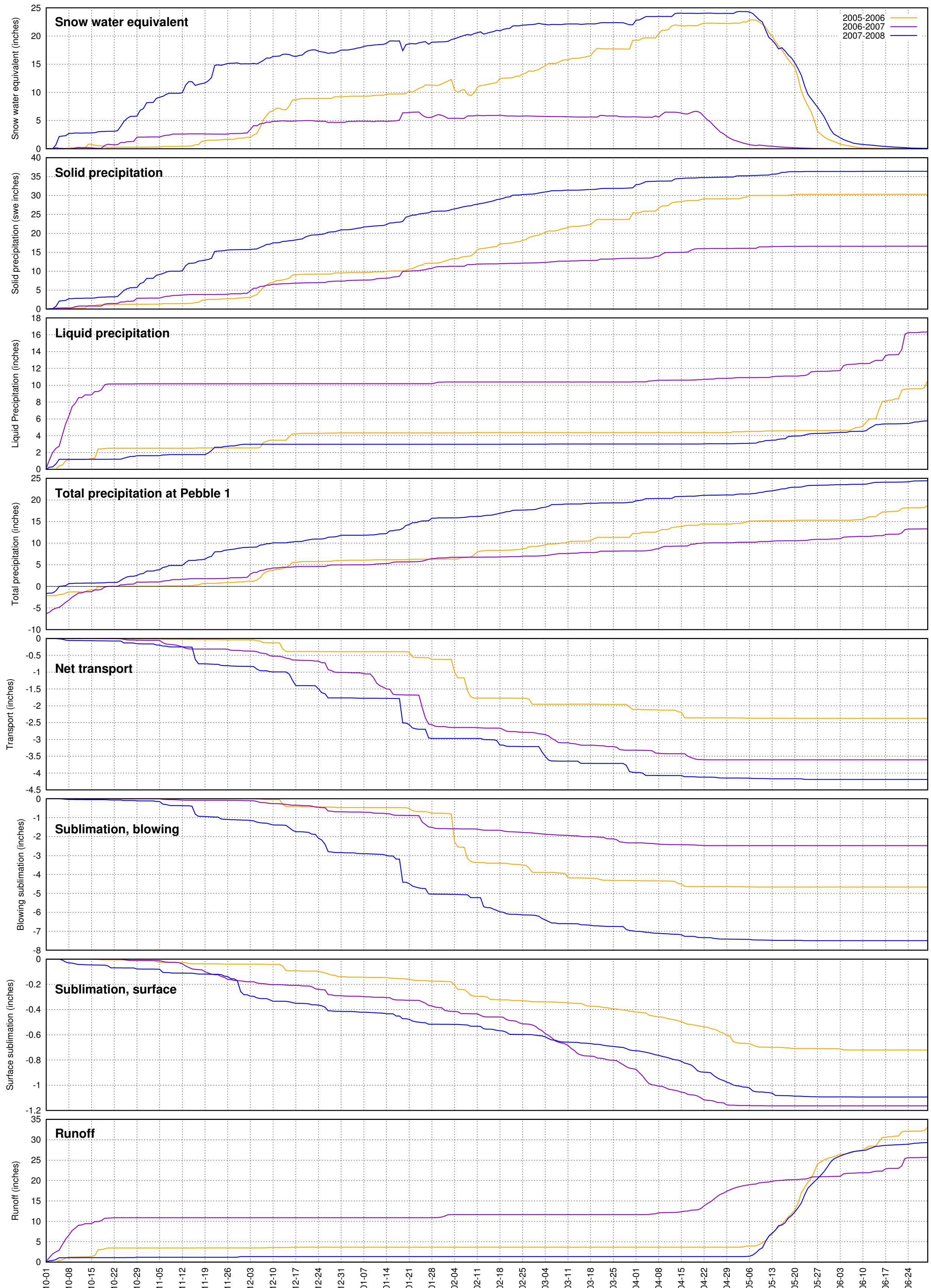
SnowModel Output Summary: 384-foot cells, hourly timestep, precipitation factor 2.0
Mine Study Area, 2006-2007



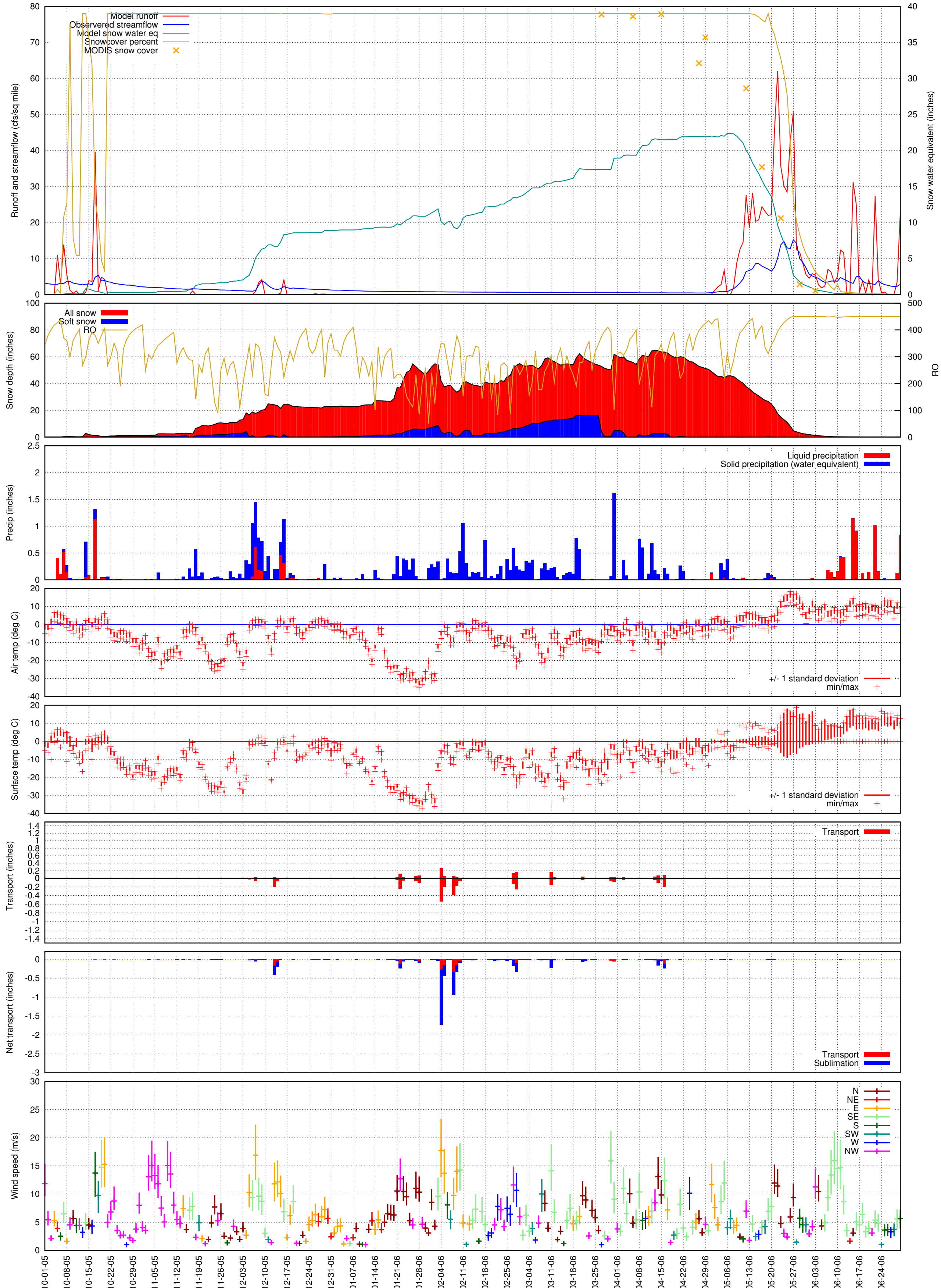
SnowModel Output Summary: 384-foot cells, hourly timestep, precipitation factor 2.0
Mine Study Area, 2007-2008



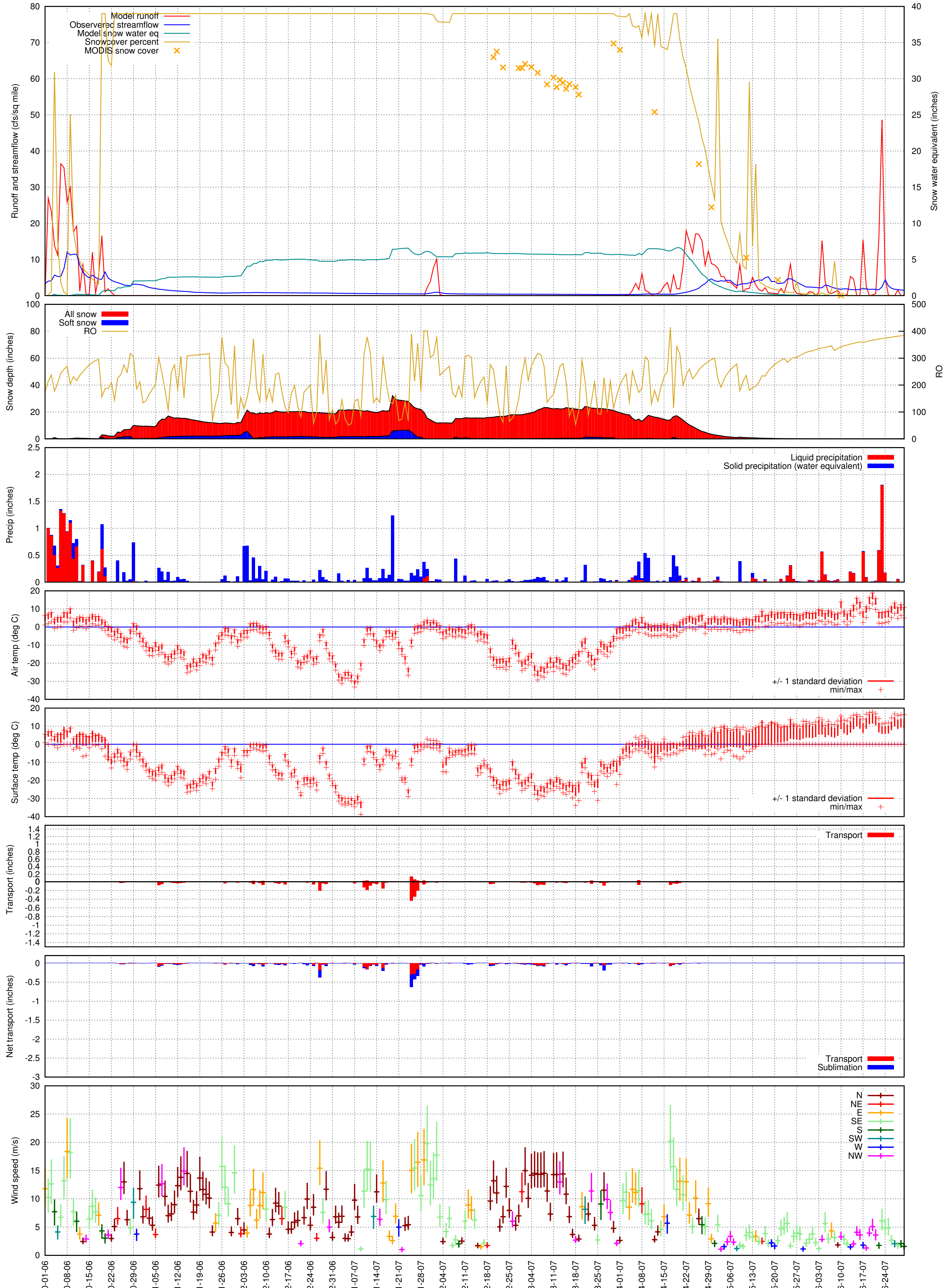
SnowModel Output Summary: 384-foot cells, hourly timestep, precipitation factor 2.0
Mine Study Area, Water Balance Summary, 2005-2008



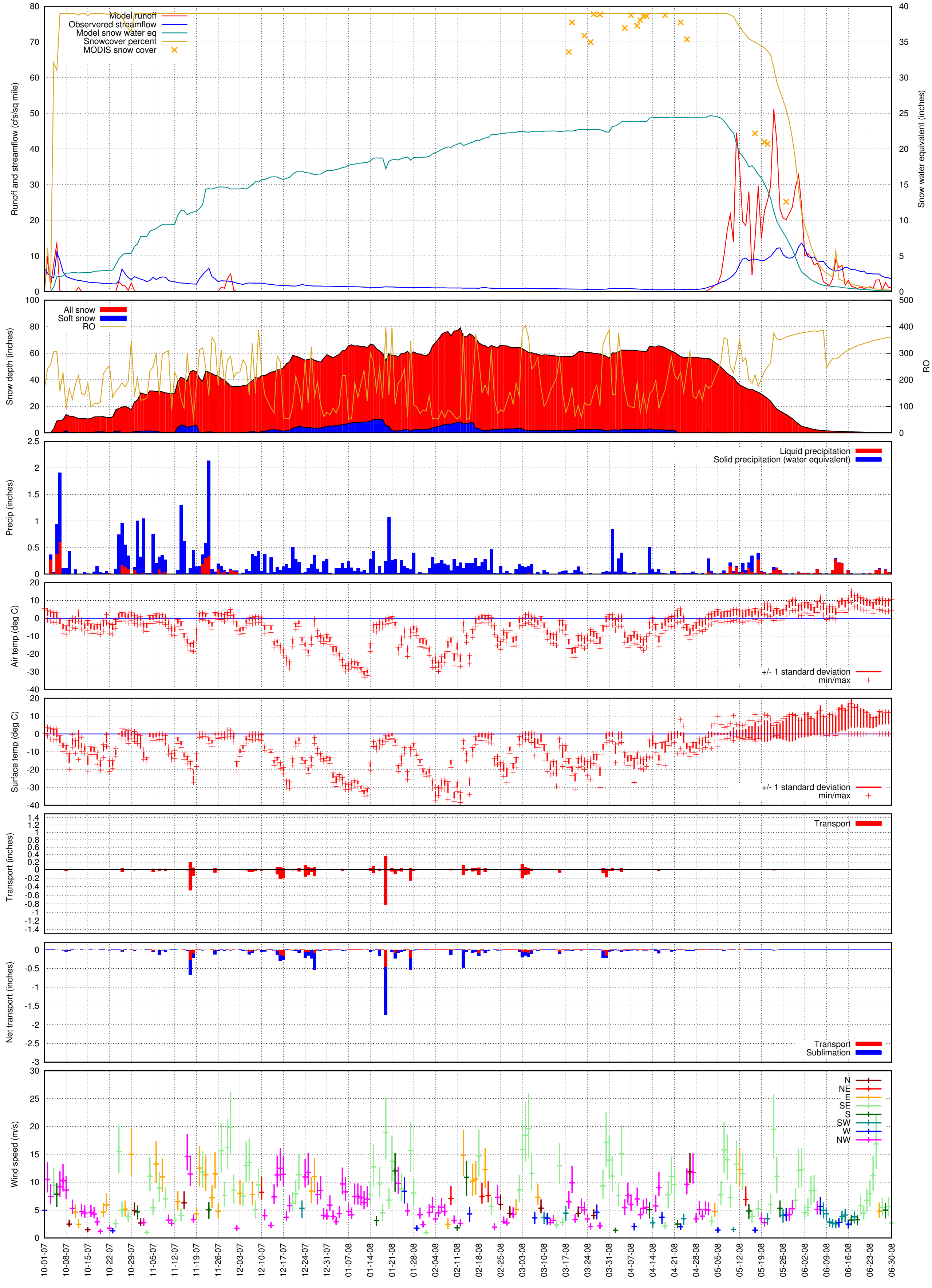
SnowModel Output Summary: 384-foot cells, hourly timestep, precipitation factor 2.0
Basin NK100A, 2005-2006



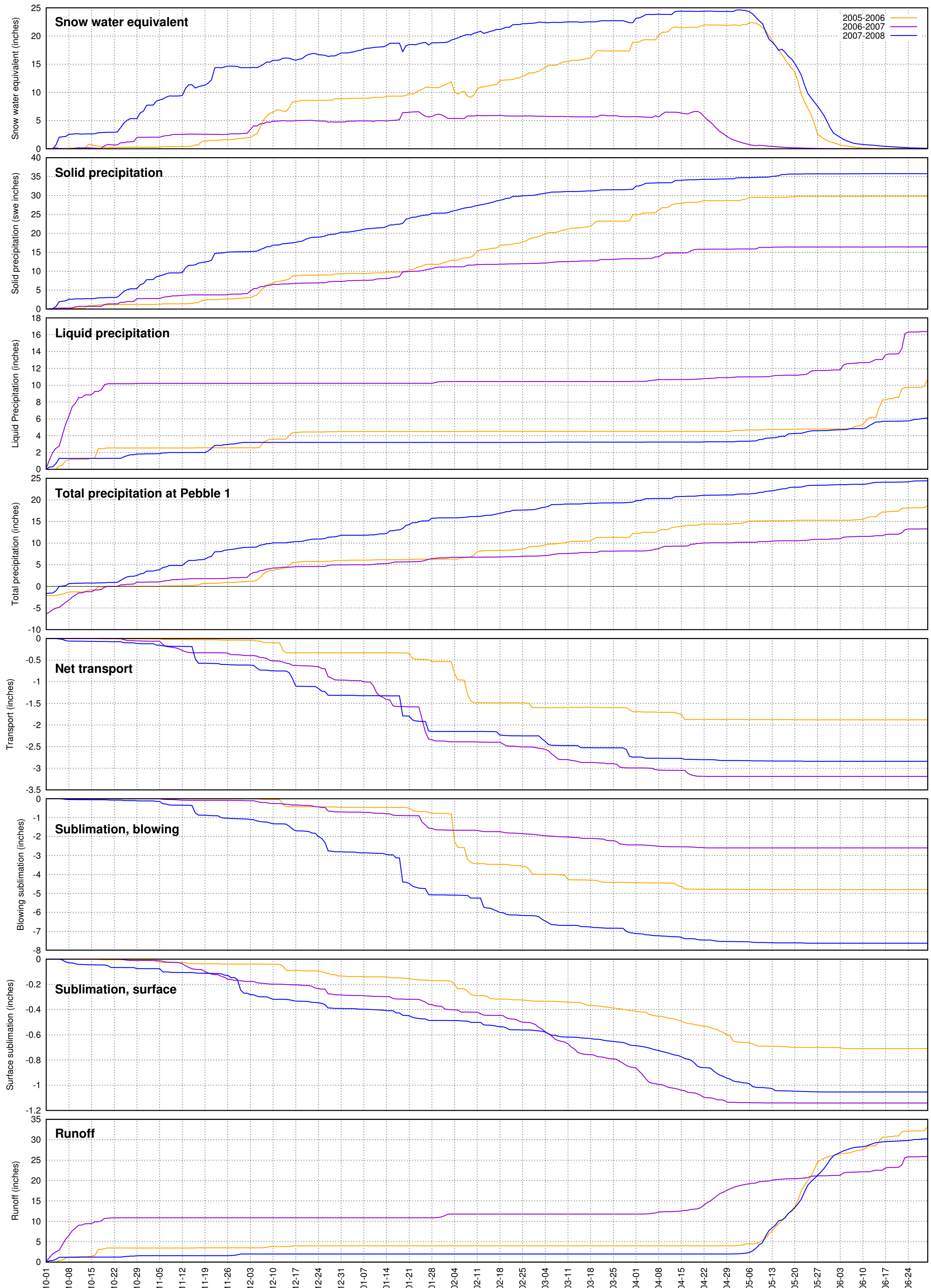
SnowModel Output Summary: 384-foot cells, hourly timestep, precipitation factor 2.0
Basin NK100A, 2006-2007



SnowModel Output Summary: 384-foot cells, hourly timestep, precipitation factor 2.0
Basin NK100A, 2007-2008



SnowModel Output Summary: 384-foot cells, hourly timestep, precipitation factor 2.0
Basin NK100A, Water Balance Summary, 2005-2008



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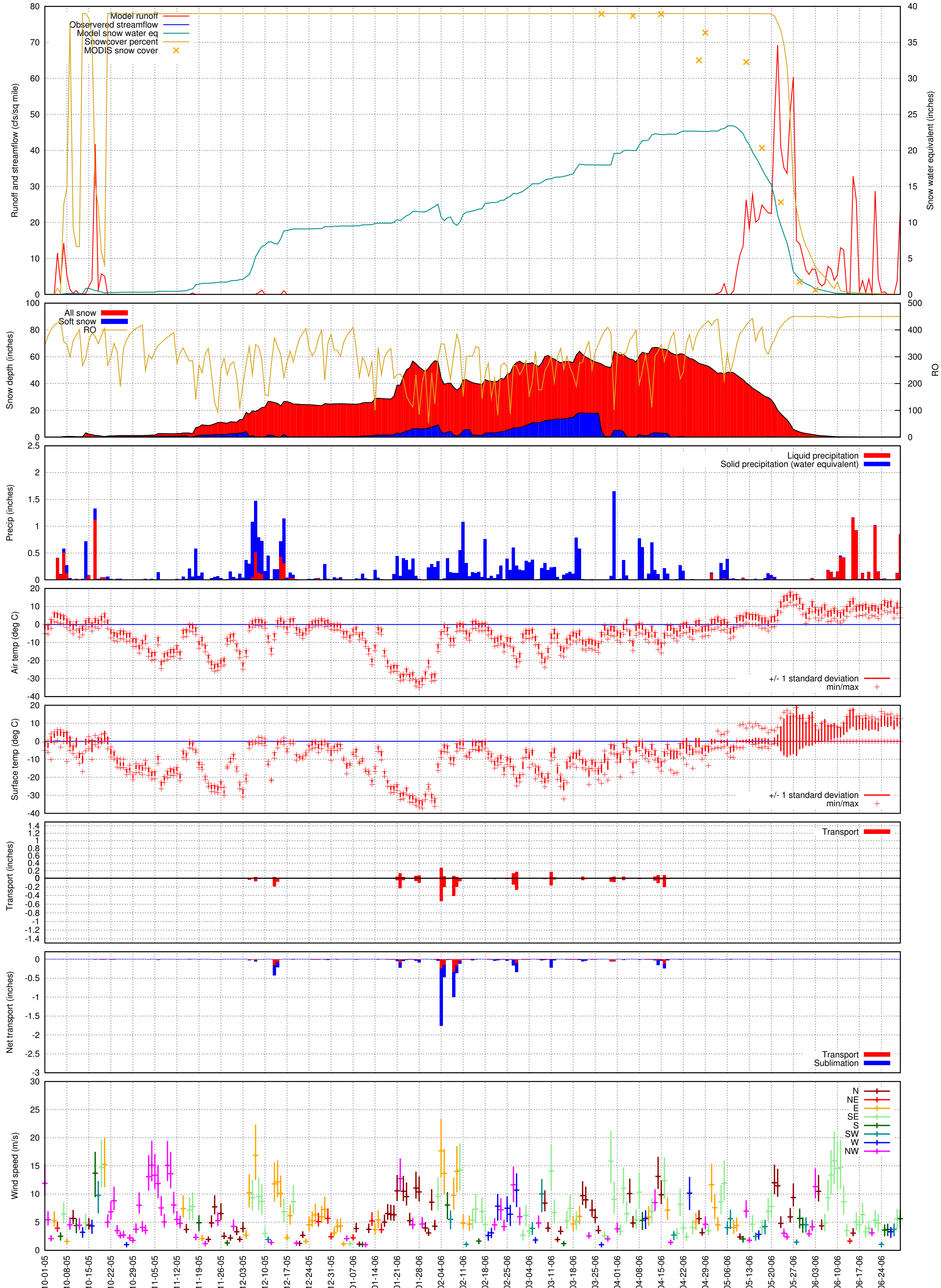
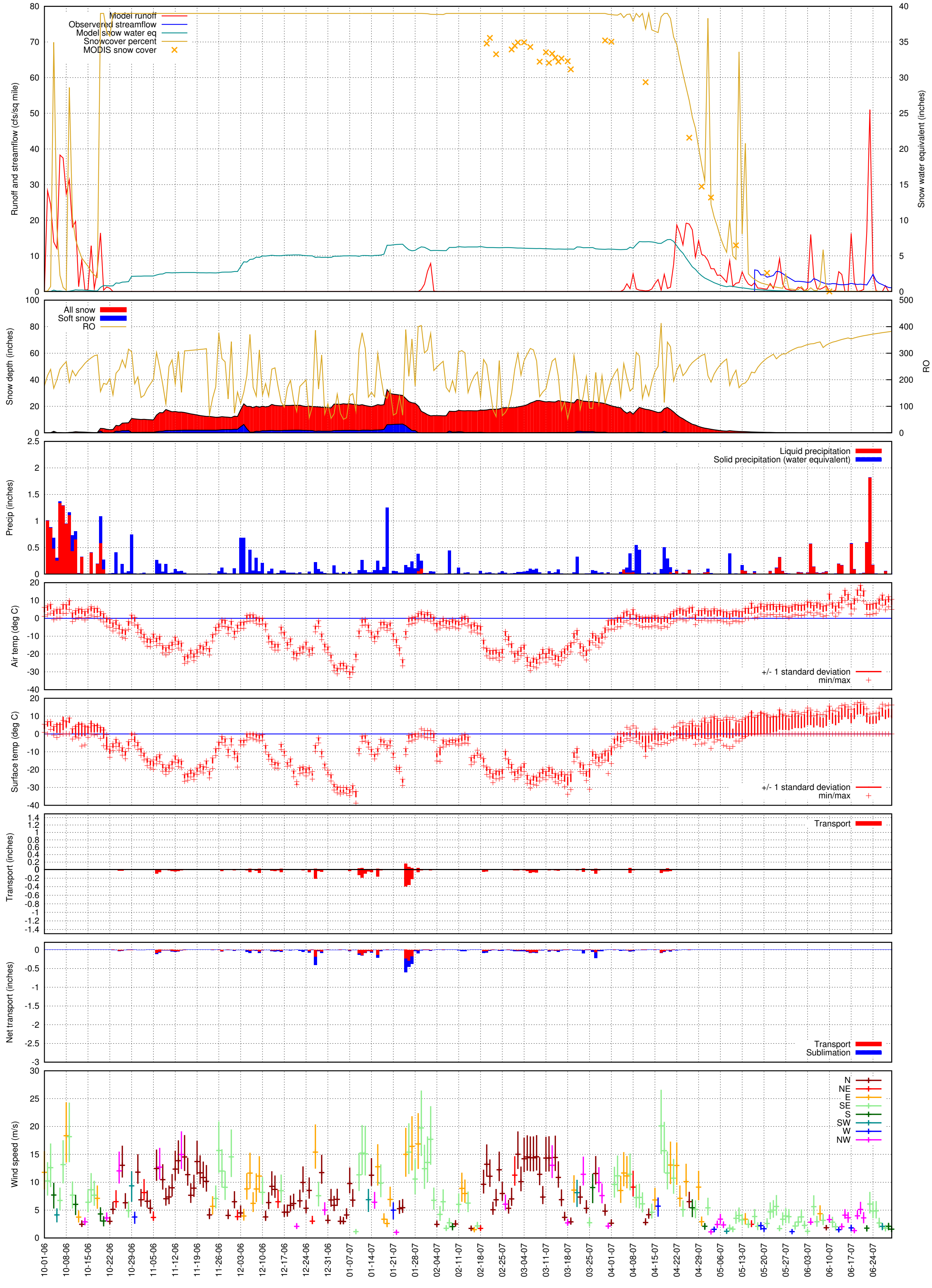
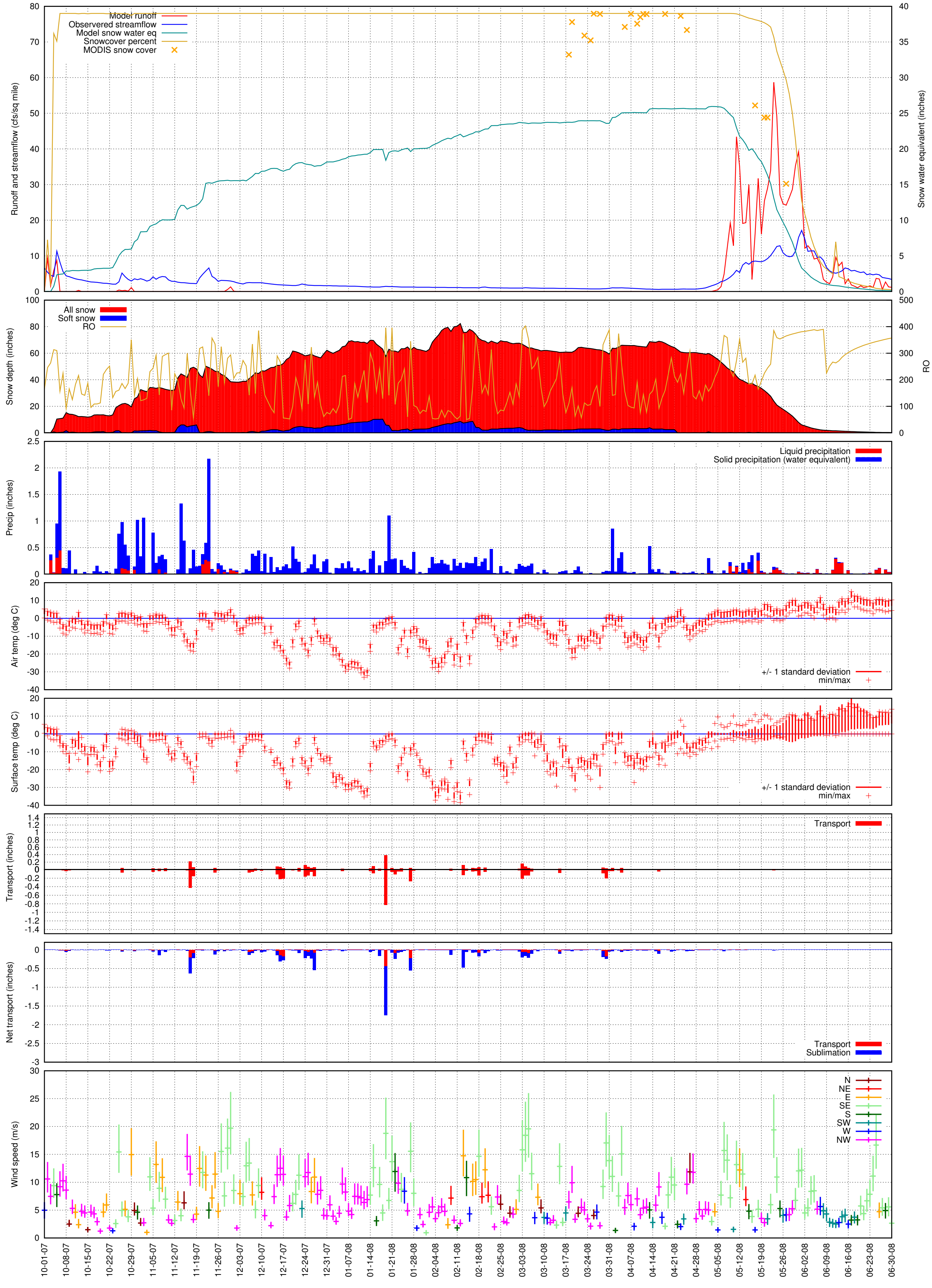
Basin NK100A1, 2005-2006



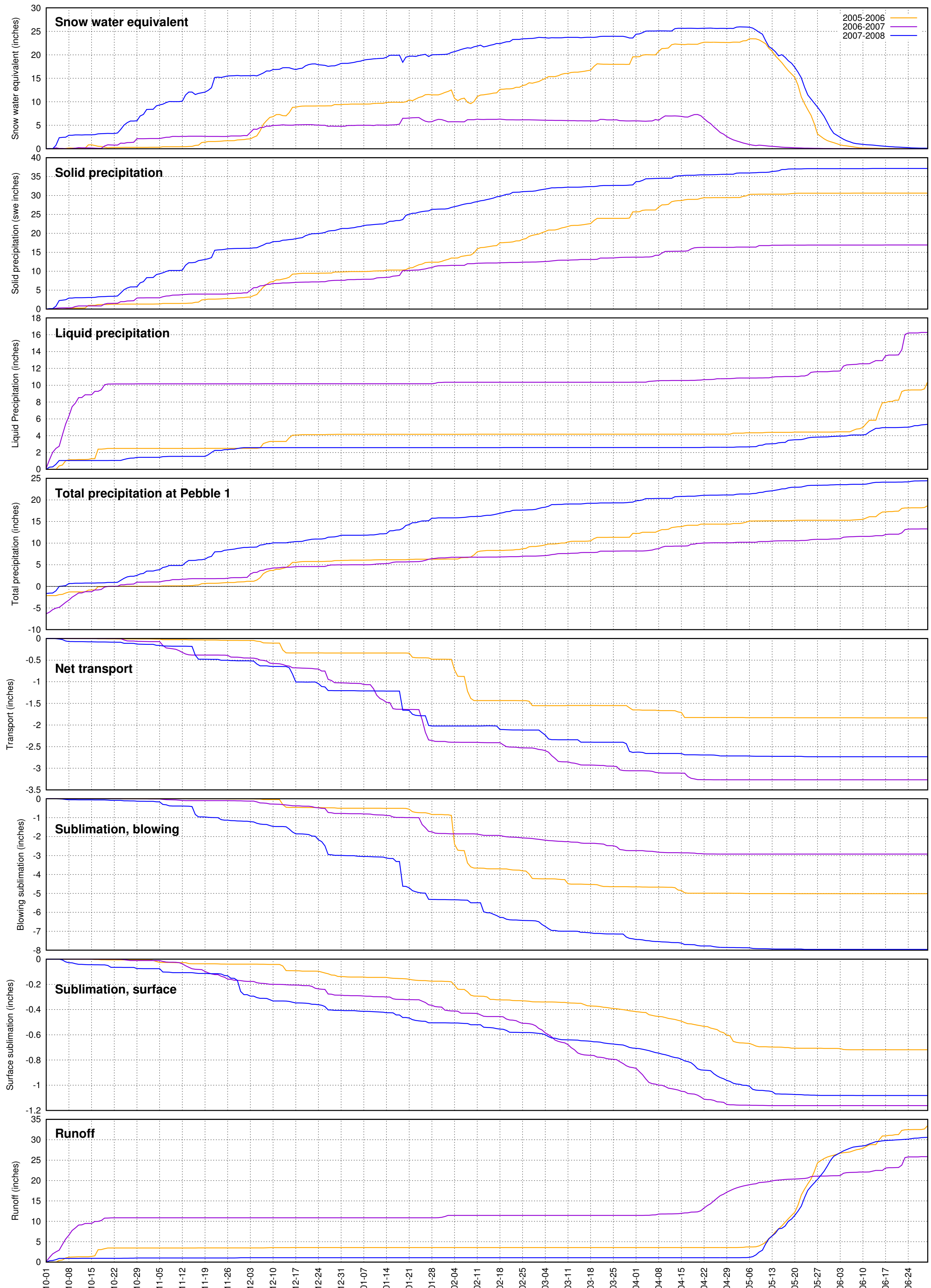
SnowModel Output Summary: 384-foot cells, hourly timestep, precipitation factor 2.0
Basin NK100A1, 2006-2007



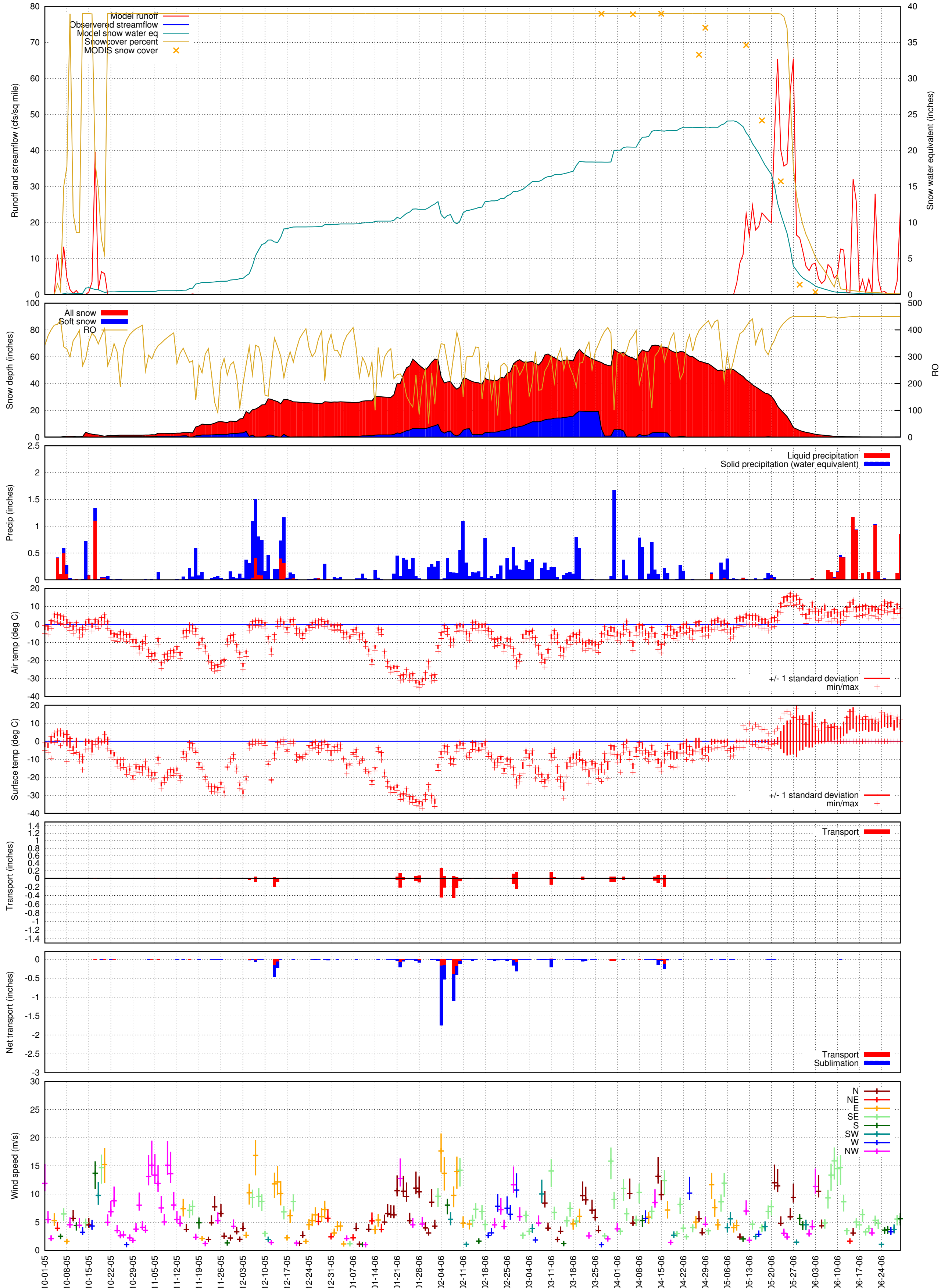
SnowModel Output Summary: 384-foot cells, hourly timestep, precipitation factor 2.0
Basin NK100A1, 2007-2008



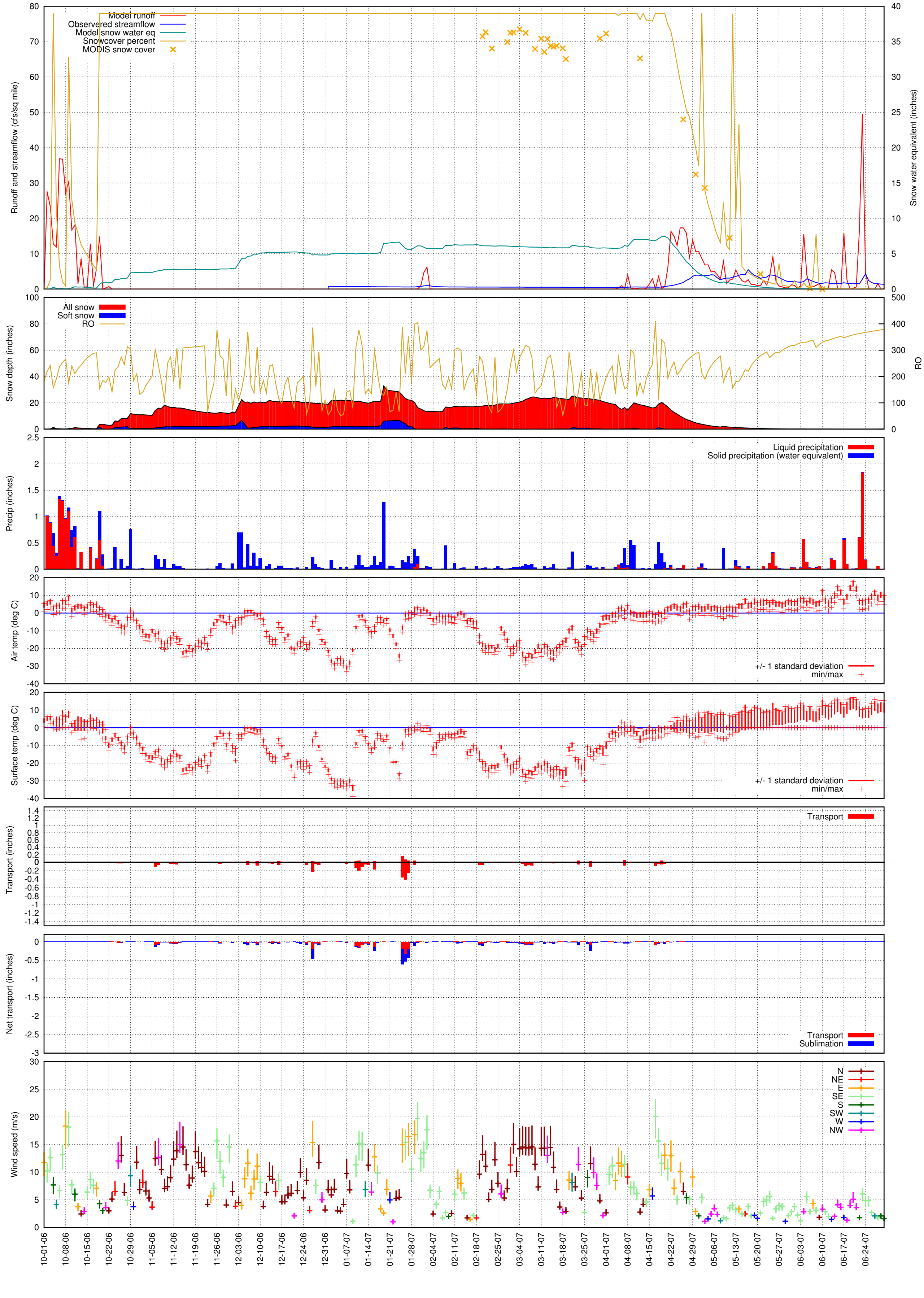
SnowModel Output Summary: 384-foot cells, hourly timestep, precipitation factor 2.0
Basin NK100A1, Water Balance Summary, 2005-2008



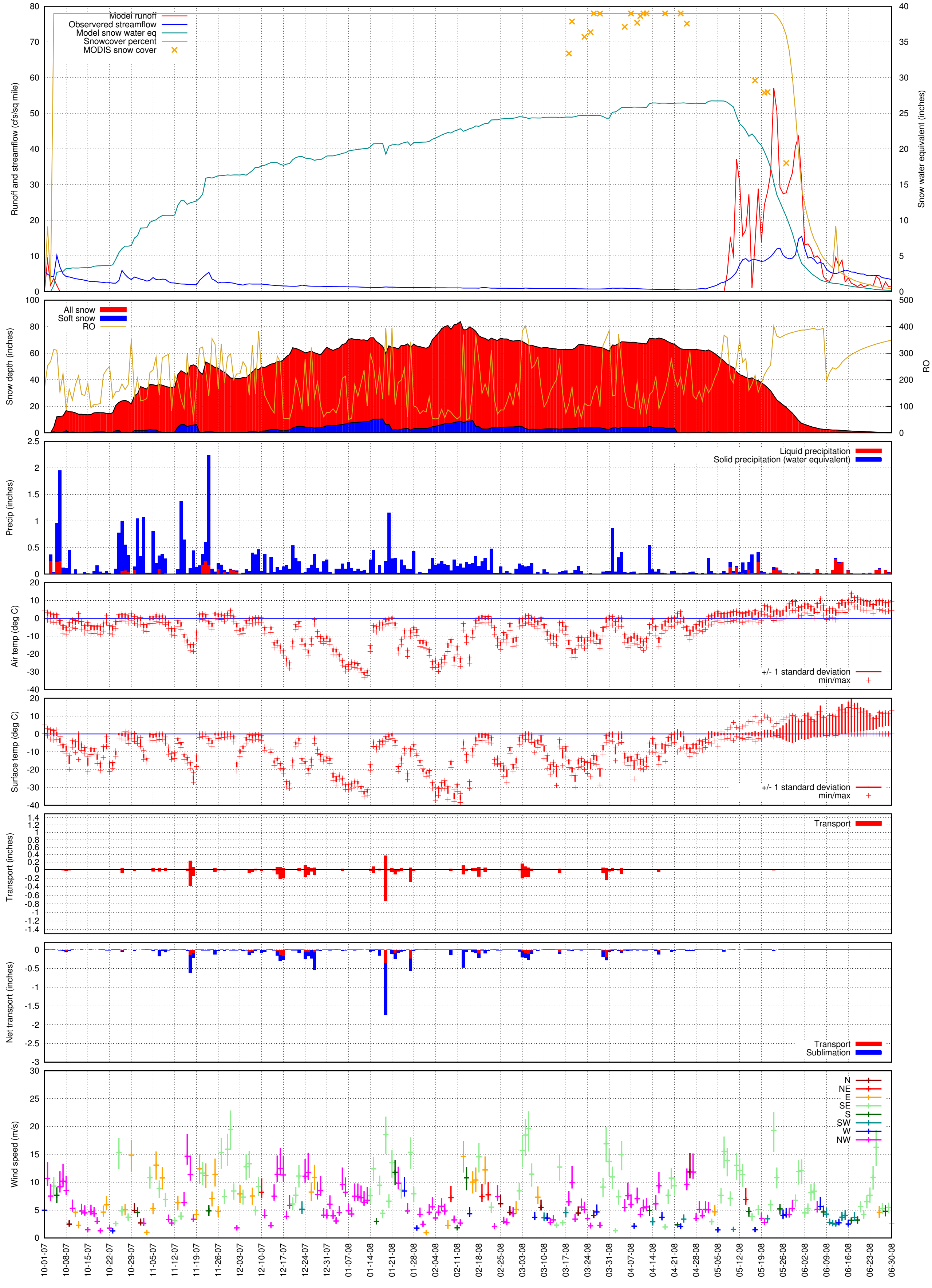
SnowModel Output Summary: 384-foot cells, hourly timestep, precipitation factor 2.0
Basin NK100B, 2005-2006



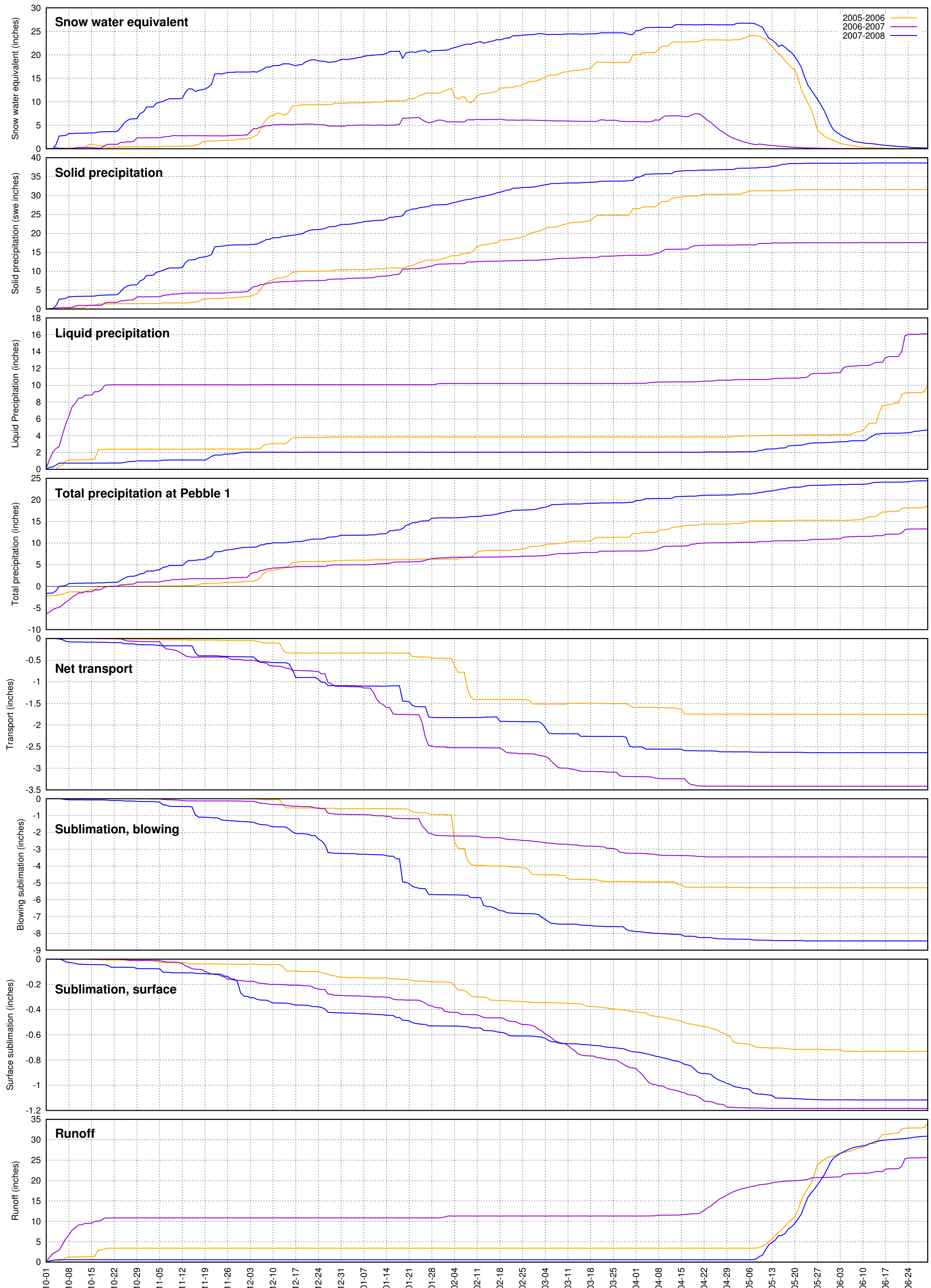
SnowModel Output Summary: 384-foot cells, hourly timestep, precipitation factor 2.0
Basin NK100B, 2006-2007



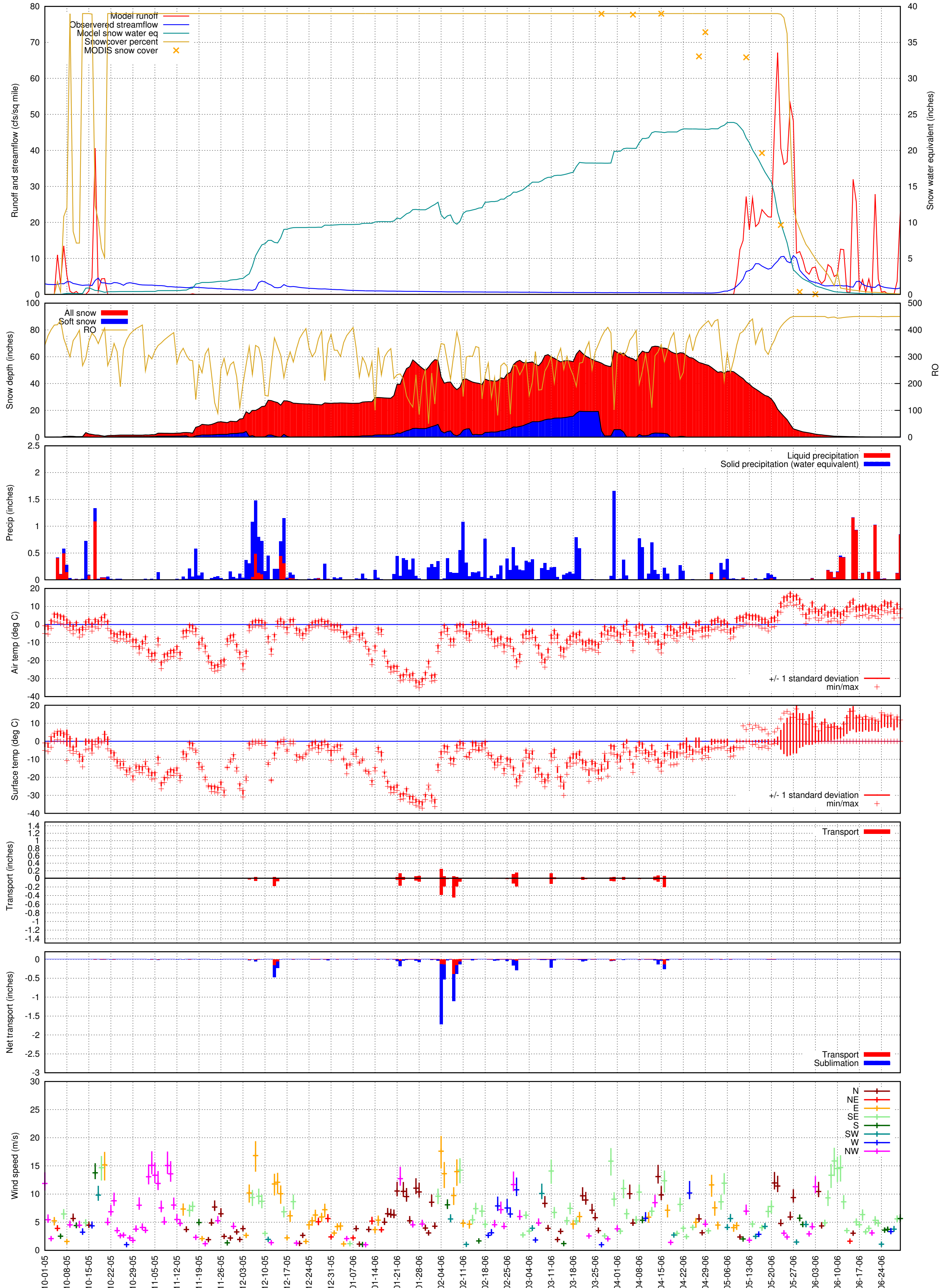
SnowModel Output Summary: 384-foot cells, hourly timestep, precipitation factor 2.0
Basin NK100B, 2007-2008



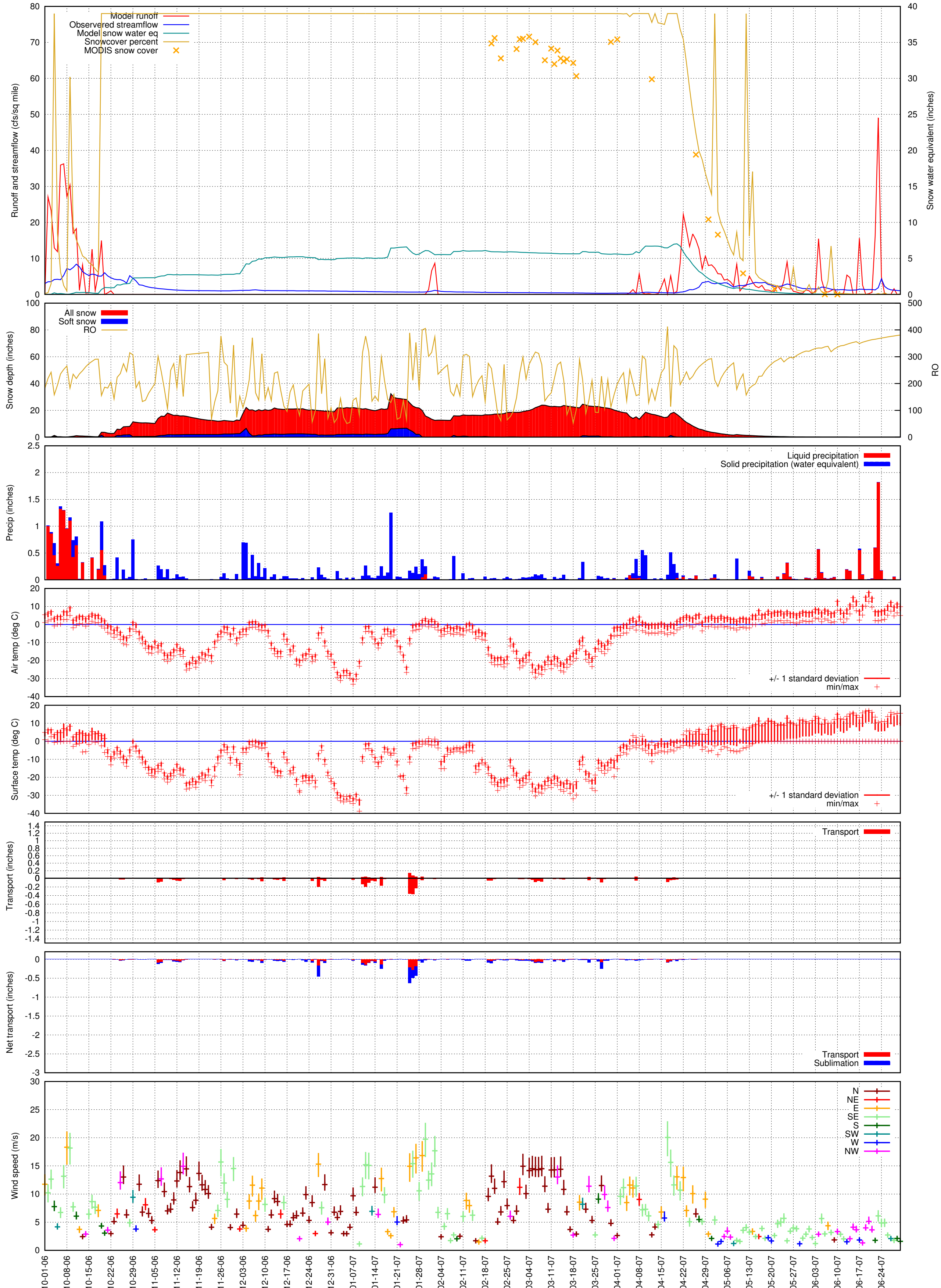
SnowModel Output Summary: 384-foot cells, hourly timestep, precipitation factor 2.0
Basin NK100B, Water Balance Summary, 2005-2008



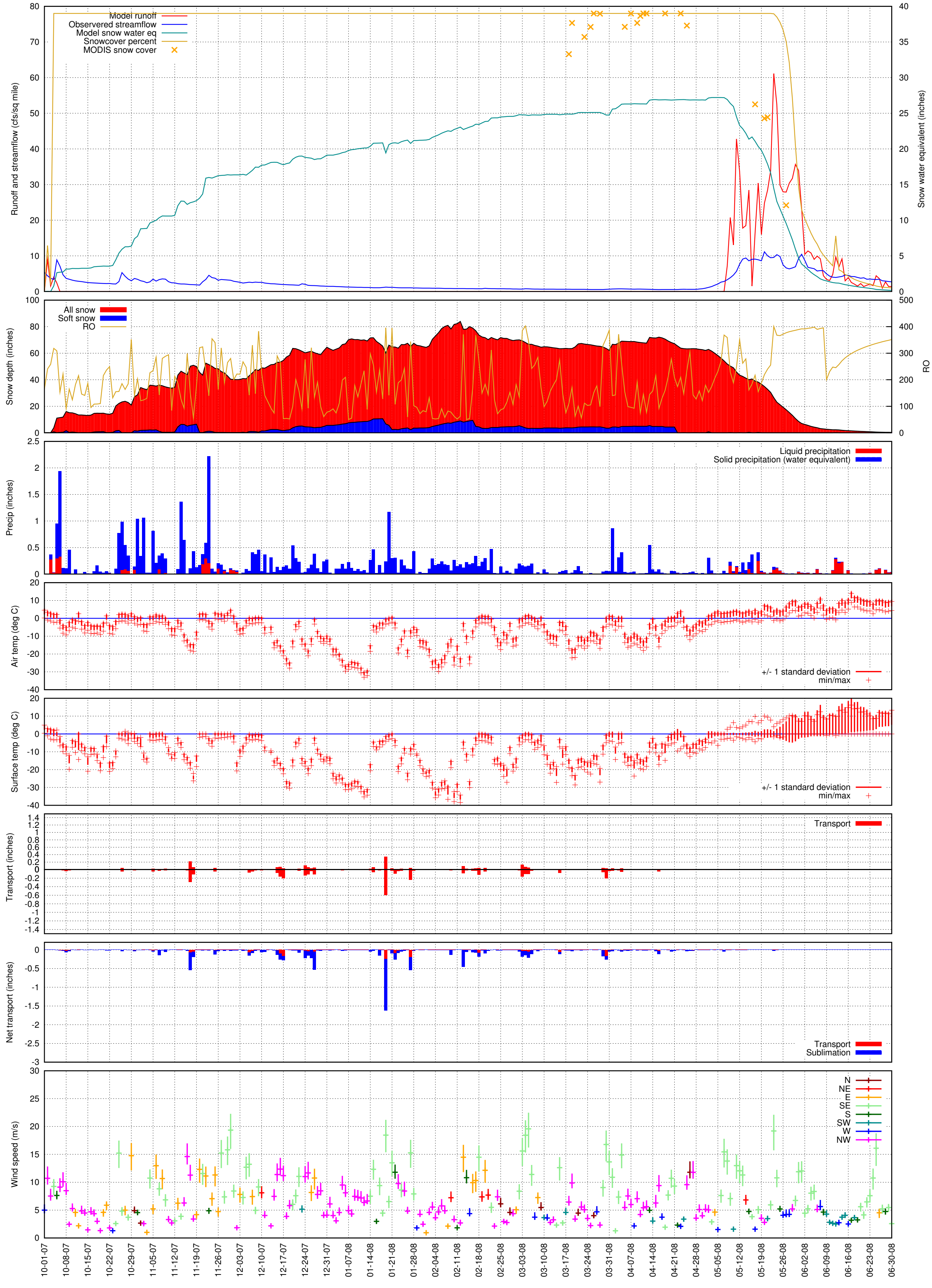
SnowModel Output Summary: 384-foot cells, hourly timestep, precipitation factor 2.0
Basin NK100C, 2005-2006



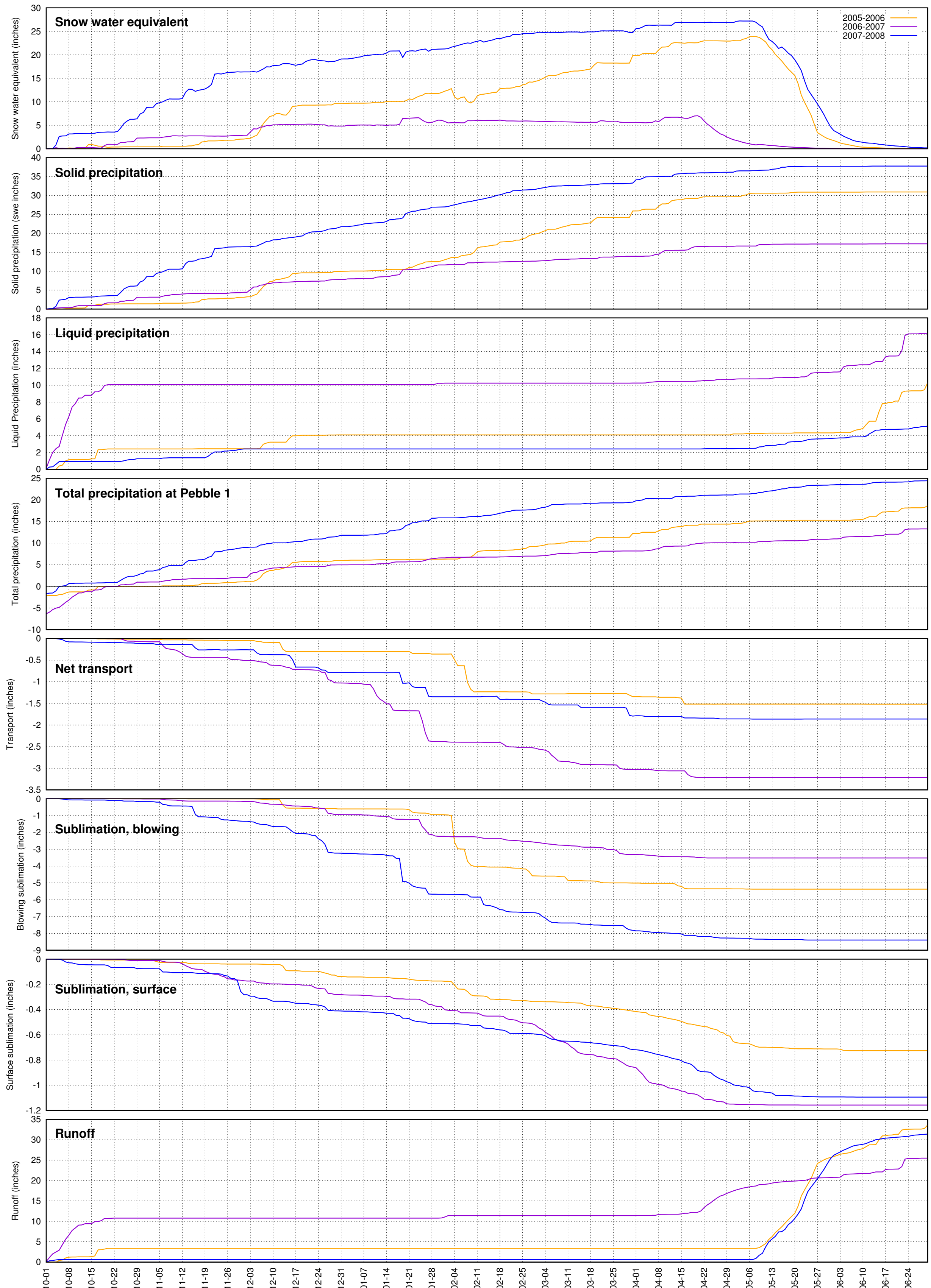
SnowModel Output Summary: 384-foot cells, hourly timestep, precipitation factor 2.0
Basin NK100C, 2006-2007



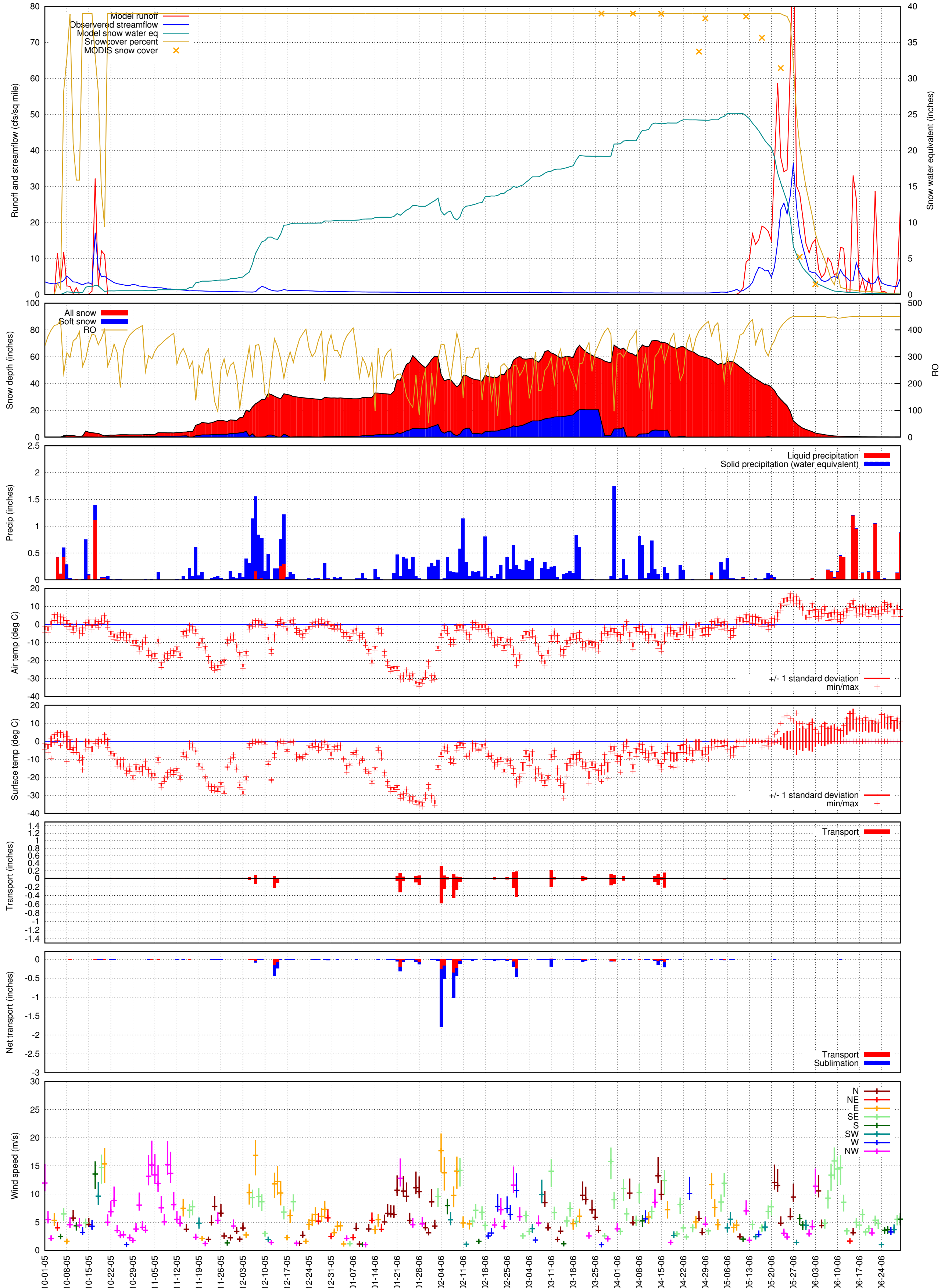
SnowModel Output Summary: 384-foot cells, hourly timestep, precipitation factor 2.0
Basin NK100C, 2007-2008



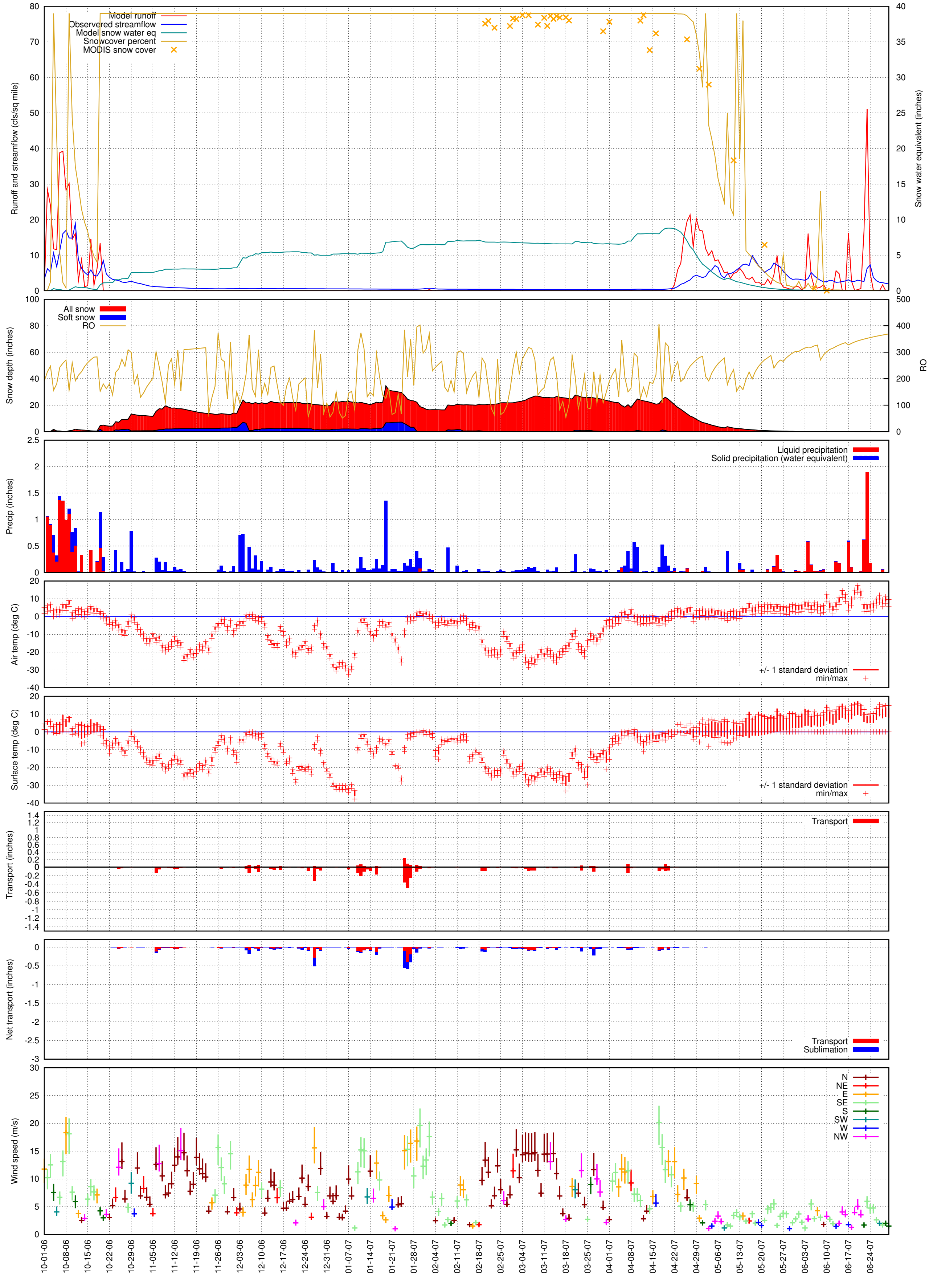
SnowModel Output Summary: 384-foot cells, hourly timestep, precipitation factor 2.0
Basin NK100C, Water Balance Summary, 2005-2008



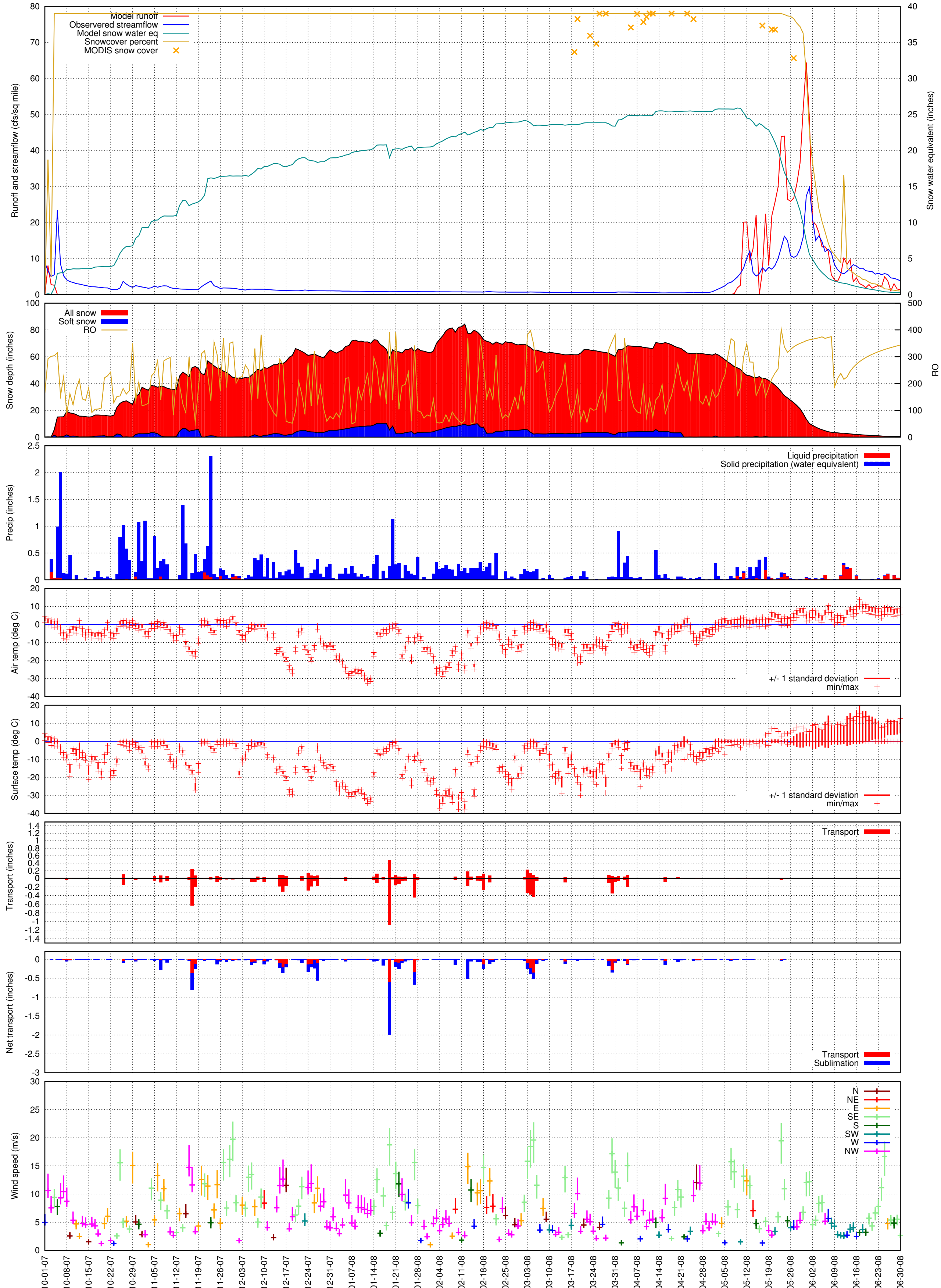
SnowModel Output Summary: 384-foot cells, hourly timestep, precipitation factor 2.0
Basin NK119A, 2005-2006



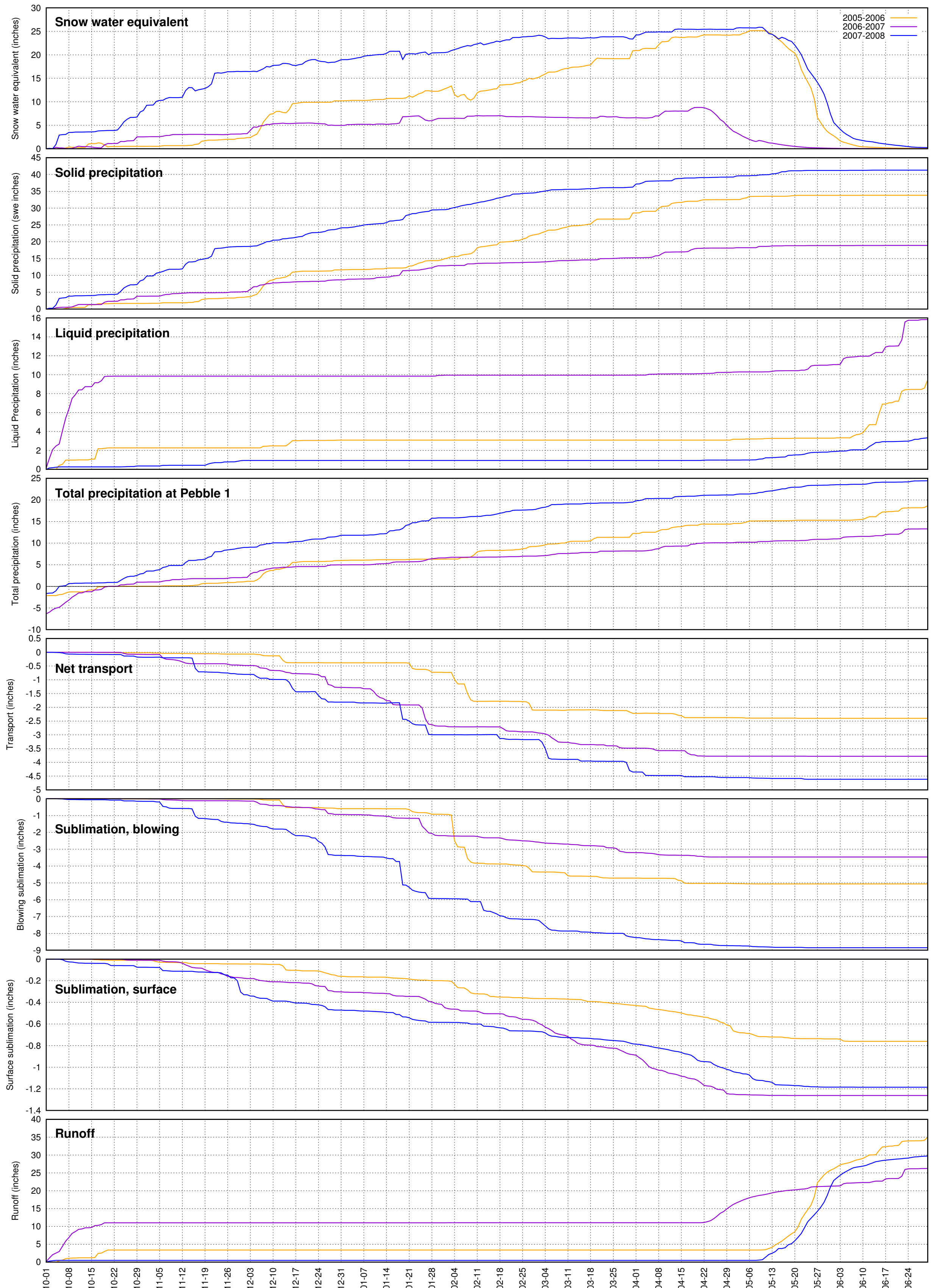
SnowModel Output Summary: 384-foot cells, hourly timestep, precipitation factor 2.0
Basin NK119A, 2006-2007



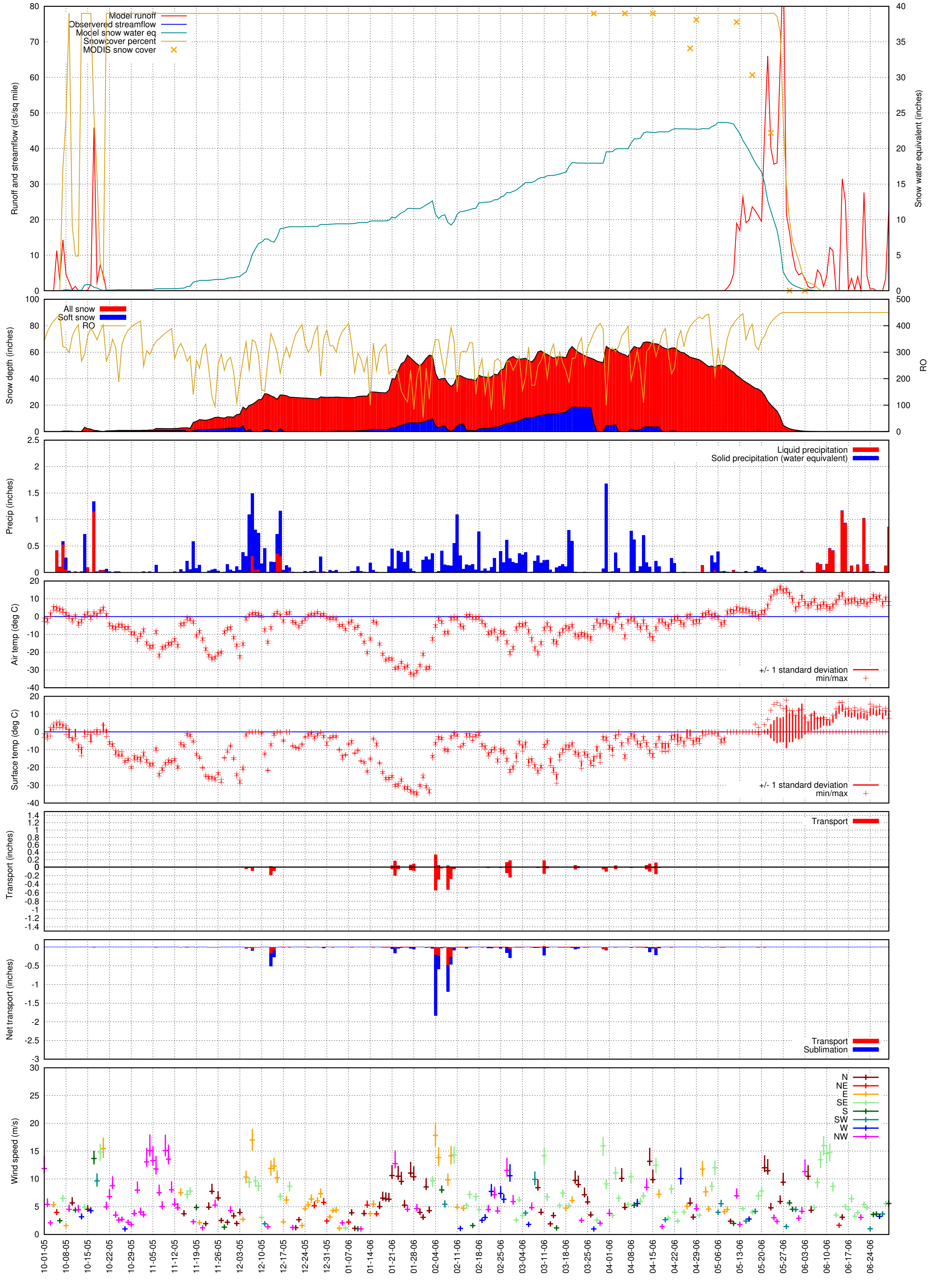
SnowModel Output Summary: 384-foot cells, hourly timestep, precipitation factor 2.0
Basin NK119A, 2007-2008



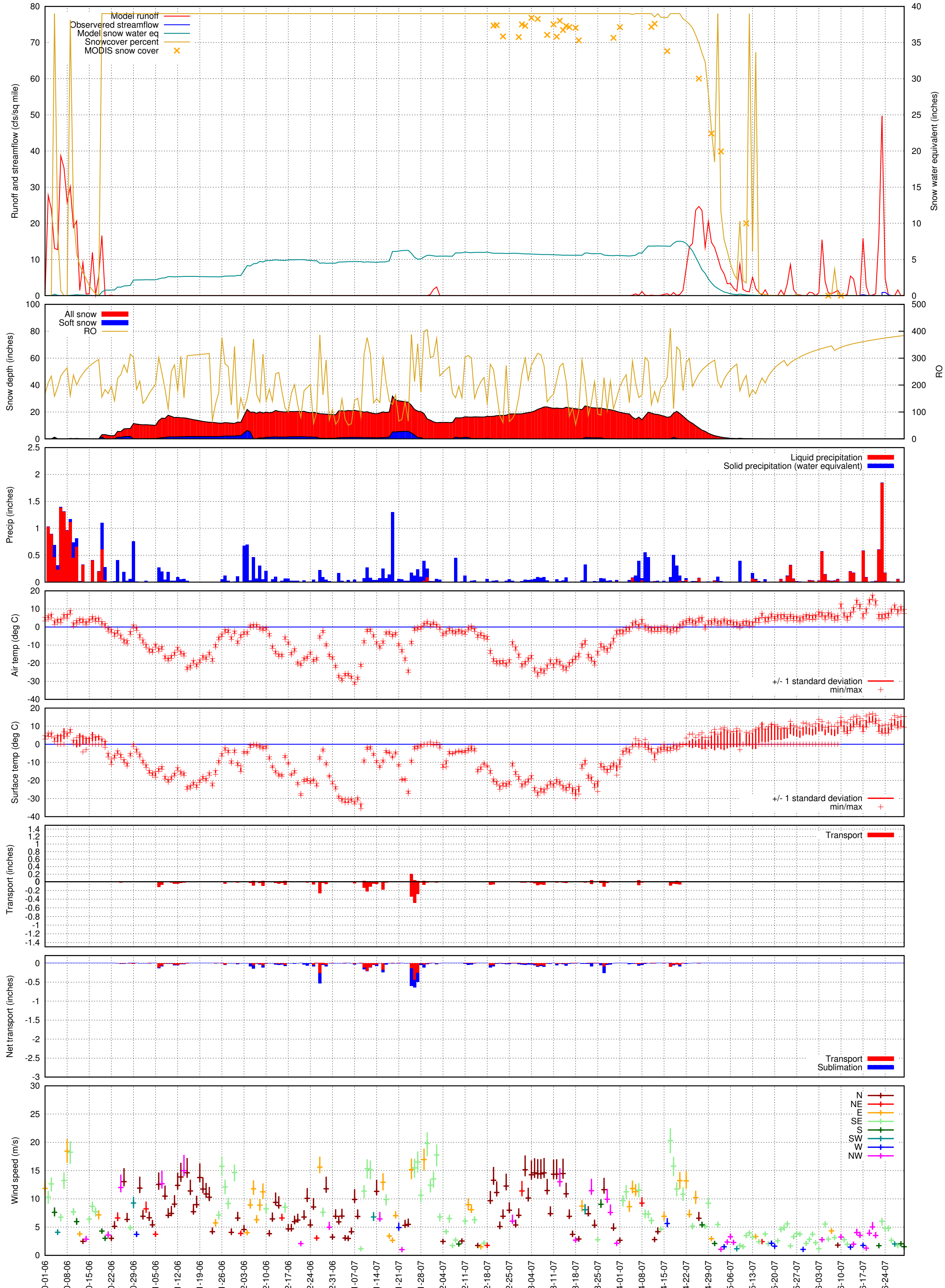
SnowModel Output Summary: 384-foot cells, hourly timestep, precipitation factor 2.0
Basin NK119A, Water Balance Summary, 2005-2008



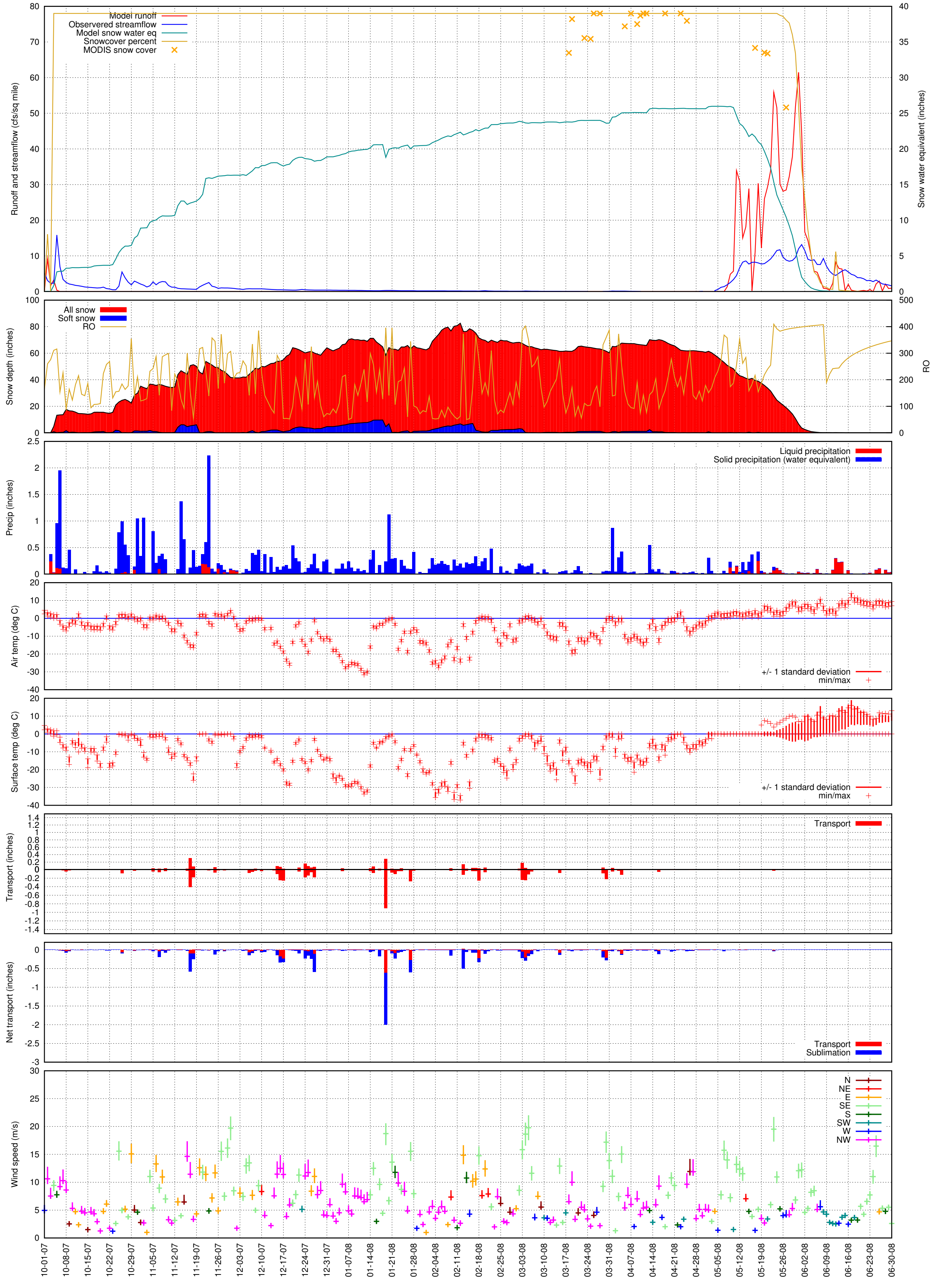
SnowModel Output Summary: 384-foot cells, hourly timestep, precipitation factor 2.0
Basin NK119B, 2005-2006



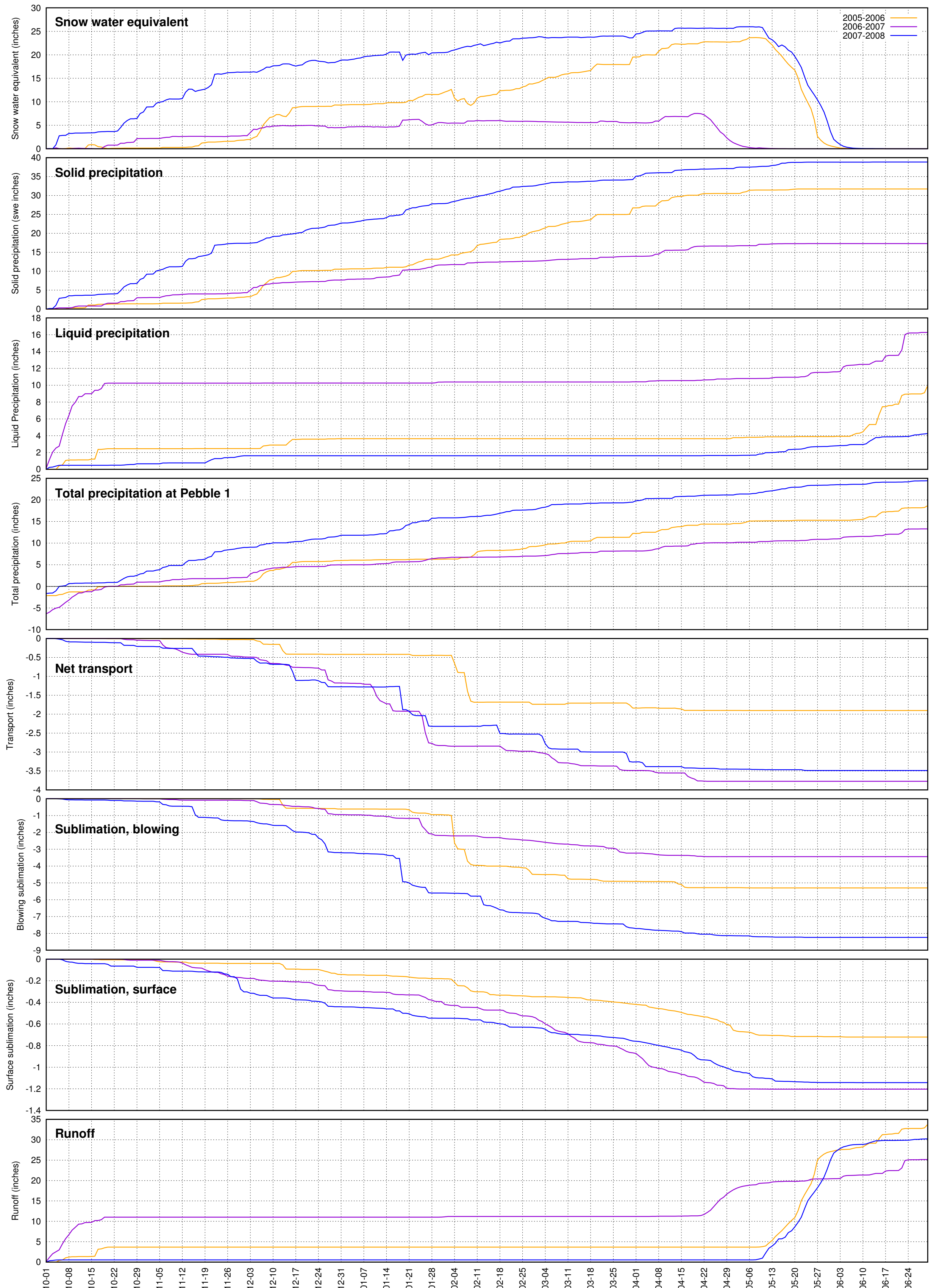
SnowModel Output Summary: 384-foot cells, hourly timestep, precipitation factor 2.0
Basin NK119B, 2006-2007



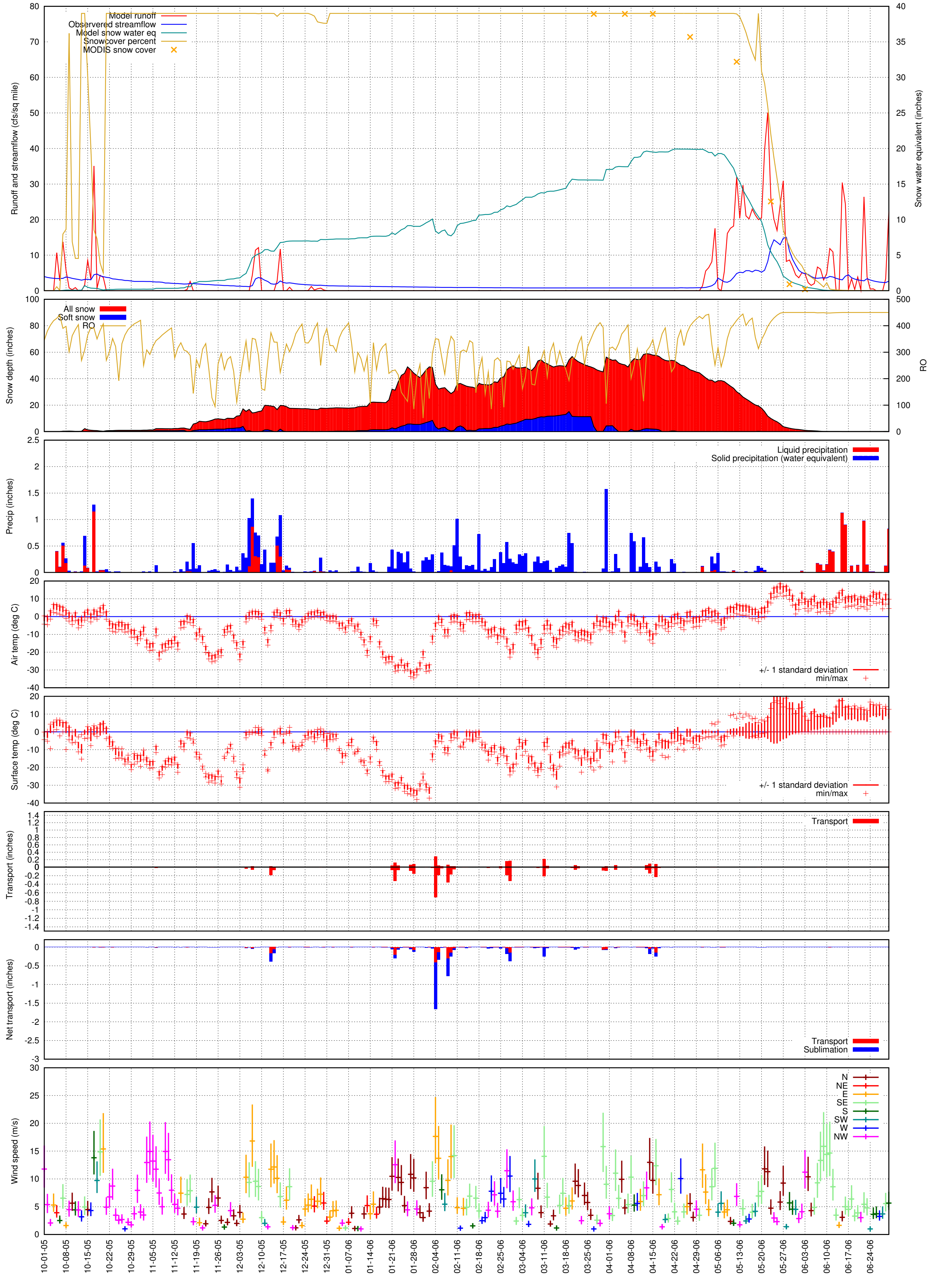
SnowModel Output Summary: 384-foot cells, hourly timestep, precipitation factor 2.0
Basin NK119B, 2007-2008



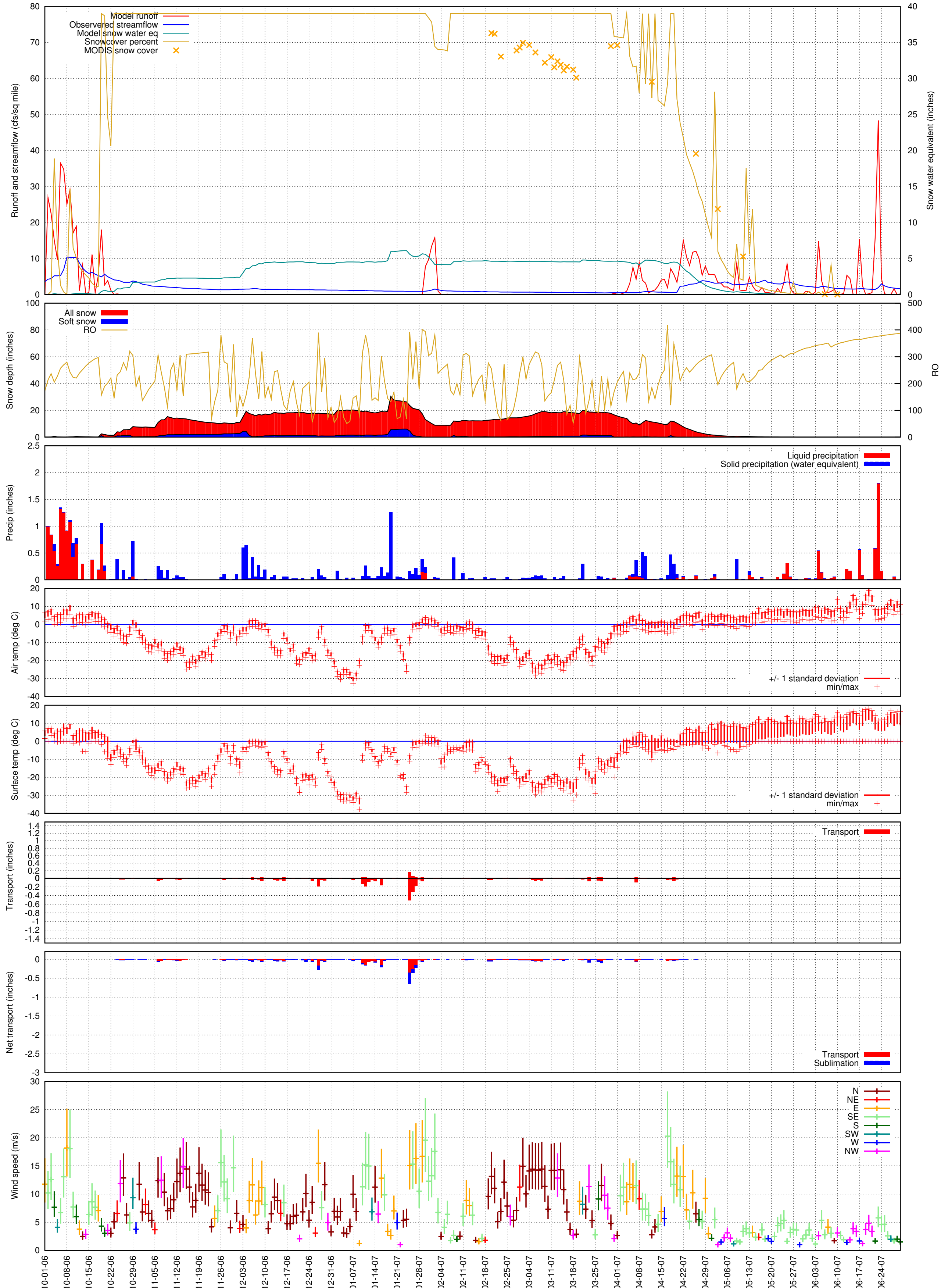
SnowModel Output Summary: 384-foot cells, hourly timestep, precipitation factor 2.0
Basin NK119B, Water Balance Summary, 2005-2008



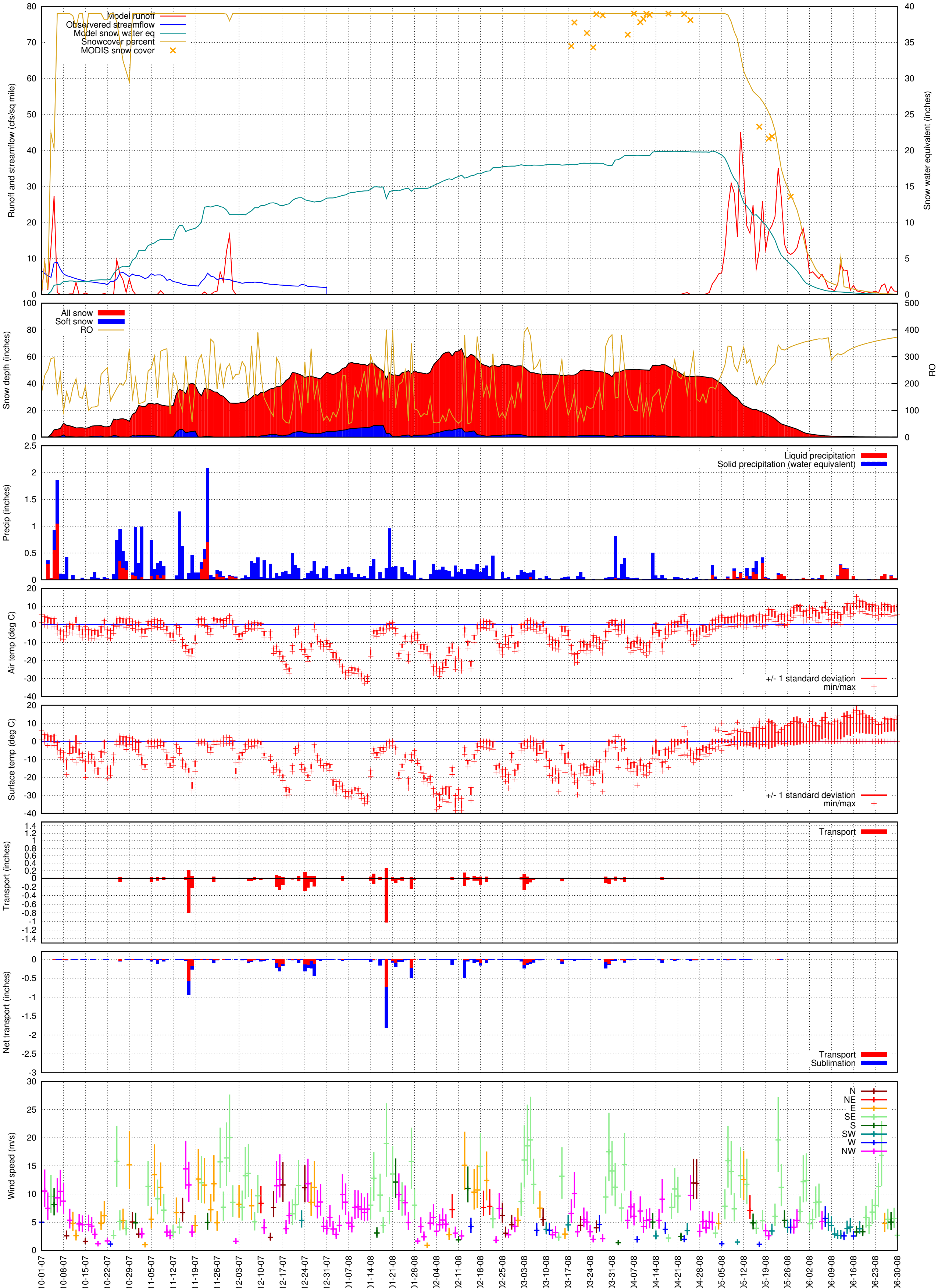
SnowModel Output Summary: 384-foot cells, hourly timestep, precipitation factor 2.0
Basin SK100A, 2005-2006



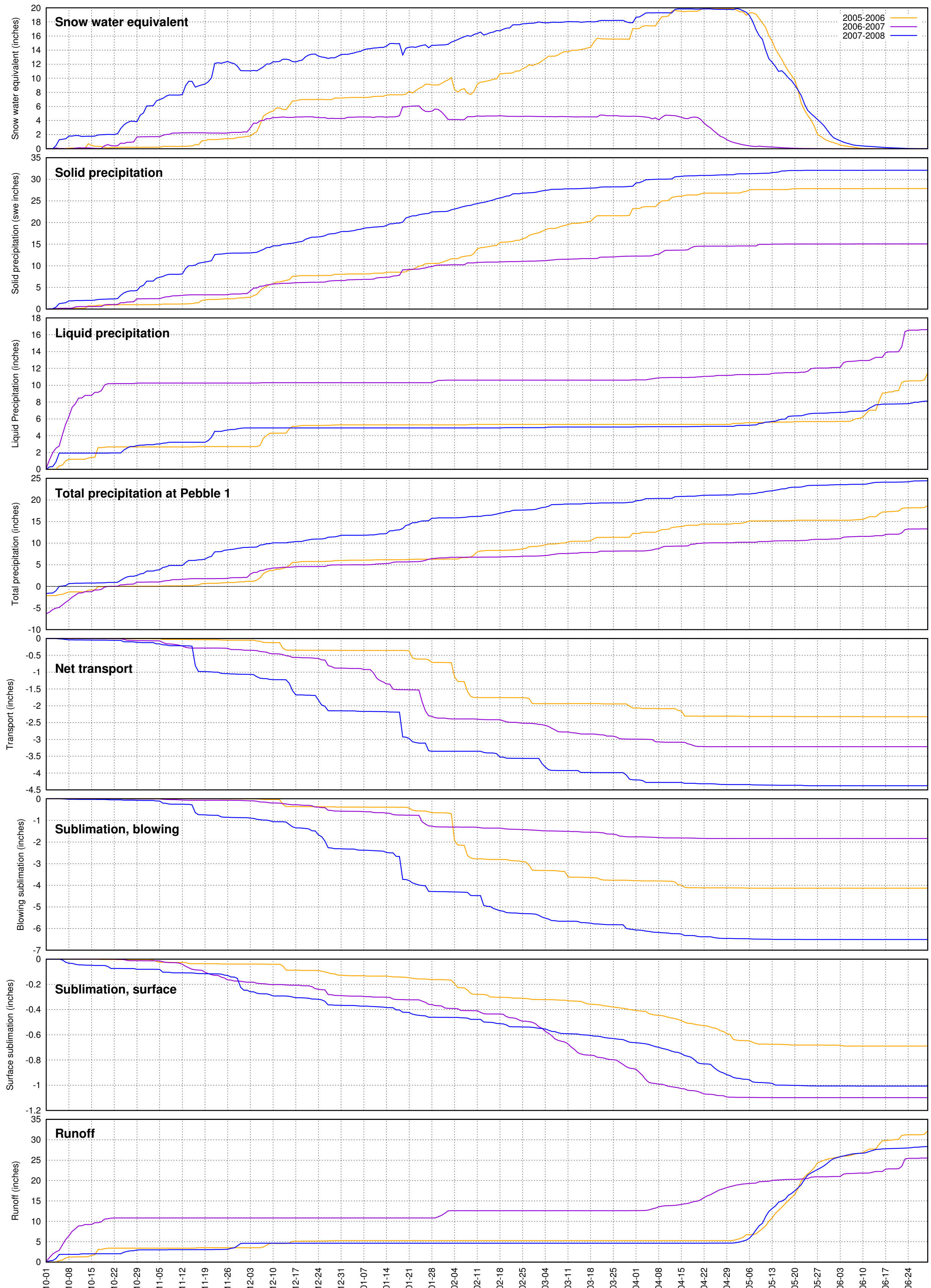
SnowModel Output Summary: 384-foot cells, hourly timestep, precipitation factor 2.0
Basin SK100A, 2006-2007



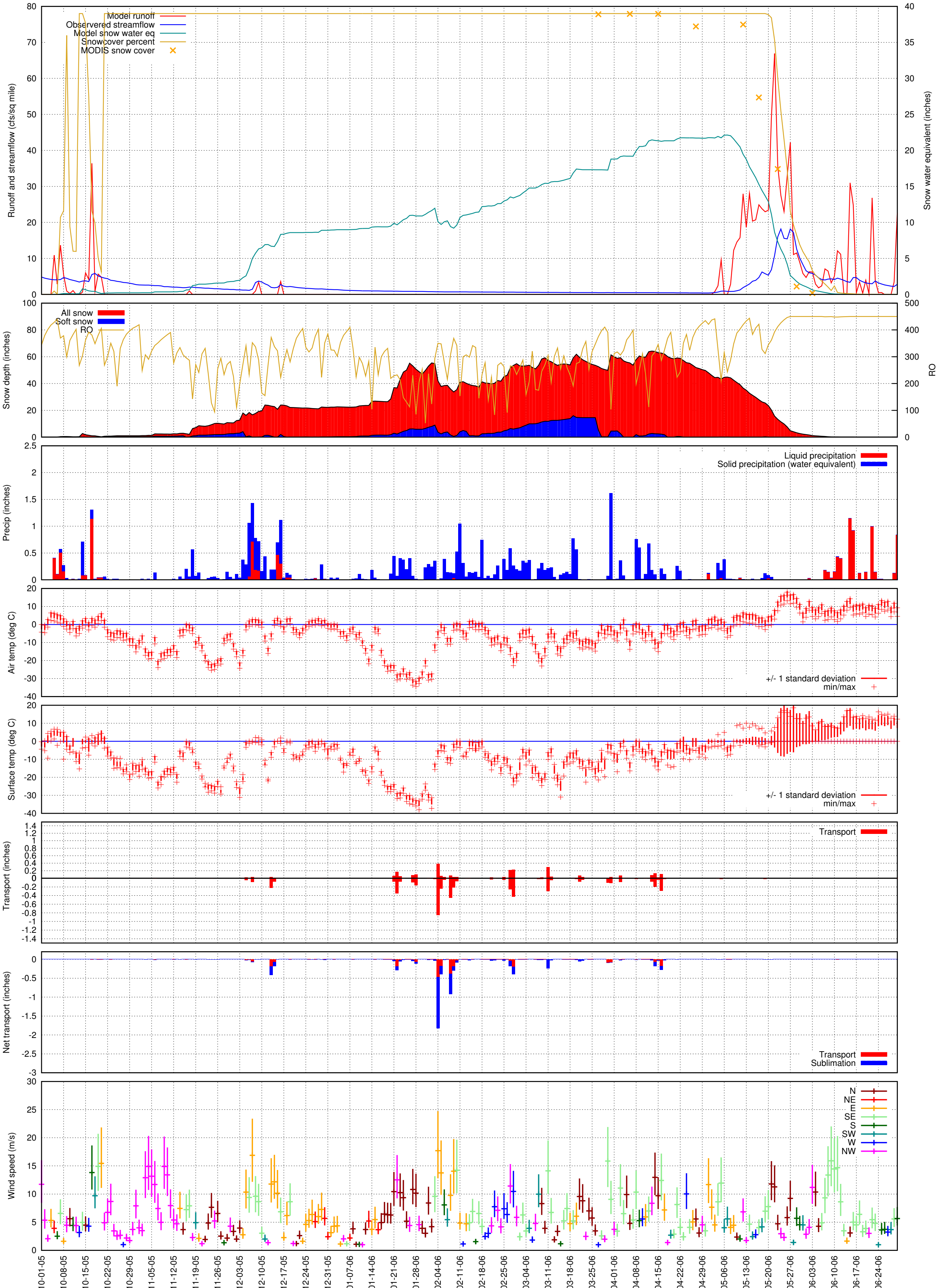
SnowModel Output Summary: 384-foot cells, hourly timestep, precipitation factor 2.0
Basin SK100A, 2007-2008



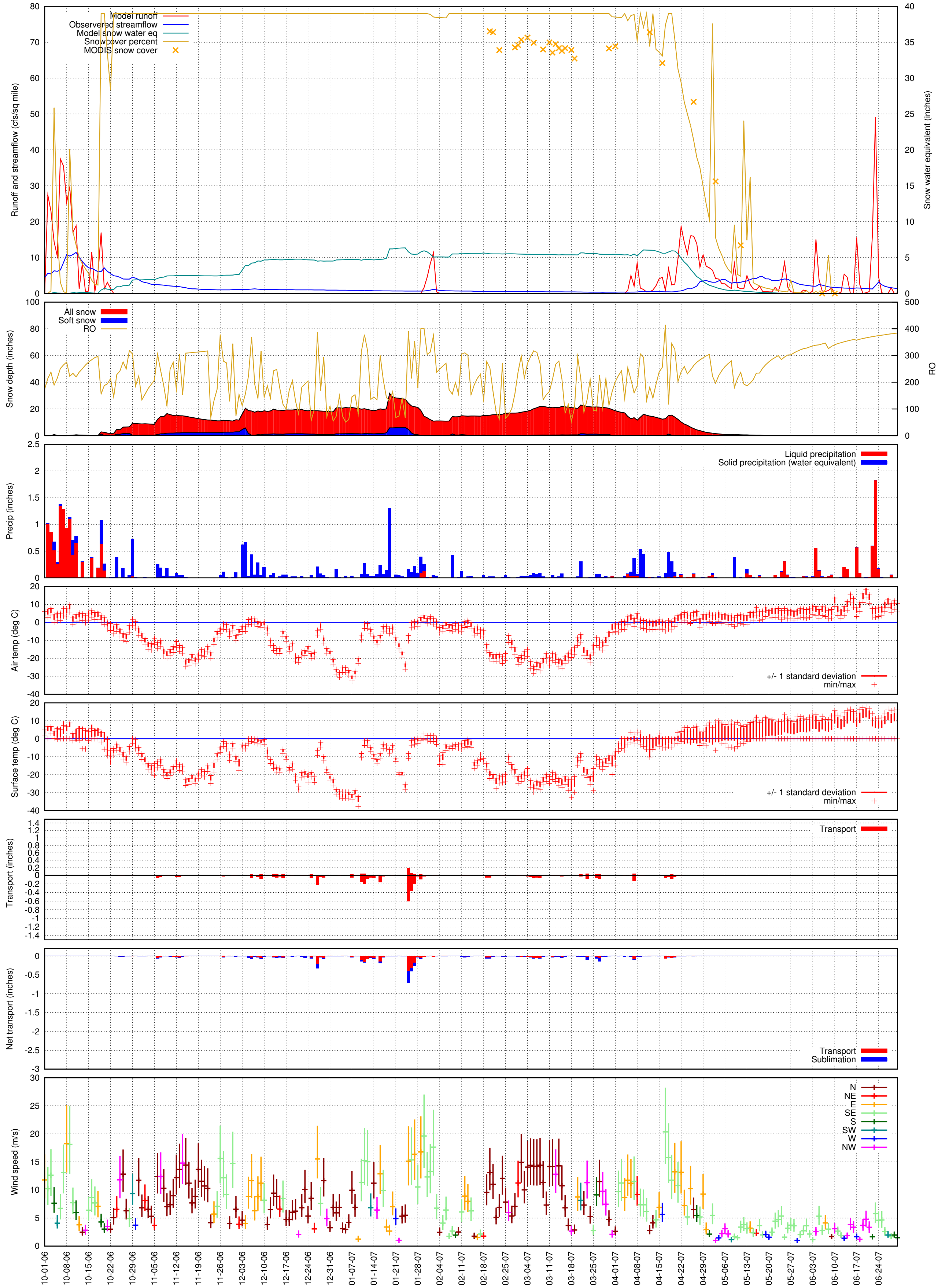
SnowModel Output Summary: 384-foot cells, hourly timestep, precipitation factor 2.0
Basin SK100A, Water Balance Summary, 2005-2008



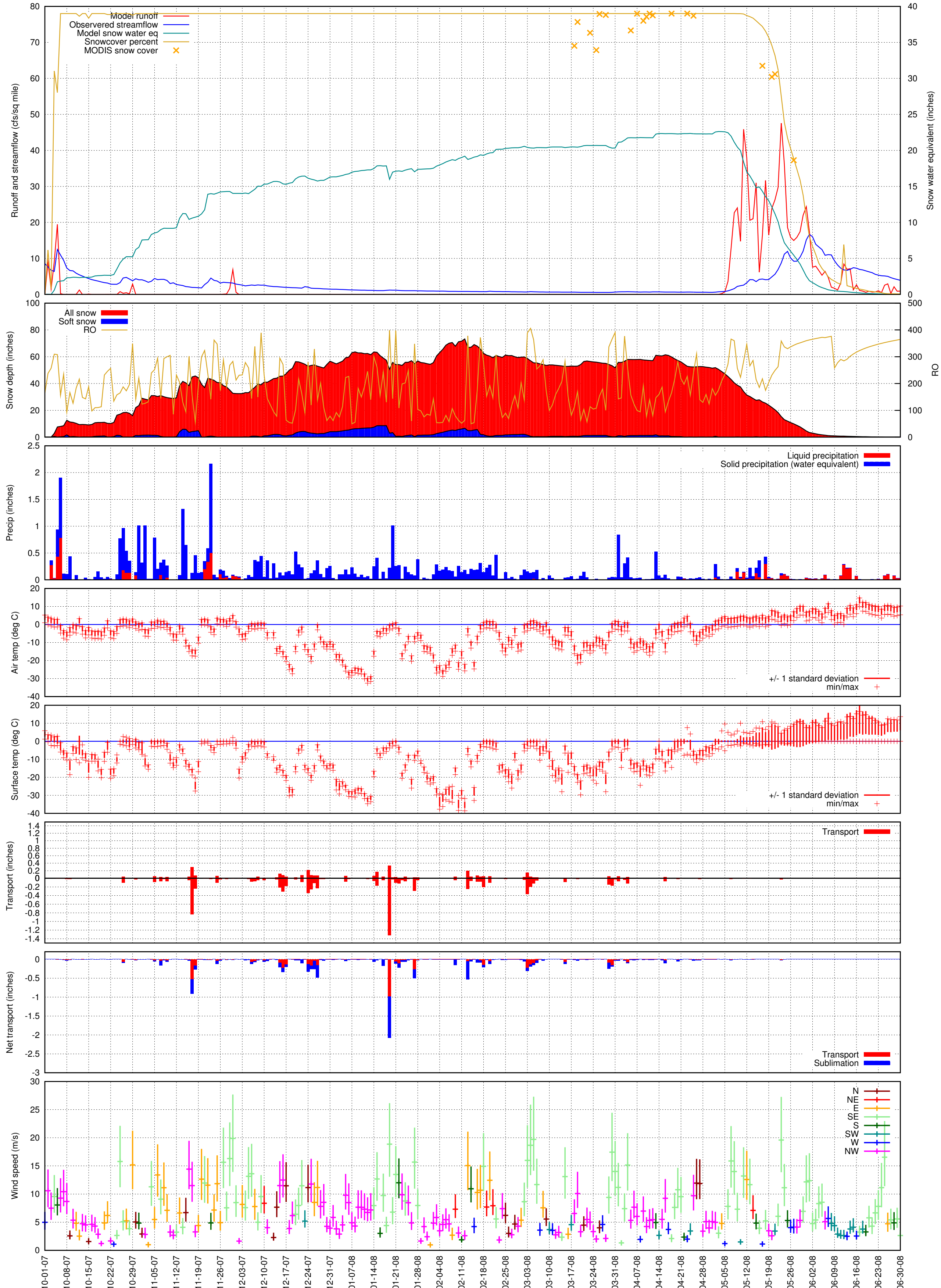
SnowModel Output Summary: 384-foot cells, hourly timestep, precipitation factor 2.0
Basin SK100B, 2005-2006



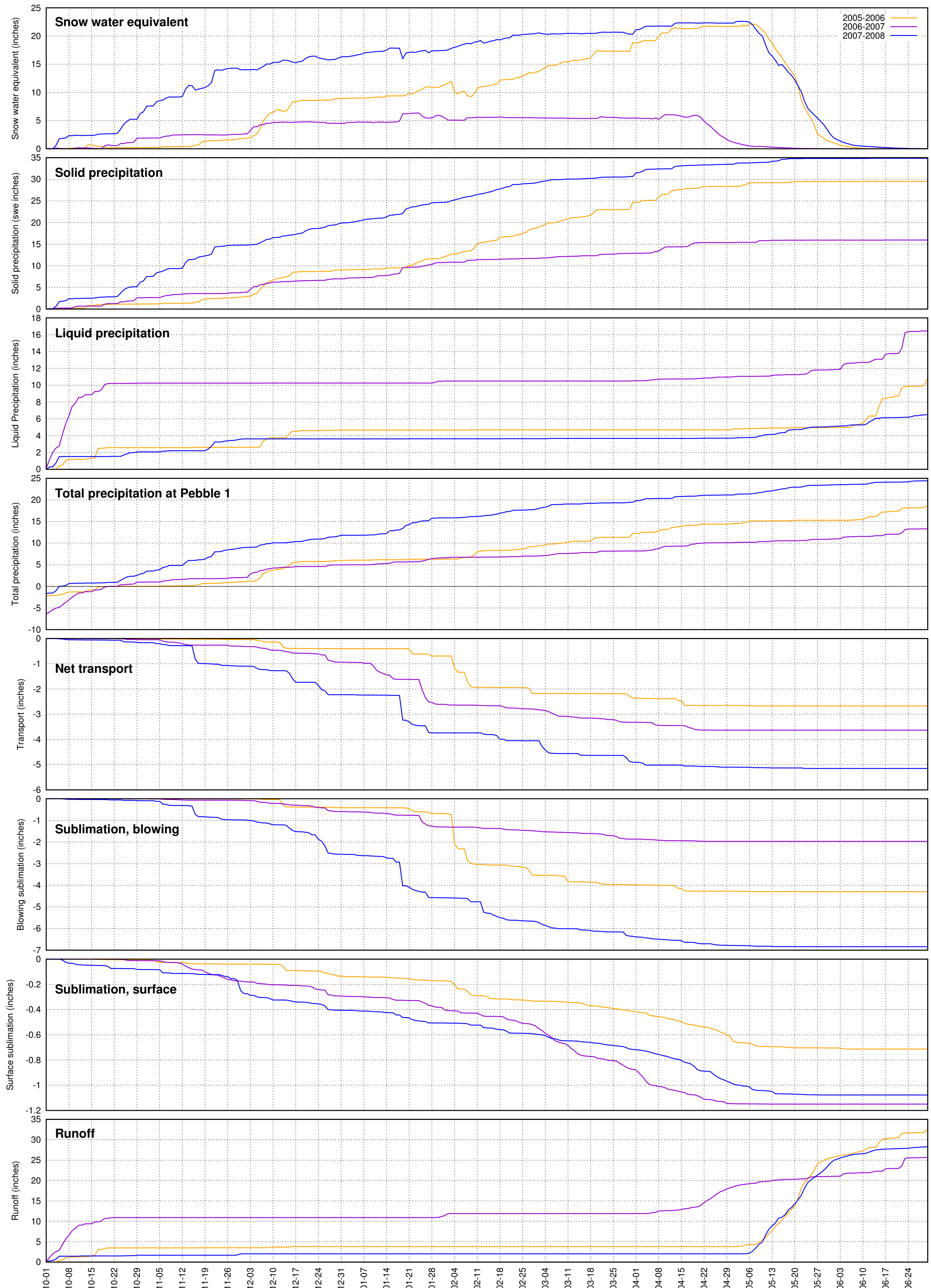
SnowModel Output Summary: 384-foot cells, hourly timestep, precipitation factor 2.0
Basin SK100B, 2006-2007



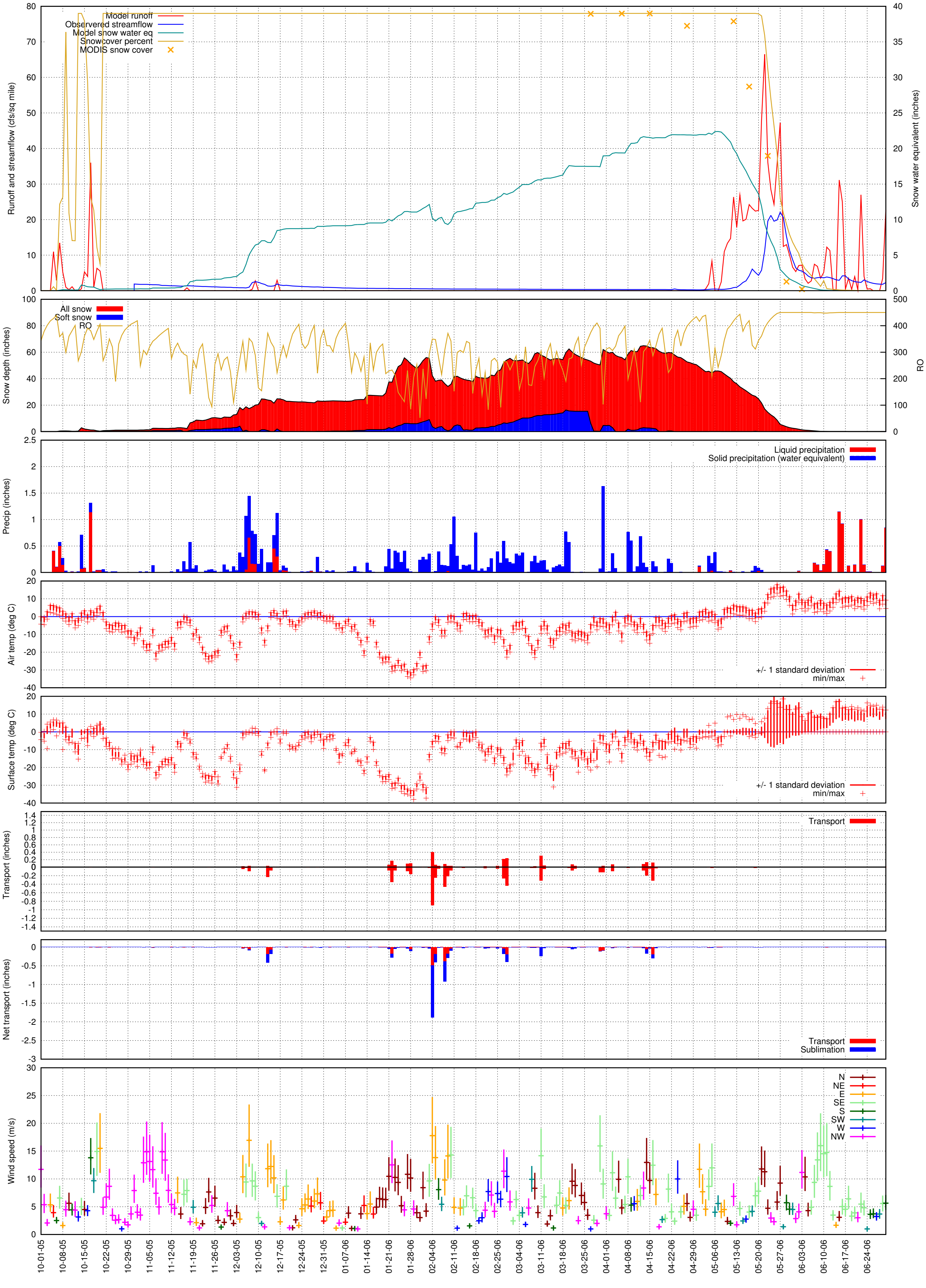
SnowModel Output Summary: 384-foot cells, hourly timestep, precipitation factor 2.0
Basin SK100B, 2007-2008



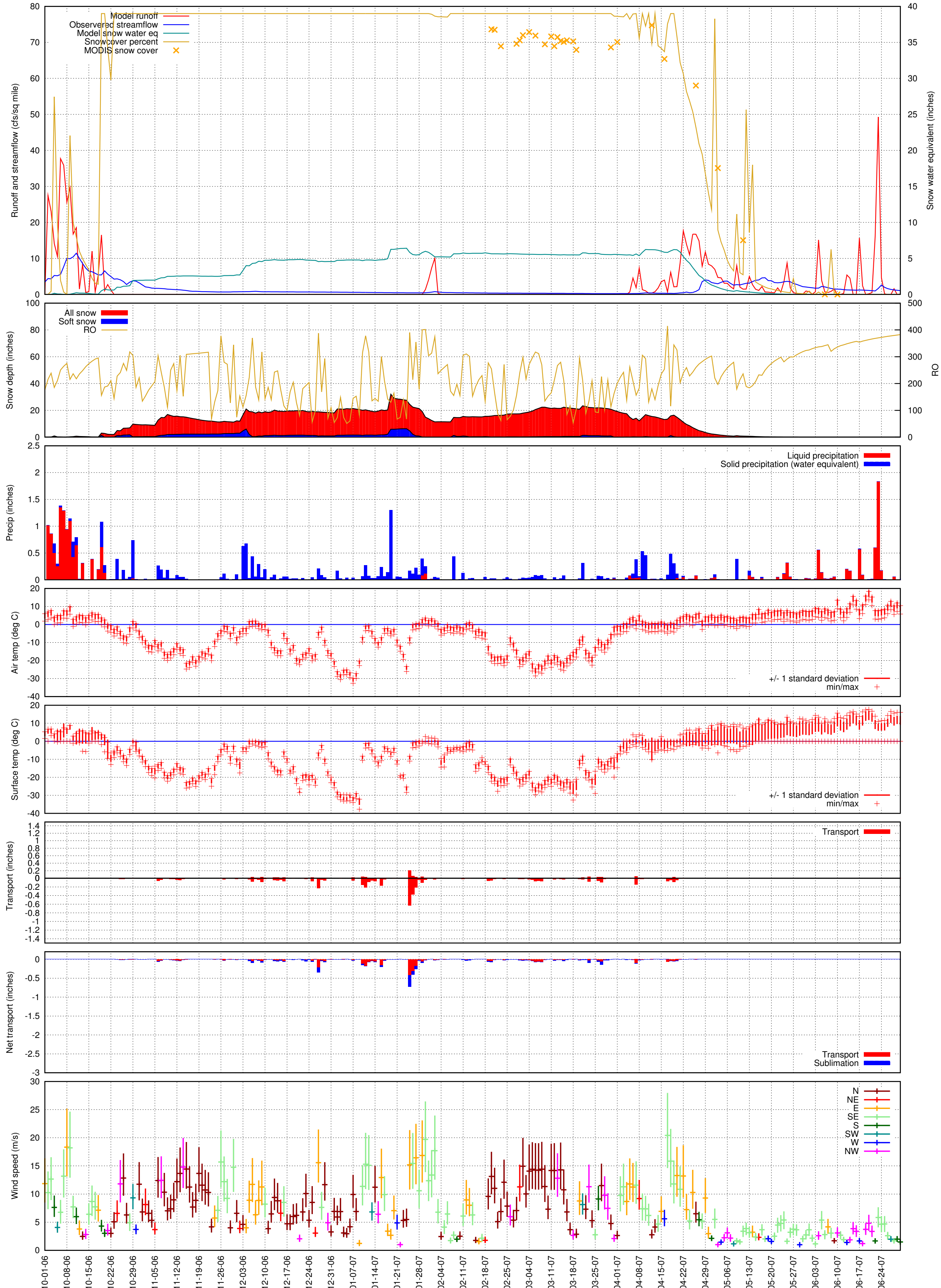
SnowModel Output Summary: 384-foot cells, hourly timestep, precipitation factor 2.0
Basin SK100B, Water Balance Summary, 2005-2008



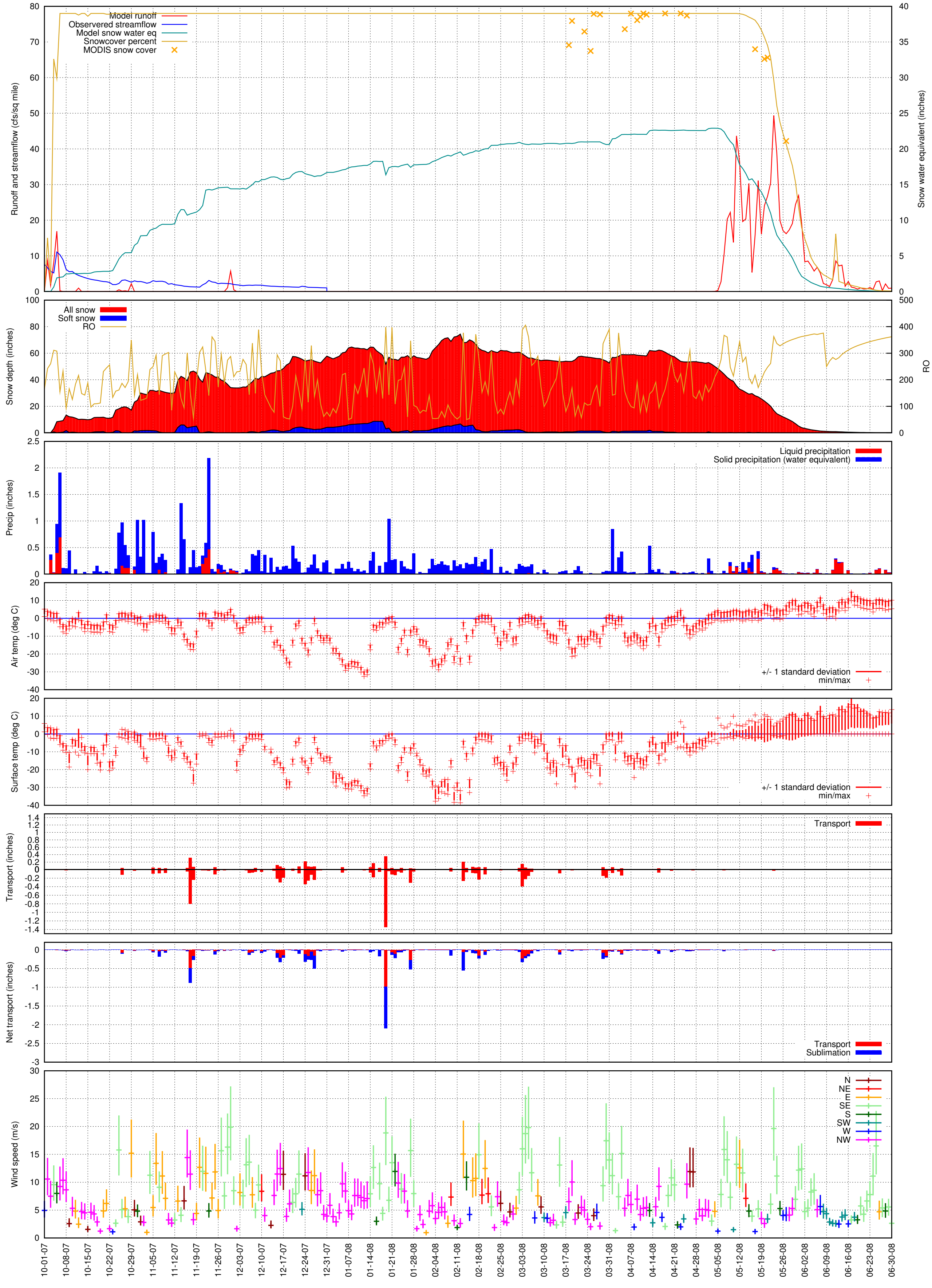
SnowModel Output Summary: 384-foot cells, hourly timestep, precipitation factor 2.0
Basin SK100B1, 2005-2006



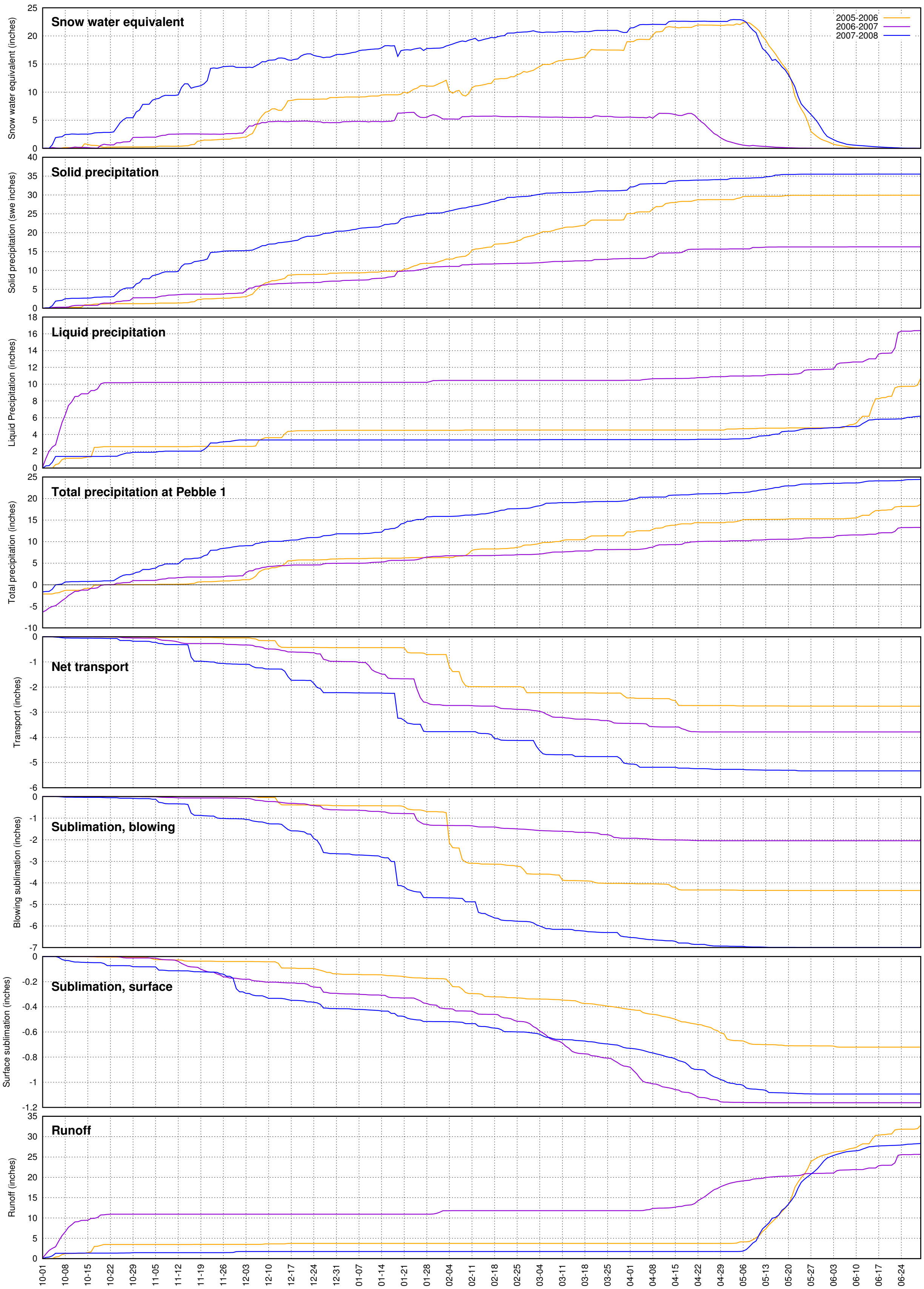
SnowModel Output Summary: 384-foot cells, hourly timestep, precipitation factor 2.0
Basin SK100B1, 2006-2007



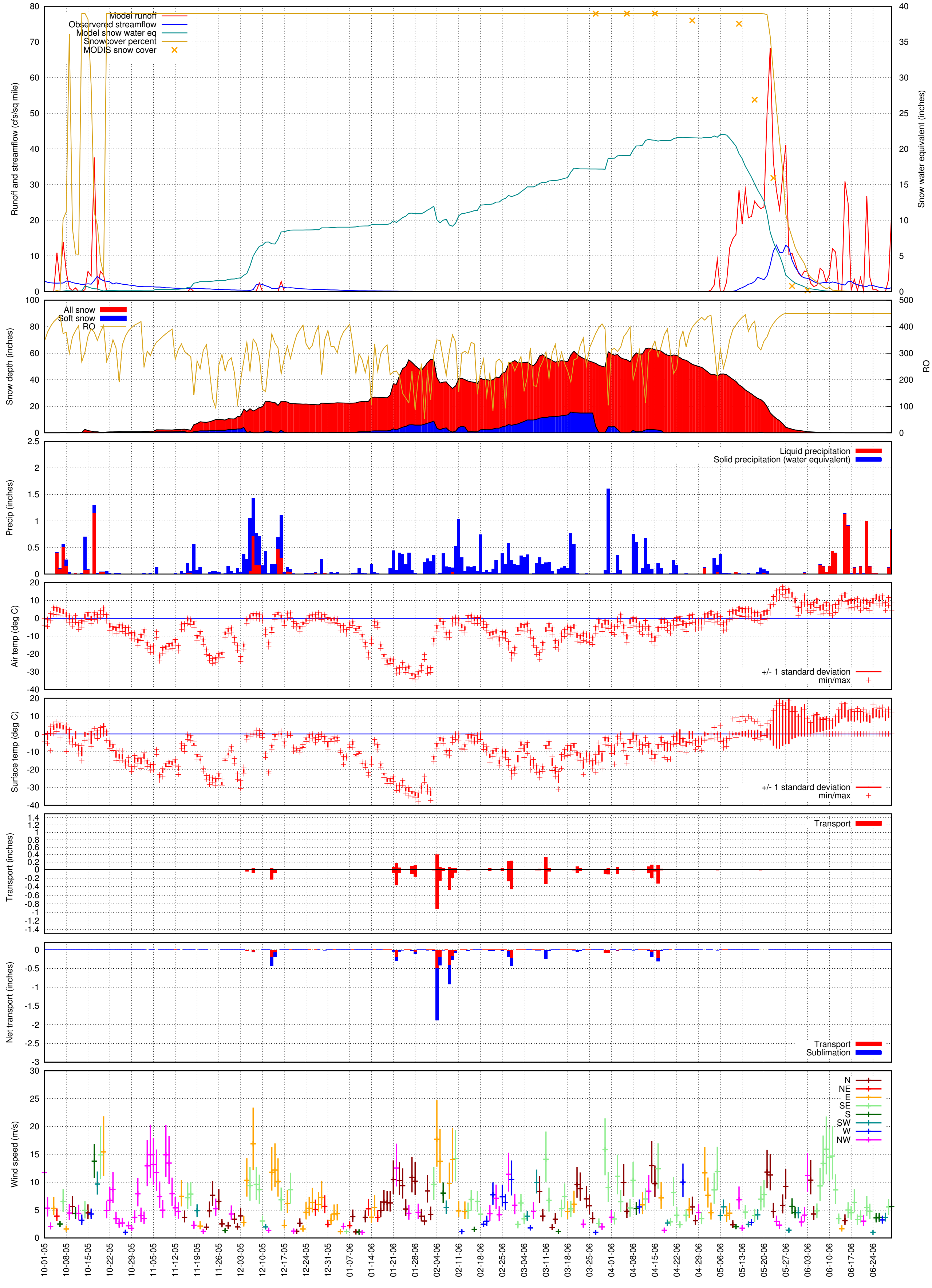
SnowModel Output Summary: 384-foot cells, hourly timestep, precipitation factor 2.0
Basin SK100B1, 2007-2008



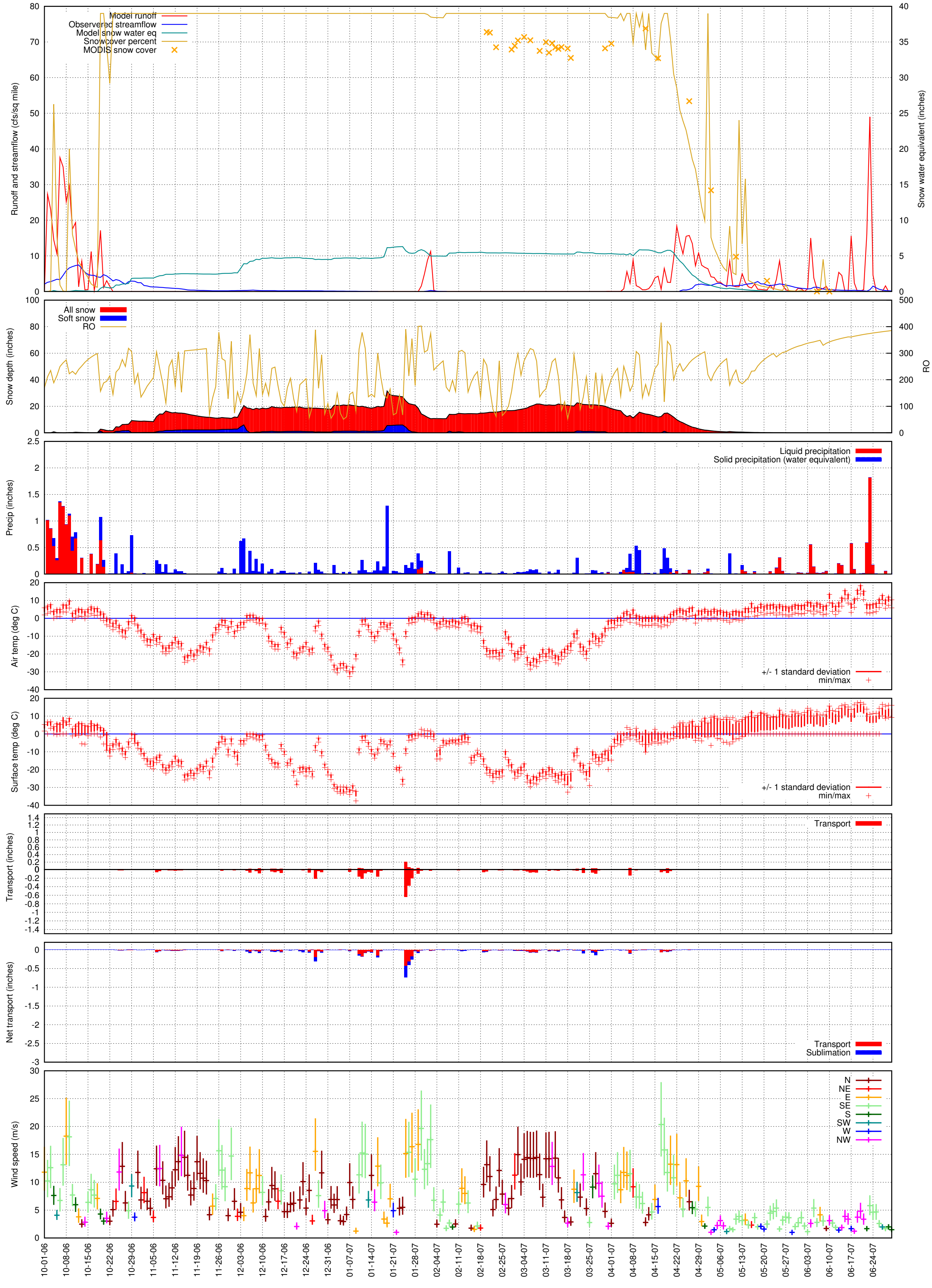
SnowModel Output Summary: 384-foot cells, hourly timestep, precipitation factor 2.0
Basin SK100B1, Water Balance Summary, 2005-2008



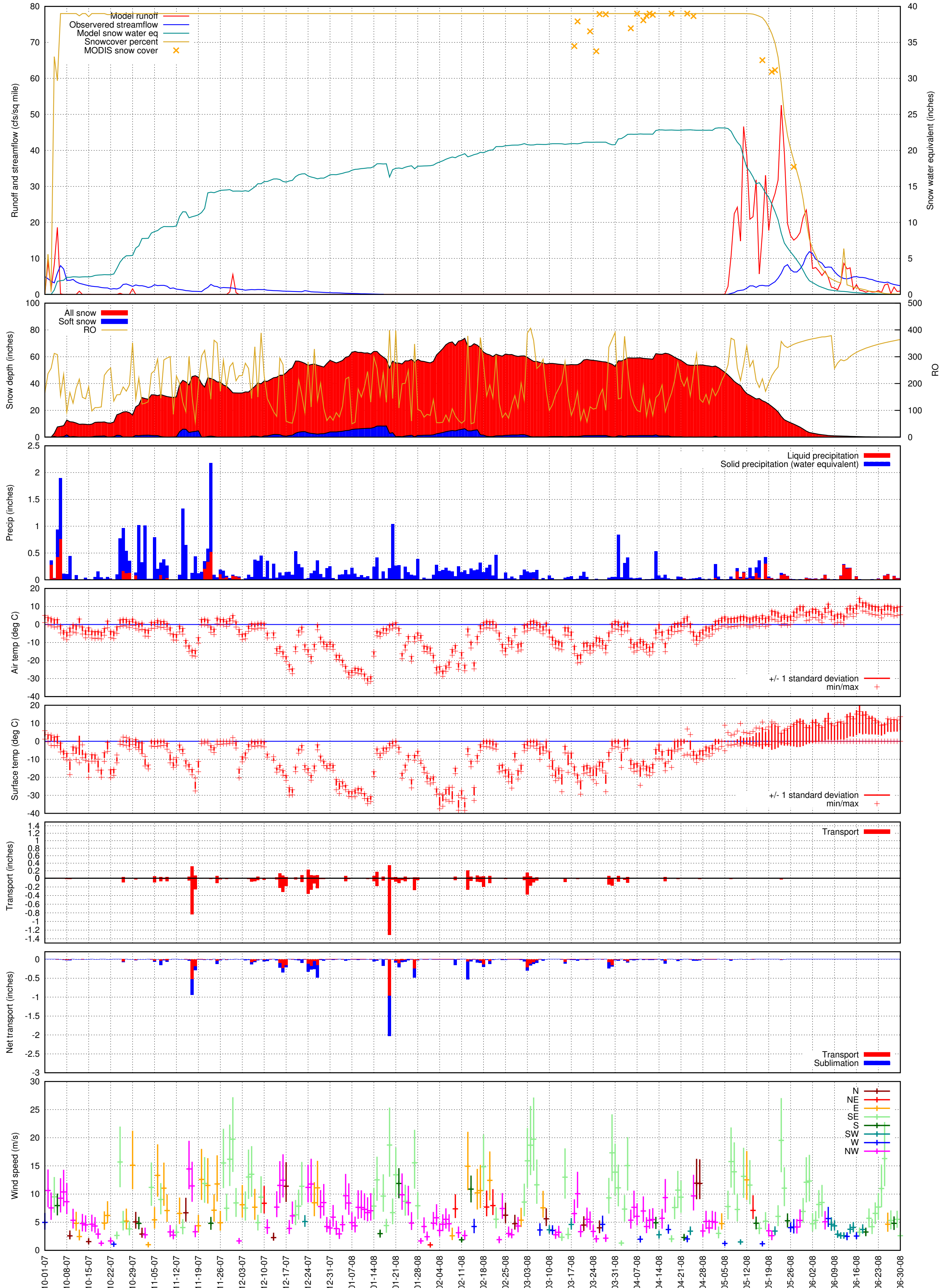
SnowModel Output Summary: 384-foot cells, hourly timestep, precipitation factor 2.0
Basin SK100C, 2005-2006



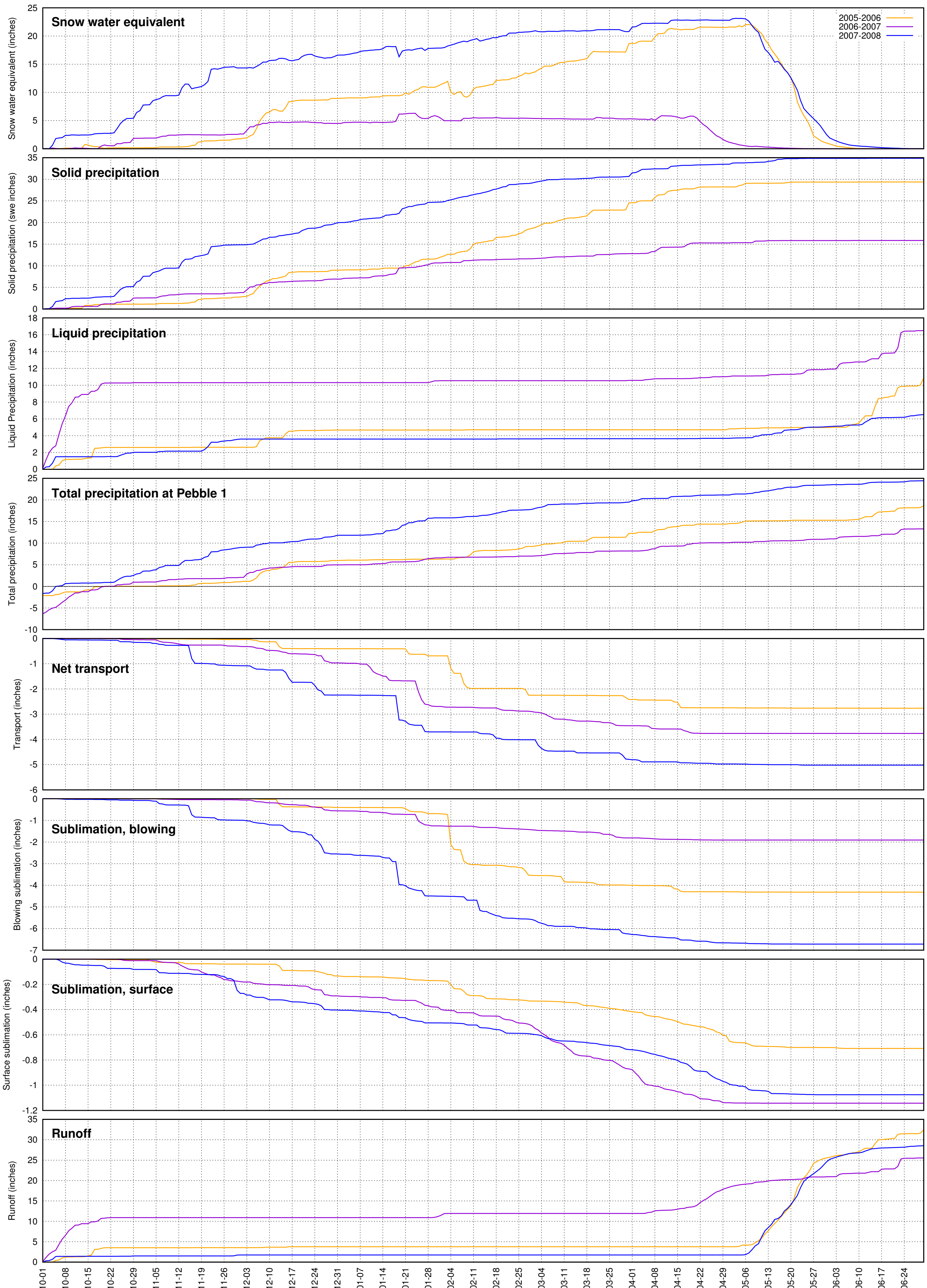
SnowModel Output Summary: 384-foot cells, hourly timestep, precipitation factor 2.0
Basin SK100C, 2006-2007



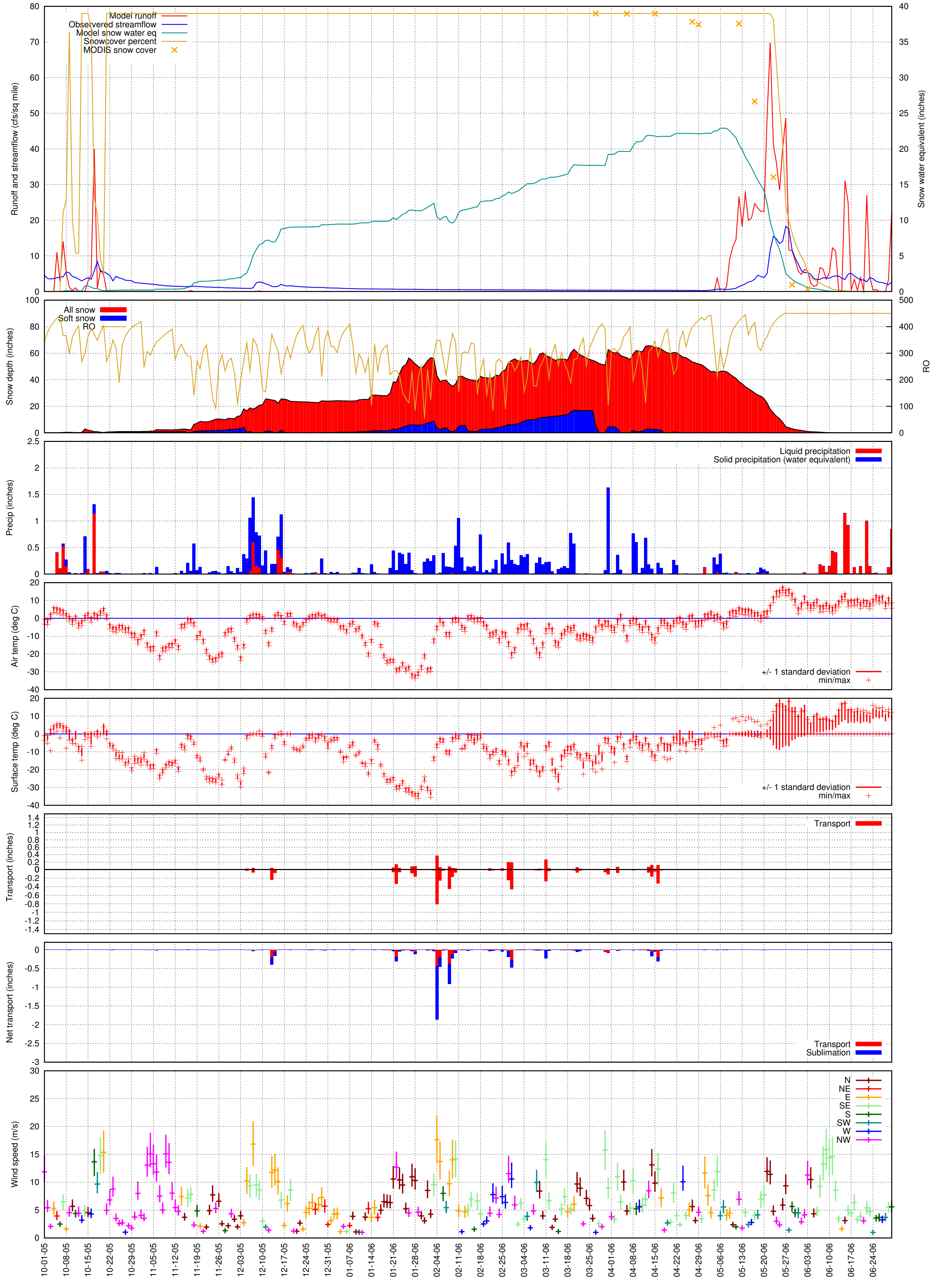
SnowModel Output Summary: 384-foot cells, hourly timestep, precipitation factor 2.0
Basin SK100C, 2007-2008



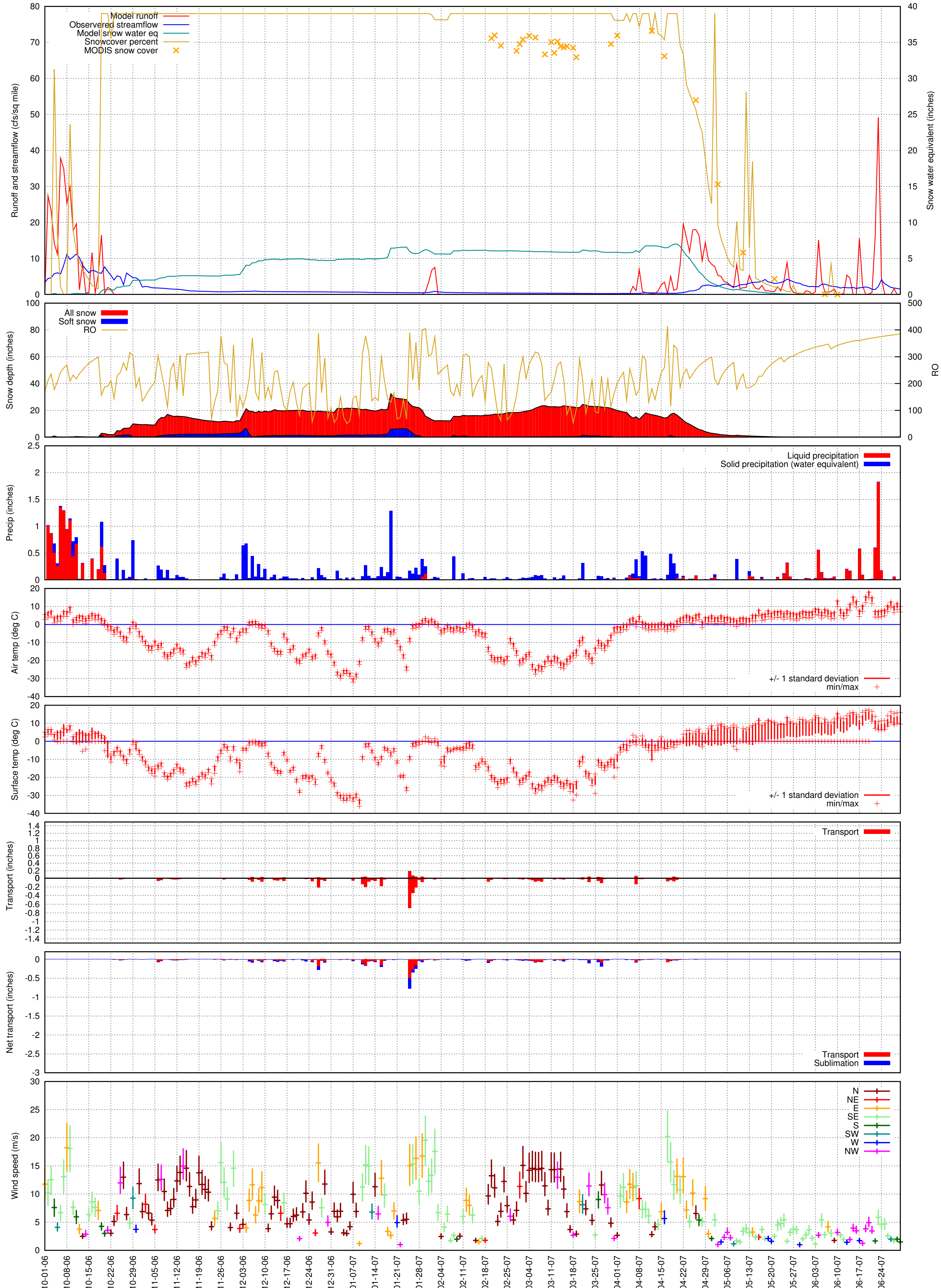
SnowModel Output Summary: 384-foot cells, hourly timestep, precipitation factor 2.0
Basin SK100C, Water Balance Summary, 2005-2008



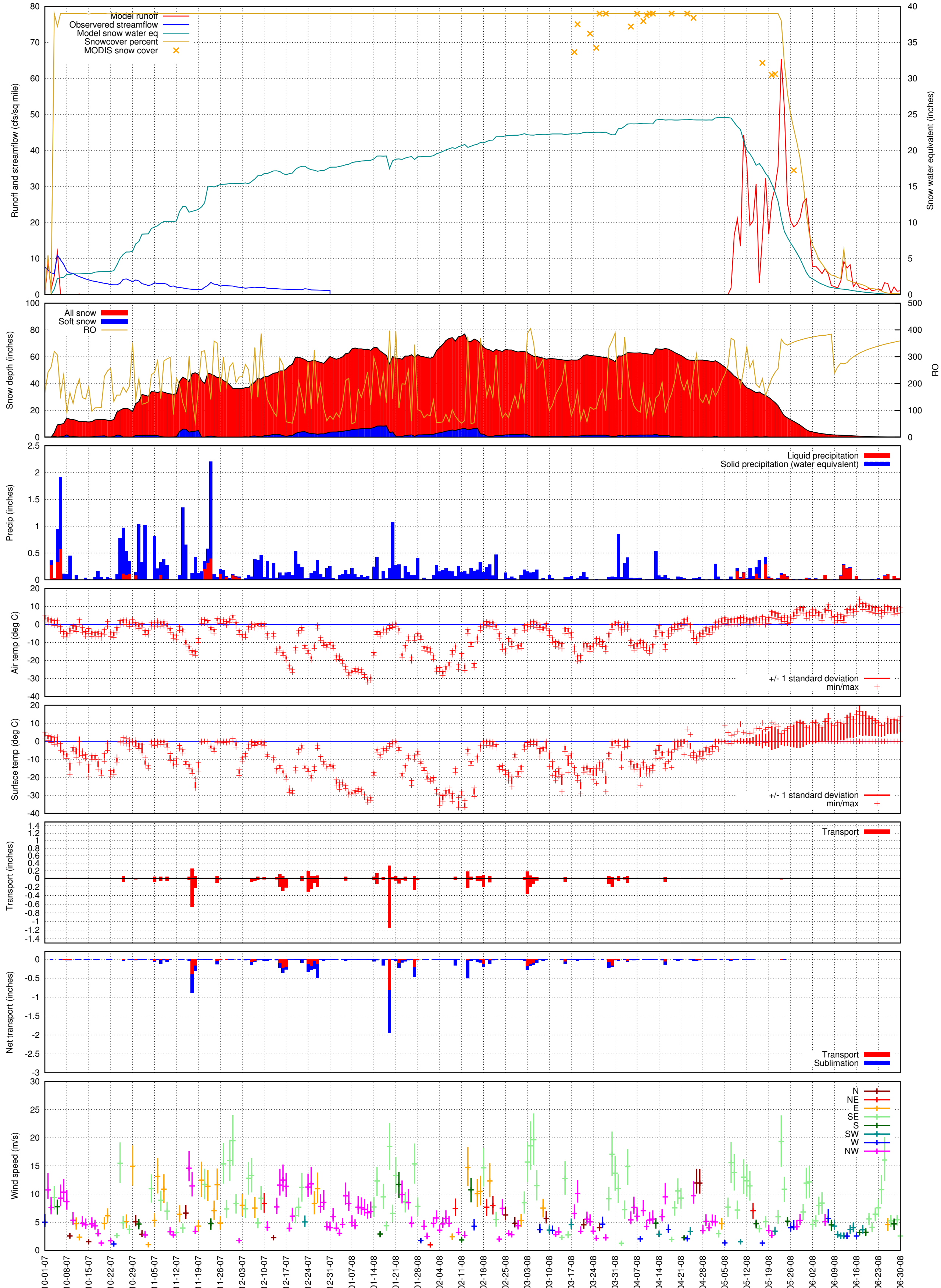
SnowModel Output Summary: 384-foot cells, hourly timestep, precipitation factor 2.0
Basin SK100F, 2005-2006



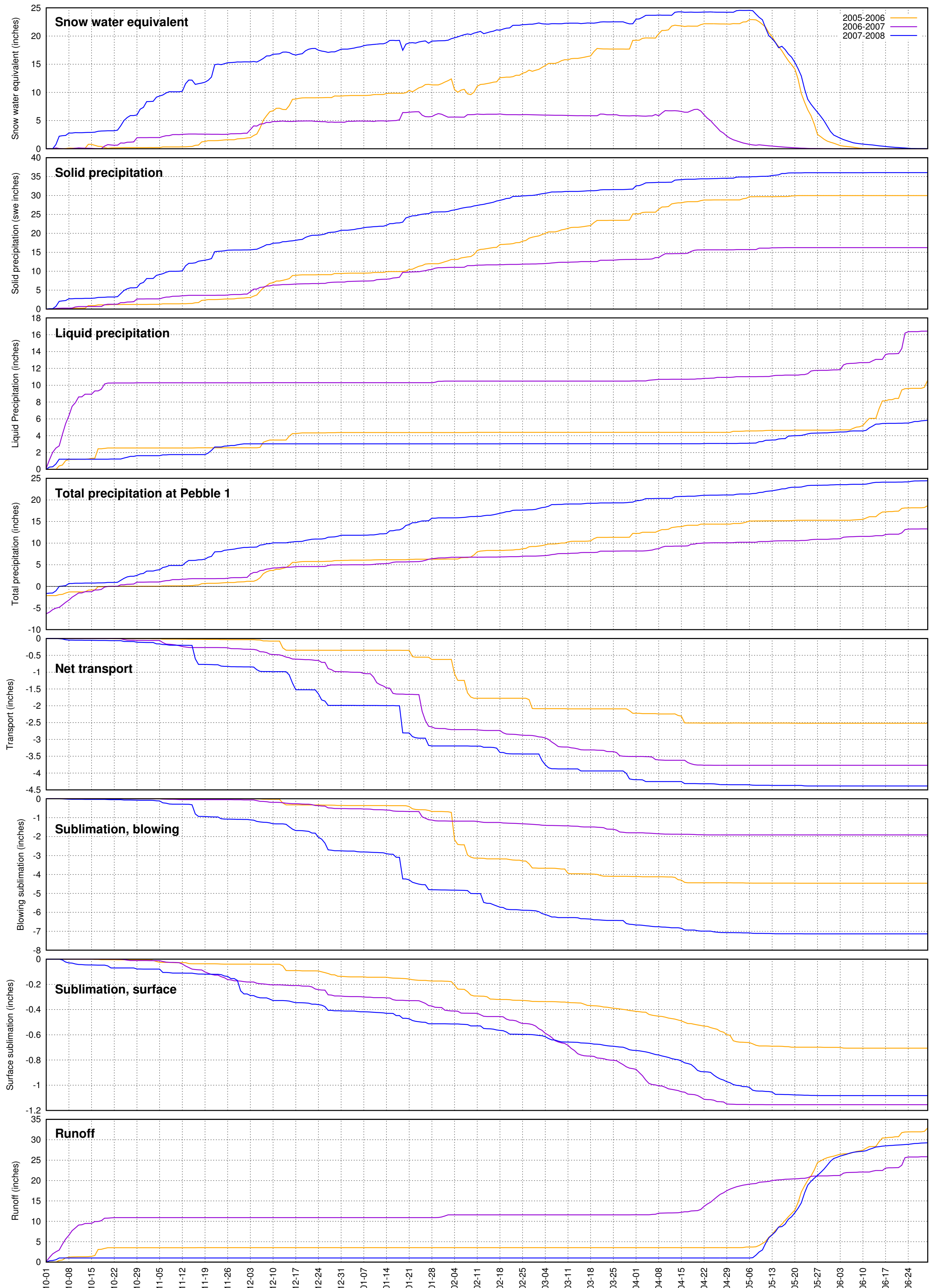
SnowModel Output Summary: 384-foot cells, hourly timestep, precipitation factor 2.0
Basin SK100F, 2006-2007



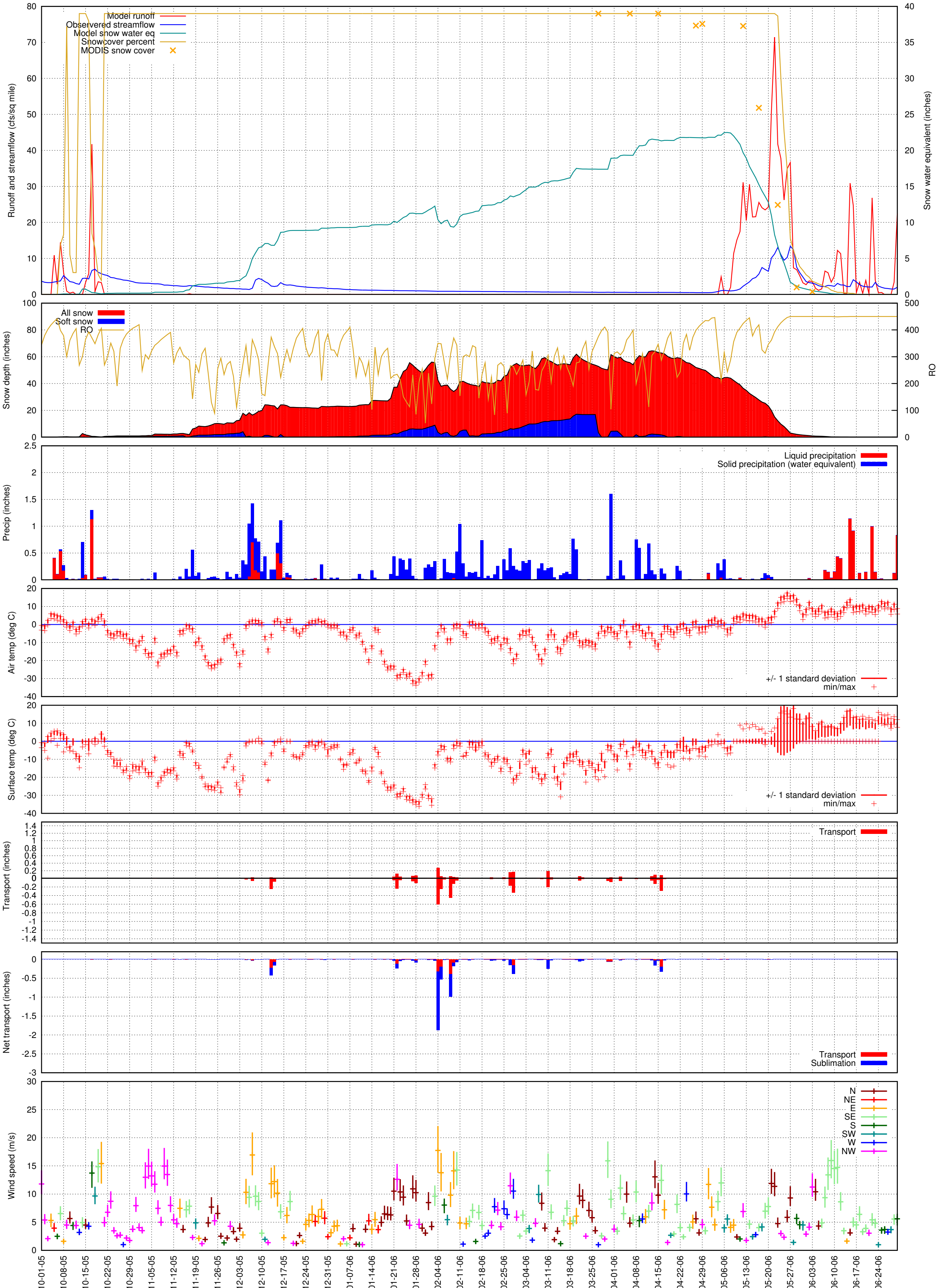
SnowModel Output Summary: 384-foot cells, hourly timestep, precipitation factor 2.0
Basin SK100F, 2007-2008



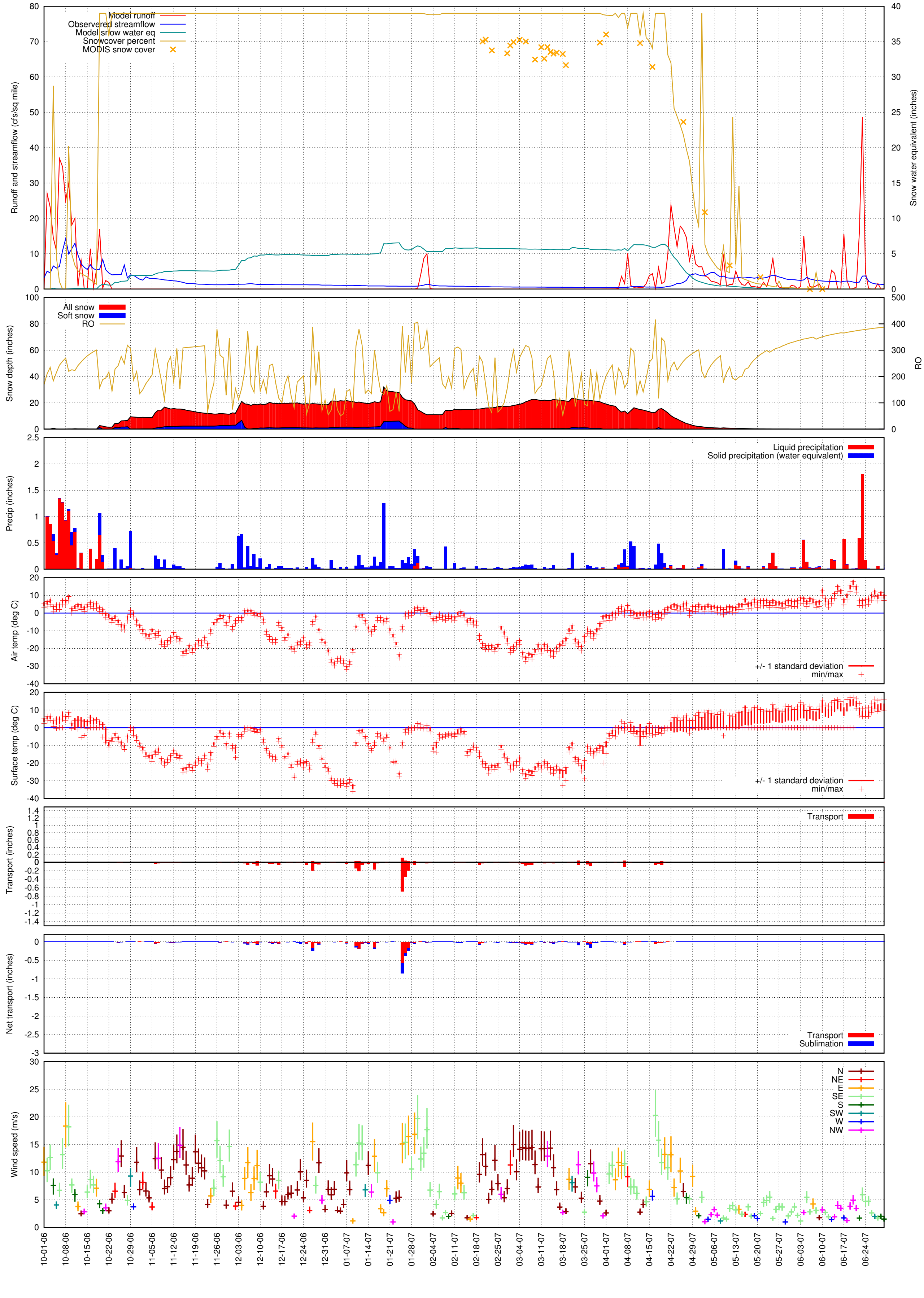
SnowModel Output Summary: 384-foot cells, hourly timestep, precipitation factor 2.0
Basin SK100F, Water Balance Summary, 2005-2008



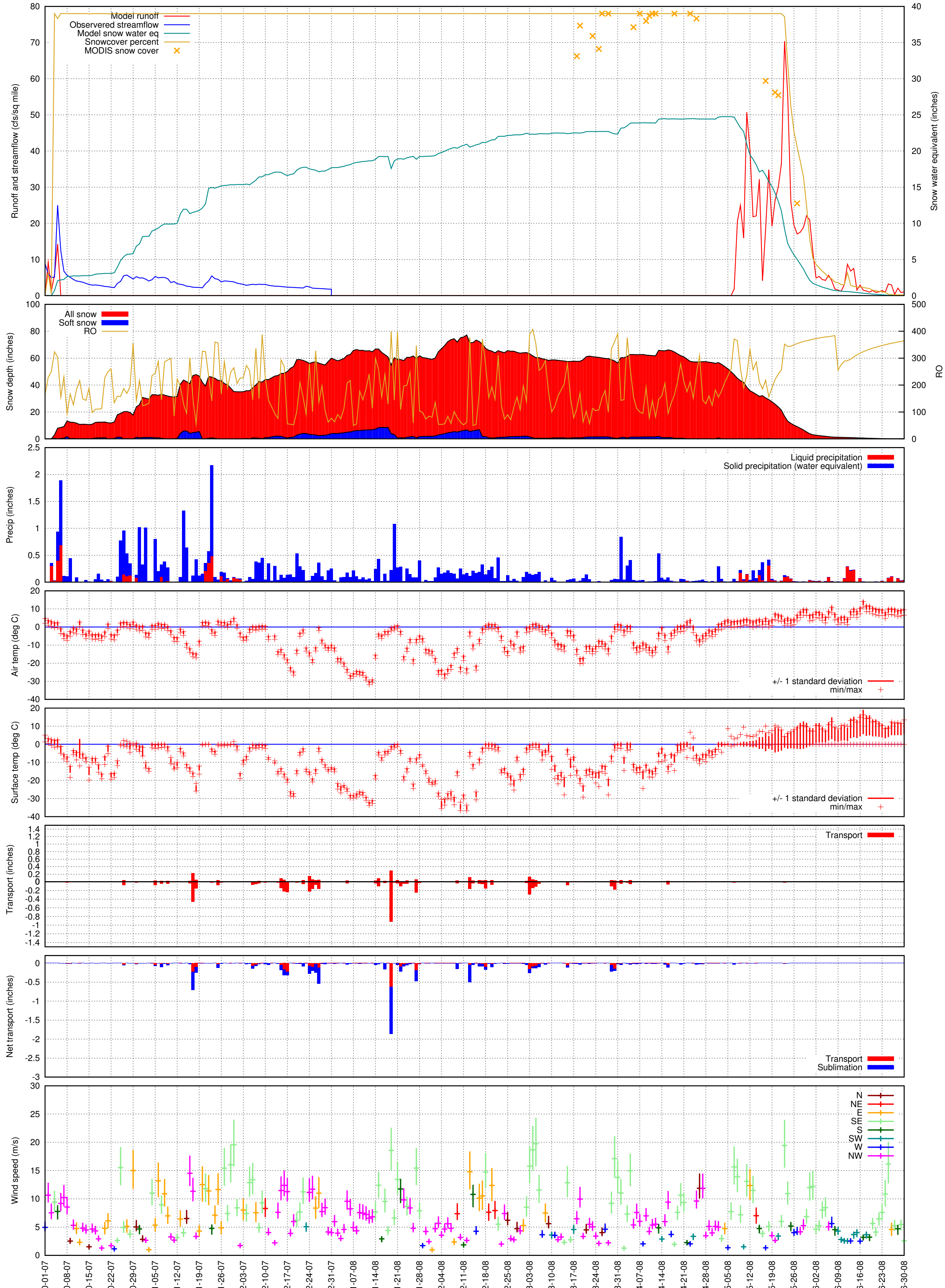
SnowModel Output Summary: 384-foot cells, hourly timestep, precipitation factor 2.0
Basin SK100G, 2005-2006



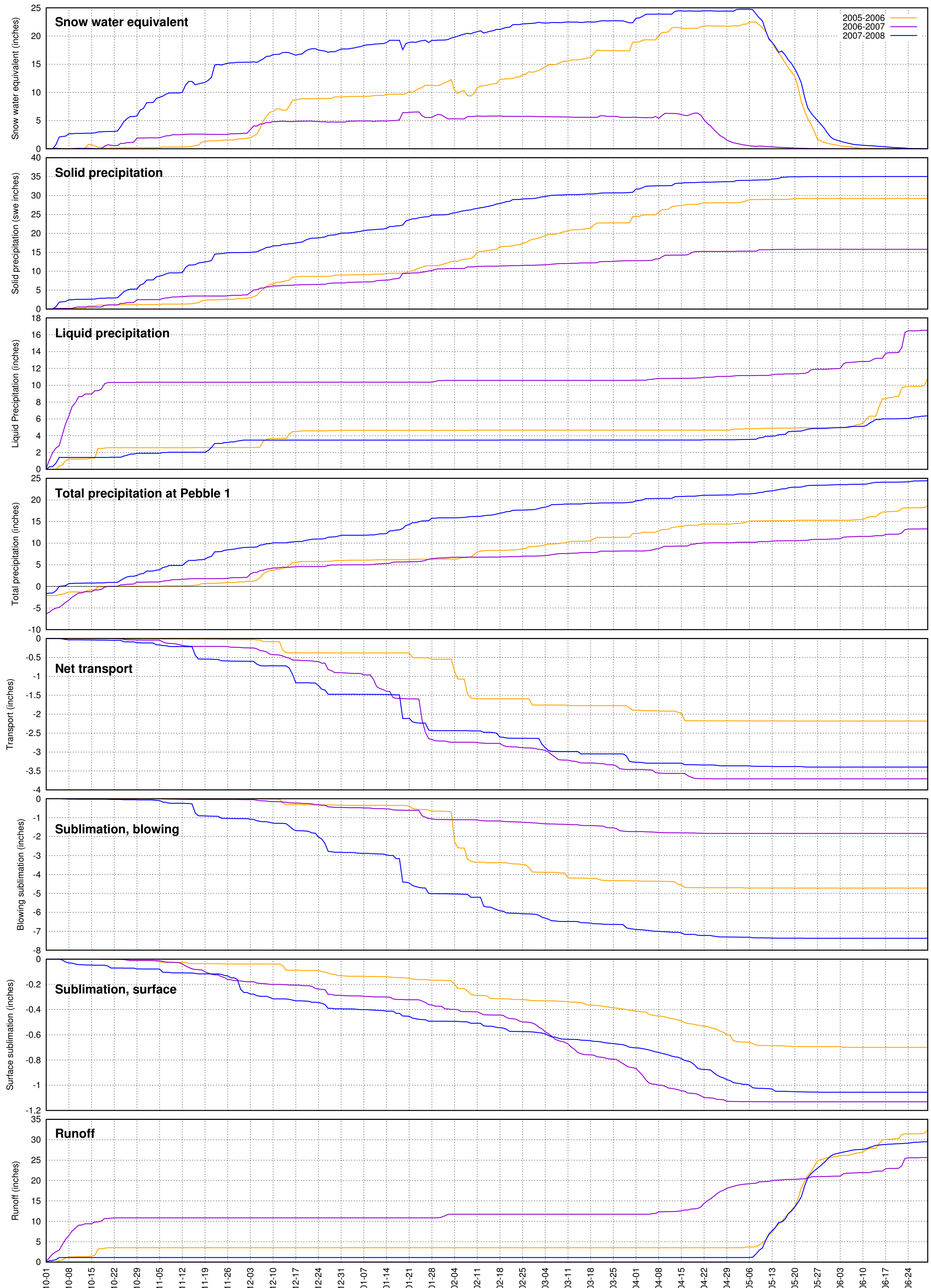
SnowModel Output Summary: 384-foot cells, hourly timestep, precipitation factor 2.0
Basin SK100G, 2006-2007



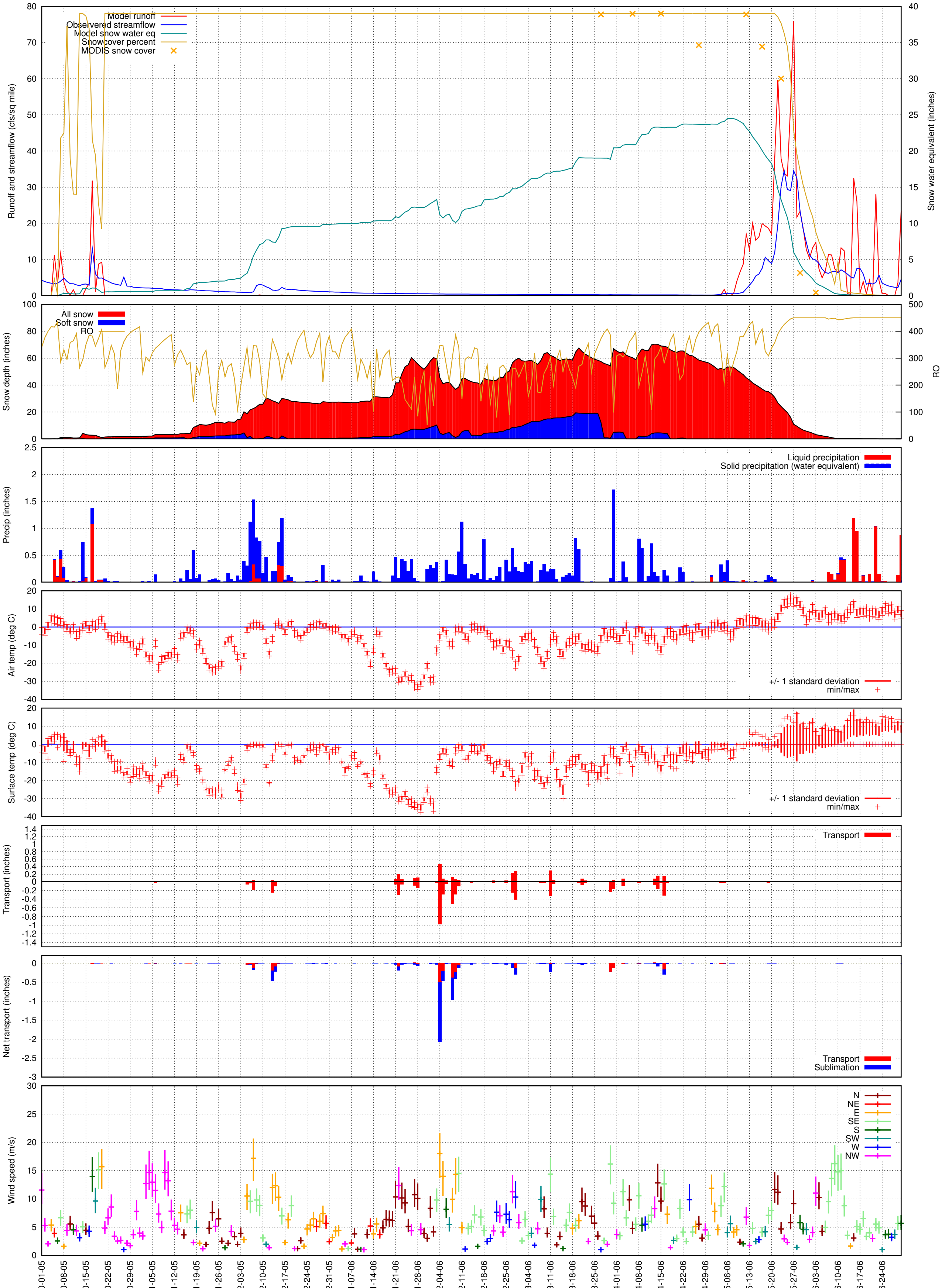
SnowModel Output Summary: 384-foot cells, hourly timestep, precipitation factor 2.0
Basin SK100G, 2007-2008



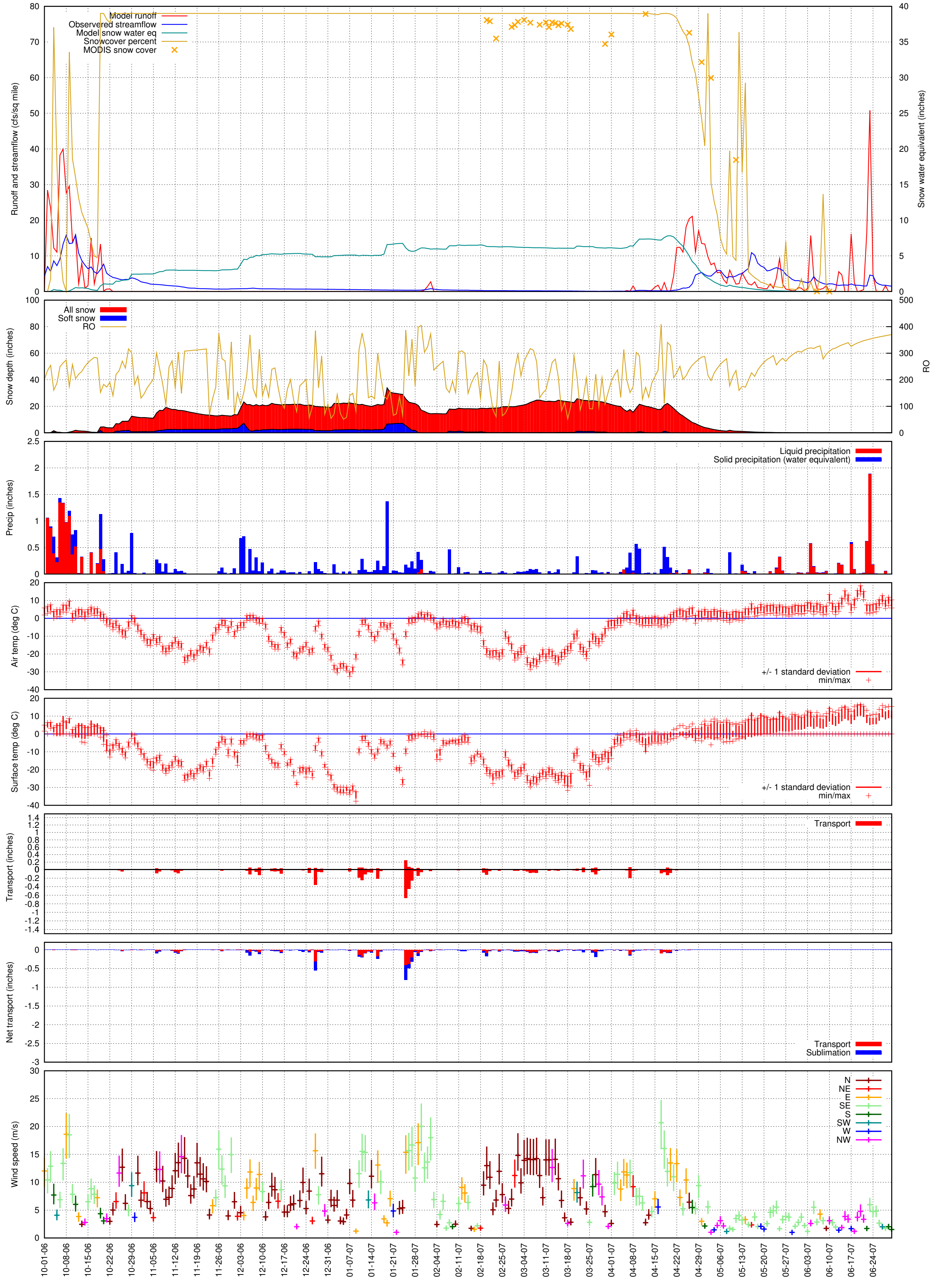
SnowModel Output Summary: 384-foot cells, hourly timestep, precipitation factor 2.0
Basin SK100G, Water Balance Summary, 2005-2008



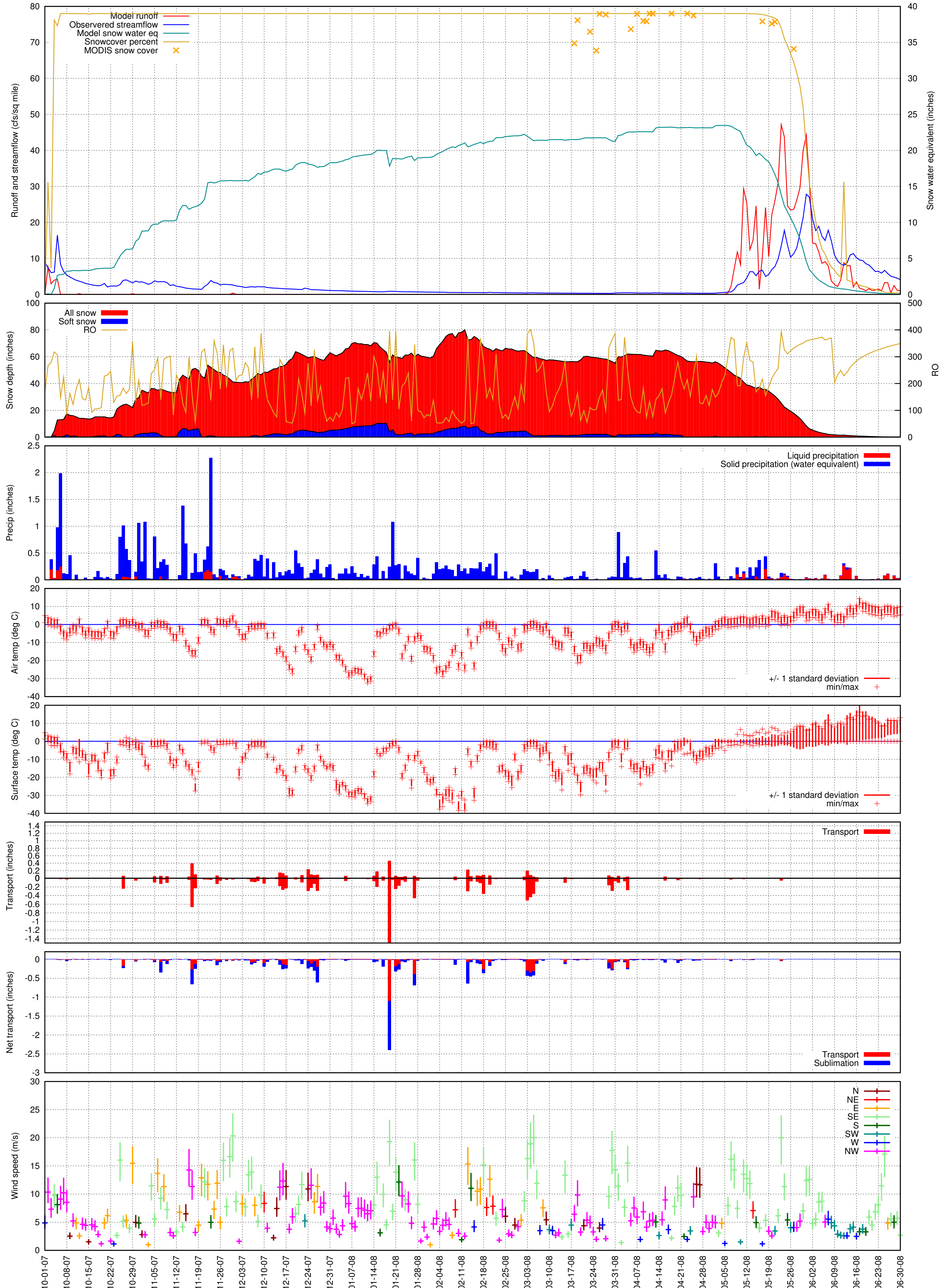
SnowModel Output Summary: 384-foot cells, hourly timestep, precipitation factor 2.0
Basin SK119A, 2005-2006



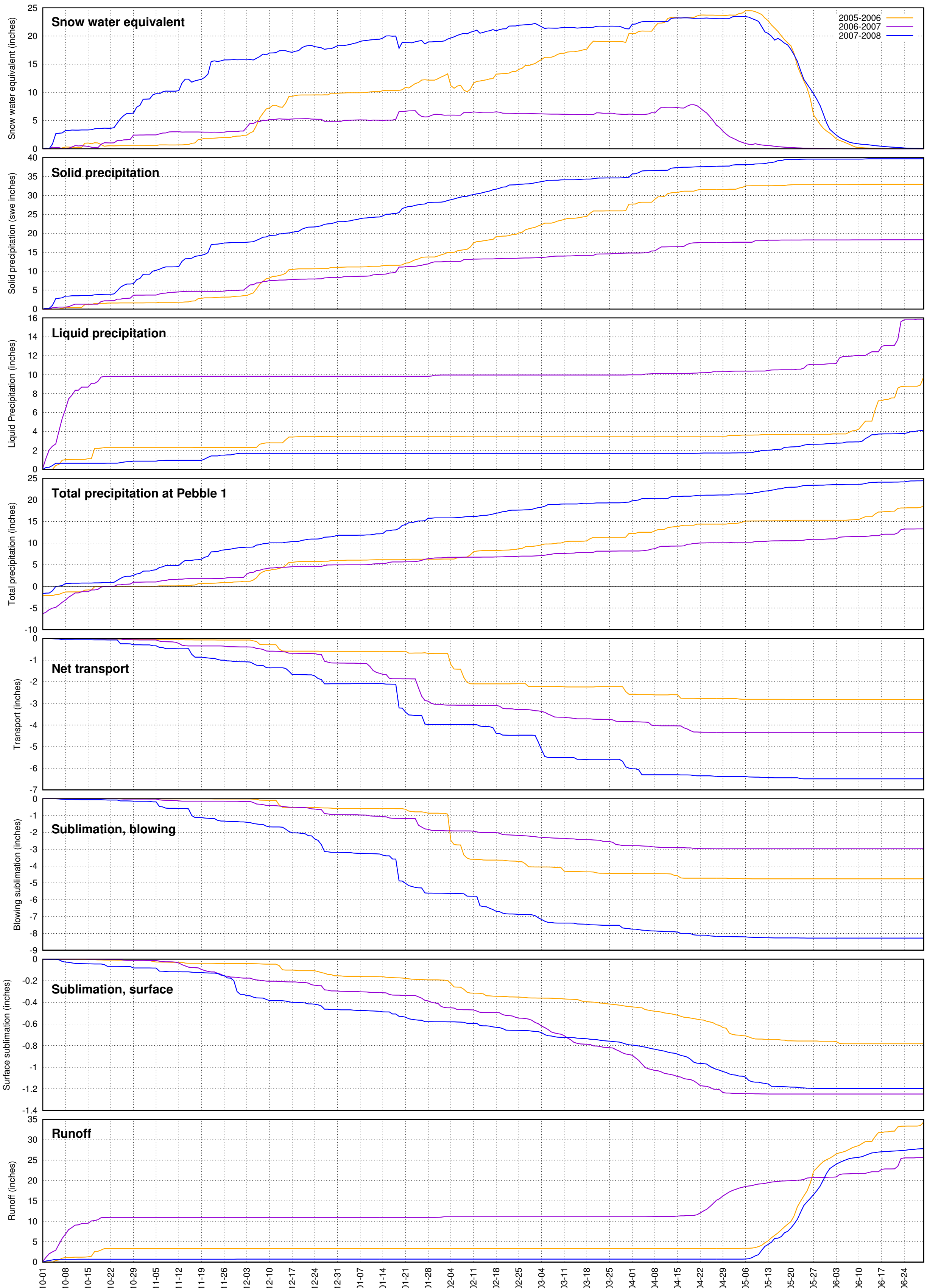
SnowModel Output Summary: 384-foot cells, hourly timestep, precipitation factor 2.0
Basin SK119A, 2006-2007



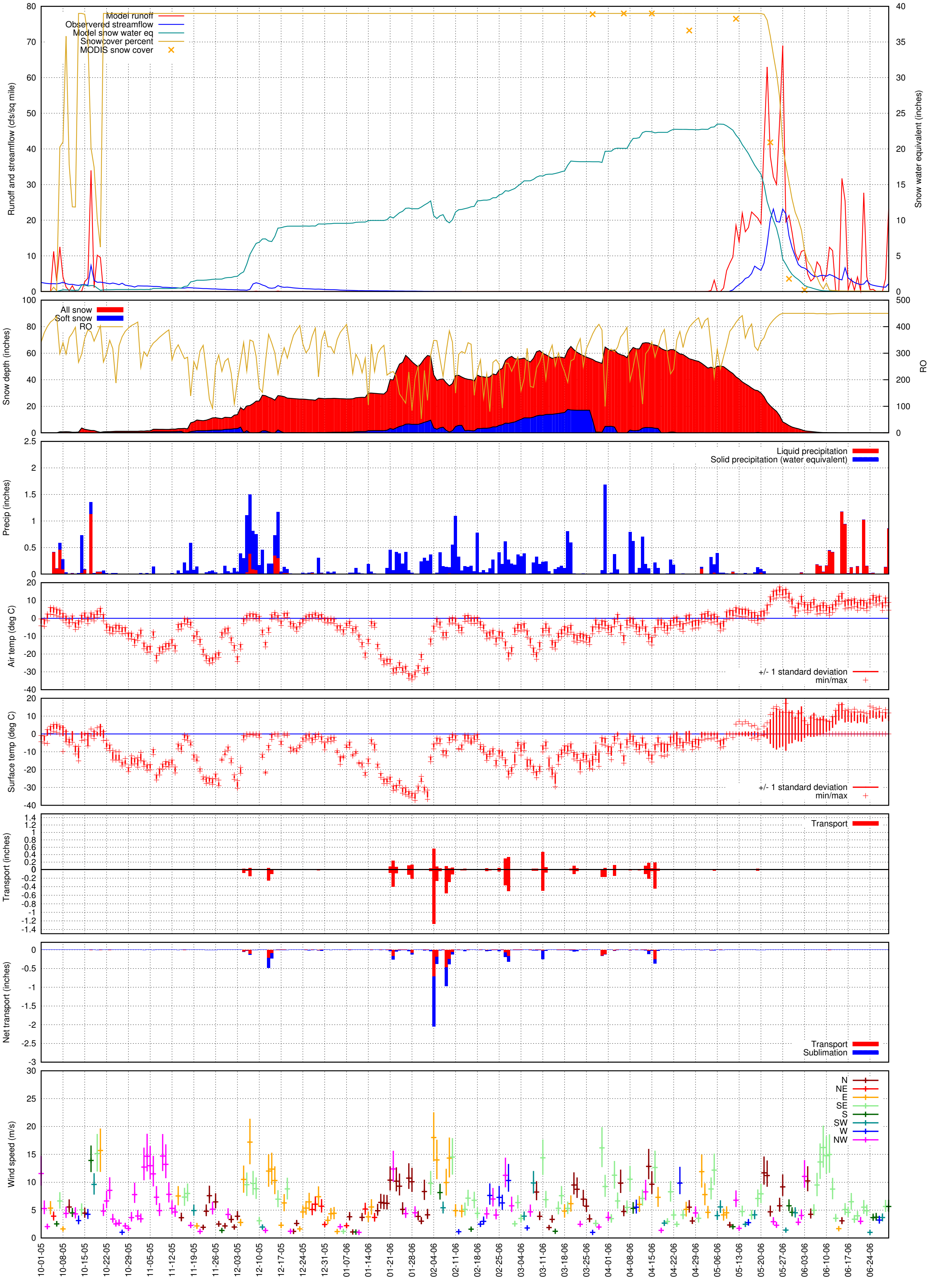
SnowModel Output Summary: 384-foot cells, hourly timestep, precipitation factor 2.0
Basin SK119A, 2007-2008



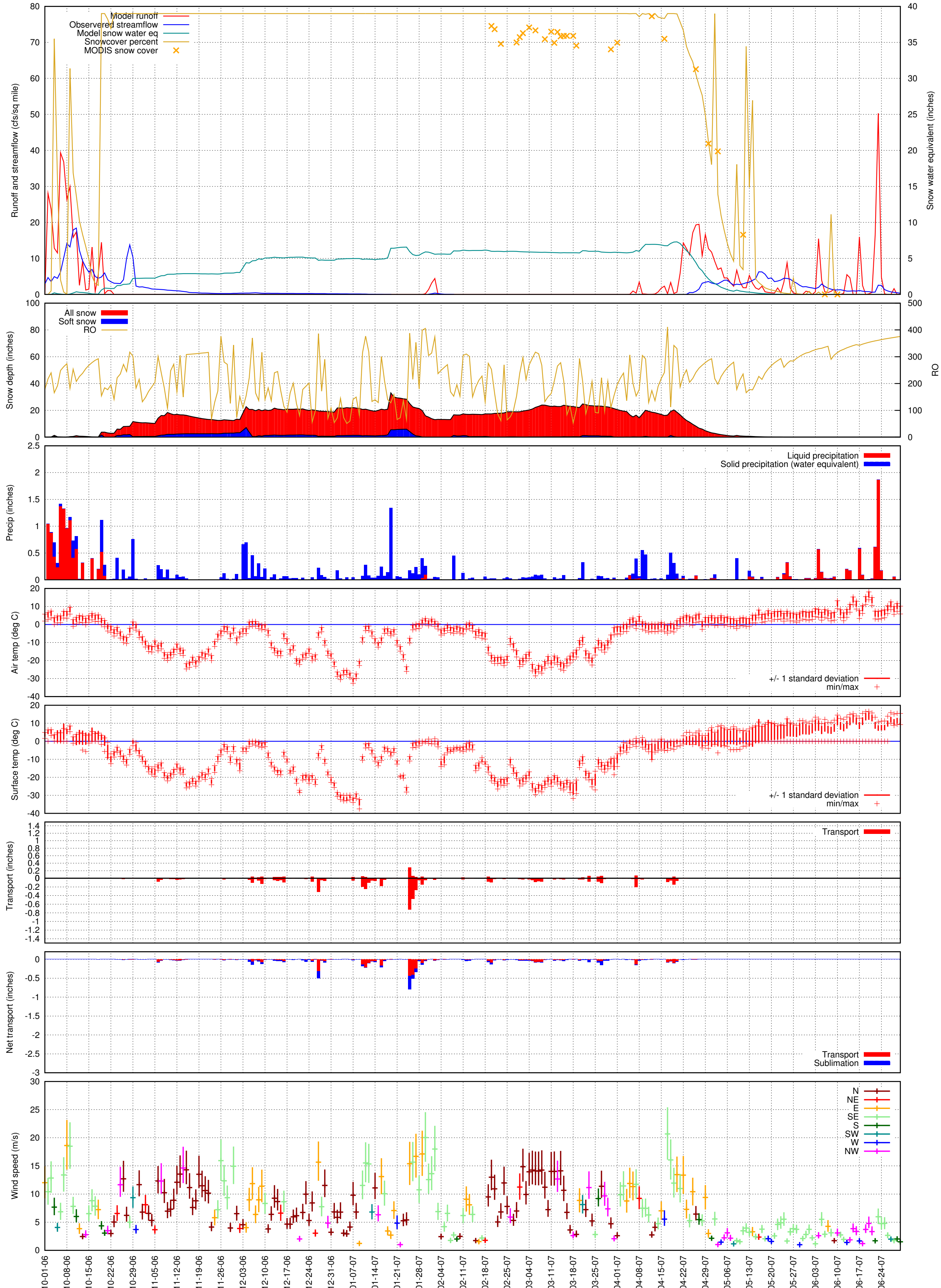
SnowModel Output Summary: 384-foot cells, hourly timestep, precipitation factor 2.0
Basin SK119A, Water Balance Summary, 2005-2008



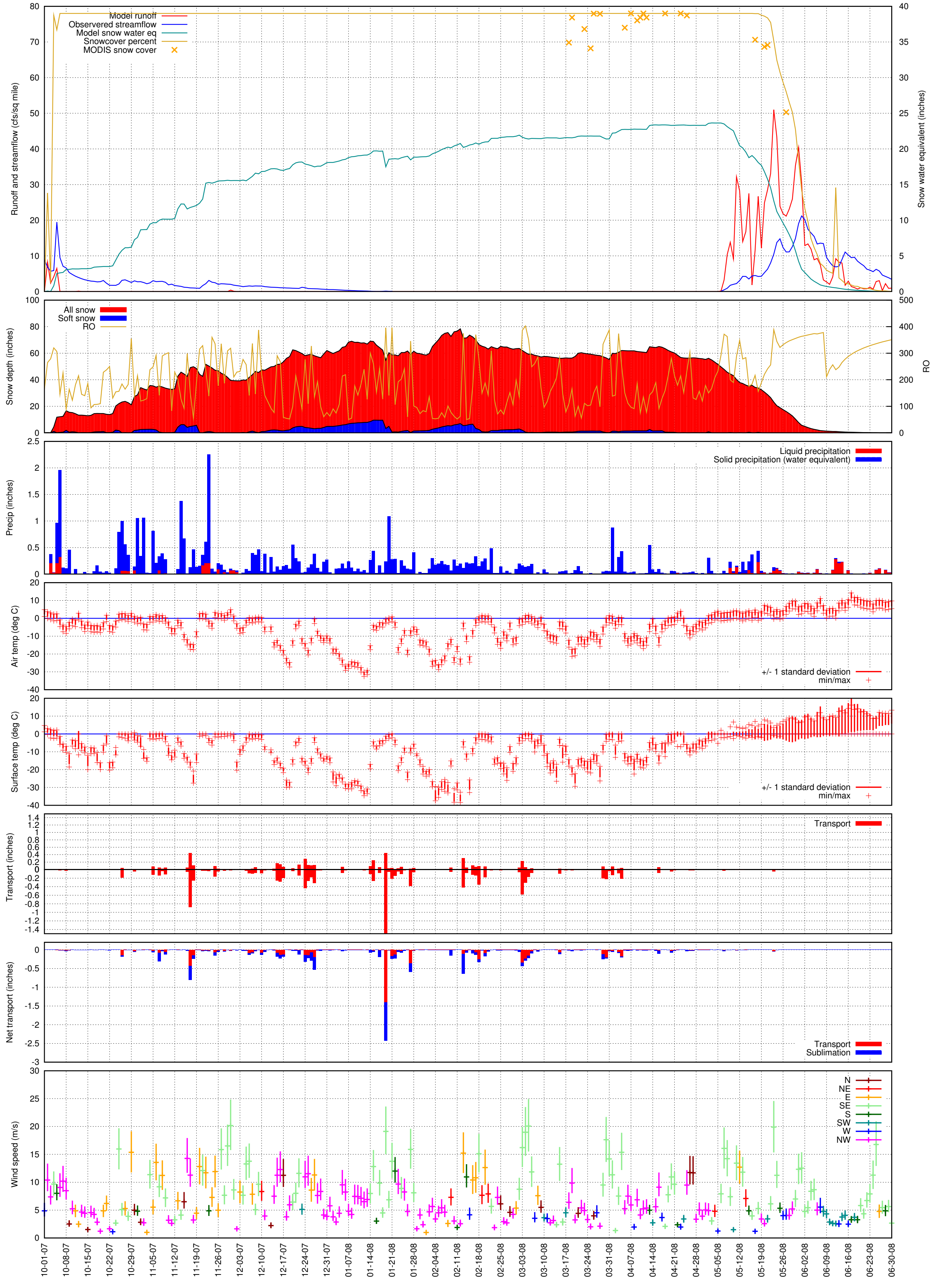
SnowModel Output Summary: 384-foot cells, hourly timestep, precipitation factor 2.0
Basin SK124A, 2005-2006



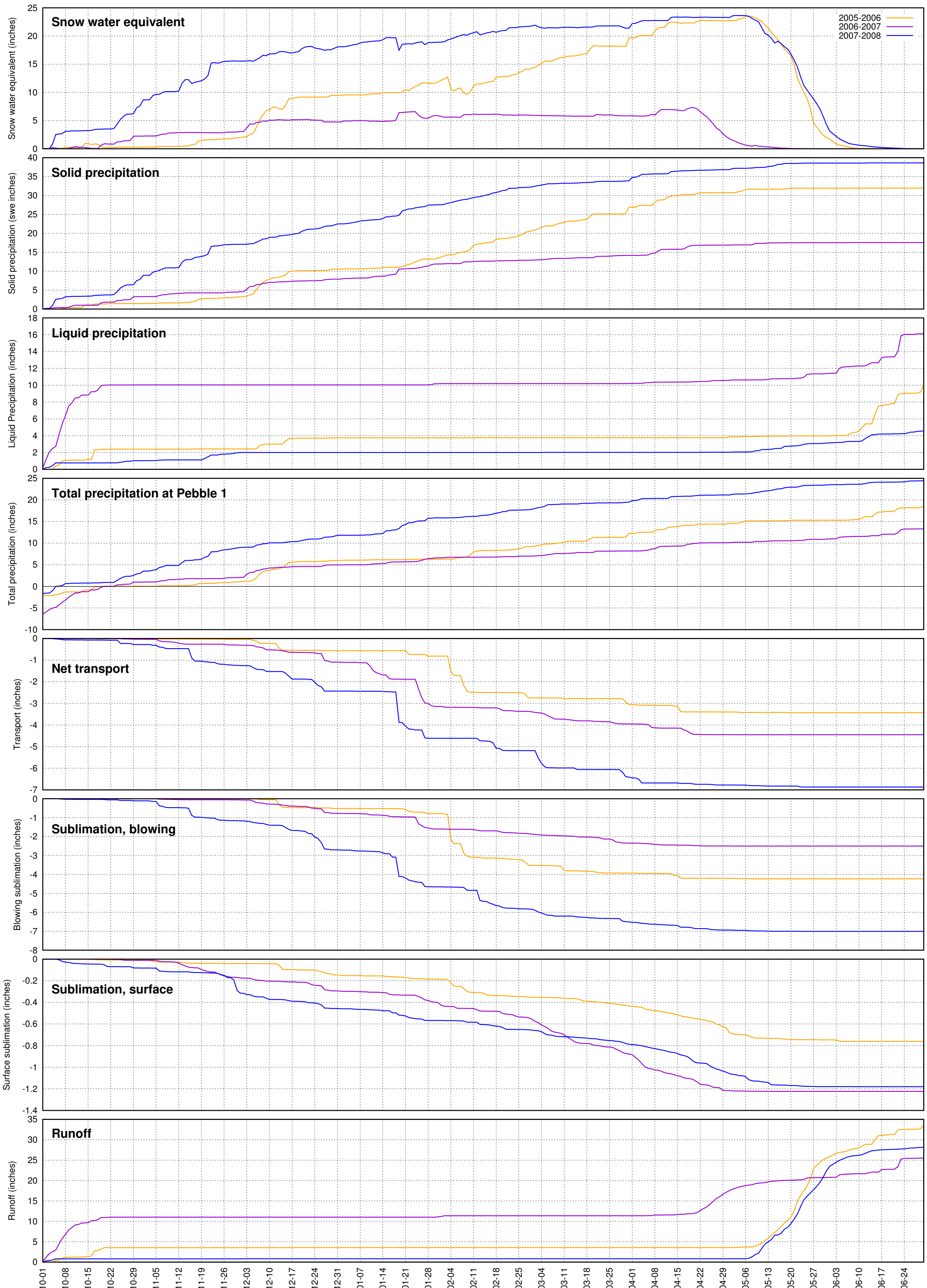
SnowModel Output Summary: 384-foot cells, hourly timestep, precipitation factor 2.0
Basin SK124A, 2006-2007



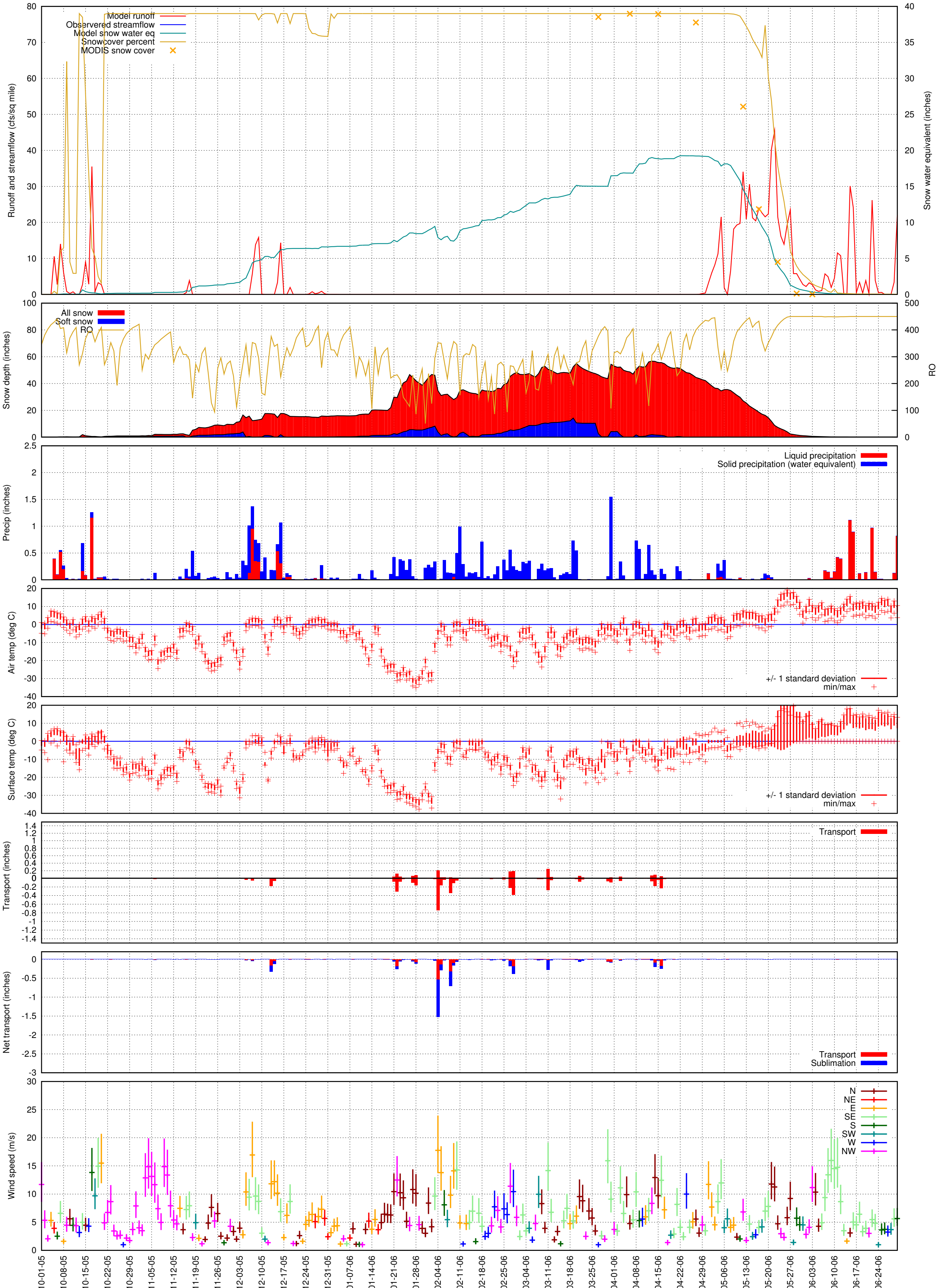
SnowModel Output Summary: 384-foot cells, hourly timestep, precipitation factor 2.0
Basin SK124A, 2007-2008



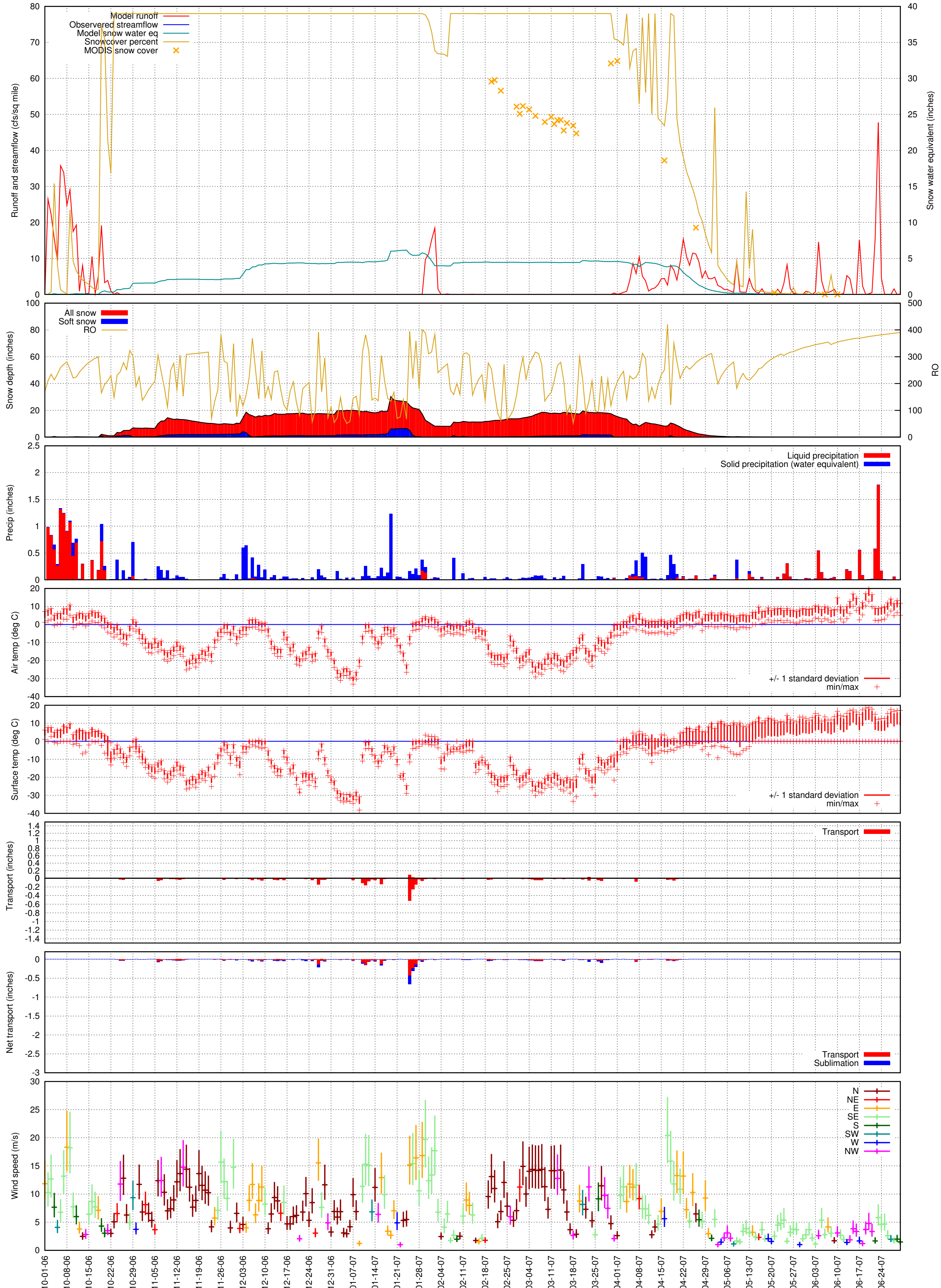
SnowModel Output Summary: 384-foot cells, hourly timestep, precipitation factor 2.0
Basin SK124A, Water Balance Summary, 2005-2008



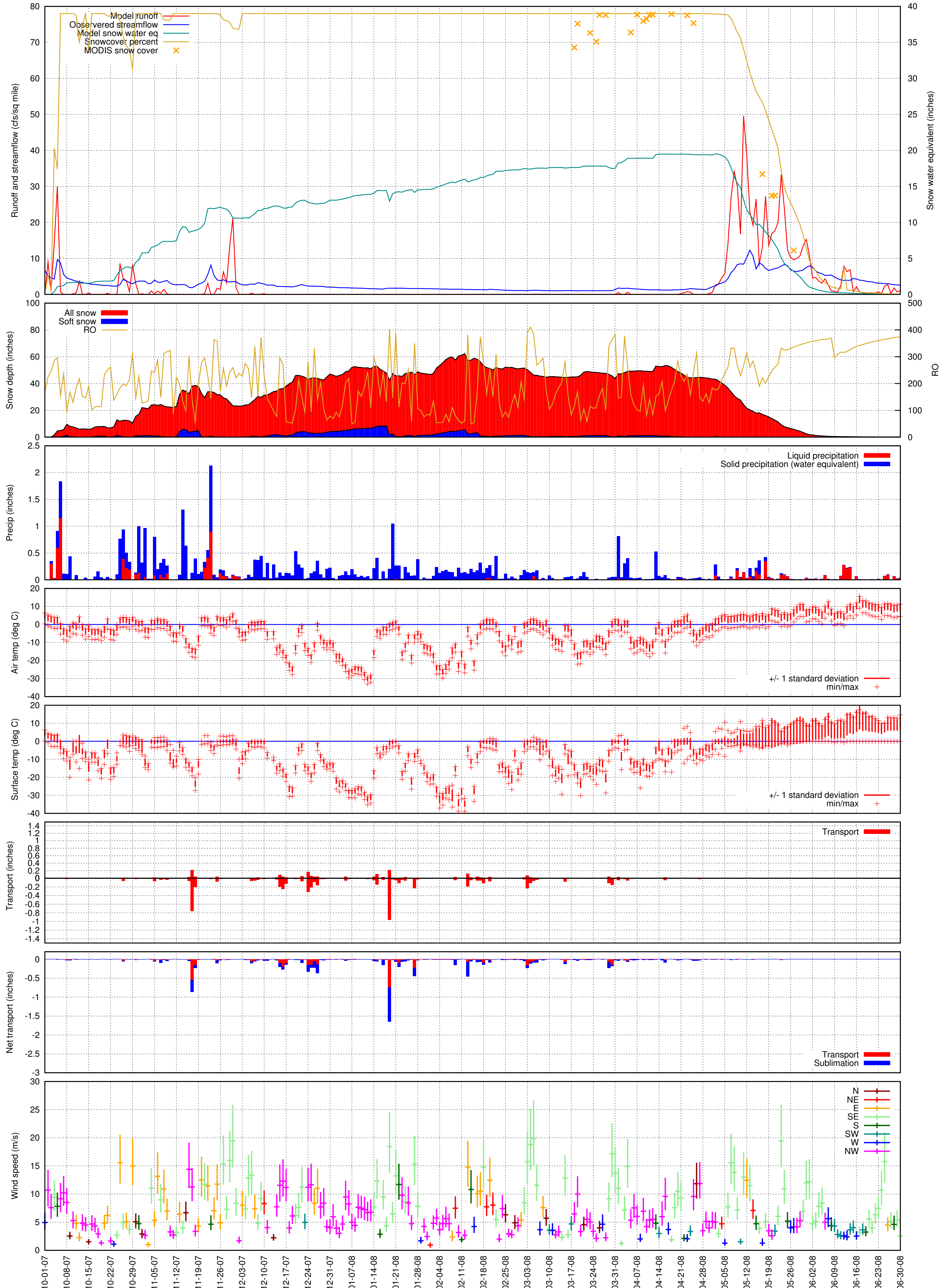
SnowModel Output Summary: 384-foot cells, hourly timestep, precipitation factor 2.0
Basin UT100APC1, 2005-2006



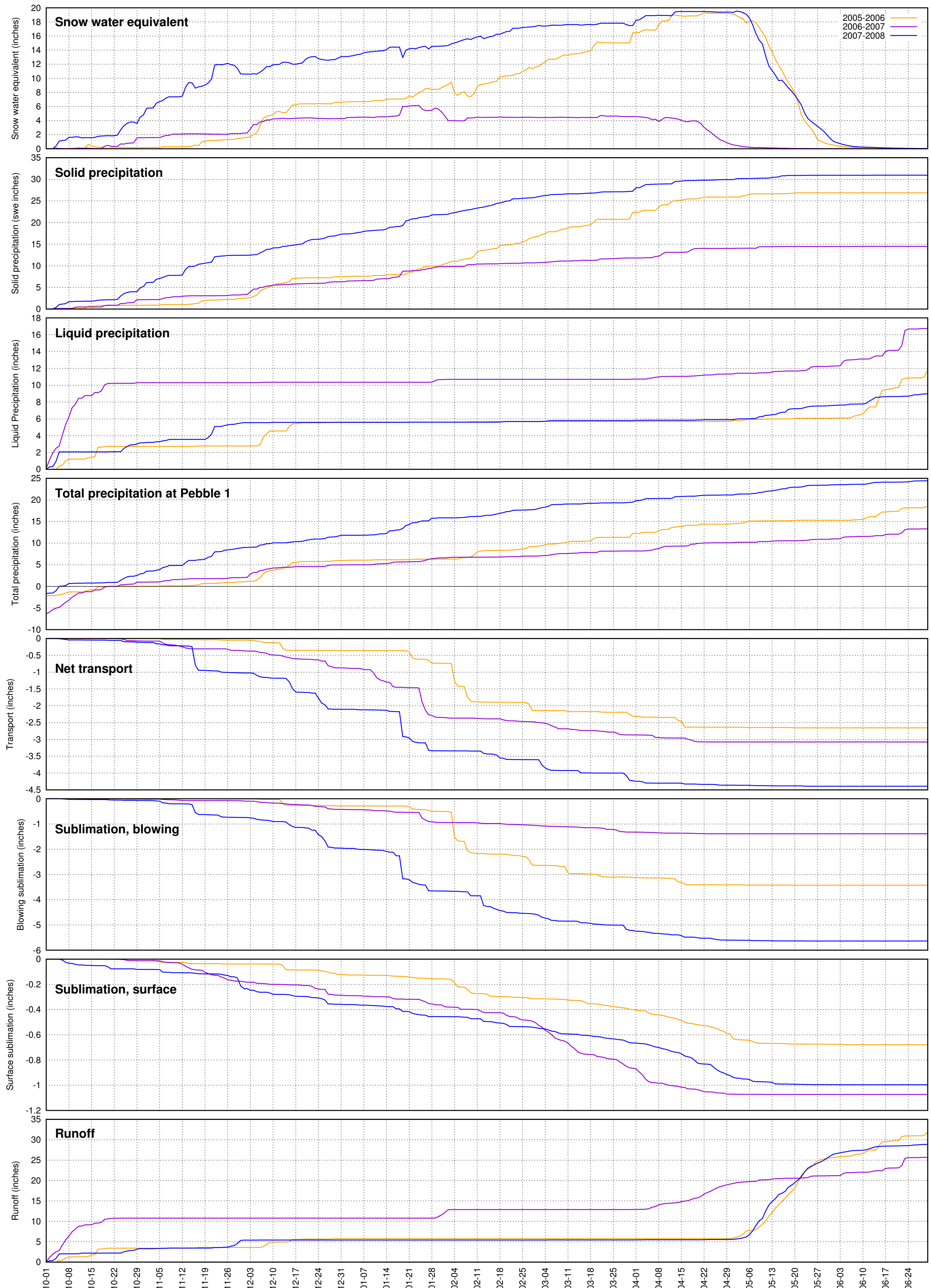
SnowModel Output Summary: 384-foot cells, hourly timestep, precipitation factor 2.0
Basin UT100APC1, 2006-2007



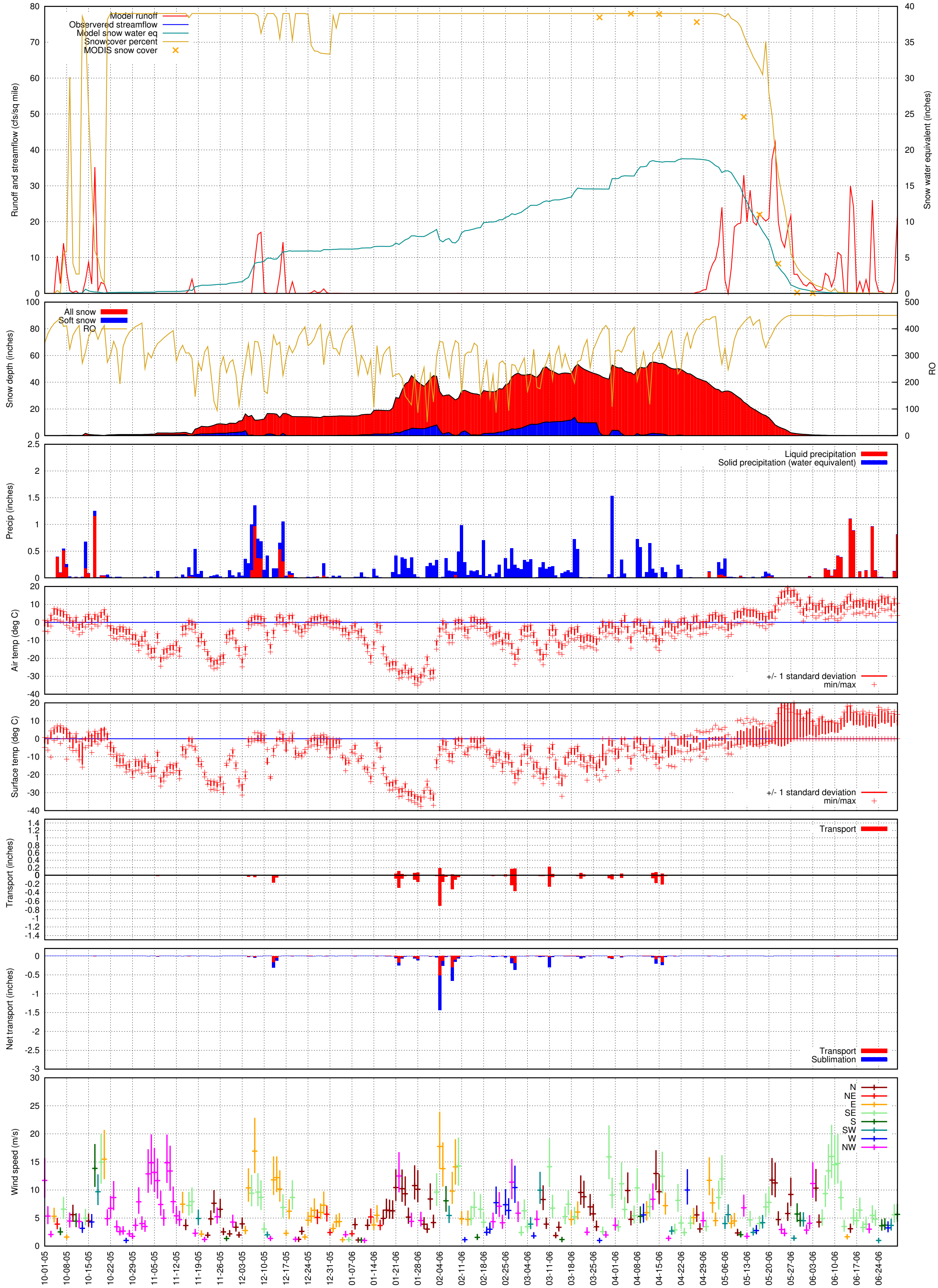
SnowModel Output Summary: 384-foot cells, hourly timestep, precipitation factor 2.0
Basin UT100APC1, 2007-2008



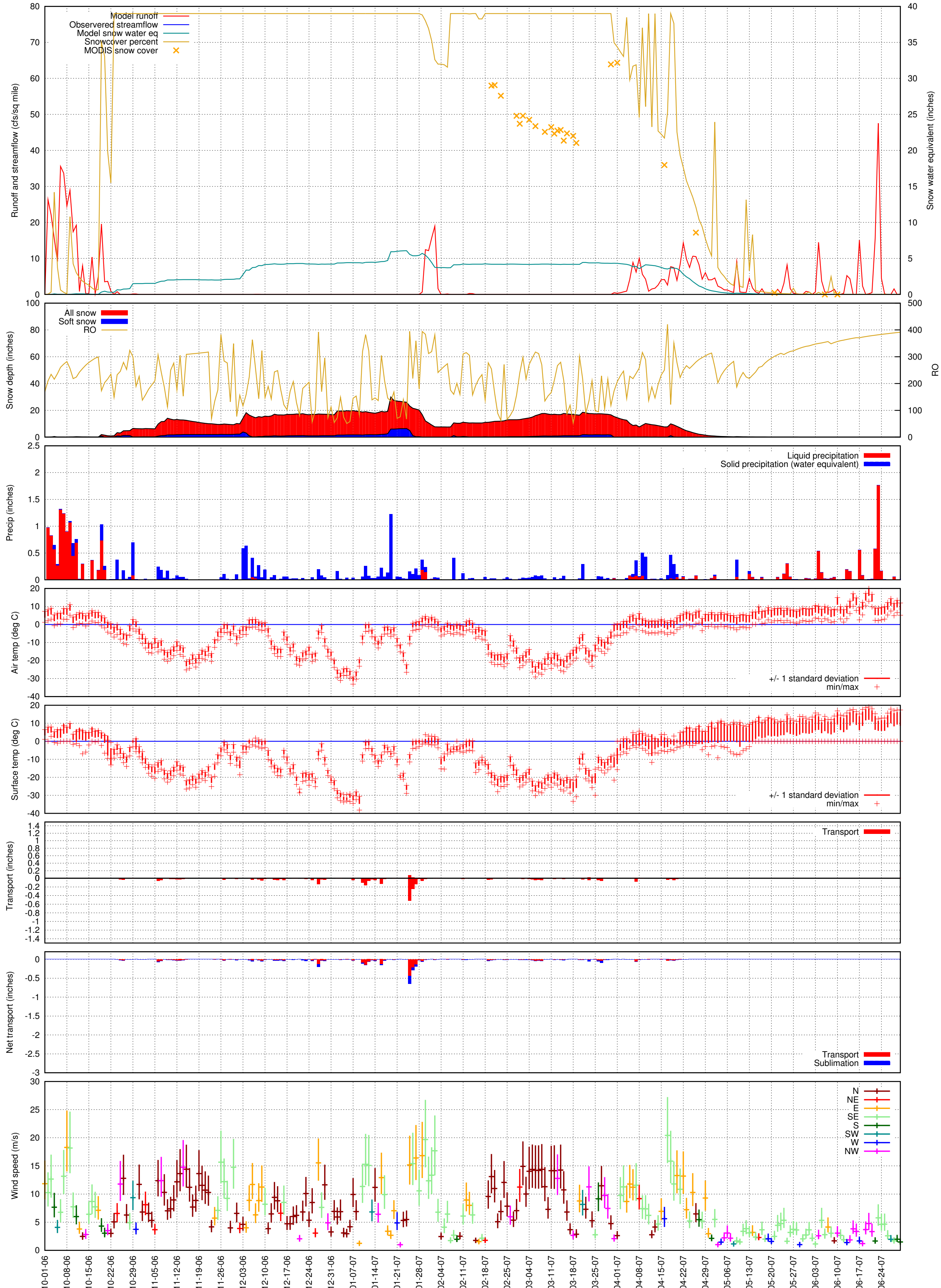
SnowModel Output Summary: 384-foot cells, hourly timestep, precipitation factor 2.0
Basin UT100APC1, Water Balance Summary, 2005-2008



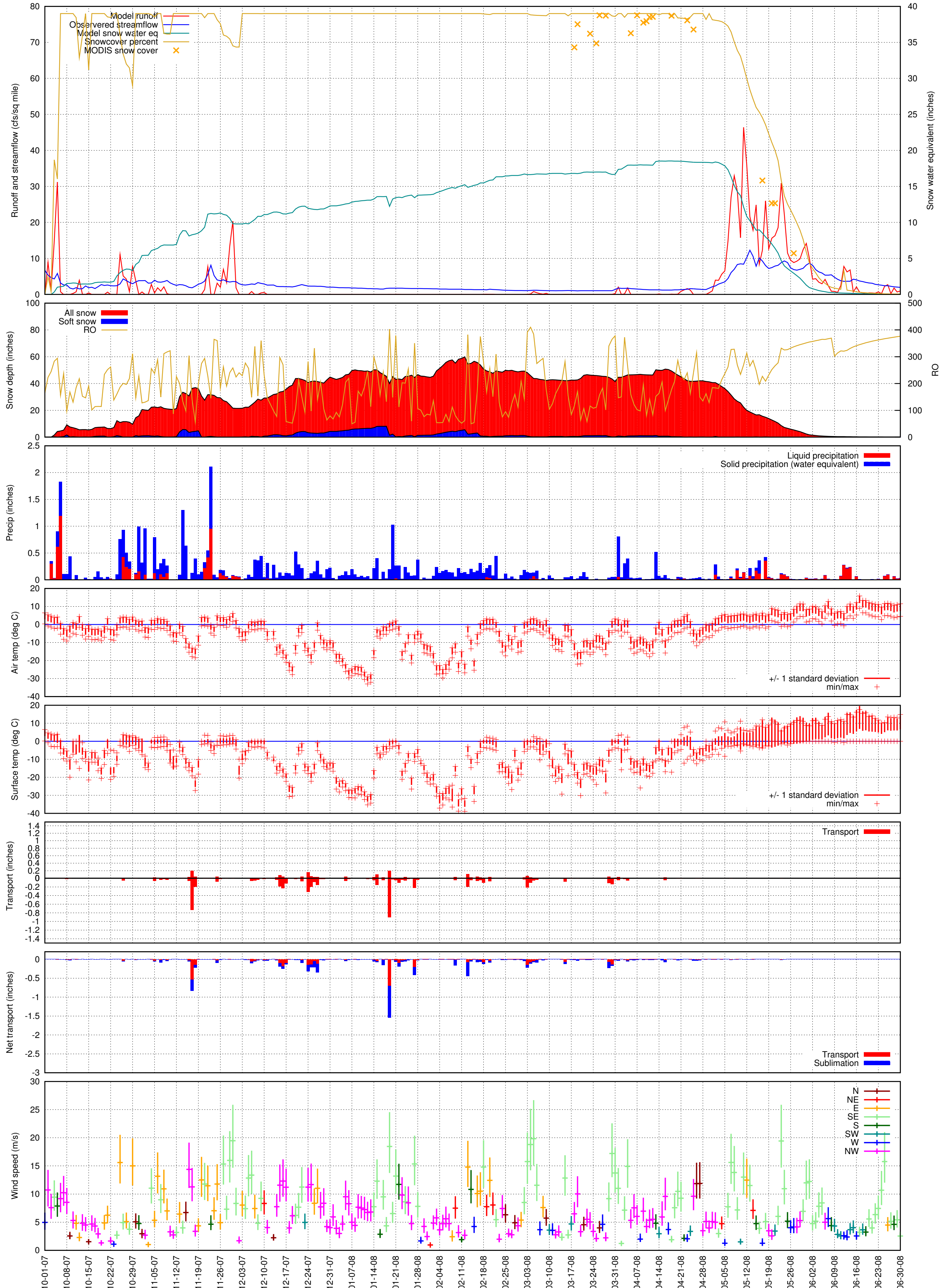
SnowModel Output Summary: 384-foot cells, hourly timestep, precipitation factor 2.0
Basin UT100APC2, 2005-2006



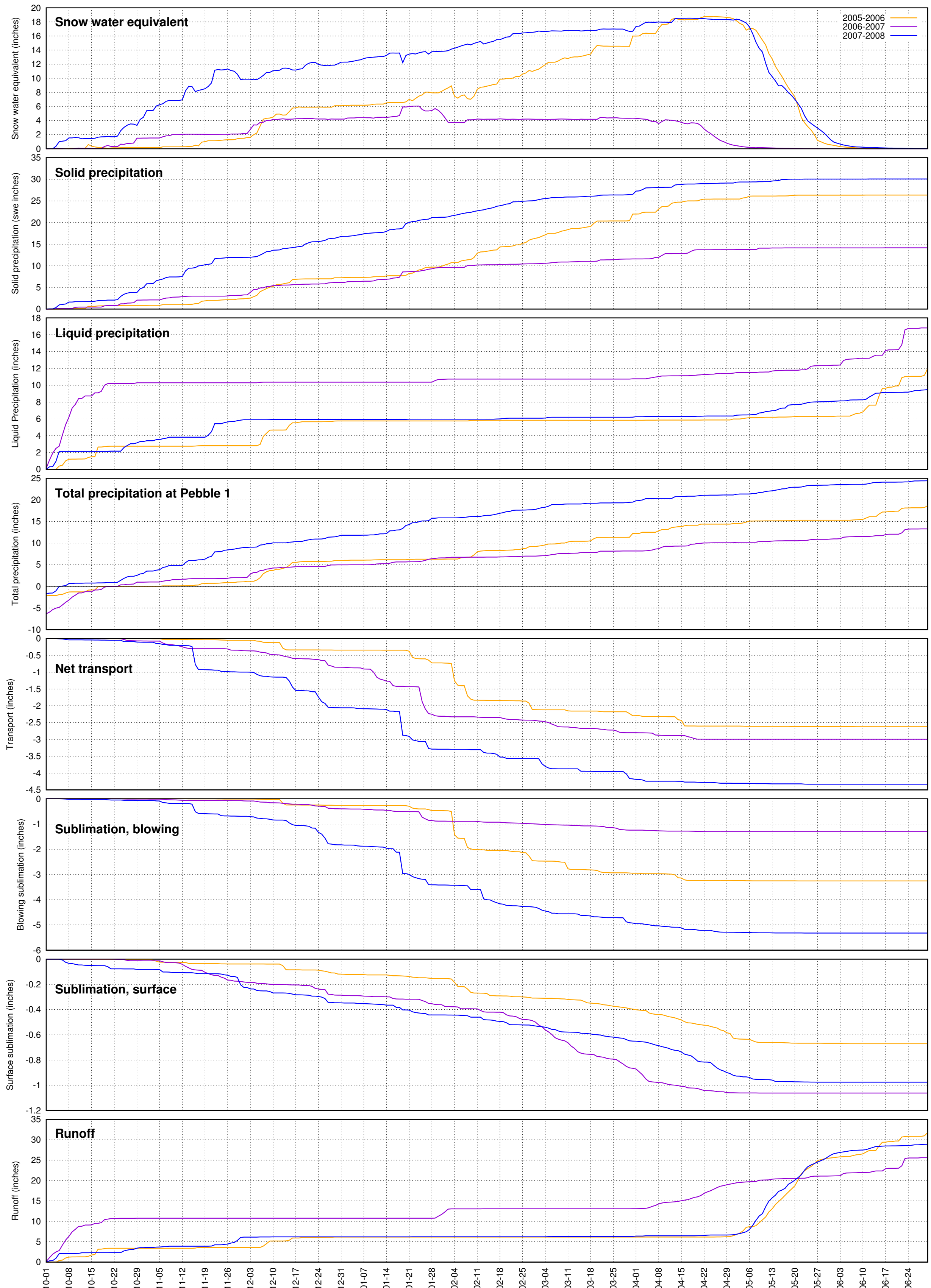
SnowModel Output Summary: 384-foot cells, hourly timestep, precipitation factor 2.0
Basin UT100APC2, 2006-2007



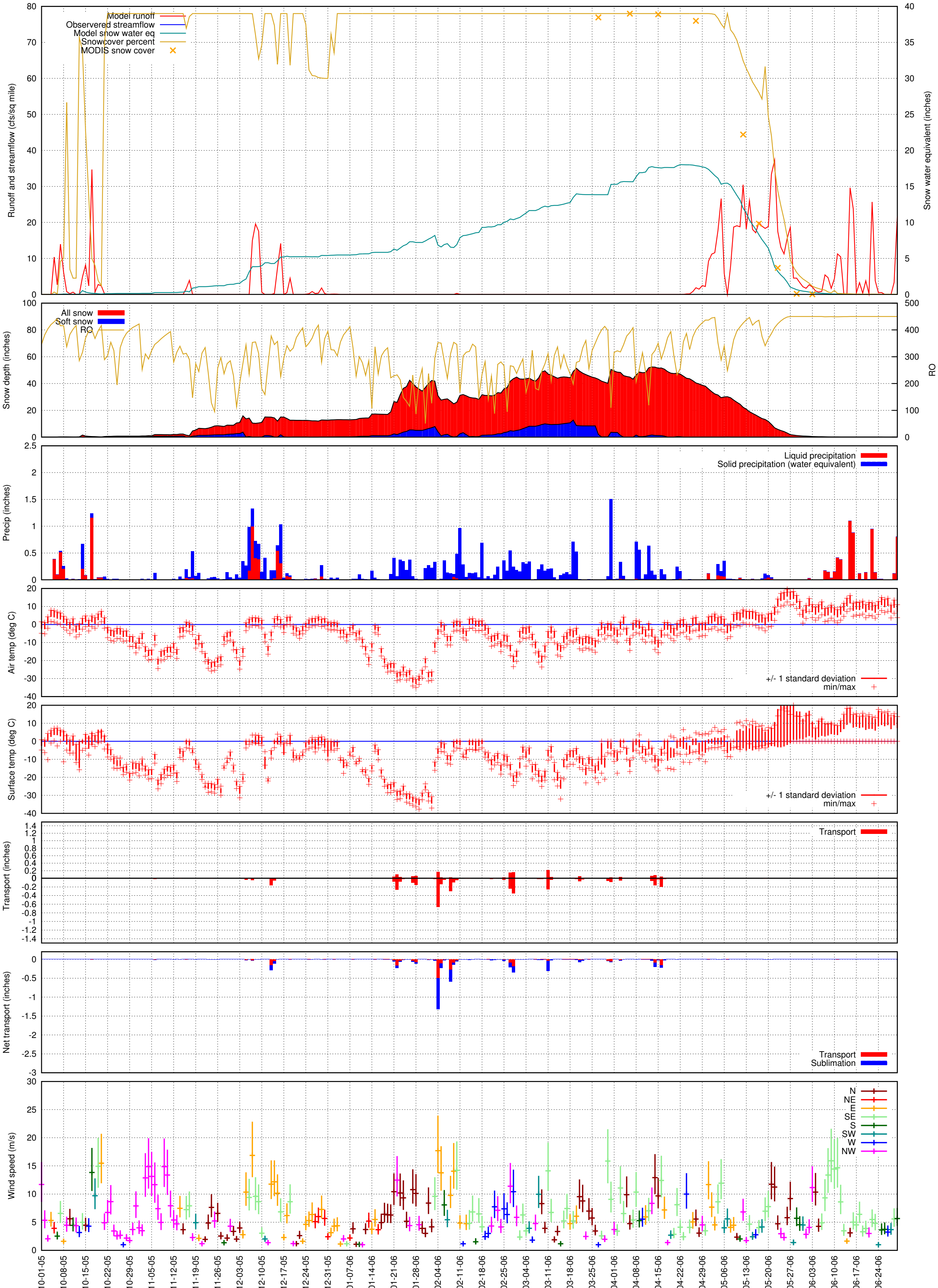
SnowModel Output Summary: 384-foot cells, hourly timestep, precipitation factor 2.0
Basin UT100APC2, 2007-2008



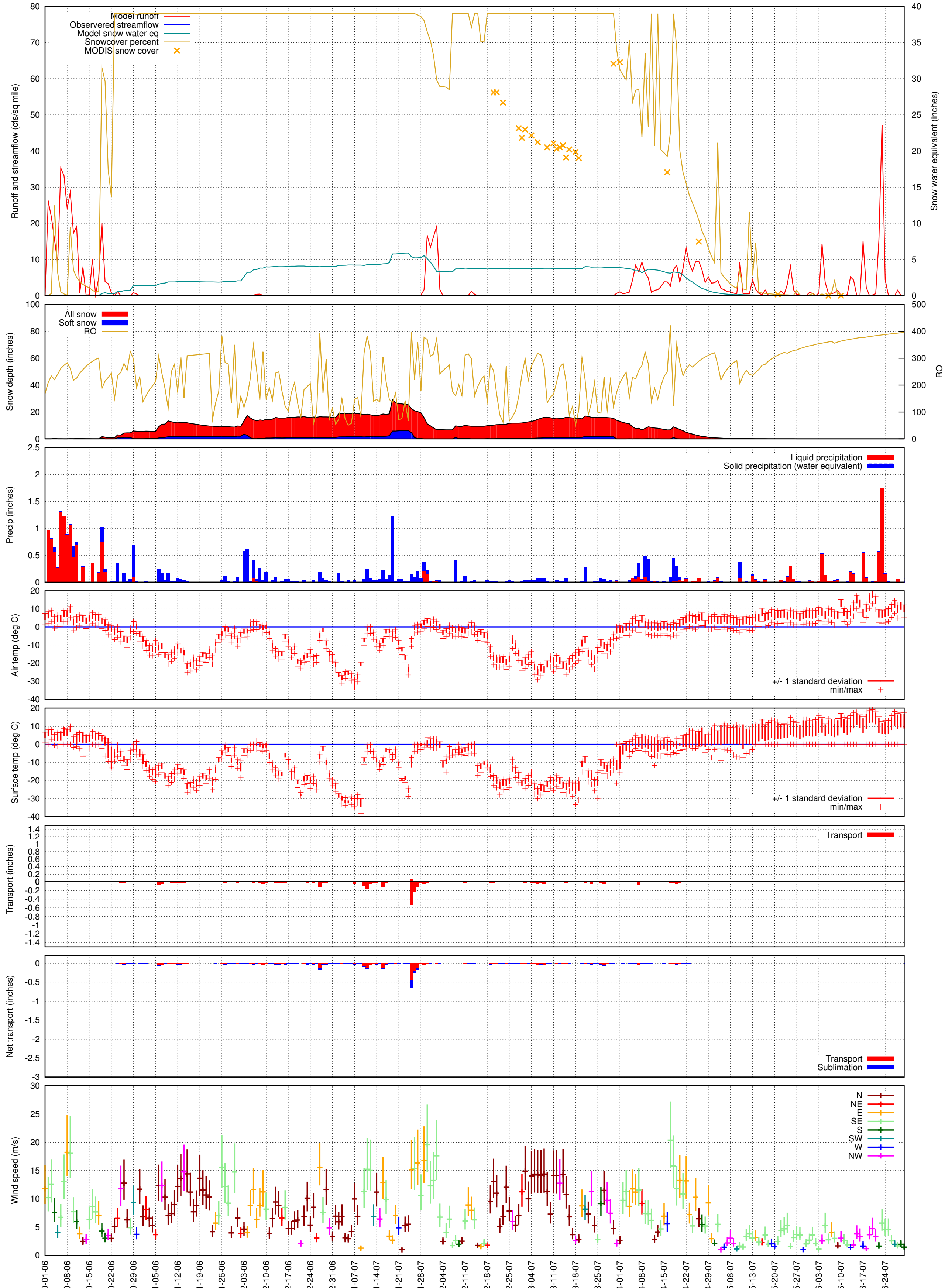
SnowModel Output Summary: 384-foot cells, hourly timestep, precipitation factor 2.0
Basin UT100APC2, Water Balance Summary, 2005-2008



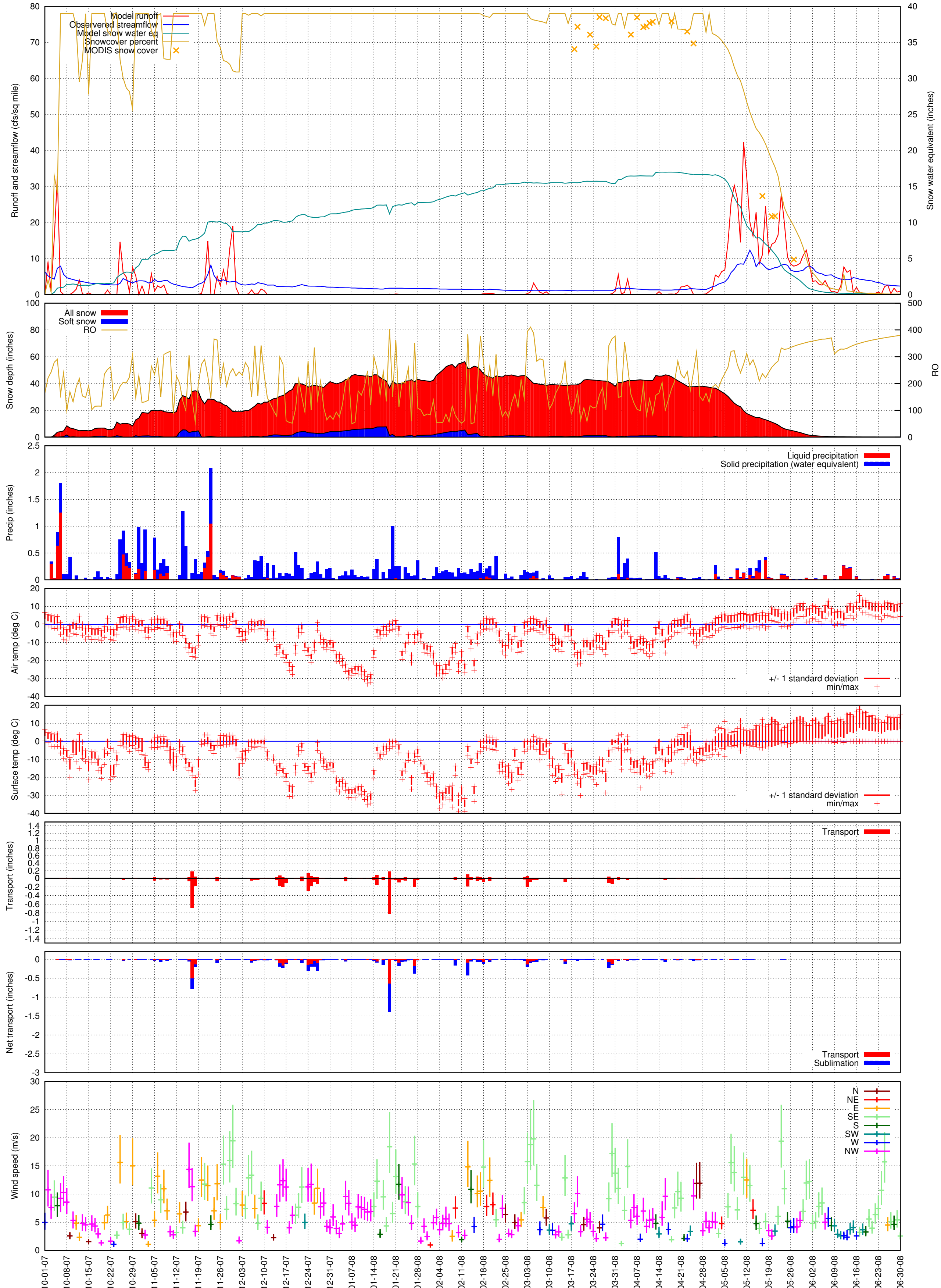
SnowModel Output Summary: 384-foot cells, hourly timestep, precipitation factor 2.0
Basin UT100APC3, 2005-2006



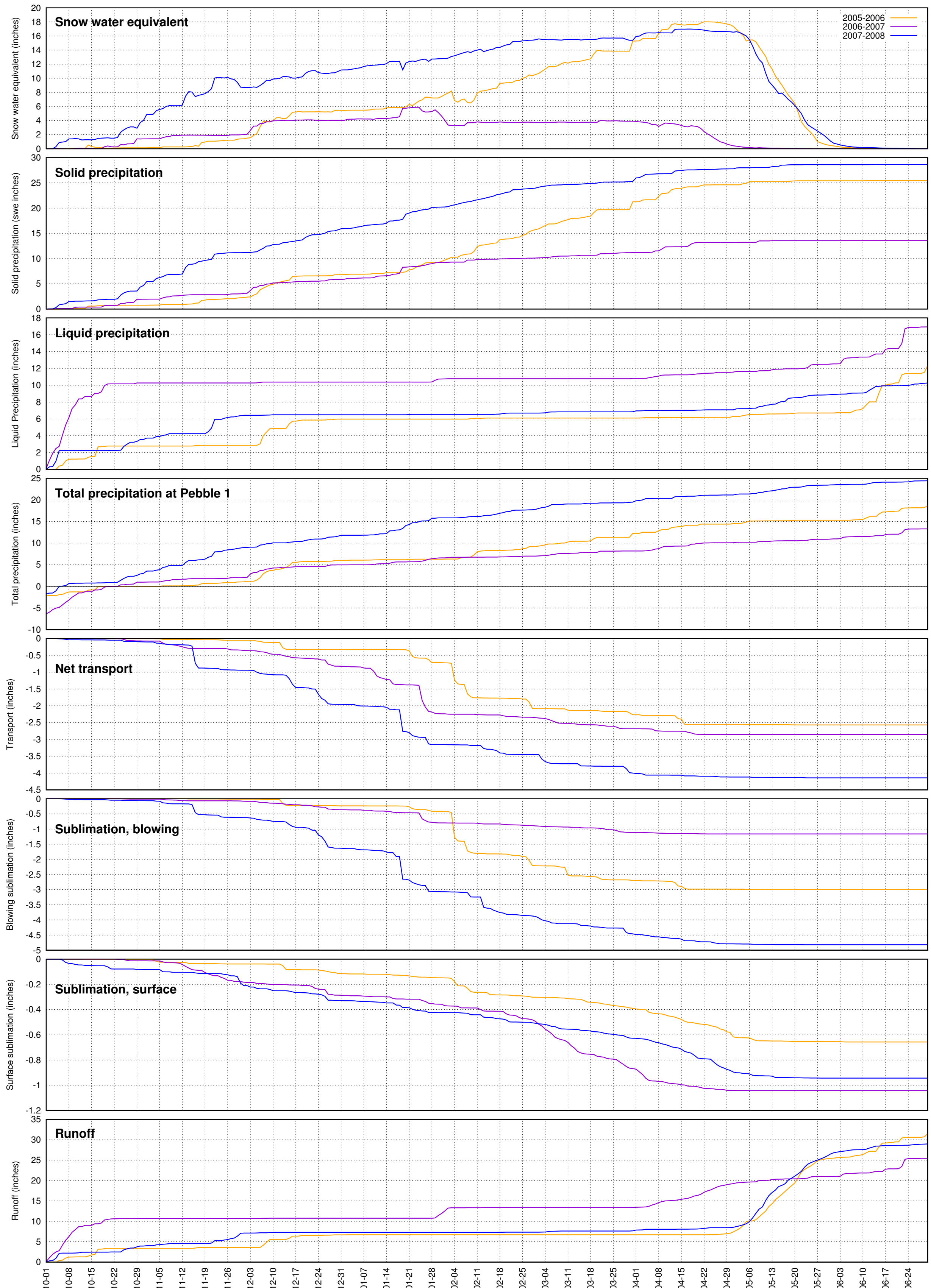
SnowModel Output Summary: 384-foot cells, hourly timestep, precipitation factor 2.0
Basin UT100APC3, 2006-2007



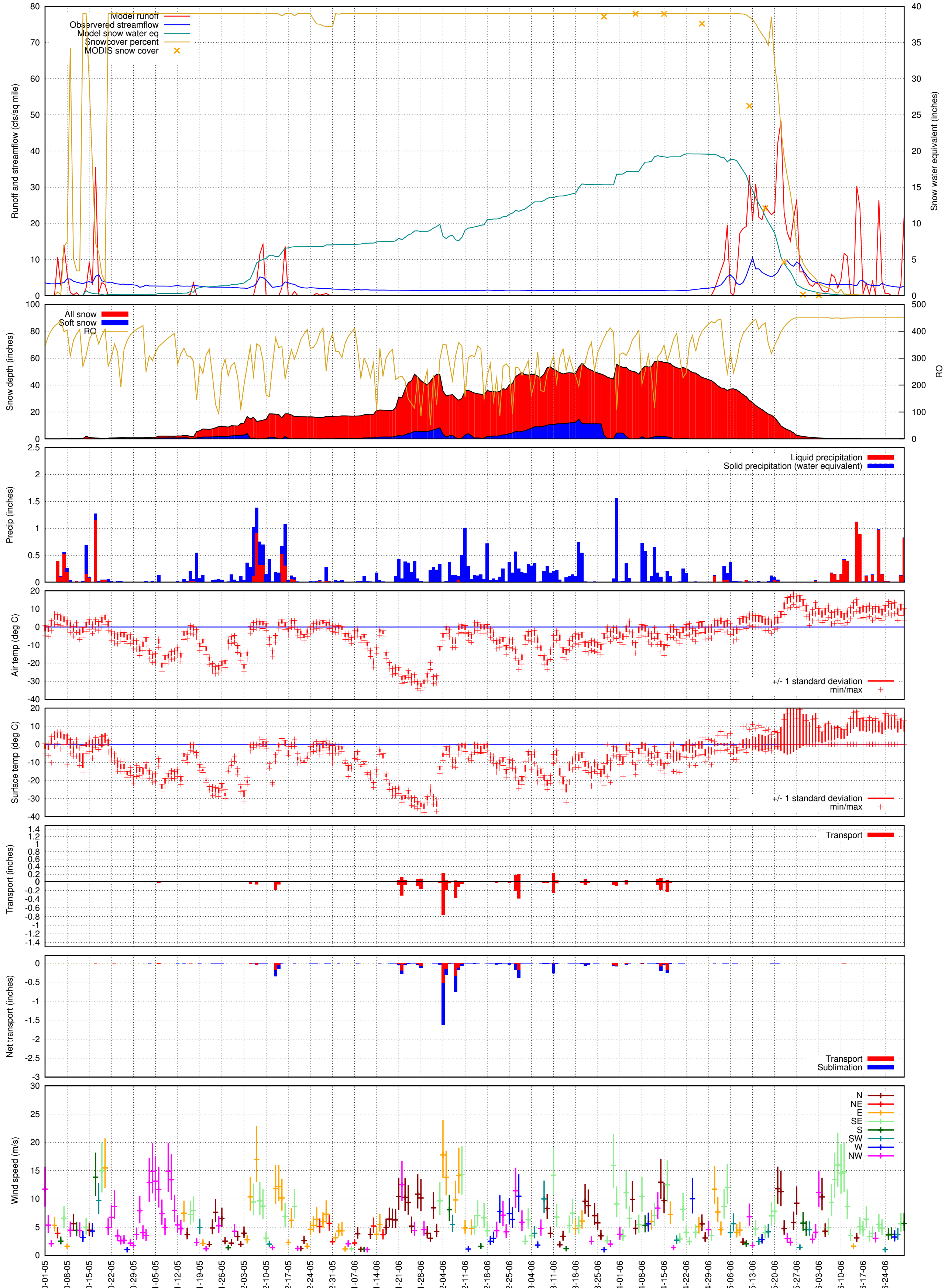
SnowModel Output Summary: 384-foot cells, hourly timestep, precipitation factor 2.0
Basin UT100APC3, 2007-2008



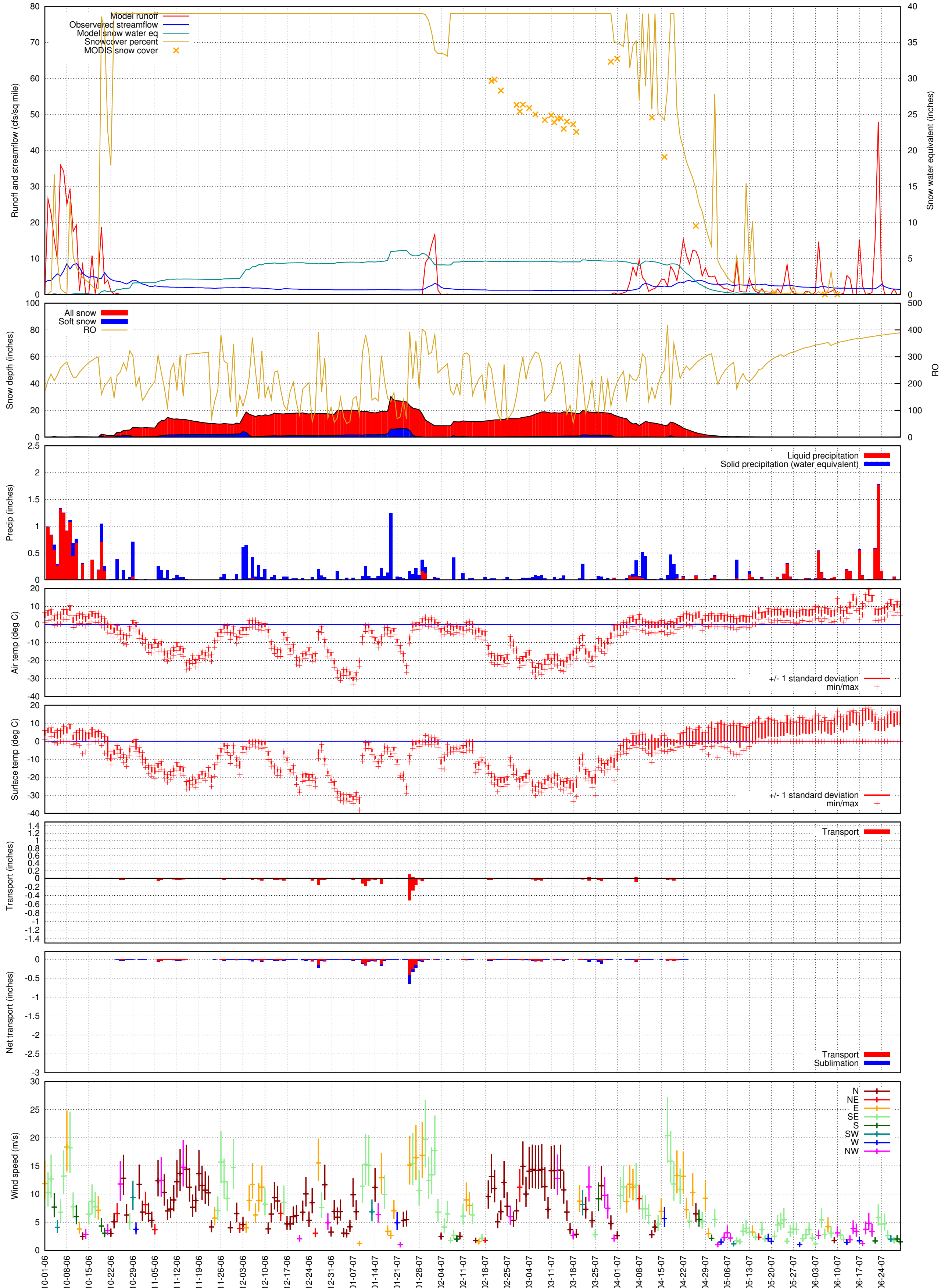
SnowModel Output Summary: 384-foot cells, hourly timestep, precipitation factor 2.0
Basin UT100APC3, Water Balance Summary, 2005-2008



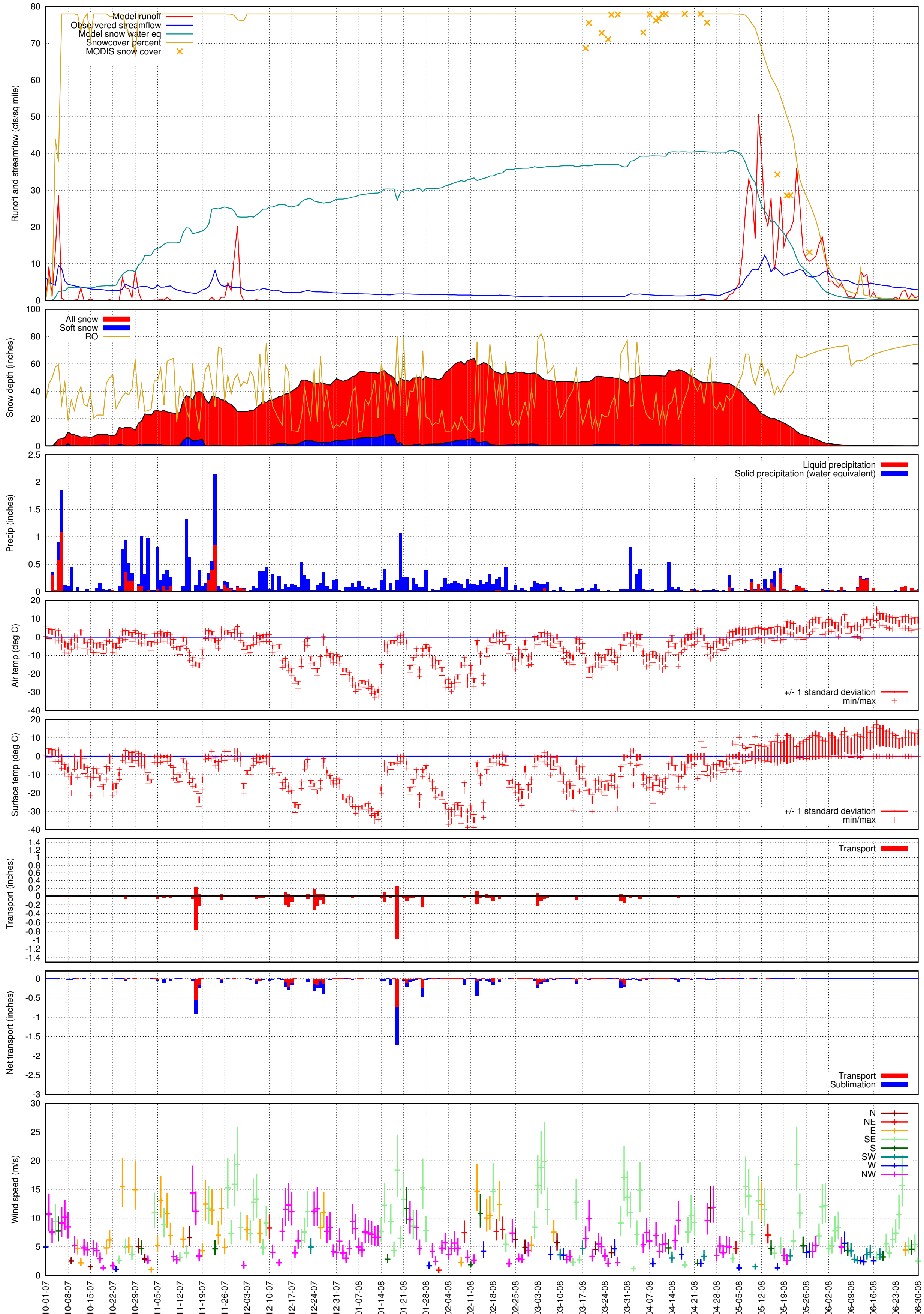
SnowModel Output Summary: 384-foot cells, hourly timestep, precipitation factor 2.0
Basin UT100B, 2005-2006



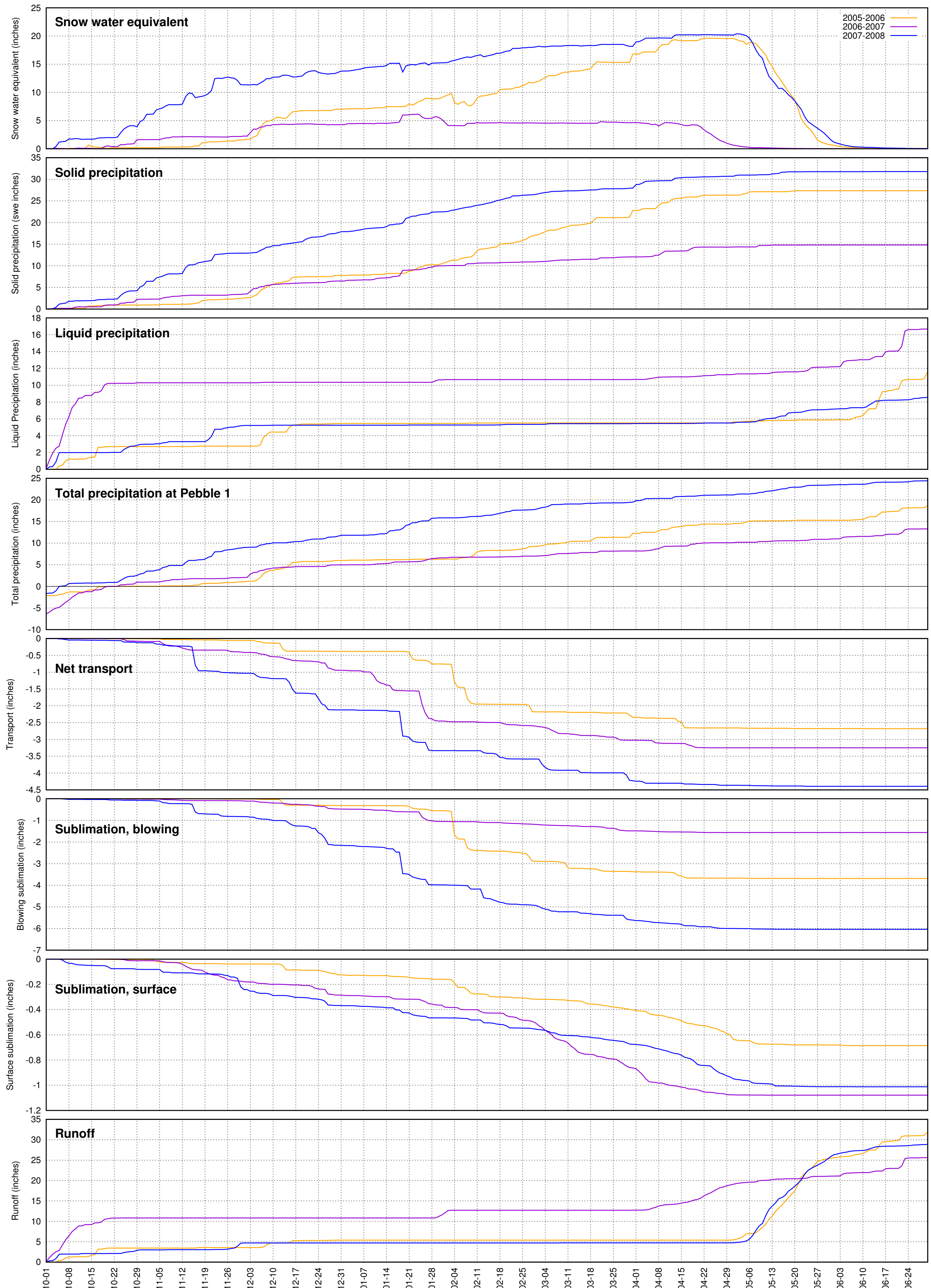
SnowModel Output Summary: 384-foot cells, hourly timestep, precipitation factor 2.0
Basin UT100B, 2006-2007



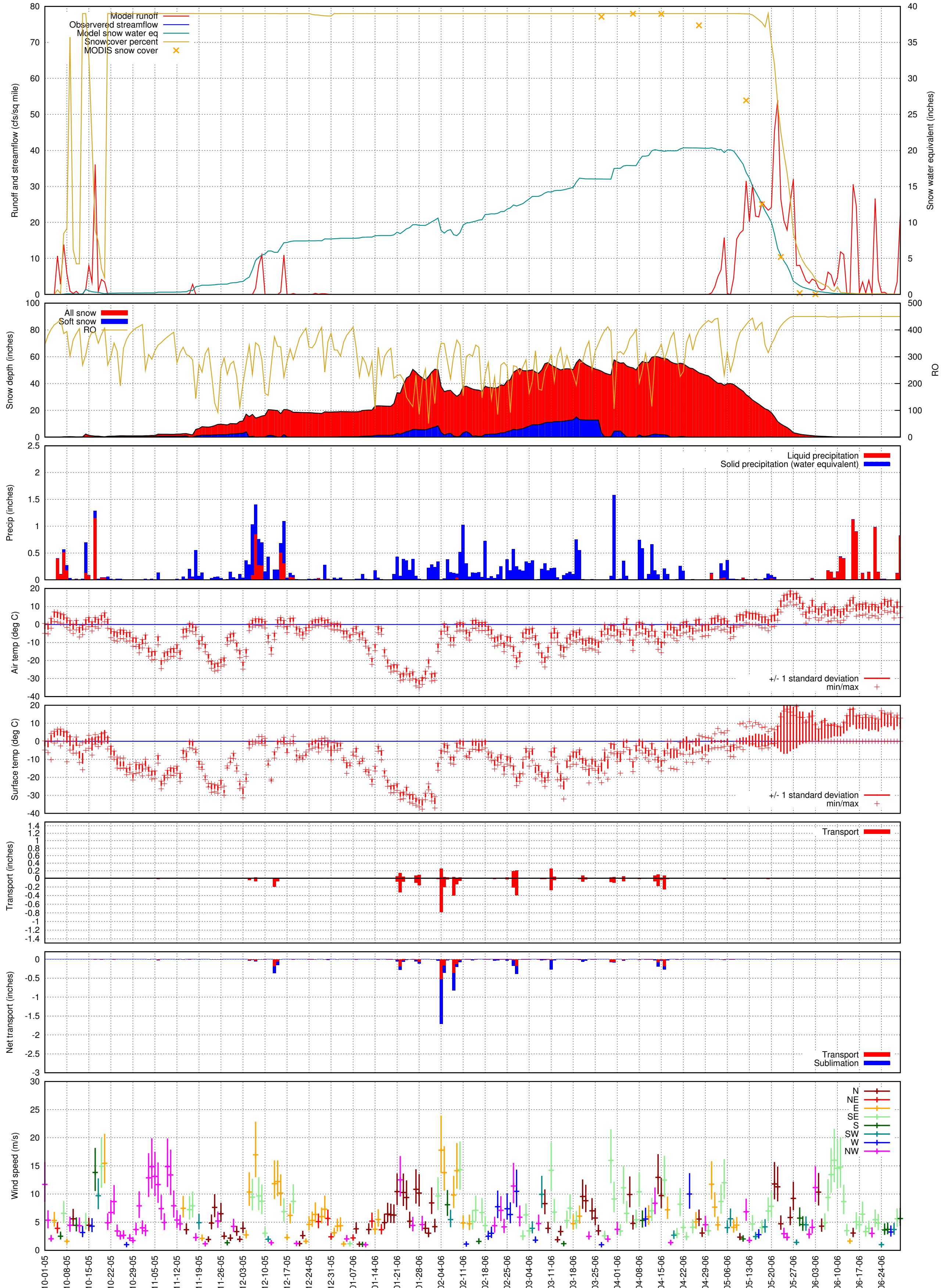
SnowModel Output Summary: 384-foot cells, hourly timestep, precipitation factor 2.0
Basin UT100B, 2007-2008



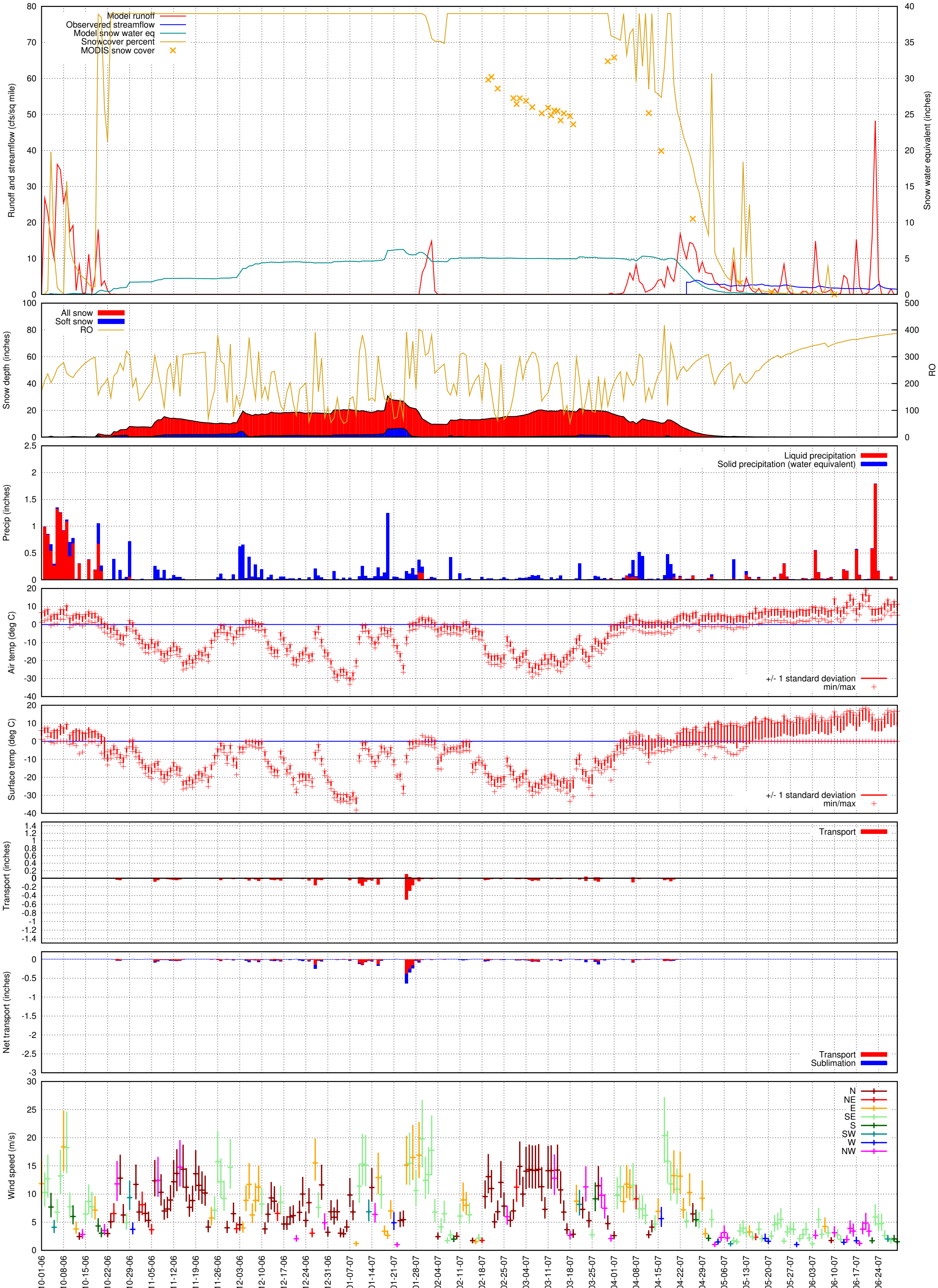
SnowModel Output Summary: 384-foot cells, hourly timestep, precipitation factor 2.0
Basin UT100B, Water Balance Summary, 2005-2008



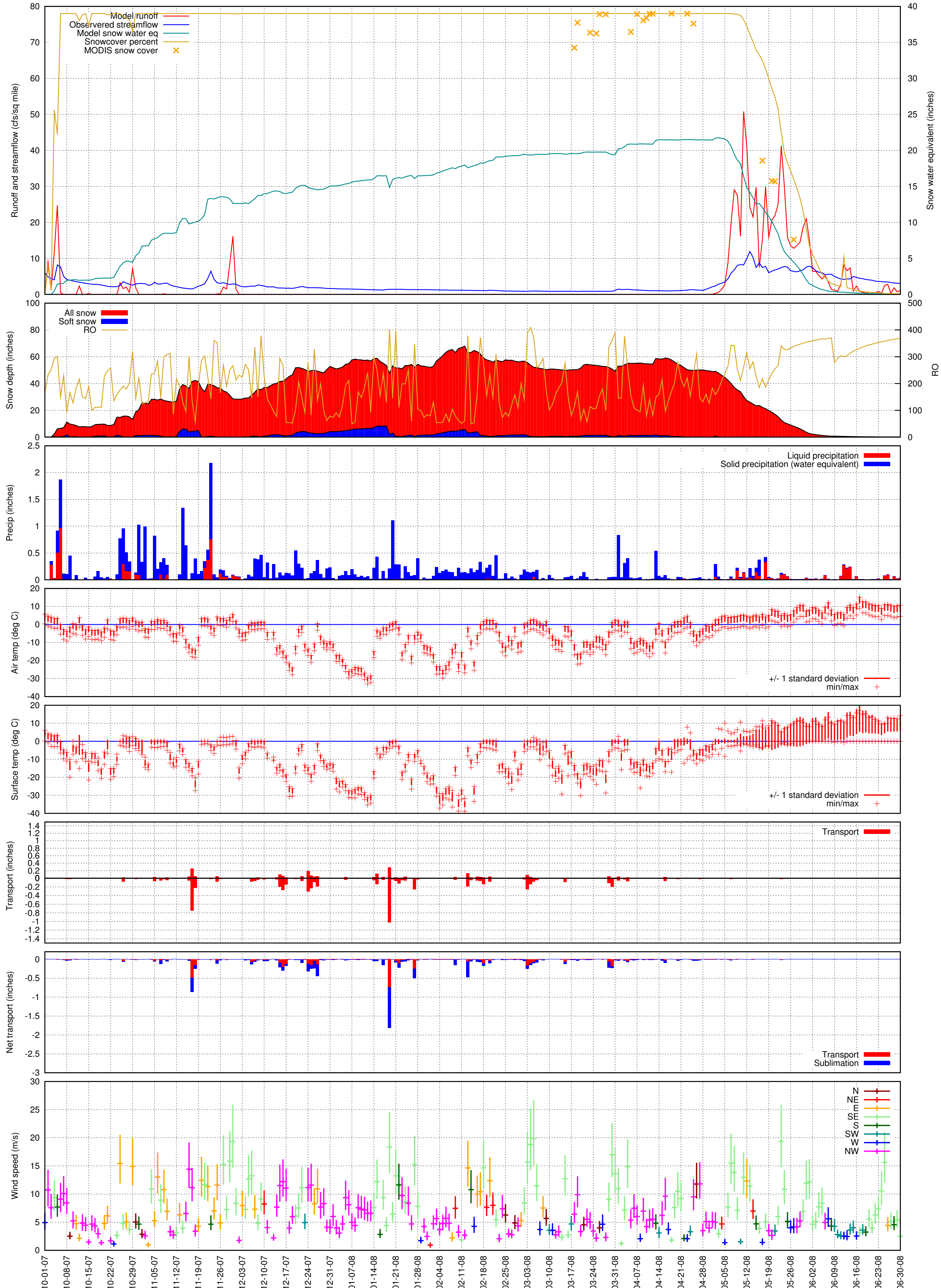
SnowModel Output Summary: 384-foot cells, hourly timestep, precipitation factor 2.0
Basin UT100C, 2005-2006



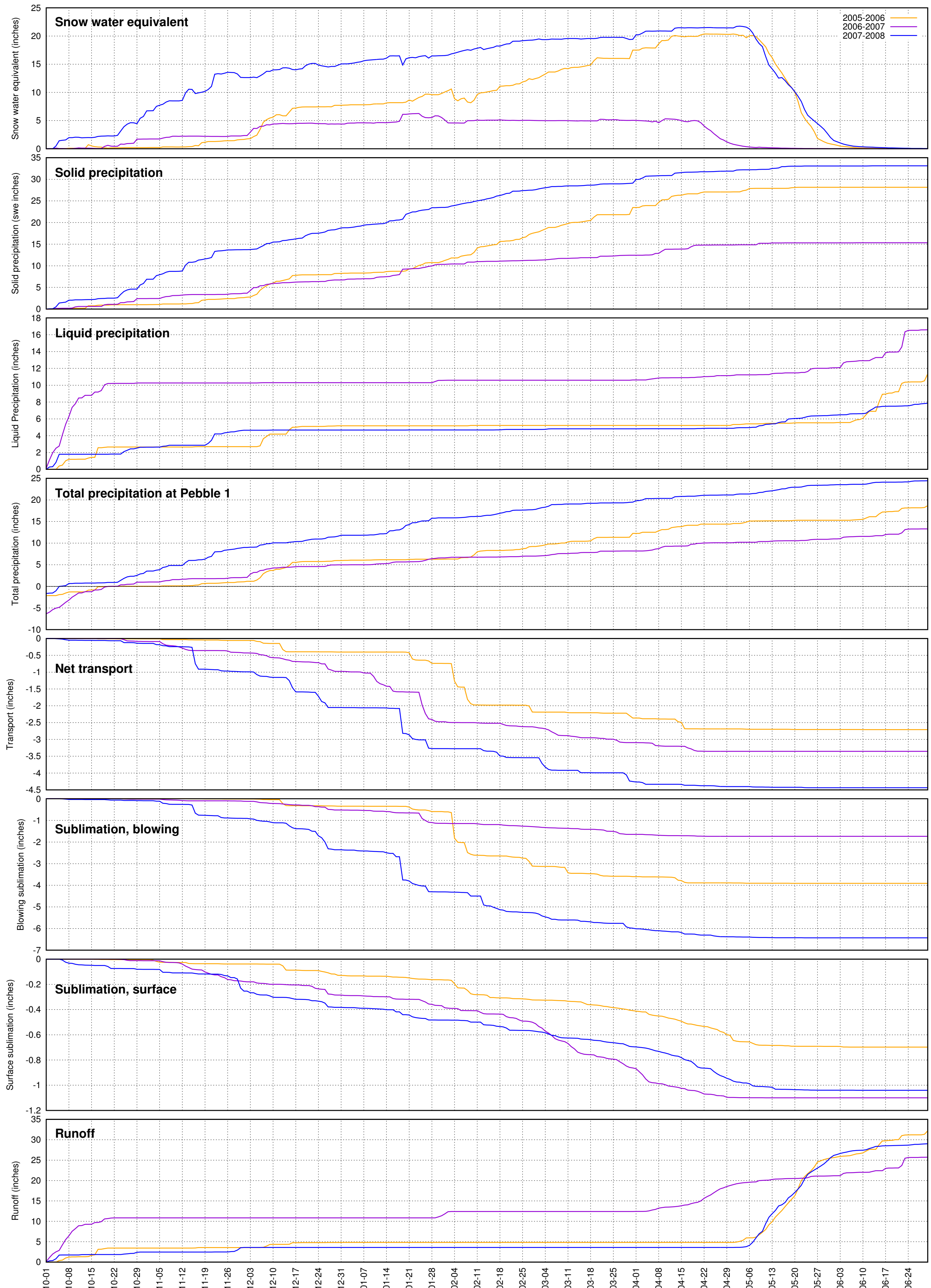
SnowModel Output Summary: 384-foot cells, hourly timestep, precipitation factor 2.0
Basin UT100C, 2006-2007



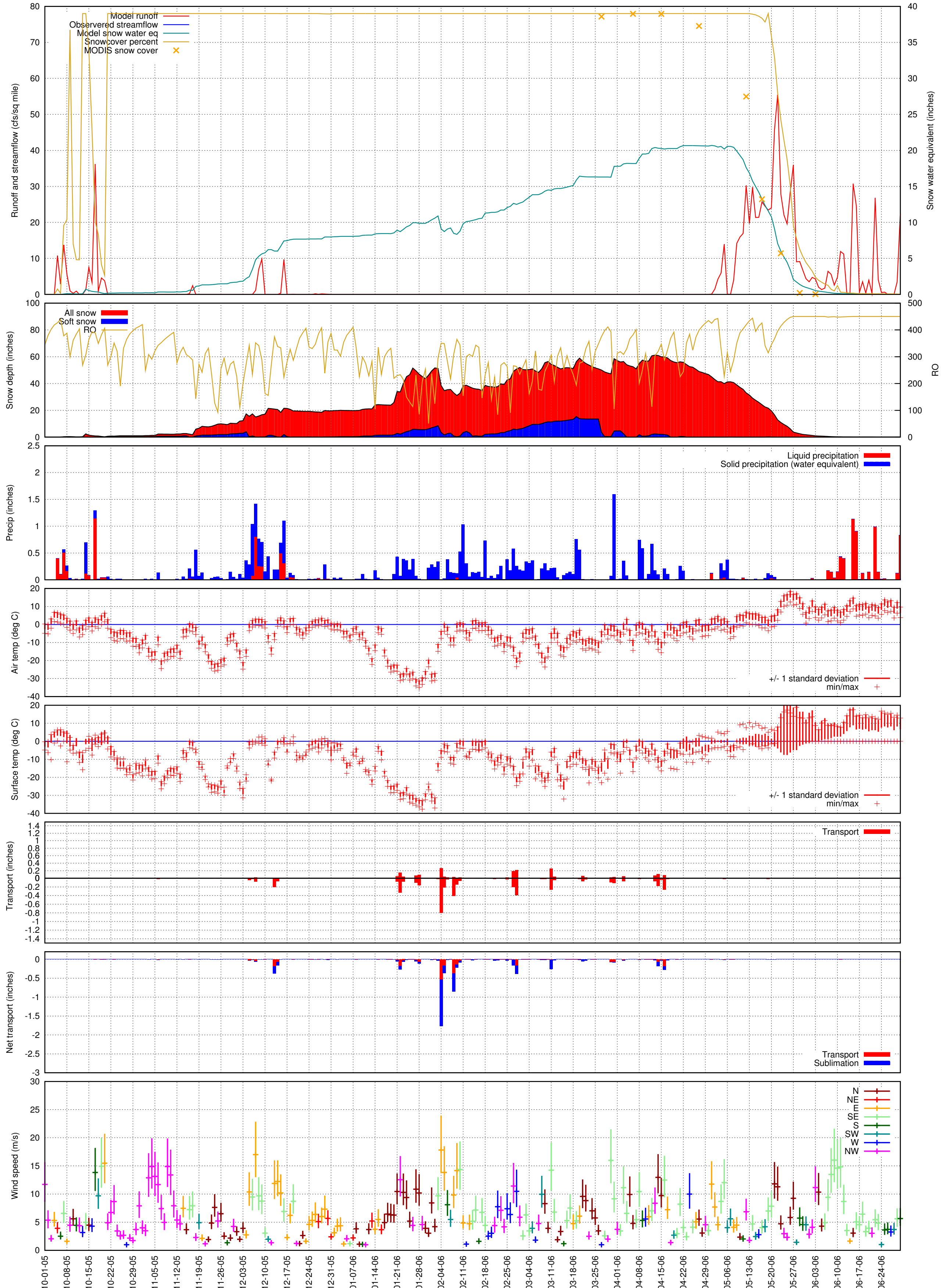
SnowModel Output Summary: 384-foot cells, hourly timestep, precipitation factor 2.0
Basin UT100C, 2007-2008



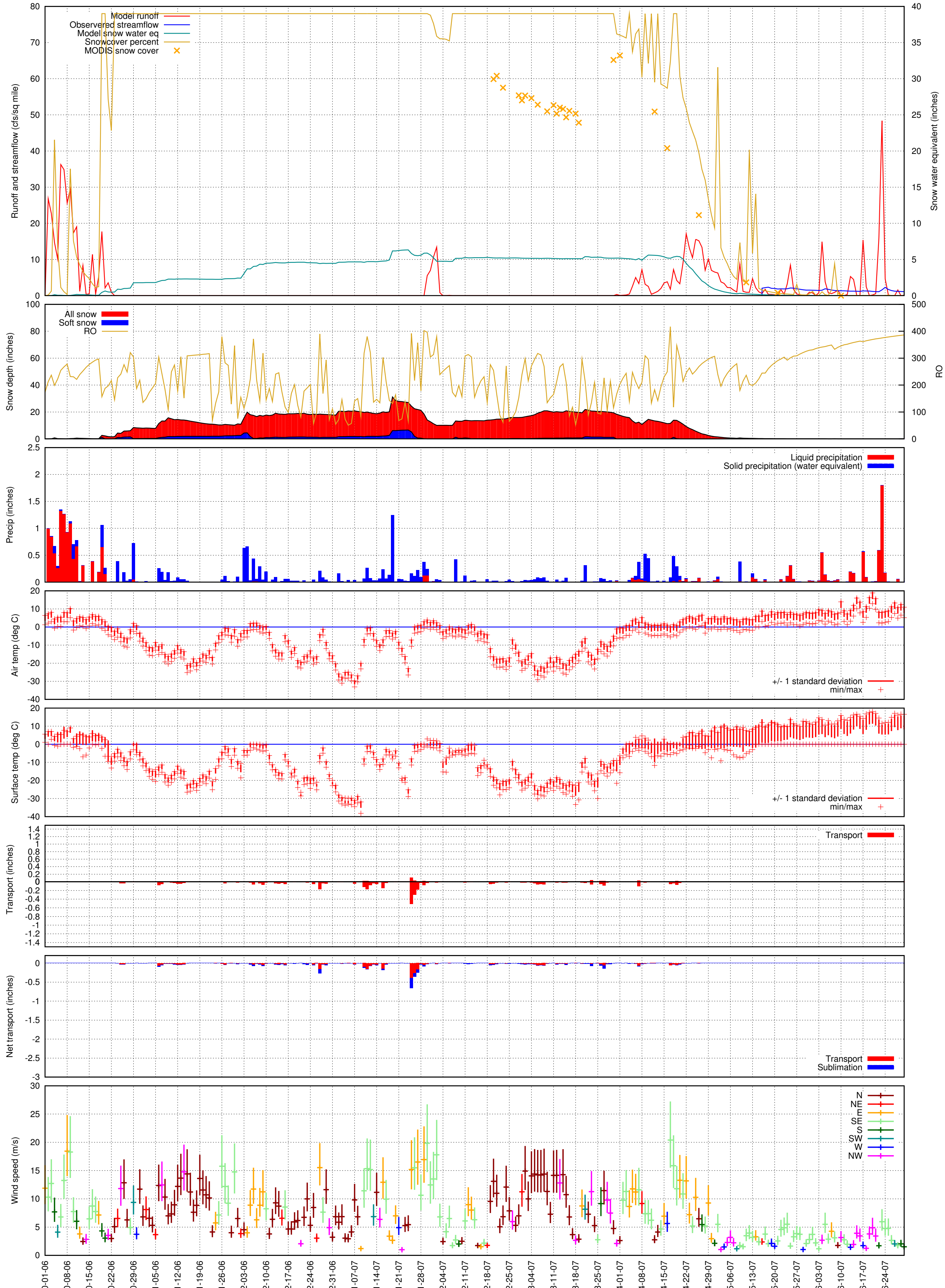
SnowModel Output Summary: 384-foot cells, hourly timestep, precipitation factor 2.0
Basin UT100C, Water Balance Summary, 2005-2008



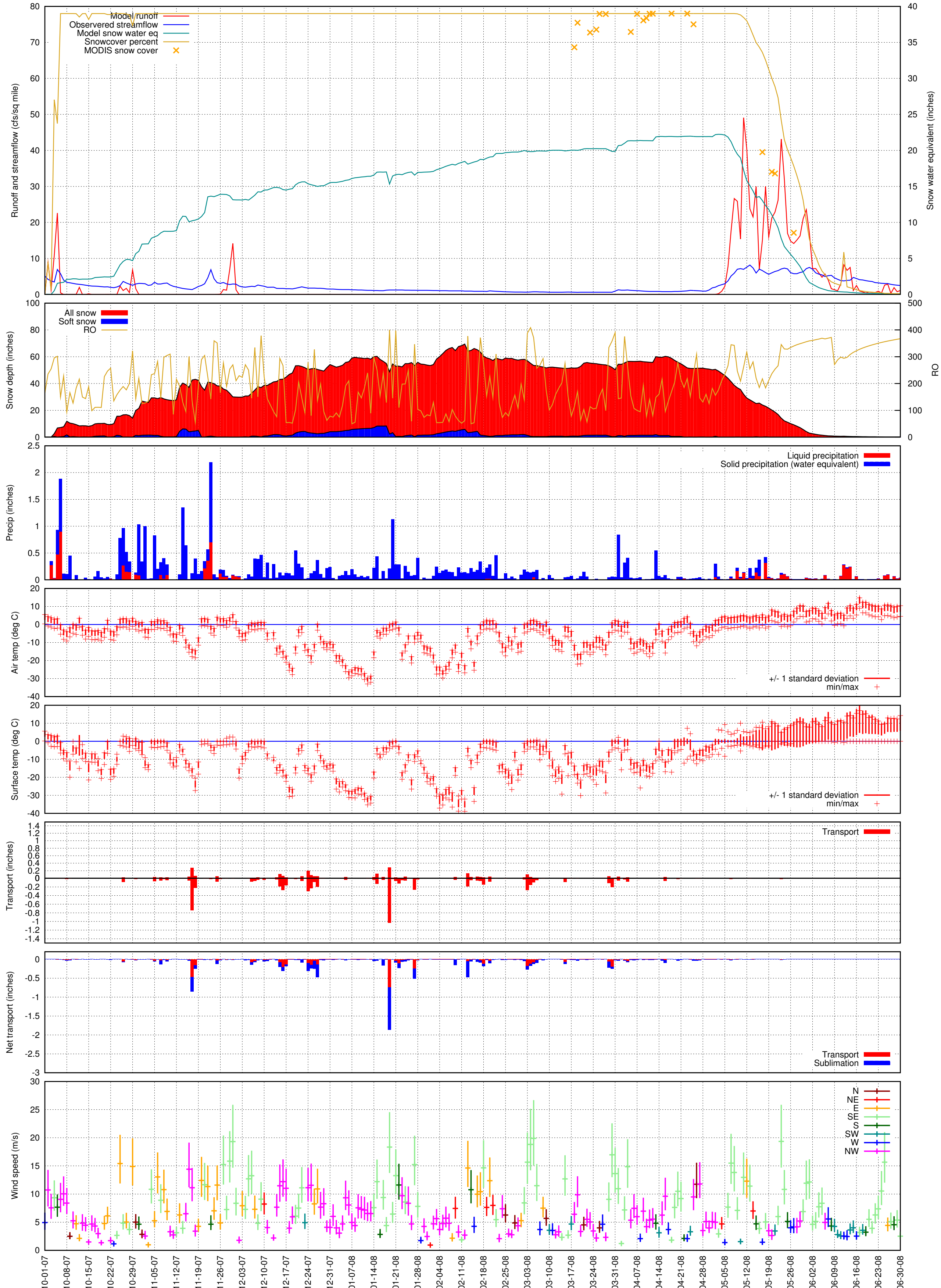
SnowModel Output Summary: 384-foot cells, hourly timestep, precipitation factor 2.0
Basin UT100C1, 2005-2006



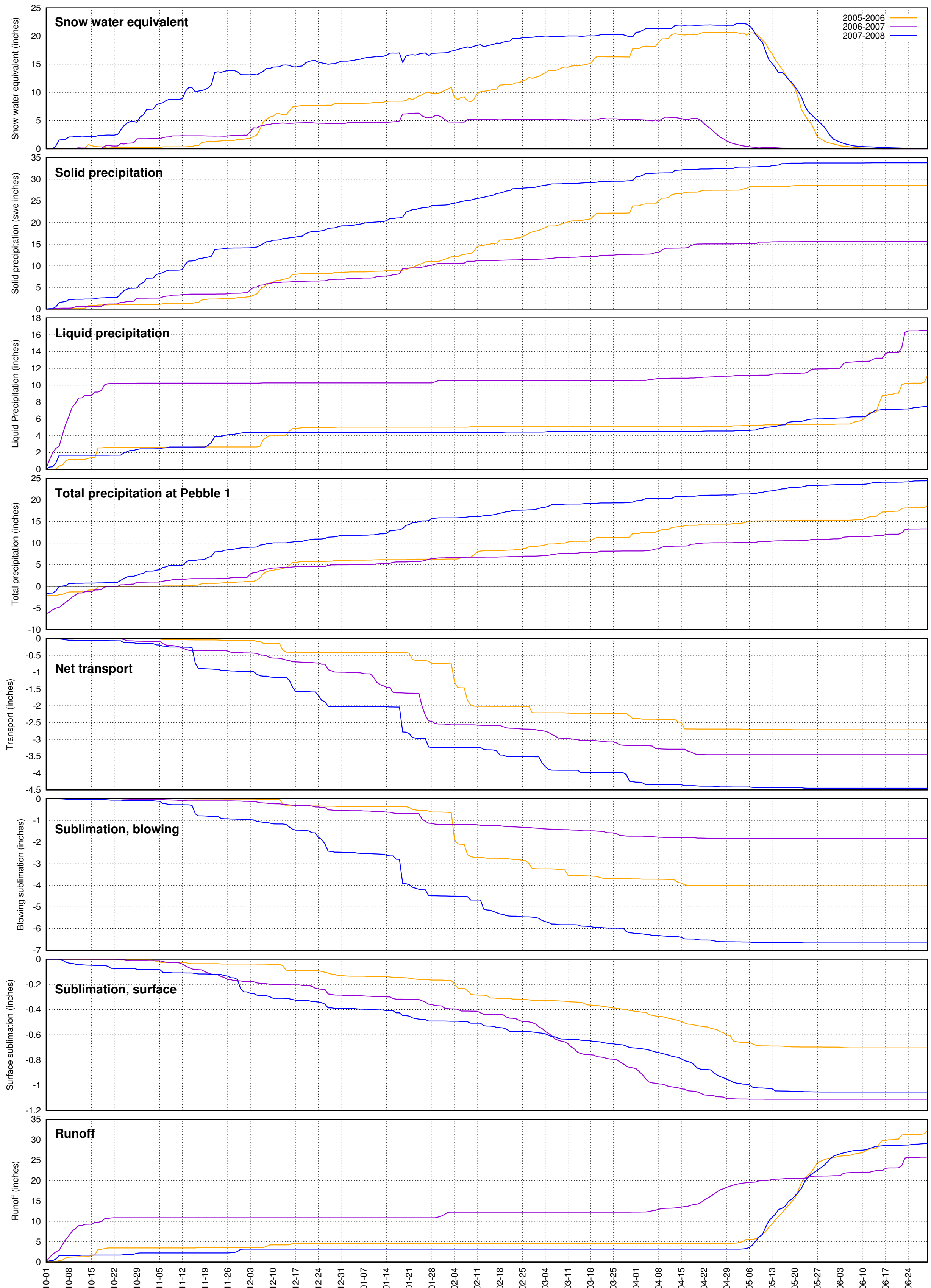
SnowModel Output Summary: 384-foot cells, hourly timestep, precipitation factor 2.0
Basin UT100C1, 2006-2007



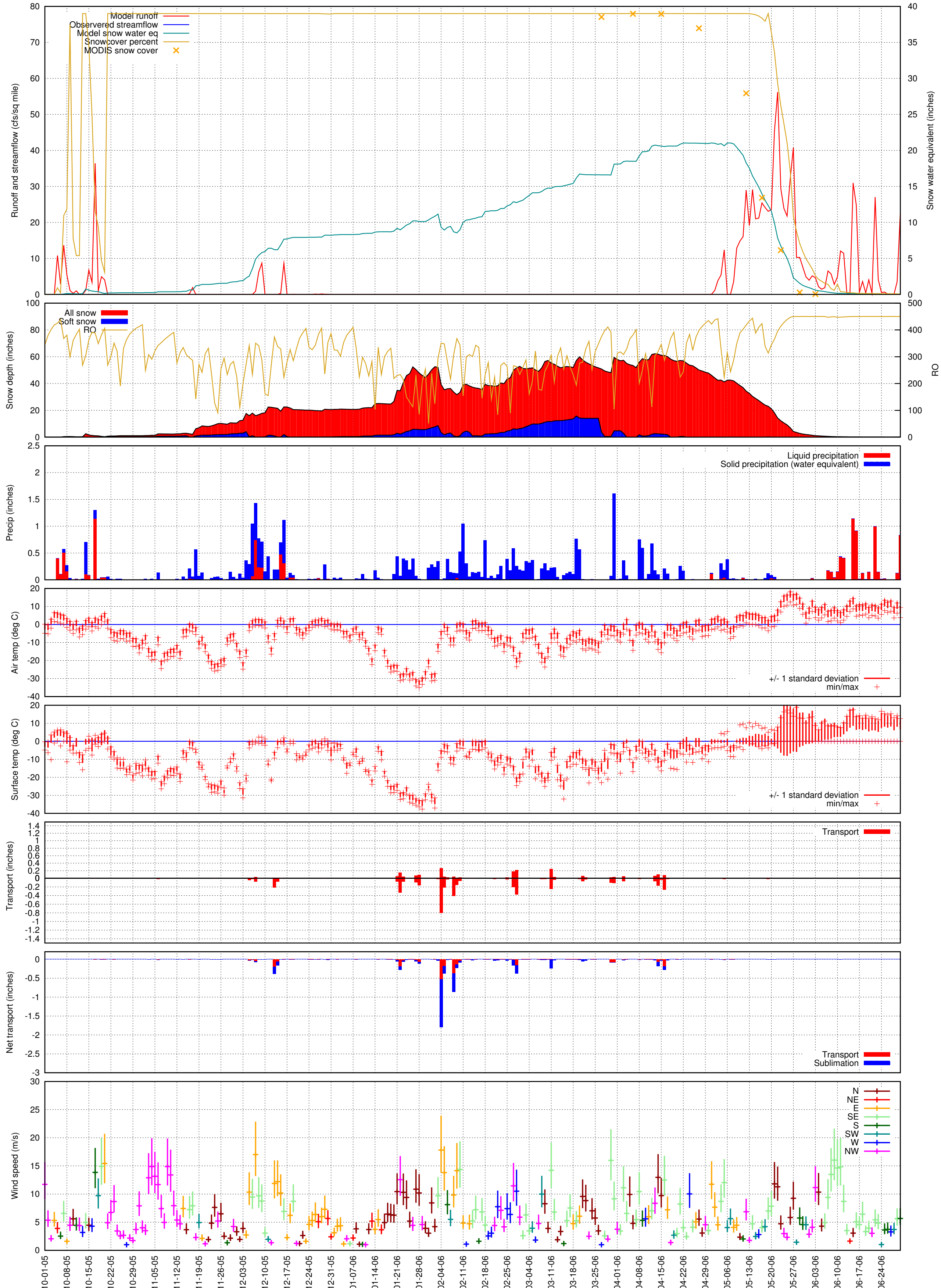
SnowModel Output Summary: 384-foot cells, hourly timestep, precipitation factor 2.0
Basin UT100C1, 2007-2008



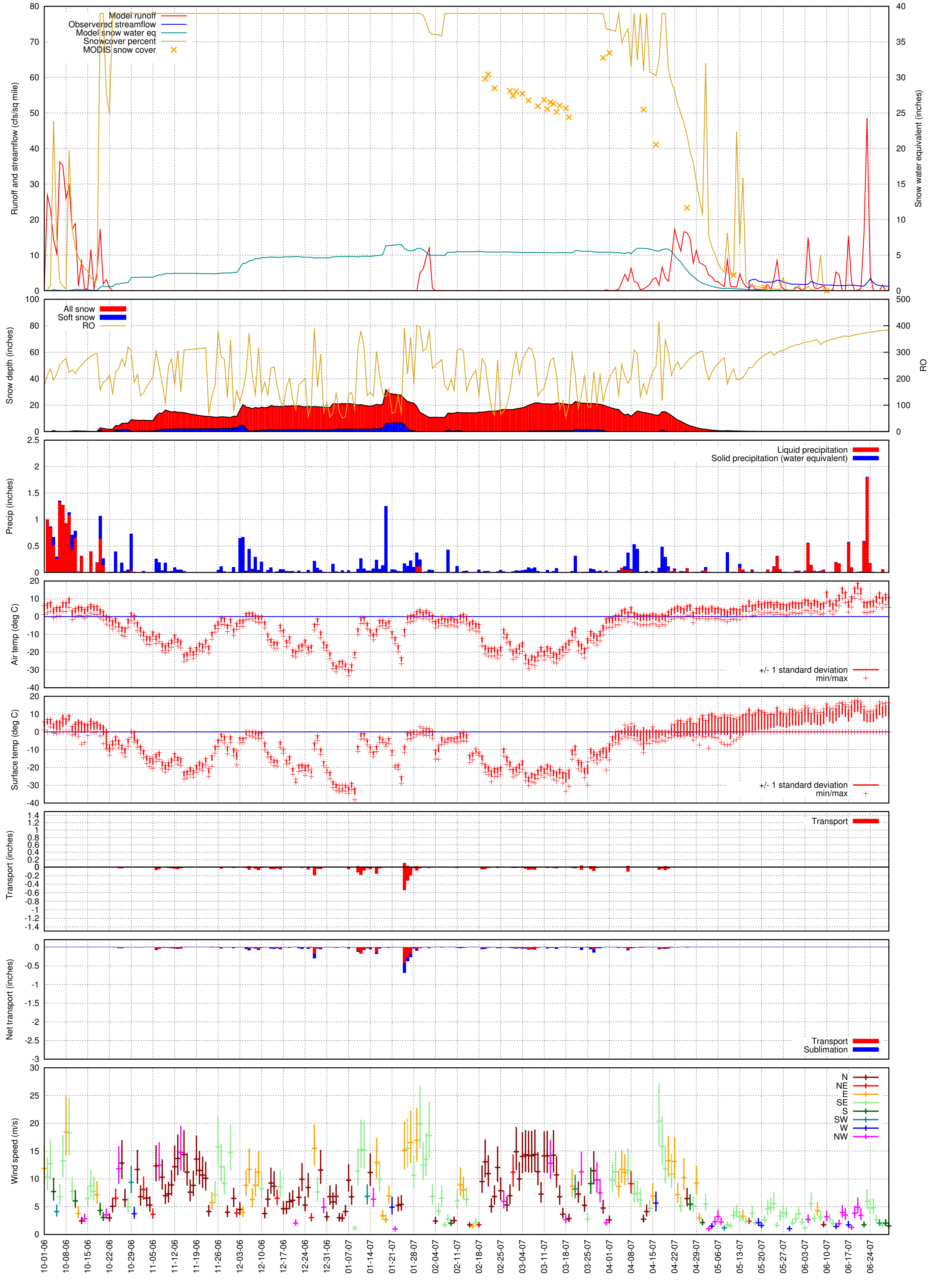
SnowModel Output Summary: 384-foot cells, hourly timestep, precipitation factor 2.0
Basin UT100C1, Water Balance Summary, 2005-2008



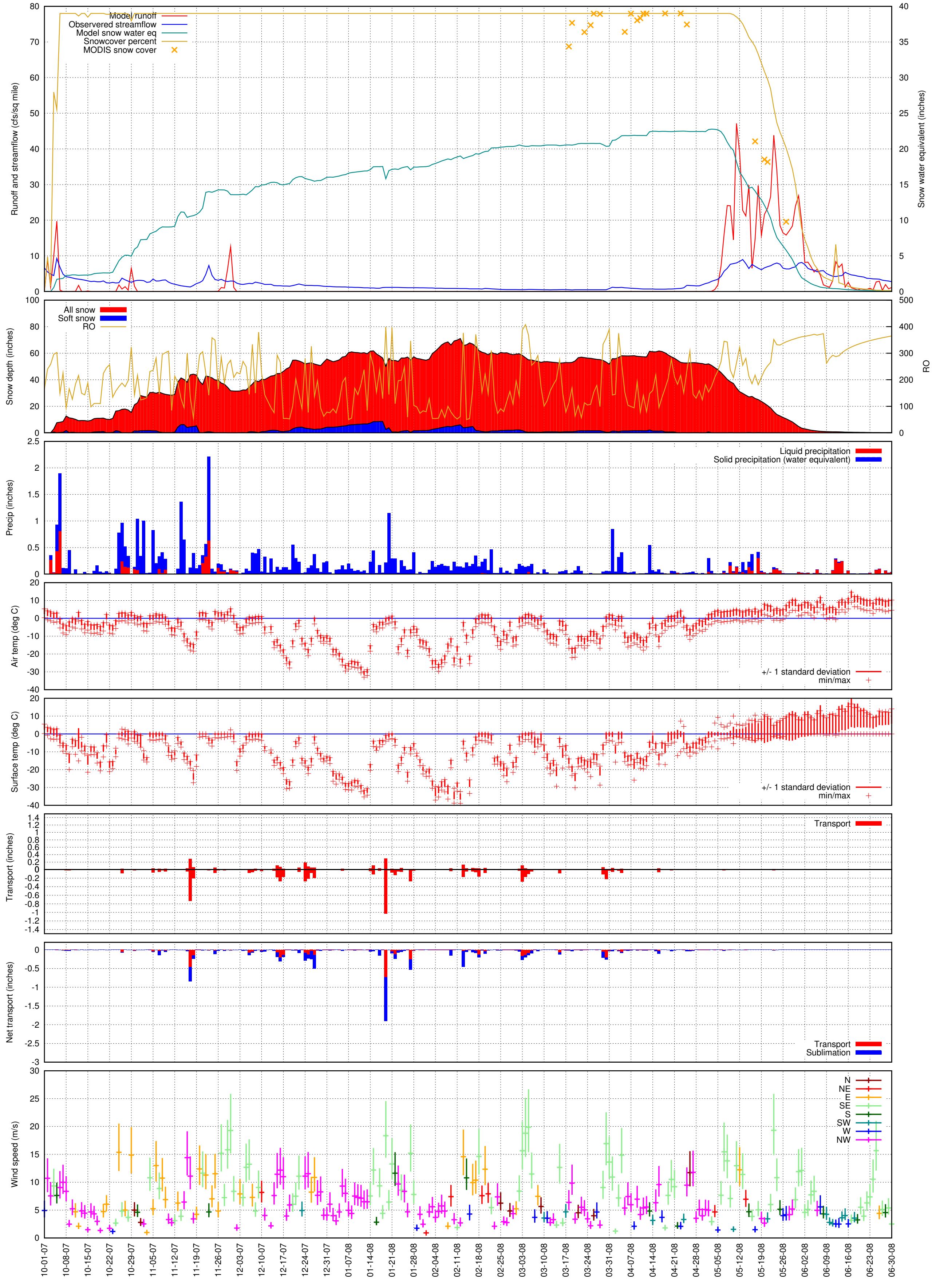
SnowModel Output Summary: 384-foot cells, hourly timestep, precipitation factor 2.0
Basin UT100C2, 2005-2006



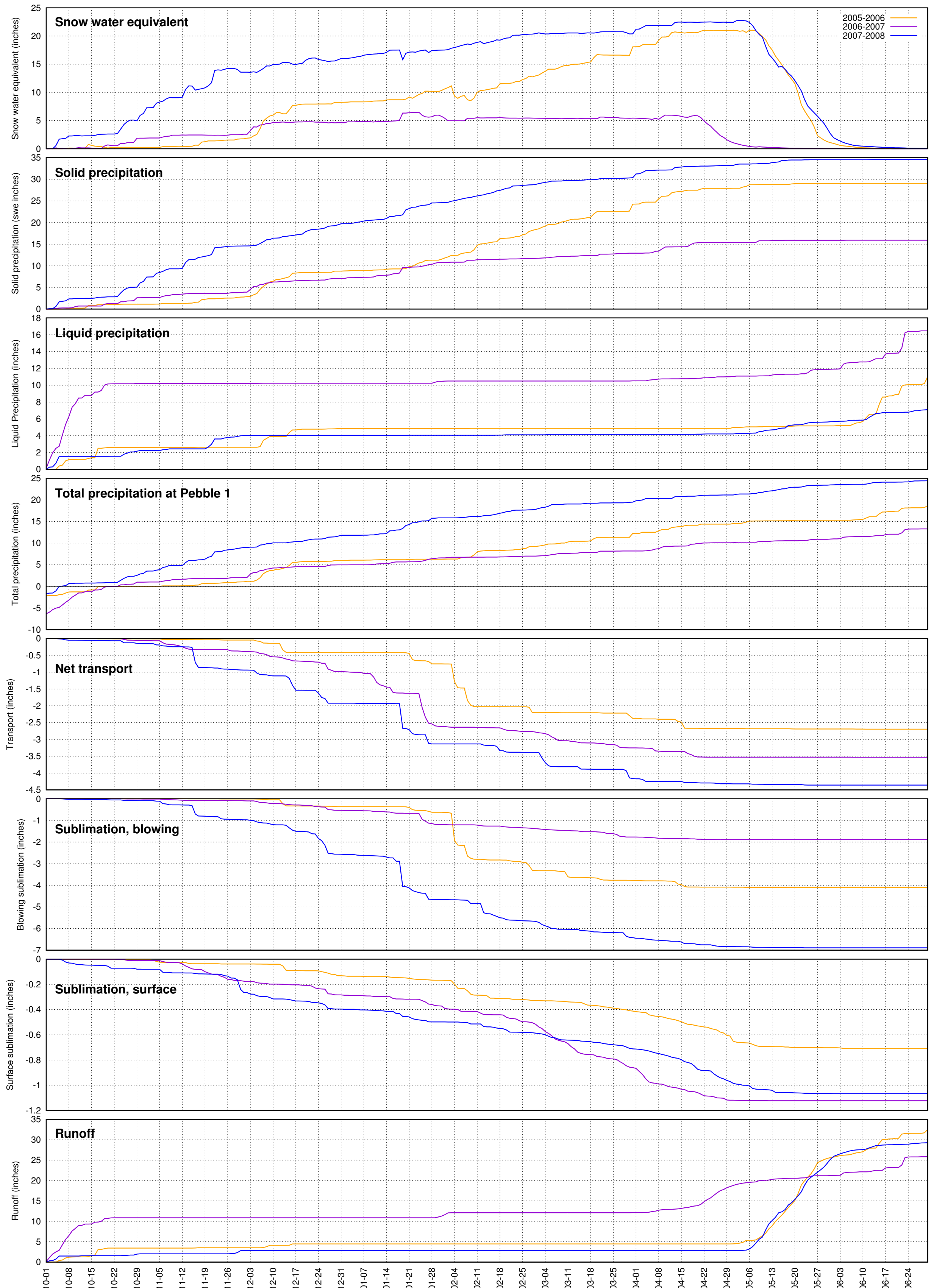
SnowModel Output Summary: 384-foot cells, hourly timestep, precipitation factor 2.0
Basin UT100C2, 2006-2007



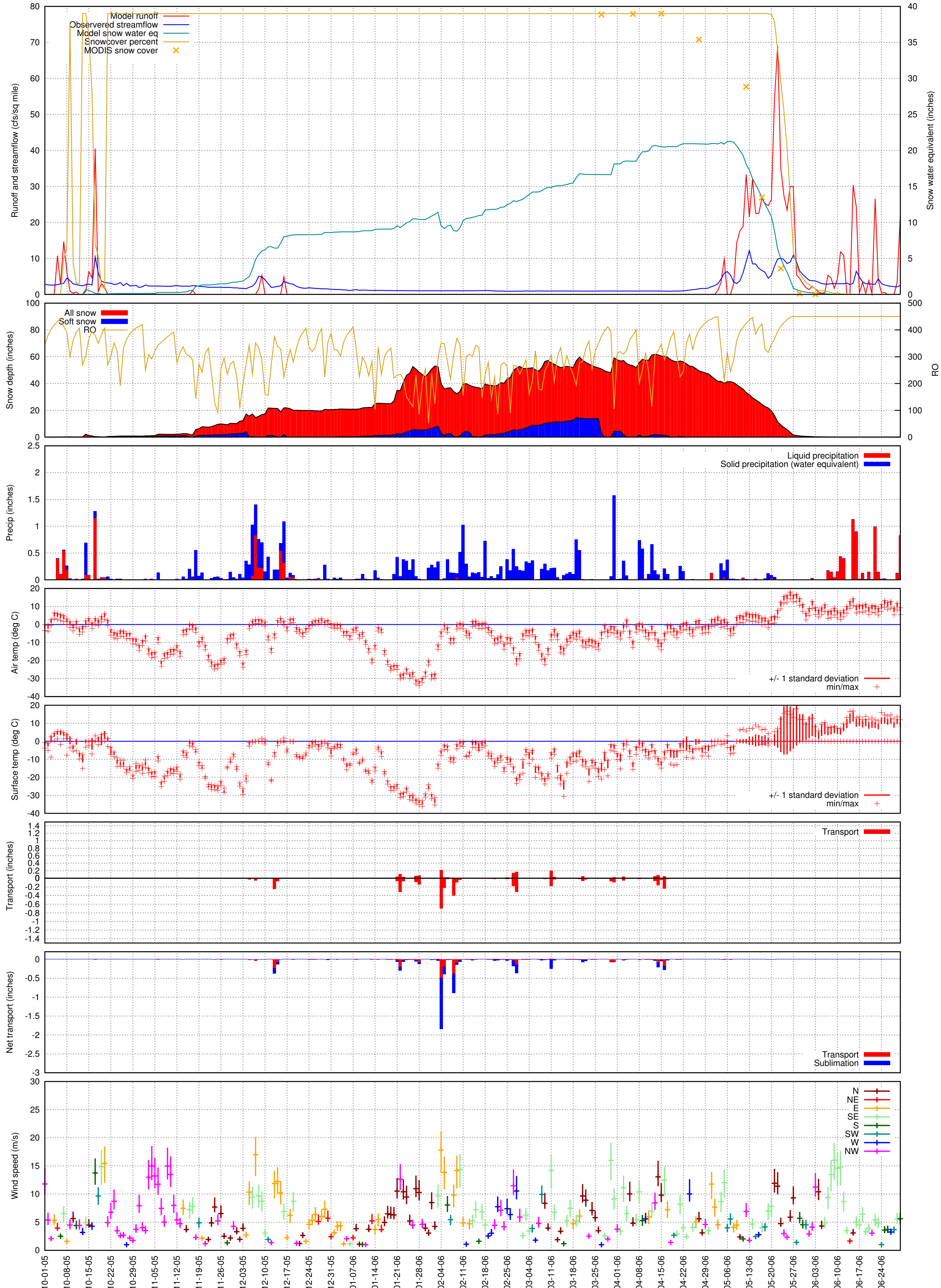
SnowModel Output Summary: 384-foot cells, hourly timestep, precipitation factor 2.0
Basin UT100C2, 2007-2008



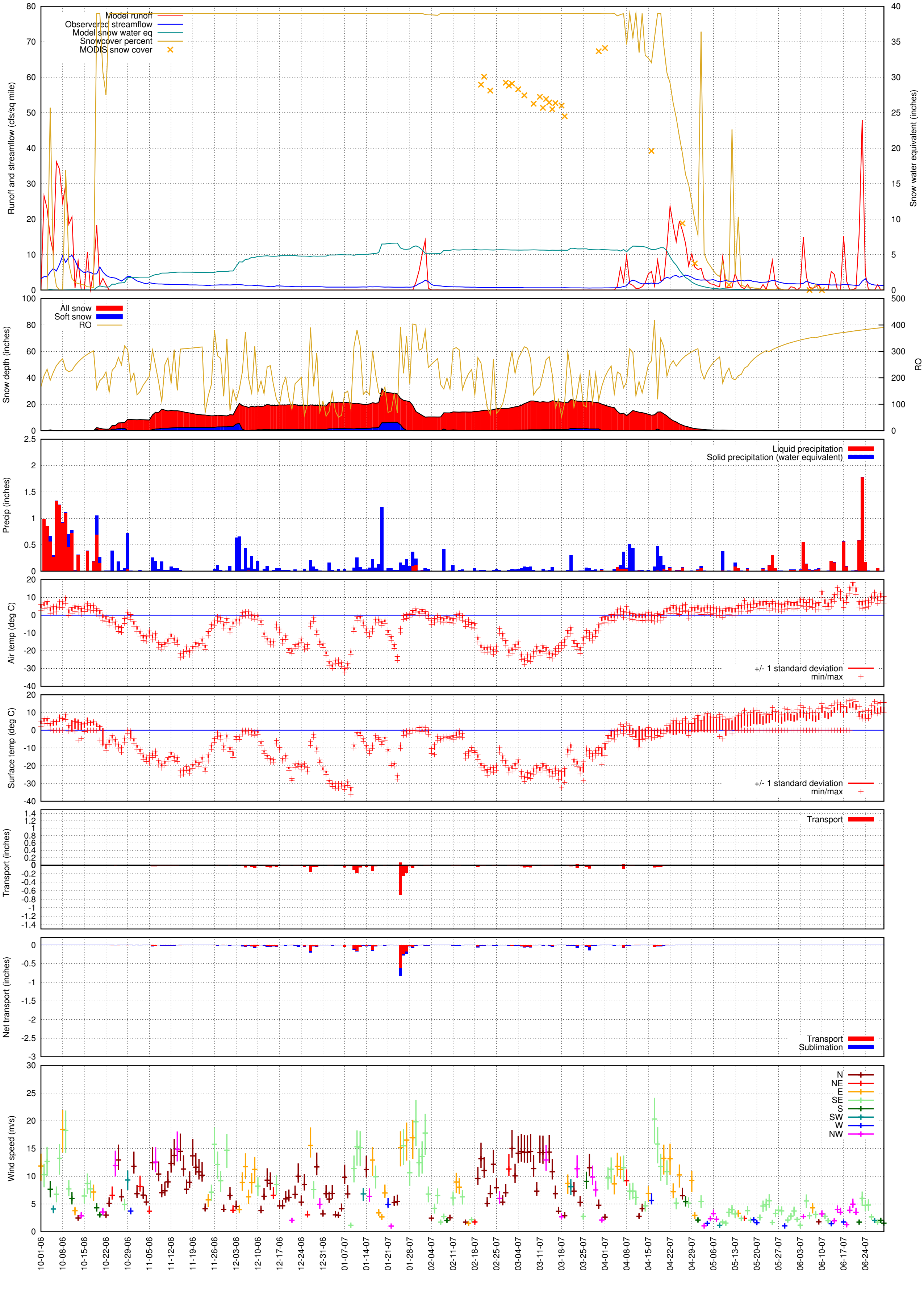
SnowModel Output Summary: 384-foot cells, hourly timestep, precipitation factor 2.0
Basin UT100C2, Water Balance Summary, 2005-2008



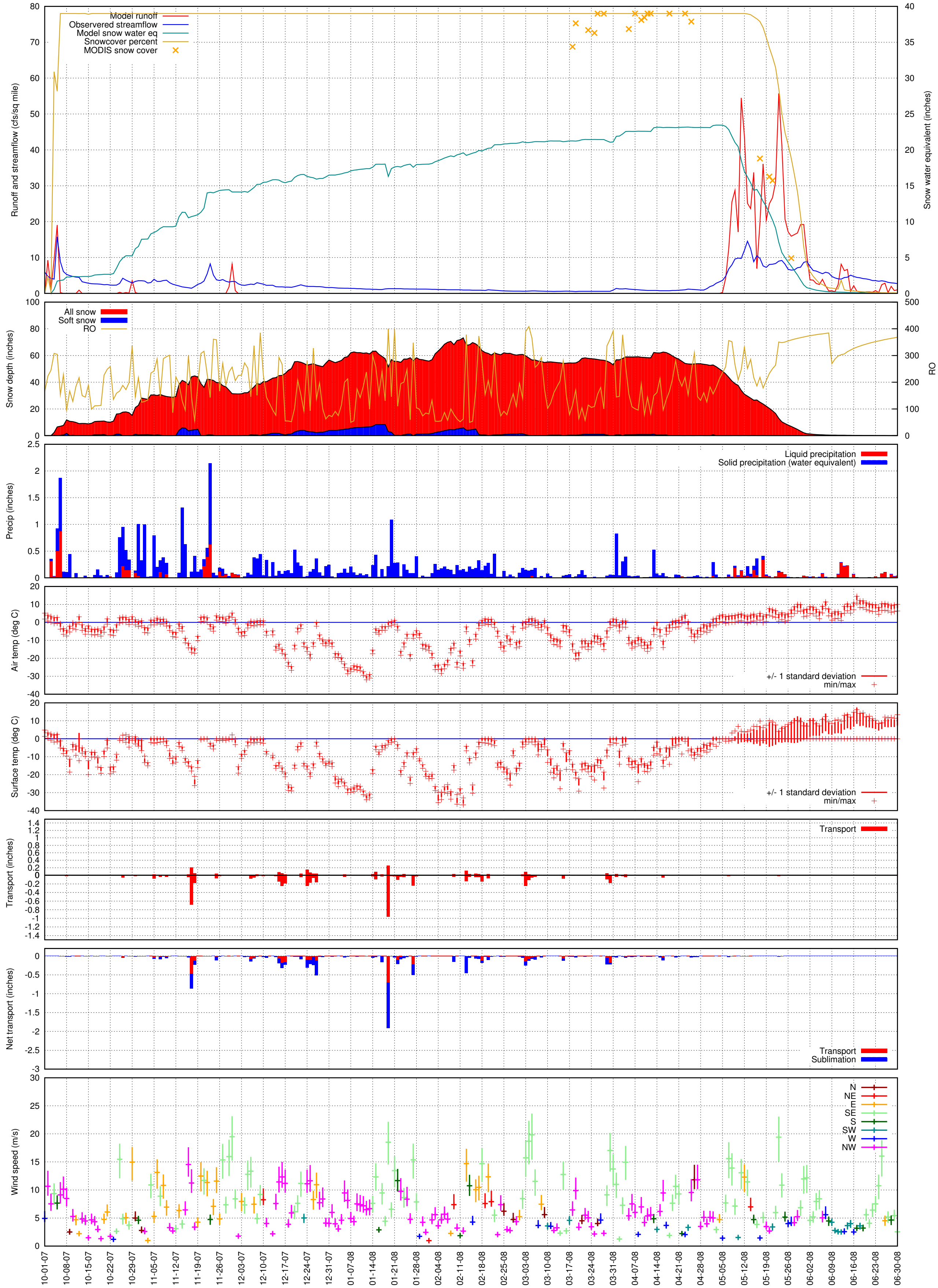
SnowModel Output Summary: 384-foot cells, hourly timestep, precipitation factor 2.0
Basin UT100D, 2005-2006



SnowModel Output Summary: 384-foot cells, hourly timestep, precipitation factor 2.0
Basin UT100D, 2006-2007



SnowModel Output Summary: 384-foot cells, hourly timestep, precipitation factor 2.0
Basin UT100D, 2007-2008



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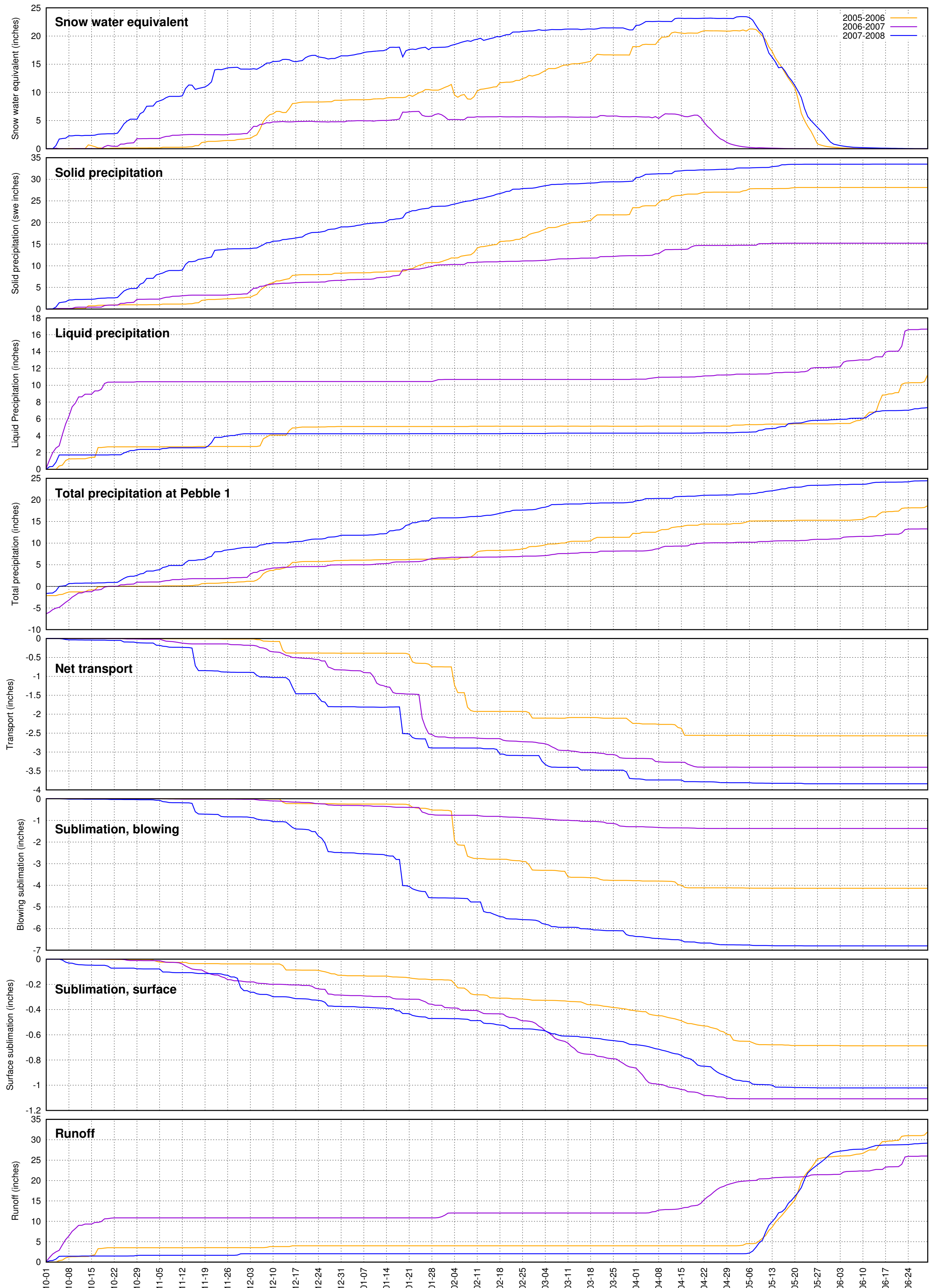
Basin UT100D, Water Balance Summary, 2005-2008



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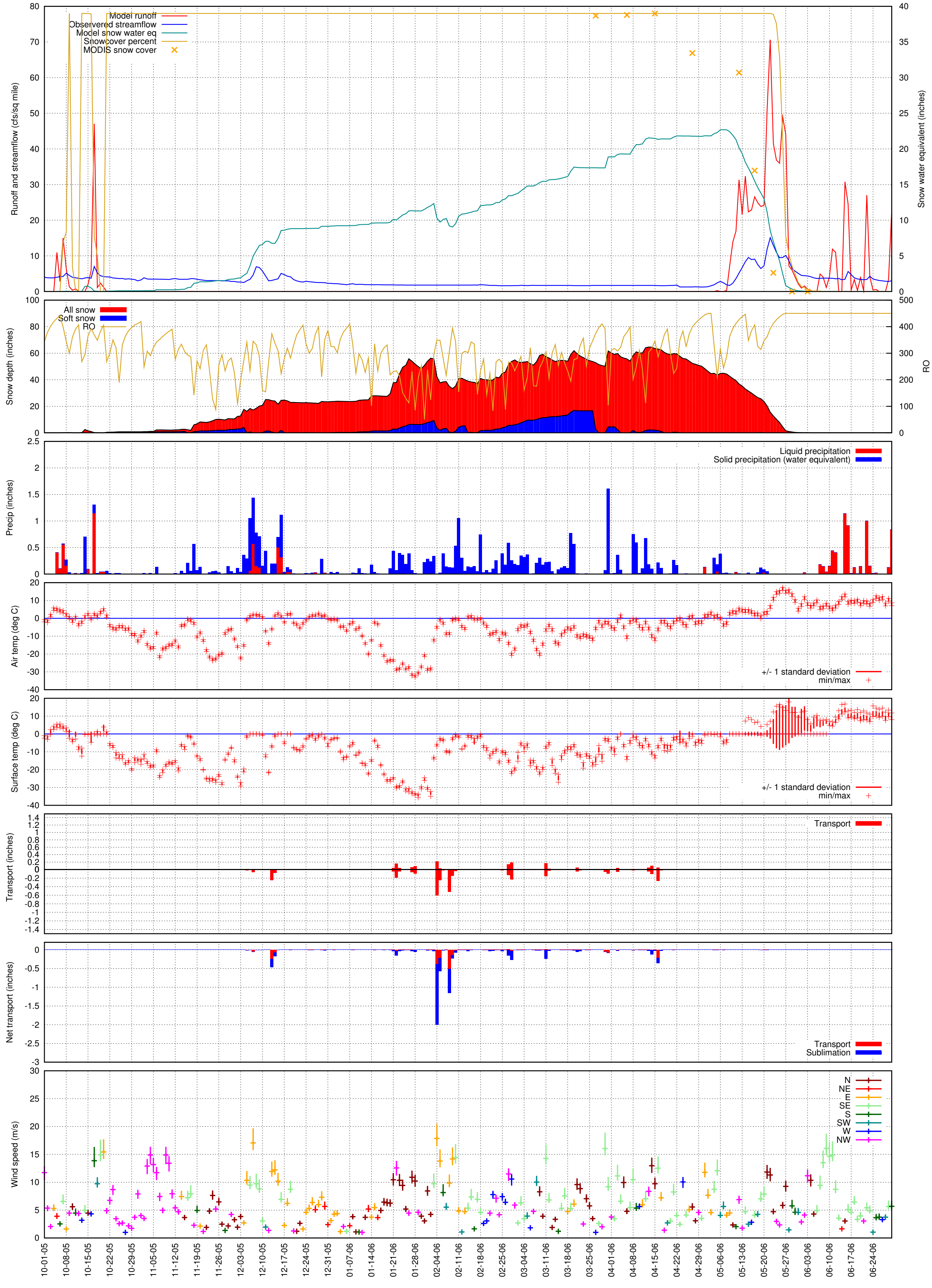
Basin UT100E, 2005-2006



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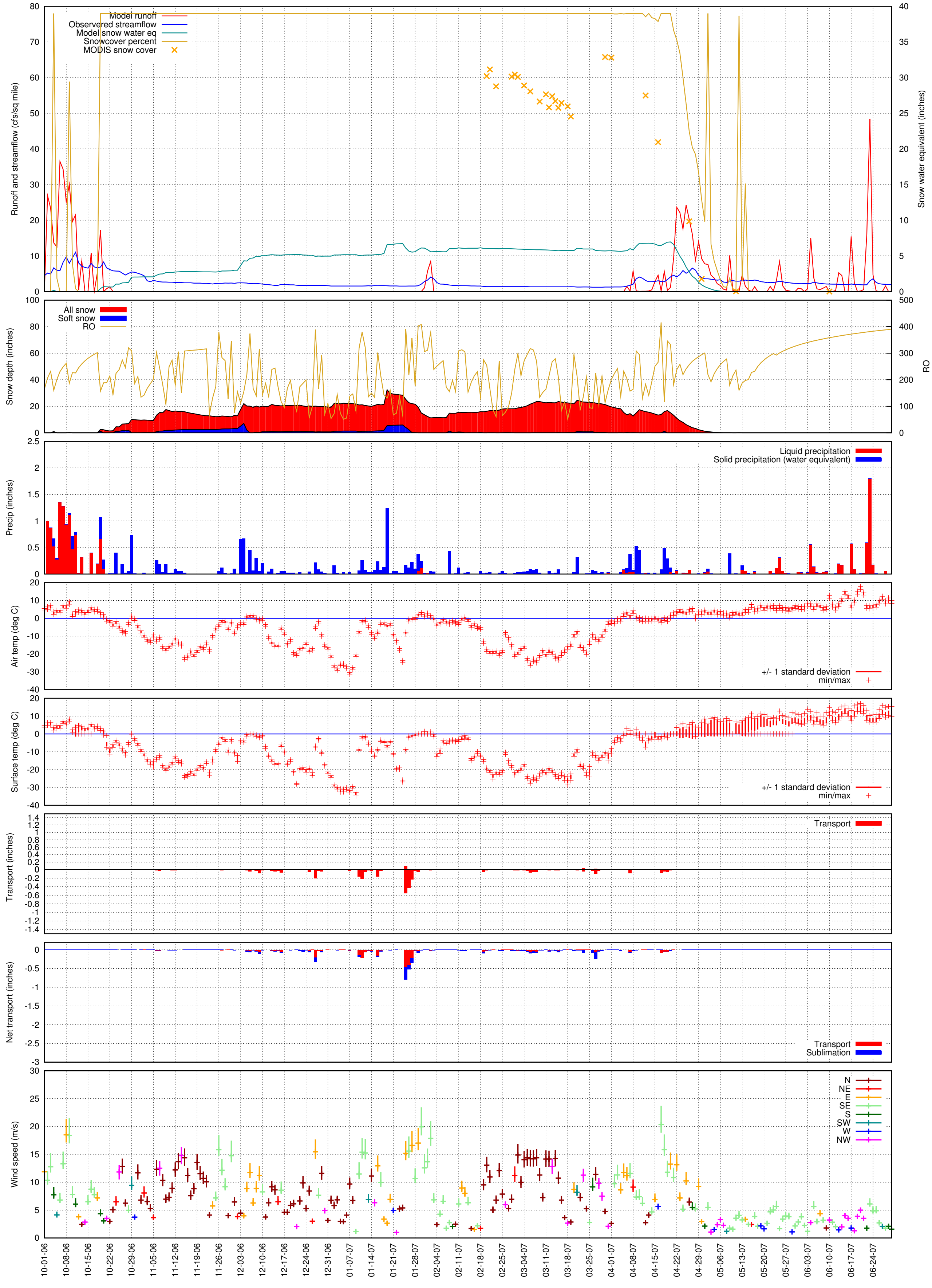
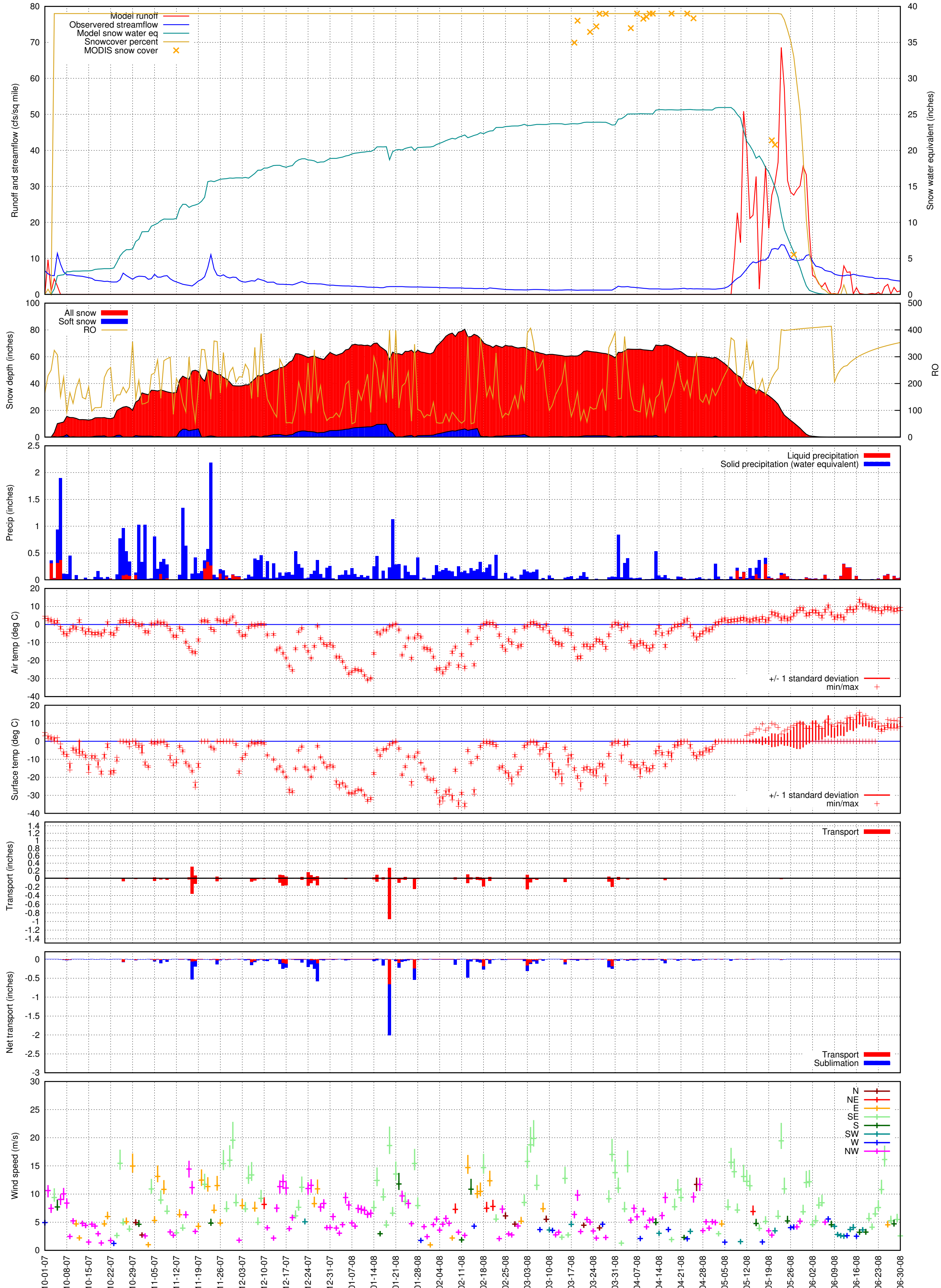
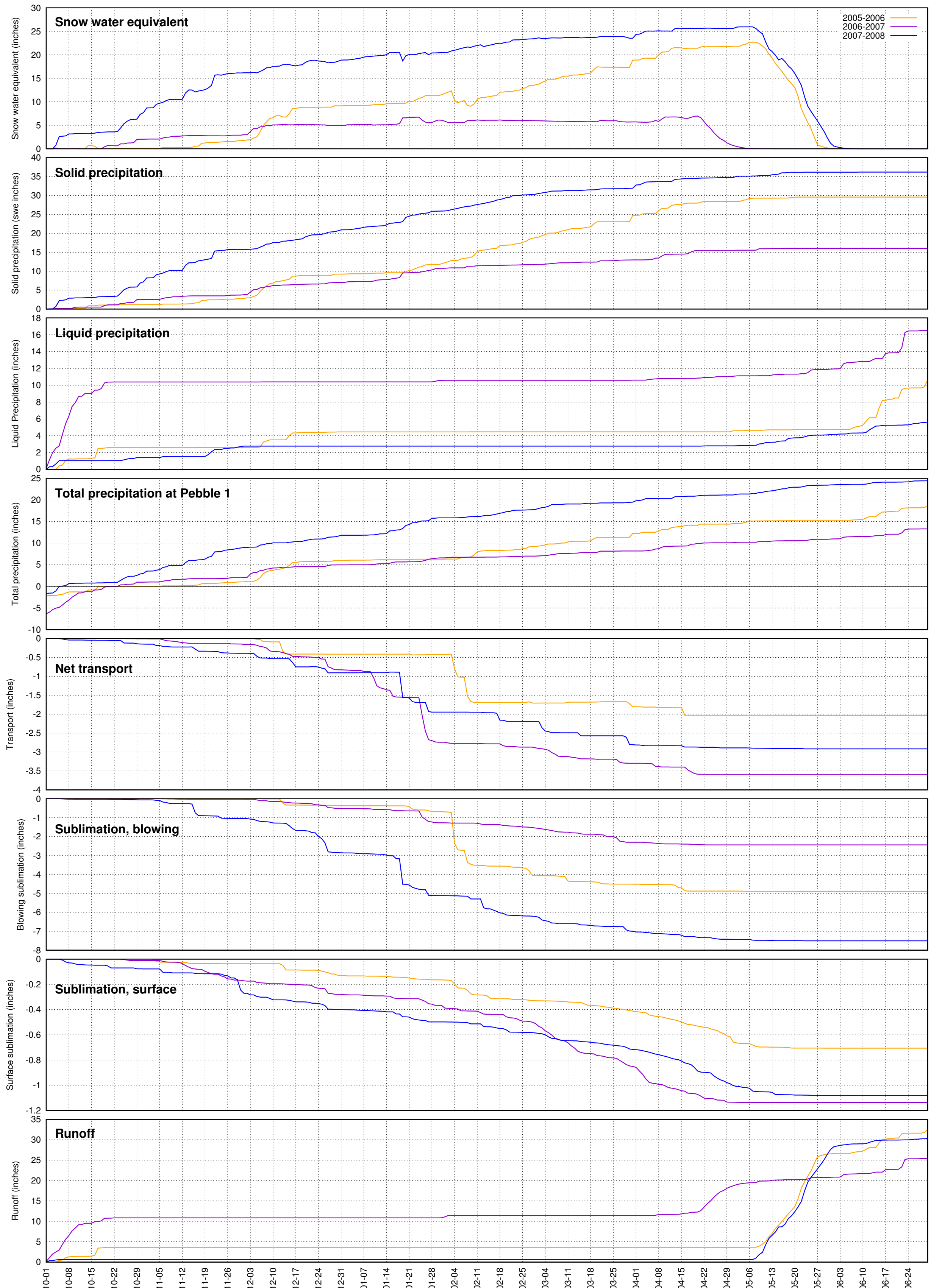


SnowModel Output Summary: 384-foot cells, hourly timestep, precipitation factor 2.0
Basin UT100E, 2007-2008



SnowModel Output Summary: 384-foot cells, hourly timestep, precipitation factor 2.0
Basin UT100E, Water Balance Summary, 2005-2008



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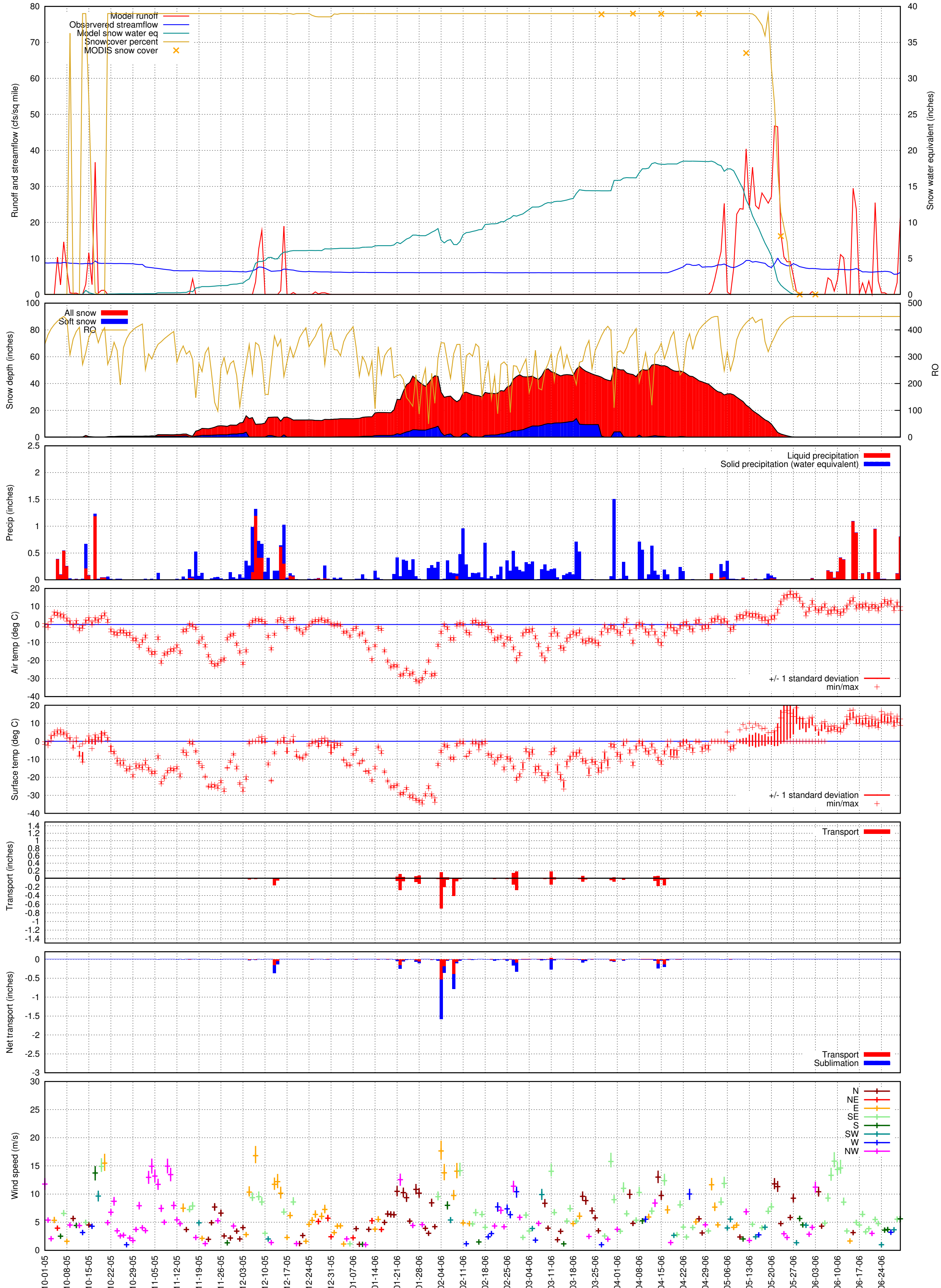
Basin UT119A, 2005-2006



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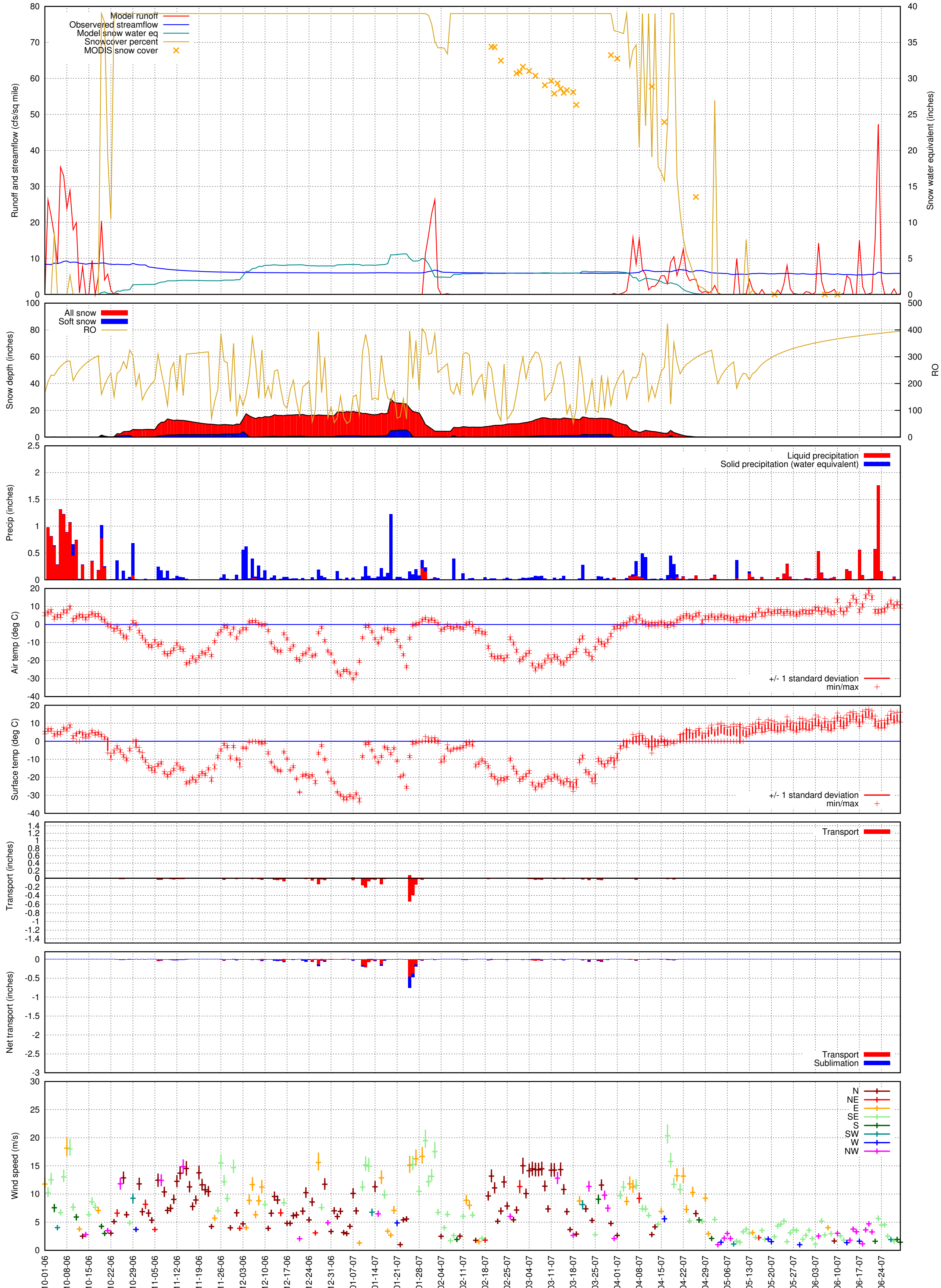

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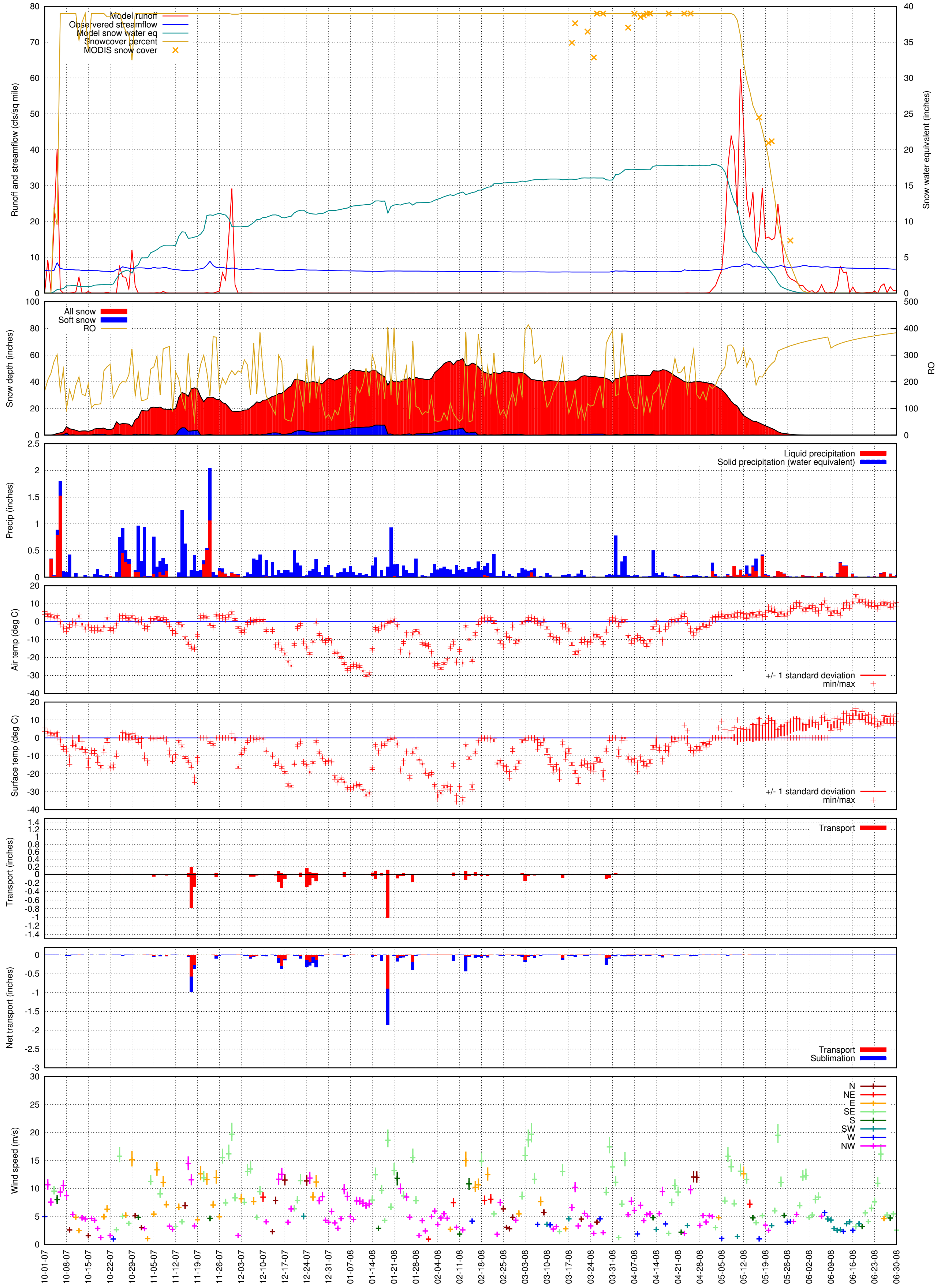

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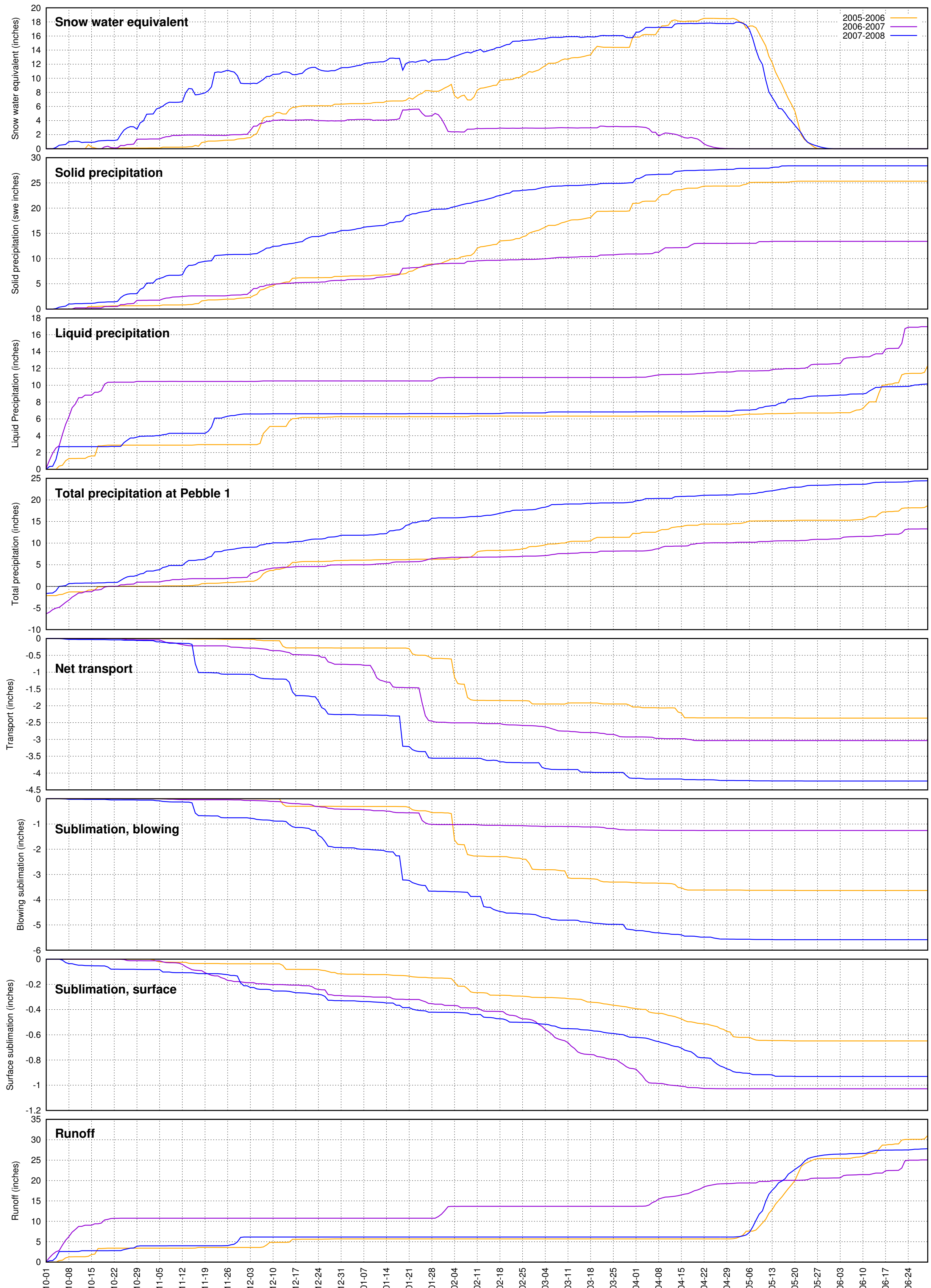
Basin UT119A, Water Balance Summary, 2005-2008



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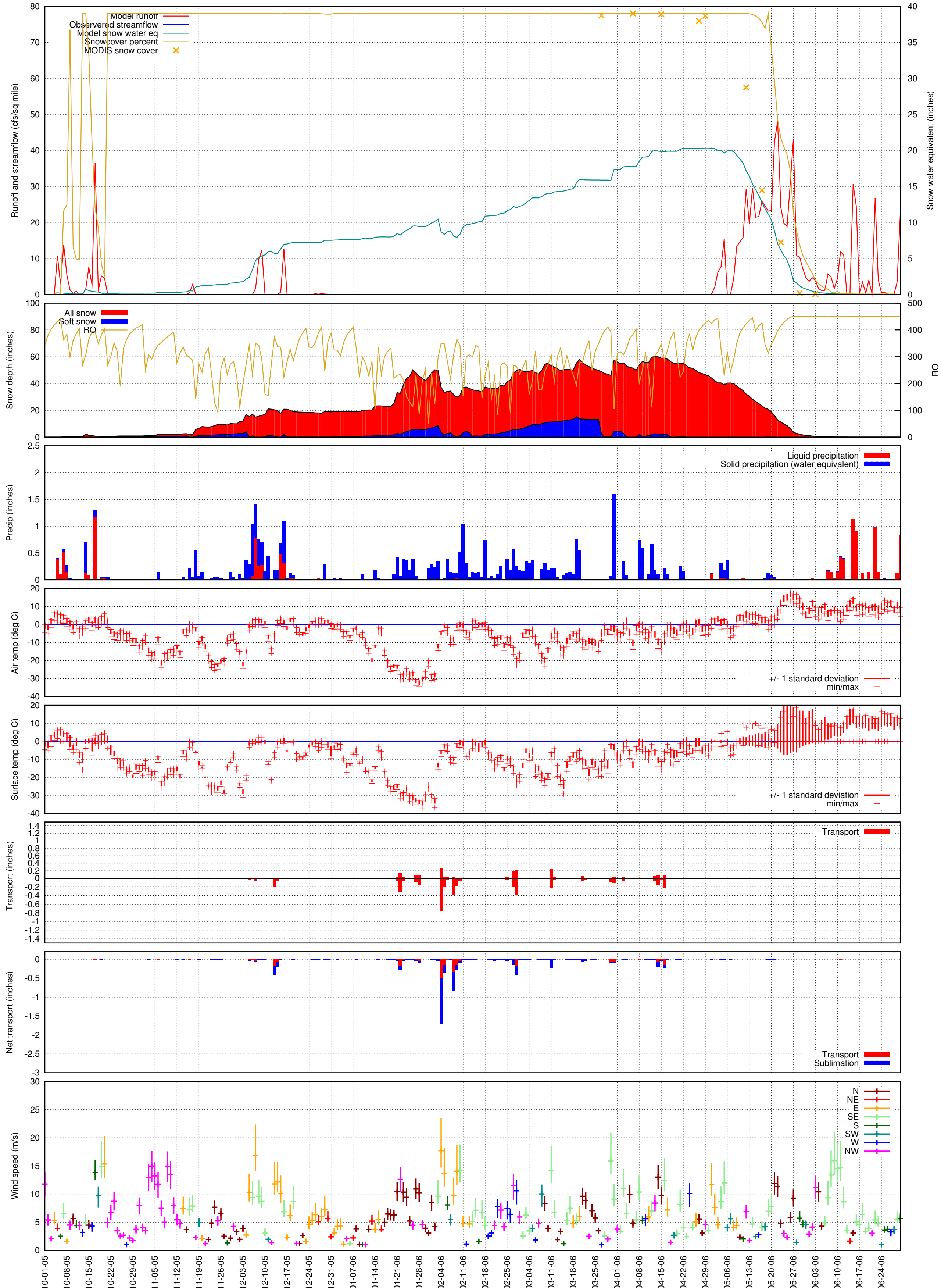
Basin UT135A, 2005-2006



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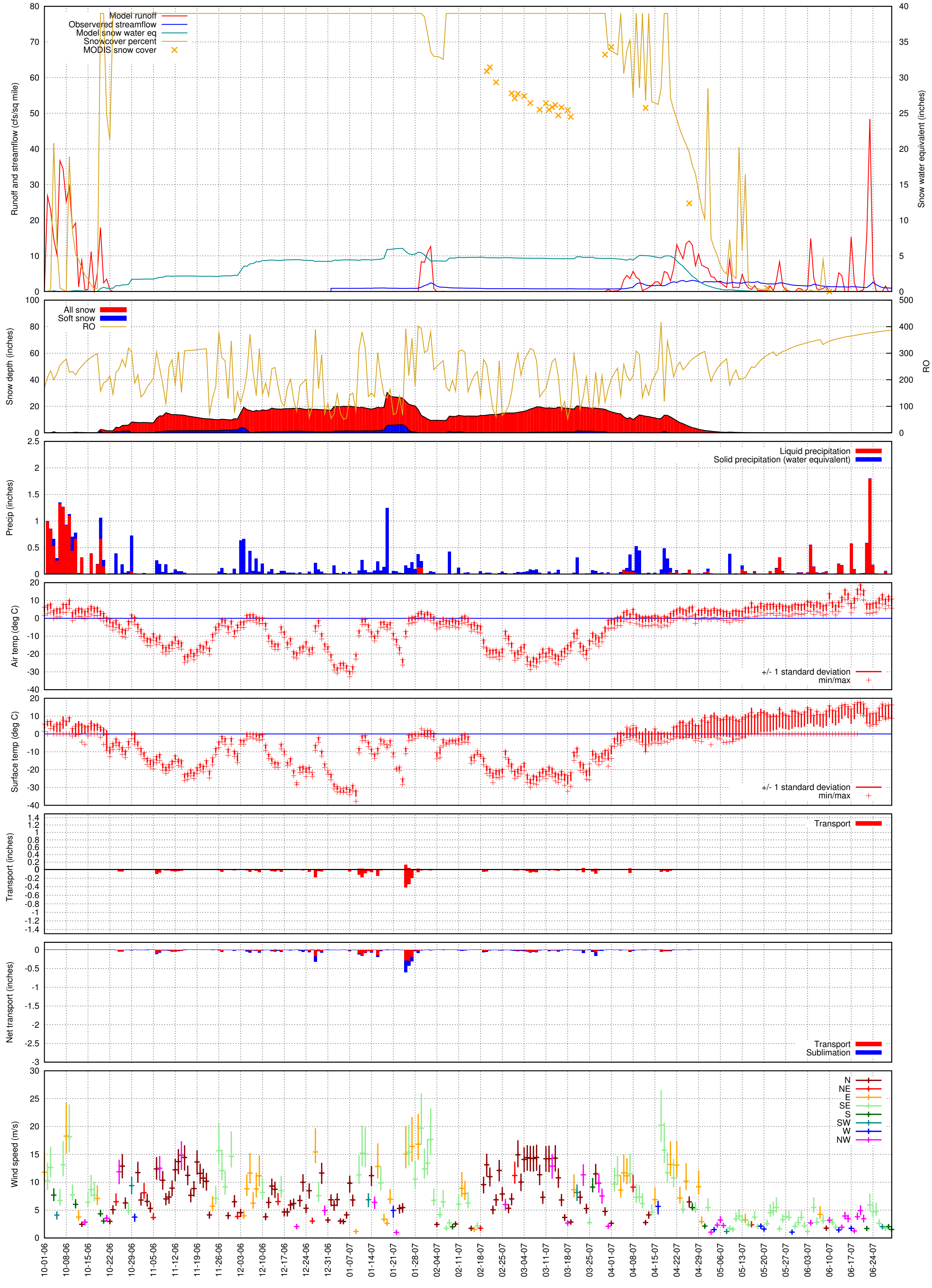
Basin UT135A, 2006-2007



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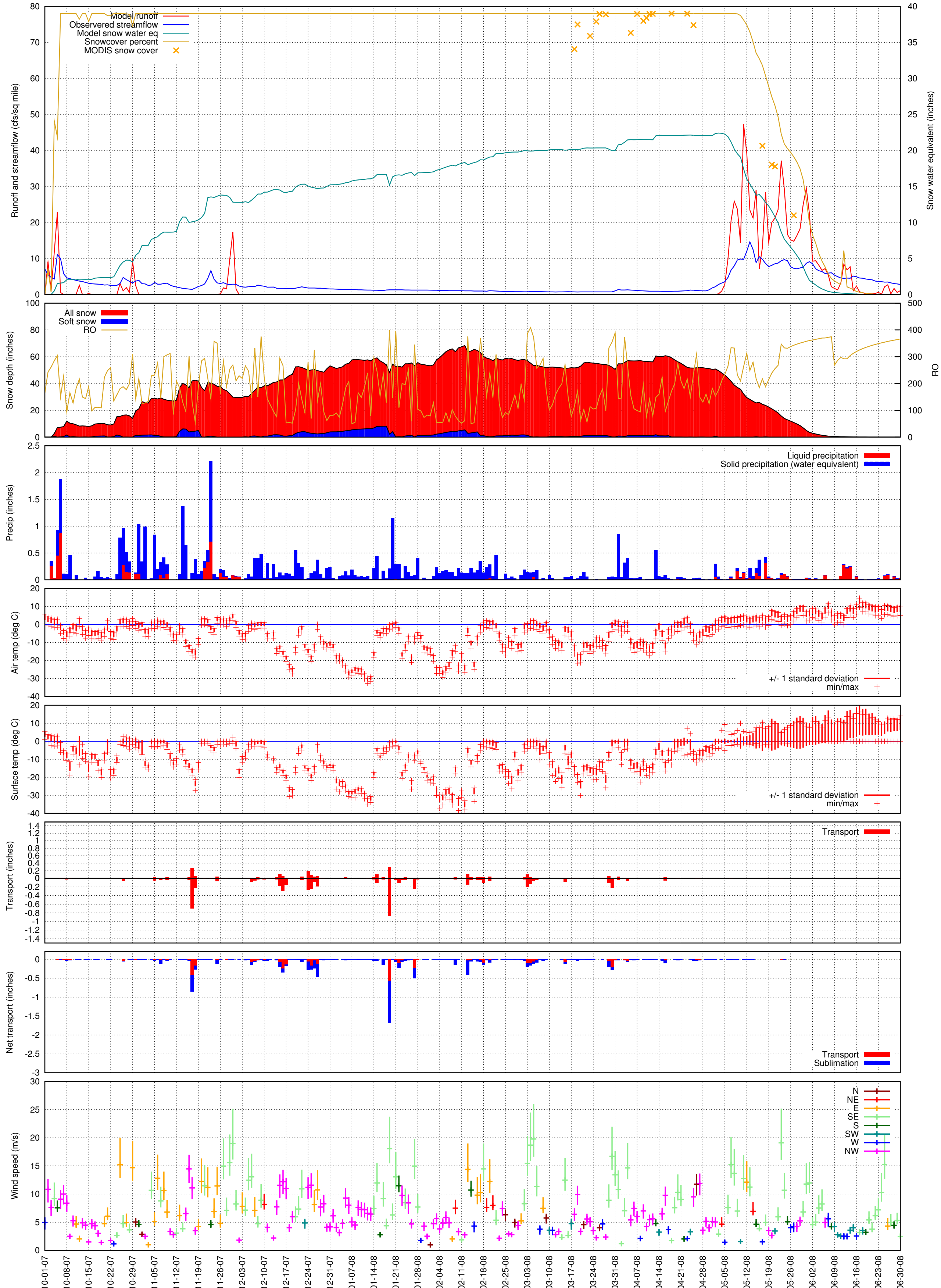
Basin UT135A, 2007-2008



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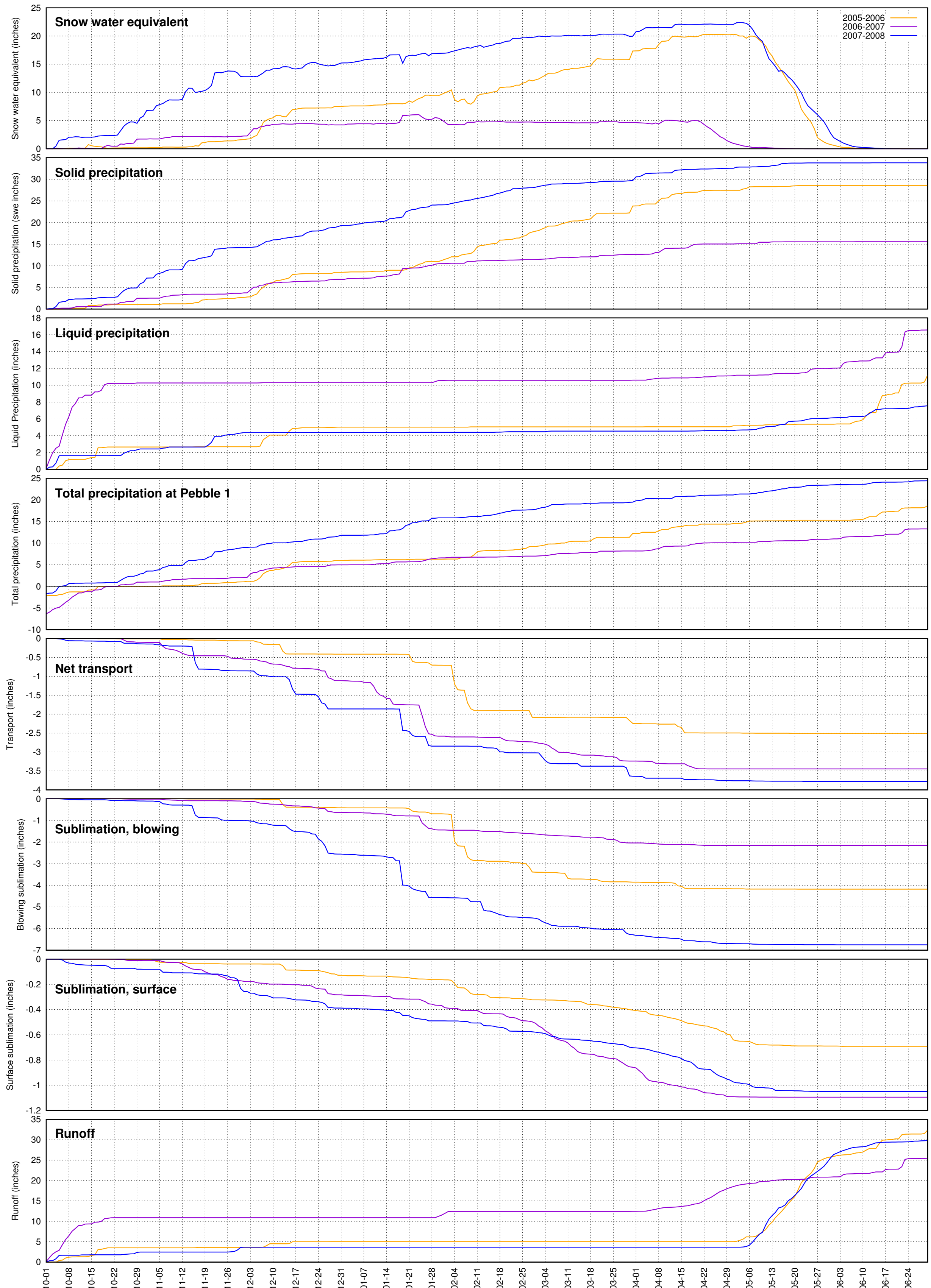
Basin UT135A, Water Balance Summary, 2005-2008



APPENDIX 7.2E

Small Pools—Mine Study Area

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ACRONYMS AND ABBREVIATIONS

°C	degree(s) Celsius
EBD	environmental baseline document
ppm	parts per million
SD	standard deviation

SMALL POOLS—MINE STUDY AREA

1. INTRODUCTION

Wetlands and related deep-water habitats cover greater than 50 percent of the land surface in Alaska (Hall et al., 1994). These wetlands and deep-water habitats provide a variety of ecological and economic functions. For example, Alaska wetlands and deep-water habitats provide habitat for neotropical migratory birds that use the Pacific Americas, Mississippi Americas, and East Asian/Australian flyways (DeGraaf and Rappole, 1995), including approximately 70,000 swans, 1 million geese, and 12 million ducks annually (Hall et al., 1994). The importance of these wetlands and deep-water habitats to these and other species increases significantly when droughts occur in the prairie states and Canadian provinces (Derksen and Eldridge, 1980).

Small pools are among the most prevalent and noticeable hydrological features in Alaska and similar glacial and periglacial environments (Hall et al., 1994; Tiner, 2003; Prowse et al., 2006). In subarctic Alaska, small pools typically occur as moraine, ice-scour, or dead-ice depressions on the undulating, often low-permeability terrain (Prowse et al., 2006). Many of these small pools are closed-basin depressions, where surface water inflows and outflows are negligible (Marsh and Woo, 1977; Tiner, 2003; Ferone and Devito, 2004; Prowse et al., 2006; Woo and Guan, 2006). Such small pools are particularly common in the Cook Inlet Region of southcentral Alaska, where five major Pleistocene glacial advances and numerous minor Holocene glacial advances have been recorded (Karlstrom, 1964). Little hydrologic research has been conducted on these common yet understudied systems, with much of this limited research focused on small pools occurring as thermokarst depressions (Marsh and Woo, 1977; Woo et al., 1981; Woo and Xia, 1995; Woo and Guan, 2006) rather than small pools occurring as kettle, moraine, and ice-scour depressions (Ferone and Devito, 2004).

The Pebble Project small pools study was initiated in 2005, with major field work occurring in 2006 and 2007. The broad objective of the study was to quantify the surface water and groundwater interactions in small pools and the hydrological connectivity between small pools and broader hydrological landscapes. The project had two phases. The first phase focused on extensive data collection and analysis at seven small pools at three sites, and the second phase expanded on this through limited data collection and analysis at 123 small pools throughout the region. Throughout, this study was guided by the hypothesis that there are two types of small pools that differ with respect to water sources and hydrodynamics. One type are small pools that have inflows by meltwater and direct precipitation, outflows by evapotranspiration and groundwater recharge, and are seasonally inundated because infiltration through the low-permeability surficial deposits is slow. The other type are small pools that have inflows by meltwater, direct precipitation, and groundwater discharge; outflows by evapotranspiration and groundwater recharge; and are perennially inundated because of the groundwater throughflow.

2. STUDY OBJECTIVES

The specific objectives of the small pools study were as follows.

- To describe and quantify the surface water and groundwater interactions between small pools and the broader hydrological landscape.
- To test the hypothesis that there are two types of small pools which differ with respect to water sources and hydrodynamics.
- To develop a methodology by which remote sensing and/or field data can be used to rapidly distinguish between the two types of small pools.

3. STUDY AREA

The Pebble small pools study area includes 100,934 hectares located west of Cook Inlet, southwest of Lake Clark, and north of Iliamna Lake, in southwest Alaska (Figure 1). The study area is in the Nushagak-Big River Hill physiographic division, which is characterized by low, rolling hills separated by wide, shallow valleys (Wahrhaftig, 1965). The study area is near the southern boundary of the discontinuous permafrost zone of Alaska (Péwé, 1975), though field observations suggest that the study area lacks permafrost. The predominant vegetation is scrub-shrub, largely composed of various combinations of dwarf trees and tall, low, and dwarf shrubs (Viereck et al., 1992).

The study area is primarily underlain by Upper Cretaceous-Tertiary intrusive rocks including granodiorite, quartz monzonite, and quartz diorite, which are partially covered by Tertiary and Quaternary volcanic and sedimentary rocks and deposits (Detterman and Reed, 1973b). There were at least four major Pleistocene glacial advances: the Mak Hill glaciations, with surficial deposits greater than 39,000 years before present (Detterman and Reed, 1973a; Mann and Peteet, 1994; Hamilton and Klieforth, 2010), and the Kvichak, Iliamna, and Newhalen stades of the Brooks Lake glaciation, with surficial deposits ranging from 26,000 to 10,000 years before present (Detterman and Reed, 1973a; Stilwell and Kaufman, 1996; Hamilton and Klieforth, 2010). These glacial advances left complex surficial deposits, including arcuate (i.e., bow-shaped) end moraines enclosing irregular, hummocky ground moraines; linear lateral moraines on the lower elevations of valley sidewalls; irregular, hummocky ice-contact melt-water deposits; and pitted outwash plains and valley trains extending down valley from end moraines. Kettle depressions are prominent features in many of these surficial deposits.

4. PREVIOUS STUDIES

No other previous studies of small pools are known to exist for the study area.

5. SCOPE OF WORK

Field reconnaissance and project design, site selection, and infrastructure installation for the first phase of the field data collection occurred in 2005. Major field work for the first and second phases of the field data collection occurred in 2006 and 2007, respectively. The study was conducted by Coshow

Environmental, Inc., with assistance from Three Parameters Plus, Inc., SLR International Corp, Water Management Consultants, Inc., Hoefler Consulting Group, Inc. (now part of SLR International Corp), and Resource Data Inc. Dissolved-constituent analyses were performed by SGS Environmental Services, Inc. Quality assurance for the dissolved-constituent analyses was performed by Columbia Analytical Services, Inc.

The specific scope of the small pools study included:

- Field Data Collection (First Phase) – Conduct a detailed study of the physical and chemical hydrology of seven small pools located in three different hydrogeologic regions on the study site.
- Field Data Collection (Second Phase) – Upscale the results from the first phase of the field data collection by conducting a rapid assessment of the chemical hydrology of 123 additional small pools located throughout the study site.
- Data Analysis – Analyze and synthesize field and laboratory data, focusing on hydrological connectivity between the small pools and the broader hydrological landscape.
- Conceptual Model Development – Develop a conceptual model describing the hydrological connectivity between the small pools and the broader hydrological landscape.

As previously stated, the small pools study was conducted in two phases. In the first phase, seven small pools located in three different hydrogeologic regions were studied. At the northernmost site, there were two small pools that appeared to be flow-through pools located in relatively high-gradient lateral moraine deposits. At the middle site, there were two small pools that appeared to be perched-precipitation pools located in low-gradient ground moraine deposits. At the southernmost site, there were two small pools that appeared to be flow-through pools and one small pool that appeared to be a perched-precipitation pool located in ground moraine deposits. The southernmost site was located at a hypothesized groundwater divide between the South Fork Koktuli and Upper Talarik Basins (Smith, pers. comm., 2009b). There were no surface water outflows from any of the small pools, except for a small surface water connection between the two flow-through pools at the southernmost site.

In the second phase, 123 additional small pools located throughout the study site were studied. Of these 123 additional small pools, 45 appeared to be perched-precipitation pools and 78 appeared to be flow-through pools.

6. METHODS

This study was conducted according to the approaches described in the consolidated study program for the Pebble Project (a copy of which is provided in Appendix E of this environmental baseline document [EBD]) and the quality assurance project plan (Appendix G of the EBD). Specifics are detailed below.

6.1. Small Pools Classification

All small pools used in this study were classified *a priori* as either perched-precipitation pools or flow-through pools. The classification system was developed through repeated field observations during site reconnaissance and initial site selection, and was based on a combination of two primary parameters. The primary classification parameter was specific conductance, because specific conductance is low in precipitation (e.g., typically less than 10 microsiemens per centimeter) and much higher in shallow groundwater (e.g., typically greater than 10 and occasionally greater than 100 microsiemens per centimeter). Therefore, small pools with specific conductance less than 20 microsiemens per centimeter were classified as perched-precipitation pools, while small pools with specific conductance greater than or equal to 20 microsiemens per centimeter were classified as flow-through pools. The second classification parameter was the presence/absence of unvegetated margins by middle-late summer, because precipitation contributions would be expected to be greatest immediately following breakup while ground-water contributions would be expected to be more constant throughout the summer. Therefore, small pools with unvegetated margins by middle-late summer were classified as perched-precipitation pools, while small pools without unvegetated margins were classified as flow-through pools. A limited number of small pools had specific conductance greater than or equal to 20 microsiemens per centimeter and unvegetated margins by middle-late summer, and therefore did not fit this classification scheme. One of these special-case small pools was included in the first phase of this study, which focused on extensive data collection and analysis at seven small pools at three sites.

6.2. Chemical Hydrology

In June and August 2006, water samples (i.e., precipitation, surface water, and groundwater) were collected at the seven small pools located at the three detailed study sites (Figure 1). In August 2007, precipitation, surface water, and groundwater samples were collected at the seven small pools located at the three detailed study sites, and surface water samples were collected at the 123 additional small pools located throughout the study area (Figure 1). Precipitation samples were collected from late-spring snowfields and summer rainfall collectors. In total, 179 water samples (i.e., nine precipitation, 144 surface water, and 26 groundwater) were collected, not including duplicate and triplicate water samples used for quality assurance and quality control.

In the field, all samples were filtered through 0.45-micrometer polycarbonate membranes and placed in 125-milliliter high-density polyethylene bottles. All tubing was rinsed with large volumes of the water to be sampled prior to the collection of the samples. Piezometers were purged before samples were collected. Due to the low permeability of the deposits, piezometers were purged and sampled on consecutive days. Cation sample bottles were pre-acidified with 1 milliliter of nitric acid. All samples were stored at 4 (± 2) degrees Celsius (^{o}C) prior to analyses.

Specific conductance and pH were measured in the field using a YSI 556 MPS (YSI, Inc., Yellow Springs, Ohio) or equivalent instrument. Dissolved-constituent analyses were performed by SGS Environmental Services, Inc. Quality assurance for the dissolved-constituent analyses was performed by Columbia Analytical Services, Inc. Sodium, potassium, magnesium, calcium, and silica were measured with inductively coupled plasma-atomic emission spectroscopy by U.S. Environmental Protection Agency methods 200.7 or 200.8 (Clesceri et al., 1998; at detection limits of 0.10, 0.05, 0.02, 0.05, and 0.10 parts per million [ppm], respectively). Chloride and sulfate were measured with ion chromatography by the U.S. Environmental Protection Agency Method 300.0 (Clesceri et al., 1998; at detection limits of 0.20 ppm for both). Carbonate alkalinity was back-calculated by assuming all other cations and anions were measured and that bicarbonate accounts for the entire missing charge in charge balance error analyses. Quality assurance was provided by the primary laboratory through the analysis of duplicate water samples for approximately 20 percent of the total water samples, while quality control was provided by the quality control laboratory through the analysis of triplicate water samples for approximately 10 percent of the total water samples. Analytical precisions were typically within 1 percent.

The measured dissolved constituents represent the major dissolved constituents commonly found in naturally occurring fresh water (McCutcheon et al., 1993). Of these, sodium, magnesium, calcium, silica, and chloride behave conservatively. The concentrations of conservative solutes change largely due to mixing with other waters, evapoconcentration (i.e., the process by which solute concentrations increase as water evaporates and solutes are retained in the remaining solution), and water-rock interaction (i.e., the process by which solute concentrations increase as deposits dissolve in water), but not to chemical transformations (e.g., the dissolution of atmospheric carbon dioxide in water to form bicarbonate or carbonate) or selective uptake by plants (e.g., potassium, which is an essential nutrient). Evapoconcentration and water-rock interaction both cause solute concentrations to increase. Regional sediments are largely derived from granodiorite, quartz monzonite, and quartz diorite, which contain high concentrations of sodium, magnesium, calcium, and silica but no chloride. Therefore, silica and chloride were used as conservative natural tracers in both evapoconcentration and water-rock interaction models to determine if the observed differences in solute concentrations in the small pool surface waters could be explained by evapoconcentration of precipitation or water-rock interaction between precipitation and regional sediments. The evapoconcentration model was:

$$C_{RES} = \frac{C_{INI}}{f_{RES}}$$

where:

C is the silica or chloride concentration in ppm.

f is the fraction of water remaining as it evaporates.

RES is residual water (e.g., evaporated surface water in the pools).

INI is initial water (e.g., precipitation).

Precipitation was assigned mean silica and chloride concentrations calculated from nine precipitation samples and theoretically evaporated in a stepwise fashion with f_{RES} set to 1.00, 0.75, 0.50, and 0.25. The water-rock interaction model was run in software package PHREEQC Interactive Version 2.17.1.4468 (Parkhurst and Appelo, 1999). Precipitation was assigned mean silica and chloride concentrations calculated from nine precipitation samples and allowed to equilibrate with minerals common to regional sediments (i.e., feldspar and quartz) at the mean groundwater temperature and pH of 7 ºC and 7.5, respectively.

6.3. Physical Hydrology

Physical hydrology data were collected at the seven small pools located at the three detailed study sites (Figure 1). Precipitation was measured continuously from June through September at each of the three detailed study sites, while net radiation, temperature, relative humidity, and wind speed were measured hourly throughout the year at one location within approximately 1 to 10 kilometers of each of the three detailed study sites. Precipitation was measured with HOBO Data Logging Rain Gauges (Onset Computer Corporation, Bourne, Massachusetts), solar radiation was measured with a LI200X Silicon

Pyranometer (LI-COR, Inc., Lincoln, Nebraska), temperature was measured with a Model 062 Air Temperature Sensor (Met One, Inc., Grants Pass, Oregon), relative humidity was measured with a HMP45C-L Vaisala Temperature and RH Probe (Vaisala, Inc., Boulder, Colorado), and wind speed was measured with a F460 Wind Speed Sensor (Climatronics, Inc., Davenport, Iowa). Other meteorological variables were parameterized as necessary using standard procedures (Allen et al., 2005).

Daily reference evapotranspiration, ET_o, was computed using the American Society of Chemical Engineers Standardized Reference Evapotranspiration Equation (Allen et al., 2005), which is the most recent update of the Food and Agriculture Organization of the United Nations Penman-Montieth Equation (Doorenbos and Pruitt, 1977; Allen et al., 1998). The American Society of Chemical Engineers Standardized Reference Evapotranspiration Equation is:

$$ET_o = \frac{0.408\Delta(R_n - G) + \gamma \frac{900}{T + 273} U_2 (e_s - e_a)}{\Delta + \gamma(1 + 0.34U_2)}$$

where:

ET_o is reference evapotranspiration (millimeters per day).

Δ is the slope vapor pressure curve (kilopascals per ^{o}C).

Rn is net radiation (megajoules per square meter per day).

G is soil heat flux density (megajoules per square meter per day).

γ is the psychrometric constant (kilopascals per ^{o}C).

T is temperature (^{o}C).

U_2 is the wind speed (meters per second).

e_s is mean saturation vapor pressure (kilopascals).

e_a is actual vapor pressure (kilopascals).

Working in a variety of climates in the western United States and southern Europe, Ventura et al. (1999) showed that the root mean square of ET_o computed with the Food and Agriculture Organization Penman-Montieth Equation with respect to ET_o measured in lysimeters was consistently approximately 0.4 millimeters per day. This was approximately 25 percent of the mean daily ET_o and an order of magnitude smaller than other key terms in the water budget during the course of this study. ET_o represents atmospheric demand, given adequate availability of water, and therefore must be corrected to account for actual land cover conditions. In this case, actual ET was assumed to be equal to ET_o throughout the summer because the small pools are either open water, fully-wet sediments, or fully-wet, laterally-extensive short vegetation comparable to the reference crops to which all reference evapotranspiration equations are calibrated (Allen et al., 1998).

Stages (i.e., surface-water levels) were measured hourly with Model 3001 Levelogger Gold pressure transducers and dataloggers (Solinst, Inc., Georgetown, Ontario). Hydraulic heads (i.e., groundwater levels) were measured either hourly with Model 3001 Levelogger Gold pressure transducers and dataloggers (Solinst, Inc., Georgetown, Ontario) or monthly with a Model 101 Water Level Indicator

(Solinst, Georgetown, Ontario) or the equivalent. Hydraulic heads were measured at piezometer nests, with each piezometer having an inside diameter of approximately 5 centimeters and having open ends approximately 1.5 meters and 3.0 meters below the soil surface. Time-lag errors can arise in piezometers screened in low-conductivity formations (Hanschke and Baird, 2001). The potential for time-lag errors was minimized by using small-diameter standpipes, so small exchanges of water were sufficient to allow water in the standpipes to reach equilibrium with water in the surrounding formations.

Net groundwater recharge through the small pools to the broader hydrological landscape was computed with a water-budget approach. Water budgets were computed from the following water budget equation:

$$\Delta S = P - ET + \Delta SW + \Delta GW$$

where:

ΔS is the change in storage, i.e., the change in stage (millimeters per day).

P is precipitation (millimeters per day).

ET is evapotranspiration (millimeters per day).

ΔSW is net surface water inflow, i.e., surface-water inflow – surface-water outflow (millimeters per day).

ΔGW is net groundwater inflow, i.e., groundwater inflow – groundwater outflow (millimeters per day).

Surface-water inflows and outflows were negligible. Therefore, the water budget equation was re-written and resolved in terms of net groundwater inflow:

$$\Delta GW = \Delta S - P + ET$$

where terms are as previously defined. Net groundwater inflow was computed for the months of June to September to determine the extent to which groundwater discharged from the underlying aquifers to the small pools (i.e., the extent to which net groundwater inflow was positive) and the extent to which groundwater recharged from the small pools to the underlying aquifers (i.e., the extent to which net groundwater inflow was negative).

7. RESULTS AND DISCUSSION

7.1. Chemical Hydrology Results

Specific conductances and solute concentrations were generally lowest in precipitation and perched-precipitation pool surface water and groundwater, and highest in the flow-through pool surface water and groundwater (Table 1). Mean ± standard deviation (SD) specific conductances were 16 ± 5, 7 ± 3, 18 ± 7, 28 ± 8, and 67 ± 44 microsiemens per centimeter for precipitation, surface water in the perched-precipitation pools, groundwater underneath the perched-precipitation pools, surface water in the flow-through pools, and groundwater underneath and adjacent to the flow-through pools, respectively. Generally, mean ± SD solute concentrations were lower in the perched-precipitation pools than in the flow-through pools. This was true for the conservative solutes sodium (0.68 ± 0.18 v. 1.61 ± 0.50 ppm), magnesium (0.13 ± 0.03 v. 1.02 ± 0.37 ppm), calcium (0.41 ± 0.14 v. 4.19 ± 1.32 ppm), and silica (0.14 ± 0.06 v. 1.20 ± 1.18 ppm) but was not true for the conservative solute chloride (0.73 ± 0.16 v. 0.64 ± 0.16 ppm).

Silica and chloride concentrations measured in the perched-precipitation pools and flow-through pools show that flow-through pools are preferentially enriched with silica (Figure 2). The evapoconcentration model shows that evapoconcentration would result in the proportional enrichment of both silica and chloride, while the water-rock interaction model shows that water-rock interaction (i.e., groundwater being in contact with regional sediments) would result in the preferential enrichment of silica. Therefore, these measured and modeled results indicate that groundwater discharges to the flow-through pools but not to the perched-precipitation pools to any significant degree. A plot of magnesium and calcium indicates that precipitation, surface water in the perched-precipitation pools, groundwater underneath the perched-precipitation pools, surface water in the flow-through pools, and groundwater underneath and adjacent to the flow-through pools occur on a continuum, with precipitation and groundwater underneath and adjacent to the flow-through pools at either end of the continuum (Figure 3).

Patterns observed in the small pools at the detailed study sites also were observed in the 123 additional small pools located throughout the study site (Table 2). Specific conductances and solute concentrations were lowest in the perched-precipitation pool surface water and highest in the flow-through pool surface water. Mean ± SD specific conductances were 11 ± 5 and 48 ± 24 microsiemens per centimeter for surface water in the perched-precipitation pools and surface water in the flow-through pools, respectively. Generally, mean ± SD solute concentrations were lower in the perched-precipitation pools than in the flow-through pools. This was true for the conservative solutes sodium (0.75 ± 0.30 v. 2.14 ± 0.85 ppm), magnesium (0.27 ± 0.16 v. 1.39 ± 0.96 ppm), calcium (1.02 ± 0.74 v. 5.93 ± 3.22 ppm), and silica (0.41 ± 0.67 v. 1.68 ± 1.49 ppm) but was not true for the conservative solute chloride (0.42 ± 0.15 v. 0.40 ± 0.18 ppm).

The basic mass-balance mixing relationship observed in the surface water in the small pools at the detailed study sites also was observed in the surface water in the 123 additional small pools located throughout the study site (Figure 4). For both surface water in the small pools at the detailed study sites and for the surface water in the 123 additional small pools located throughout the study site, least-squares regression lines for magnesium versus calcium were as follows:

$$y = 0.22x + 0.07$$

The relationships were significant for both datasets, with p<0.01 for both small pools at the detailed study sites and the 123 additional small pools located throughout the study site. The p-value expresses the probability that one might conclude that there are linear relationships between the variables when no such relationships actually exist. However, variability was greater in the 123 additional small pools located throughout the study site, with R^2=0.83 and R^2=0.68 for the small pools at the detailed study sites and the 123 additional small pools located throughout the study site, respectively. The R^2 expresses the goodness of fit of the predicted values (i.e., the line) to the actual values (i.e., the points). A perfect correlation (i.e., the points are all on the line) yields an R^2 of 1.0; a perfect non-correlation (i.e., the points are randomly distributed) yields an R^2 of 0.0.

7.2. Physical Hydrology Results

The perched-precipitation pools and flow-through pools had different hydrographic characteristics (Figures 5 and 6). The perched-precipitation pools were at full pool immediately following breakup in late May/early June. Precipitation was relatively infrequent and of low intensity in June and July. During this time, the perched-precipitation pool stages declined 1.45 centimeters per day, and the perched-precipitation pools were nearly empty and had large, unvegetated margins by late July. Precipitation increased in frequency and intensity in August and September. During this time, the perched-precipitation pool stages increased slightly then remained relatively low but stable through September. Conversely, three of the four flow-through pools were at full pool throughout the summer, showing little to no effect from breakup in late May/early June, the relatively low frequency and intensity precipitation in June and July, or the relatively high frequency and intensity precipitation in August and September. The fourth flow-through pool had a distinct hydrograph, with a stage that was intermediate between the hydraulic head in the up-gradient local, perched flow system and the underlying regional, confined flow system (Figure 7).

Groundwater was observed in some piezometers adjacent to, but in all piezometers under, the perched-precipitation pools. Where found, hydraulic gradients were vertical downward indicating that groundwater recharge occurred through the perched-precipitation pools. Groundwater was observed up-gradient, underneath, and down-gradient in most of the piezometers adjacent to and under the flow-through pools indicating that groundwater flowed through the flow-through pools, with groundwater discharge occurring at the up-gradient ends of the flow-through pools and groundwater recharge occurring at the down-gradient ends of the flow-through pools. Where groundwater was present, groundwater remained unfrozen through the winter in only three locations, all of which were adjacent to or underneath flow-through pools.

Groundwater recharge occurred through both perched-precipitation pools and flow-through pools (Table 3, Figures 8 and 9). However, patterns and amounts differ, with groundwater recharge being concentrated in the early summer and larger overall in the perched-precipitation pools, and relatively uniform throughout the summer and smaller overall in the flow-through pools. Mean ± SD groundwater recharge during June through September for the perched-precipitation pools and flow-through pools was 0.82 ± 1.12 and 0.26 ± 0.97 centimeters per day, respectively. Mean groundwater recharge during June to September on the entire study site was approximately 0.19 centimeters per day (Smith, pers. comm., 2009a).

7.3. Discussion

Results indicate that there are two different types of small pools in the study area: perched-precipitation pools and flow-through pools. Though they look similar, and were formed by similar processes, these two types of small pools differ with respect to their water sources and hydrodynamics (Figures 10, 11, and 12).

Perched-precipitation pools have inflows by meltwater and direct precipitation, outflows by evapotranspiration and groundwater recharge, and are seasonally inundated because infiltration through the low-permeability surficial deposits is slow (Figures 11 and 12). These pools are typically located where groundwater discharge is unlikely to occur (e.g., shallow pools in nearly level ground moraine) and typically have wide, unvegetated margins by middle-late summer (Photograph 1). Surface water has geochemical characteristics of precipitation, while groundwater has geochemical characteristics of precipitation that has undergone slight modification due to short-term water-rock interaction (Table 1, Figures 2 and 3).

The groundwater recharge analysis suggests that groundwater periodically discharges to the perched-precipitation pools (Figure 8). However, all apparent groundwater discharge events occurred on days when precipitation was more than 1.5 centimeters per day. On these days, rainfall intensity could have exceeded infiltration capacity, generating overland flow which would have violated the assumption that surface-water inflow was negligible. Therefore, these apparent groundwater discharge events could instead have been ephemeral surface water inflow events.

Flow-through pools have inflows by meltwater, direct precipitation, and groundwater discharge; outflows by evapotranspiration and groundwater recharge; and are perennially inundated because of the groundwater throughflow (Figures 10 and 12). These pools are typically located where groundwater discharge is likely to occur (e.g., deep pools on gently to strongly sloping lateral moraines) and typically have stable, vegetated margins throughout summer (Photograph 2). Surface water has geochemical characteristics of mixed precipitation and groundwater, while groundwater has geochemical characteristics of precipitation that has undergone slight modification due to short-term water-rock interaction (Table 1, Figures 2 and 3).

One flow-through pool at the detailed study sites had a distinct hydrograph, with a stage that was intermediate between the hydraulic head in the up-gradient local, perched flow system and down-gradient in the underlying regional, confined flow system (Figure 7). Though a flow-through pool, this small pool had a wide, unvegetated margin immediately following breakup, which became increasingly flooded toward the middle-late summer (Photograph 3). This small pool was of unknown depth, though the bottom could not be seen from the air, in spite of the fact that the water was quite clear. This type of small pool appears to be an uncommon variant of the broader class of flow-through pools, in which the small pool is deep enough to penetrate through or largely through low-permeability surficial deposits, such as ground-moraine deposits, and into or close to high-permeability deep deposits, such as advance outwash deposits. These small pools are connected to local, perched flow systems, but stages are at least partly controlled by hydraulic heads in the underlying regional, confined flow systems. In this case, stage increased in the late summer, when groundwater apparently spills over a bedrock sill and thereafter flows from the South Fork Koktuli groundwater basin to the north to the Upper Talarik Basin to the south (Smith, pers. comm., 2009b).

Both types of small pools are depressional features that collect and store water. Therefore, both types of small pools serve as focal points for groundwater recharge. This is particularly true for perched-precipitation pools, where point-scale groundwater recharge rates during June to September are about three times higher than in flow-through pools and about four times higher than in the surrounding landscape (Table 3 and Figures 8 and 9). Most of the additional groundwater recharge occurs immediately following breakup. The perched-precipitation pools are empty or nearly empty when snow begins to accumulate in early fall. These empty or nearly empty depressional features accumulate aeolian-transported snow (Photograph 4). This snow melts during breakup, and this surcharge of meltwater results in high stages immediately following breakup and enhanced groundwater recharge rates immediately thereafter (Table 3 and Figure 9). Conversely, the flow-through pools are full or nearly full when snow begins to accumulate in early fall. Therefore, these full or nearly full depressional features accumulate smaller amounts of aeolian-transported snow. Lacking this surcharge of meltwater, high stages immediately following breakup and enhanced groundwater recharge immediately thereafter do not occur (Table 3 and Figure 9).

8. SUMMARY

There are two types of small pools that have been identified in the study area: perched-precipitation pools and flow-through pools. Perched-precipitation pools have inflows by meltwater and direct precipitation, outflows by evapotranspiration and groundwater recharge, and are seasonally inundated because infiltration through the low-permeability surficial deposits is slow. Flow-through pools have inflows by meltwater, direct precipitation, and groundwater discharge, outflows by evapotranspiration and groundwater recharge, and are perennially inundated because of the groundwater throughflow. Both types of small pools serve as groundwater recharge focal points. This is particularly true for perched-precipitation pools, where net groundwater recharge rates during June through September are about three times higher than in flow-through pools and about four times higher than in the surrounding landscape.

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10. GLOSSARY

Aeolian—Transport by wind.

Evapoconcentration—The process by which solutes are concentrated in a liquid that undergoes evaporation.

Evaporation—The transition of water from the liquid to the vapor phases.

Evapotranspiration—The sum of evaporation of water from a free-water surface and transpiration of water from plants.

Evapotranspiration, Actual —The evapotranspiration from a land surface under actual land-cover conditions.

Evapotranspiration, Reference—The evapotranspiration from a land surface if covered by a reference crop with specific characteristics. Similar to evaporation from a free-water surface, it can be converted to actual evapotranspiration by multiplication by a land-cover coefficient.

Full Pool—Normal high water in a depressional water body.

Groundwater Discharge—Groundwater flowing onto the land surface.

Groundwater Recharge—Surface water flowing into the subsurface.

Hydraulic Gradient—The change in hydraulic head divided by the change in distance over which the hydraulic head is measured. Being a rise/run, this is essentially the “slope” down which groundwater flows.

Hydraulic Head—The total energy per unit weight in water. This is the height to which groundwater will rise relative to a reference point if the groundwater is not otherwise confined.

Infiltration—Surface water flowing into the subsurface.

Permeability—A coefficient expressing the ease with which fluids can pass through a geologic deposit.

Piezometer—A type of groundwater monitoring well that has a screened interval at a discrete depth below the ground surface. The height to which water rises in a piezometer is the hydraulic head of the groundwater at the screened interval.

Piezometer Nest—A group of piezometers in close proximity to one another, each of which is screened at different depths below the ground surface.

Specific Conductance—A measure of the ease with which water can conduct an electrical current, which is proportional to the amount of dissolved ions in the solution.

Stage—The height of surface water in a small pool or other surface-water feature relative to a reference point. Similar to hydraulic head, though used only when referring to surface water.

Transpiration—The evaporation of water though plants.

TABLES

TABLE 1
Specific conductance, pH, and solute concentrations of water samples collected from the seven small pools located at the detailed study sites.

		Perched-Precipitation Pools		Flow-Through Pools	
Constituent	**Precipitation (n = 9)**	**Surface Water (n = 9)**	**Groundwater (n = 5)**	**Surface Water (n = 12)**	**Groundwater (n = 21)**
SC (µS/cm)	16 (±5)	7 (±3)	18 (±7)	28 (±8)	67 (±44)
pH	-	7.4 (±1.5)	7.5 (±1.8)	7.8 (±0.5)	7.4 (±0.7)
Sodium (ppm)	0.58 (±0.45)	0.68 (±0.18)	1.89 (±0.59)	1.61 (±0.50)	5.15 (±5.38)
Potassium (ppm)	0.48 (±0.50)	0.27 (±0.08)	0.56 (±0.26)	0.37 (±0.13)	0.81 (±0.43)
Magnesium (ppm)	0.11 (±0.08)	0.13 (±0.03)	0.40 (±0.15)	1.02 (±0.37)	2.27 (±1.71)
Calcium (ppm)	0.59 (±0.25)	0.41 (±0.14)	1.59 (±0.64)	4.19 (±1.32)	9.13 (±5.68)
Chloride (ppm)	0.77 (±0.66)	0.73 (±0.16)	1.14 (±0.18)	0.64 (±0.16)	1.07 (±0.68)
Sulfate (ppm)	0.62 (±0.34)	0.66 (±0.54)	1.02 (±0.44)	3.20 (±0.95)	6.94 (±6.44)
Alkalinity (ppm)	2.52 (±1.58)	1.87 (±0.65)	9.45 (±3.71)	17.57 (±5.88)	43.49 (±34.70)
Silica (ppm)	0.09 (±0.06)	0.14 (±0.06)	4.92 (±3.25)	1.20 (±1.18)	5.72 (±3.26)

Note:

Values are means (± standard deviations) for precipitation, surface water, and groundwater samples from perched-precipitation pools, and surface water and groundwater samples from flow-through pools. Groundwater samples were collected from underneath the perched-precipitation pools and underneath and adjacent to the flow-through pools.

Key:

n = number of samples

SC = specific conductance.

µS/cm = microSiemen per centimeter.

ppm = parts per million.

TABLE 2
Specific conductance, pH, and solute concentrations of water samples collected from the 123 additional small pools located throughout the study area.

Constituent	Perched-Precipitation Pools (n = 45)	Flow-Through Pools (n = 78)
SC (μS/cm)	11 (±5)	48 (±24)
pH	7.0 (±0.6)	7.2 (±0.3)
Sodium (ppm)	0.75 (±0.30)	2.14 (±0.85)
Potassium (ppm)	0.24 (±0.12)	0.36 (±0.32)
Magnesium (ppm)	0.27 (±0.16)	1.39 (±0.96)
Calcium (ppm)	1.02 (±0.74)	5.93 (±3.22)
Chloride (ppm)	0.42 (±0.15)	0.40 (±0.18)
Sulfate (ppm)	0.37 (±0.51)	2.97 (±6.97)
Alkalinity (ppm)	5.64 (±3.35)	26.84 (±12.88)
Silica (ppm)	0.41 (±0.67)	1.68 (±1.49)

Note:

Values are means (± standard deviations) for surface water samples from perched-precipitation and flow-through pools.

Key:

n = number of samples

SC = specific conductance.

μS/cm = microSiemen per centimeter.

ppm = parts per million.

TABLE 3
Net groundwater recharge through the seven small pools located at the detailed study sites.

	Perched-Precipitation Pools	Flow-Through Pools
Mean (±SD) (cm/d)	0.82 (±1.12)	0.26 (±0.97)
Maximum (cm/d)	2.78	2.28

Note:

Values are mean (± standard deviation) and maximum groundwater recharge through perched-precipitation and flow-through pools during June to September. Mean groundwater recharge on the study site was approximately 0.19 cm/d during June to September (Smith, pers. comm., 2009a).

Key:

SD = standard deviation.

cm/d = centimeter per day.

FIGURES

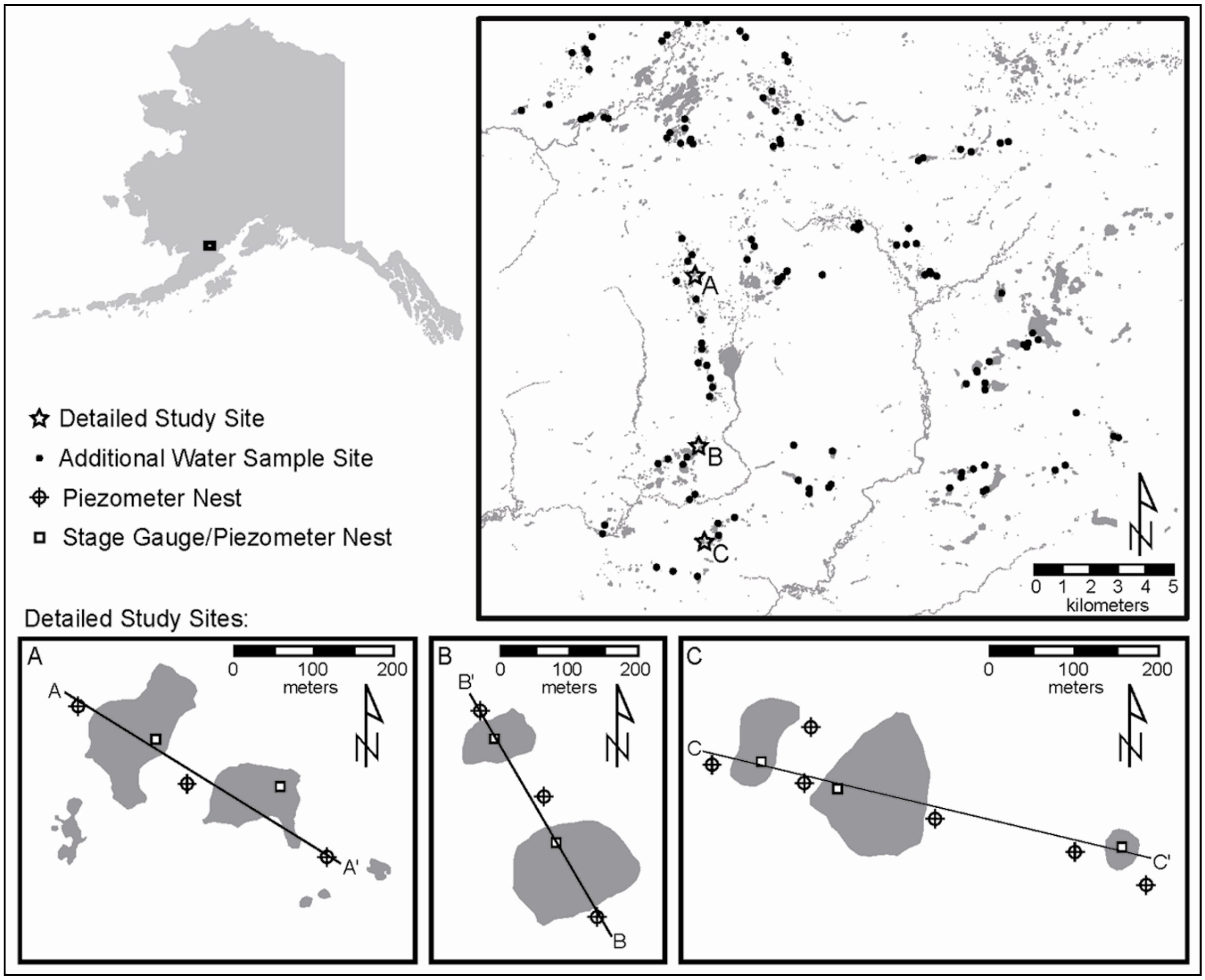

FIGURE 1
Location of the study area and the detailed study site

Note:

This figure shows the locations of the instrumentation at the seven small pools located at the detailed study sites, and of the 123 small pools located throughout the study area where additional water samples were collected. The three stars in the uppermost inset refer to the detailed study sites shown in the lowermost insets. A-A’, B-B’, and C-C’ in the lowermost insets delineate the locations of cross sections.

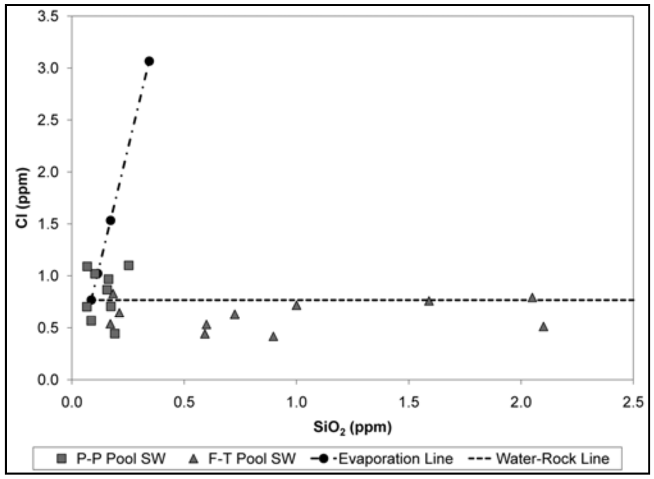

FIGURE 2
Measured and modeled silica and chloride concentrations in surface water at the perched-precipitation pools (P-P Pool SW) and flow-through pools (F-T Pool SW) located at the detailed study sites.

Note:

Cl is chloride, SiO_2 is silica, and ppm is parts per million. The modeled Evaporation Line represents the trajectory on which the residual water would trend, with solid circles representing modeled points where the fraction of water remaining as it evaporates is equal to 1.00, 0.75, 0.50, and 0.25, from bottom to top. The modeled Water-Rock Line represents the trajectory on which water in contact with regional sediments would trend as it moved toward the equilibrium condition, from left to right.

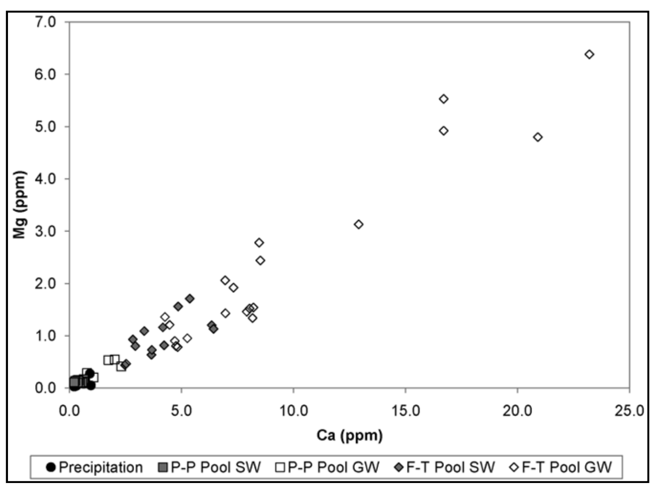

FIGURE 3
Two-end mixing line for surface water at the perched-precipitation pools (P-P Pool SW), groundwater at the perched-precipitation pools (P-P Pool GW), surface water at the flow-through pools (F-T Pool SW), and groundwater at the flow-through pools (F-T Pool GW) located at the detailed study sites.

Note:

Mg is magnesium, Ca is calcium, and ppm is parts per million.

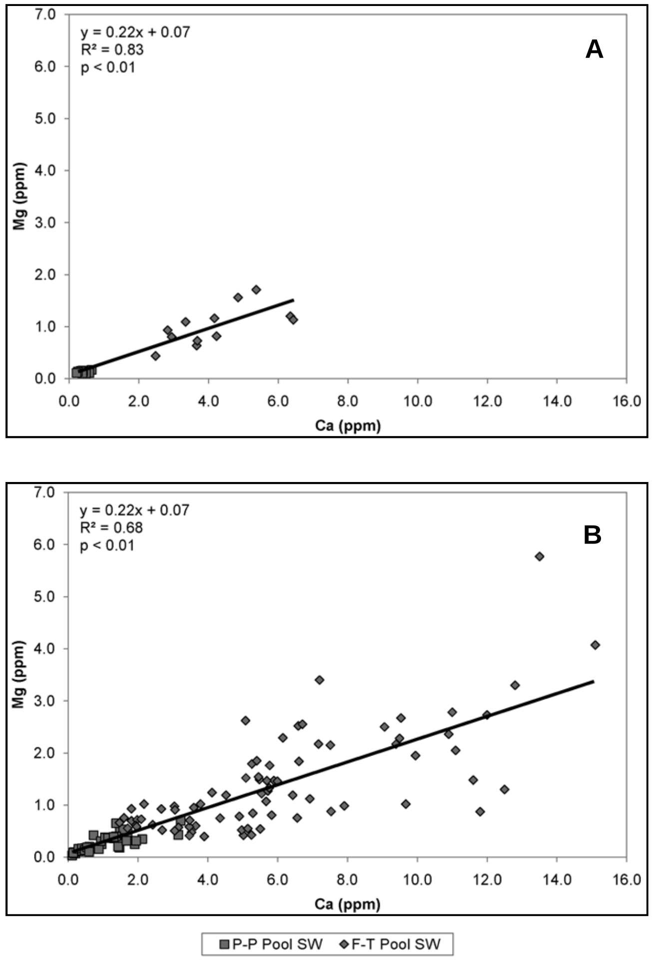

FIGURE 4

Two-end mixing lines for surface water from the perched-precipitation pools (P-P Pool SW) and flow-through pools (F-T Pool SW) located at (A) the detailed study sites and (B) the 123 additional study sites located throughout the study area.

Note:

Mg is magnesium, Ca is calcium, and ppm is parts per million. The equations $y = 0.22x + 0.07$ re the equations f the best-fit lines through each of the groups of points. The R^2 expresses the goodness of fit of the predicted values (i.e., the line) to the actual values (i.e., the points). A perfect correlation (i.e., the points are all on the line) yields an R^2 of 1.0; a perfect non-correlation (i.e., the points are randomly distributed) yields an R^2 of 0.0. The p-value expresses the probability that one might conclude that there are linear relationships between the variables when no such relationships actually exist.

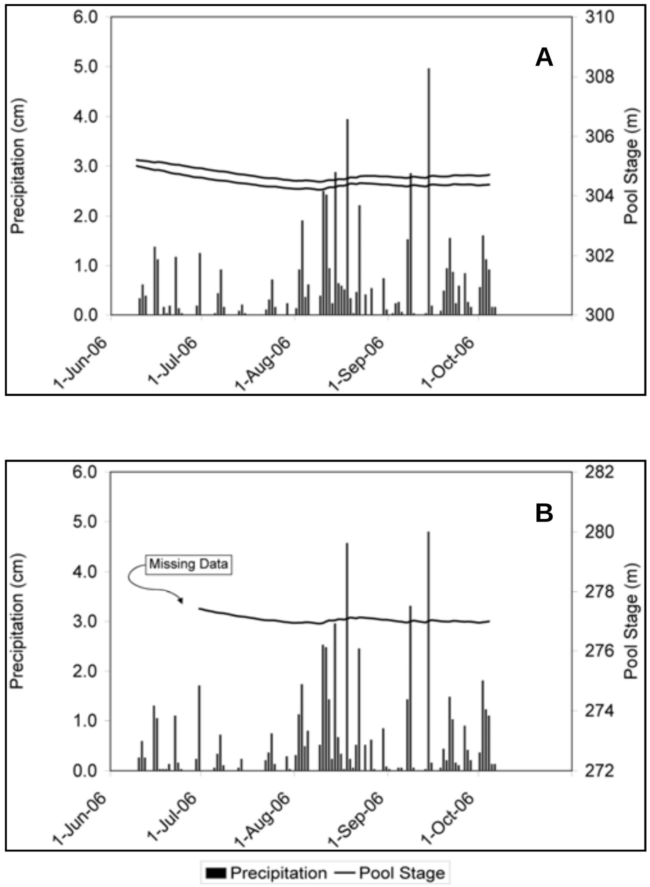

FIGURE 5

Precipitation and pool stages in elevation above mean sea level in (A) two perched-precipitation pools located at the middle detailed study site and (B) one perched-precipitation pool located at the southernmost detailed study site.

Note:

Total daily precipitation is expressed in the vertical bars while mean daily pool stage is expressed in the horizontal lines.

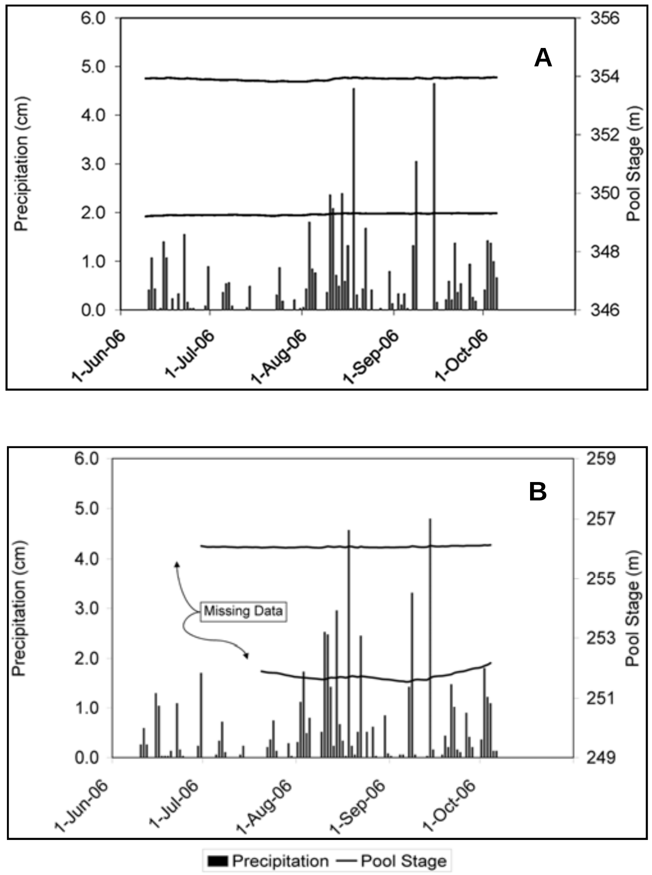

FIGURE 6
Precipitation and pool stages in elevation above mean sea level in (A) two flow-through pools located at the northernmost detailed study site and (B) two flow-through pools located at the southernmost detailed study site.

Note:

Total daily precipitation is expressed in the vertical bars while mean daily pool stage is expressed in the horizontal lines.

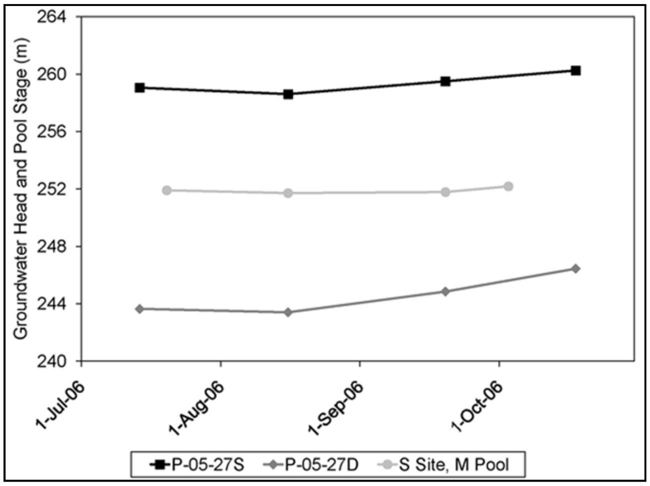

FIGURE 7
Relationship between stage in the lower flow-through pool and head in the local and regional flow systems located at the southernmost detailed study site.

Note:

P-05-27S is a shallow monitoring well screened in an up-gradient local, perched aquifer, P-05-27D is a deep monitoring well screened in an underlying regional, confined aquifer, and S Site, M Pool refers to the middle pool located at the southernmost detailed study site. Water appears to flow from the up-gradient local, perched aquifer, through the flow-through pools (e.g., S Site, M Pool), and into the underlying regional, confined aquifer. Data from the up-gradient local, perched aquifer and the underlying regional, confined aquifer are from monitoring wells that are not specifically a part of this study.

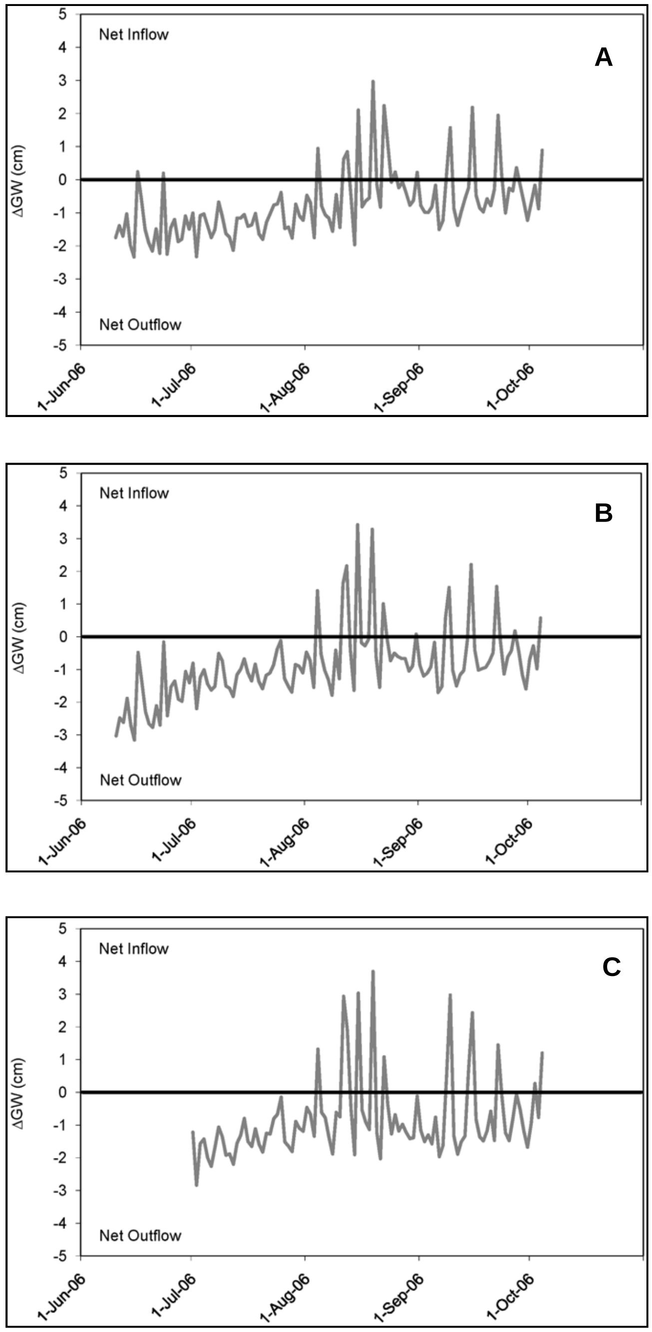

FIGURE 8

Net groundwater recharge in perched-precipitation pool located at (A and B) the middle detailed study site and (C) the southernmost detailed study site.

Note:

The straight horizontal line represents no net ground-water recharge, i.e., ground-water inflow precisely equals ground-water outflow. More ground-water flows into than out of the pools when the jagged horizontal line is above this straight horizontal line; more ground-water flows out of than into the pools when the jagged horizontal line is below the straight horizontal line. The latter case represents ground-water recharge.

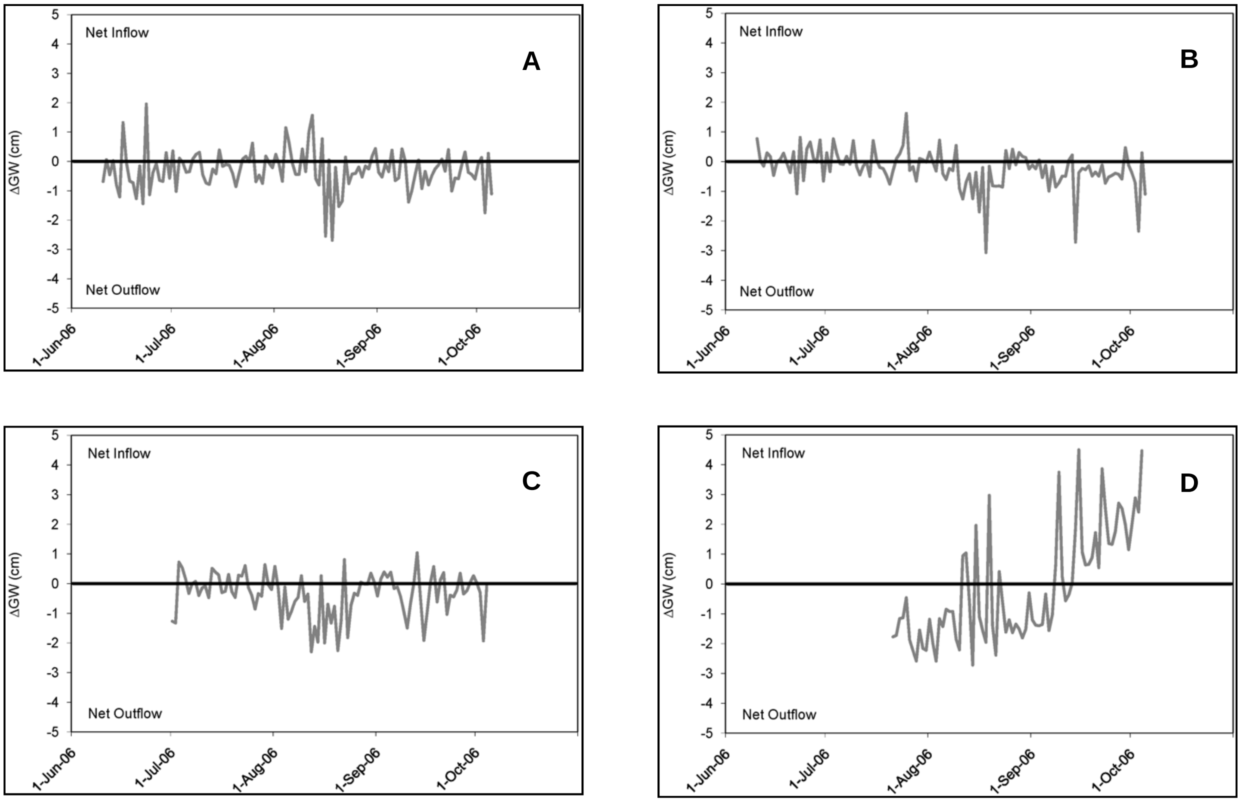

FIGURE 9
Net groundwater recharge in flow-through pools (A and B) located at the northernmost detailed study site and (C and D) located at the southernmost detailed study site.

Note:

The straight horizontal line represents no net ground-water recharge, i.e., ground-water inflow precisely equals ground-water outflow. More ground-water flows into than out of the pools when the jagged horizontal line is above this straight horizontal line; more ground-water flows out of than into the pools when the jagged horizontal line is below the straight horizontal line. The latter case represents ground-water recharge.

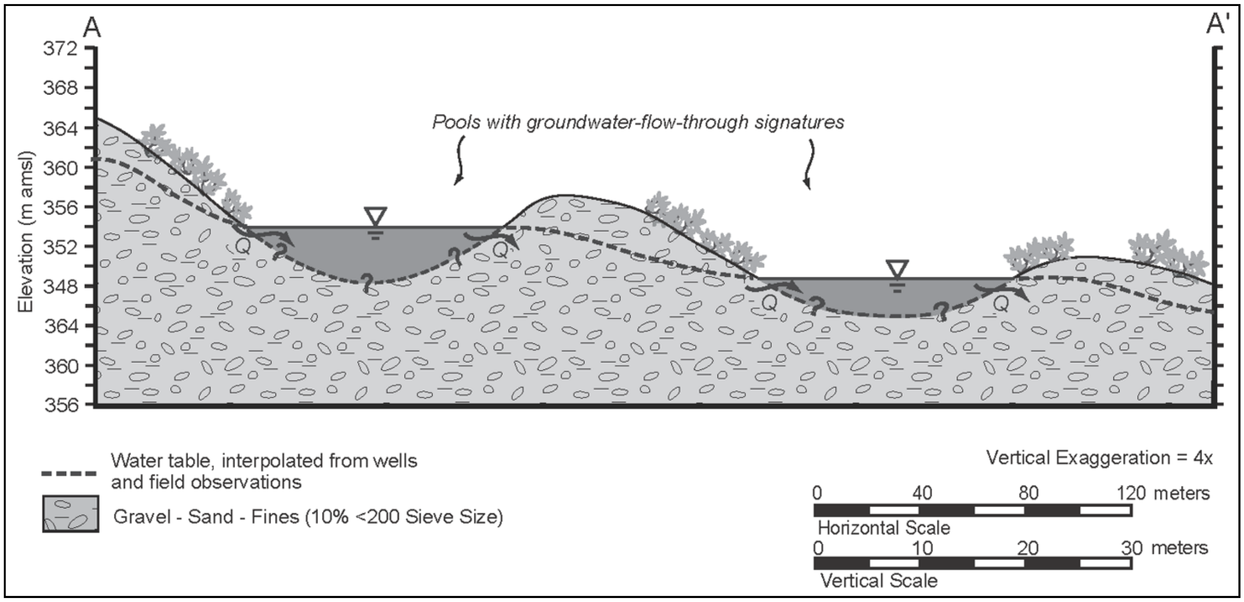

FIGURE 10
Conceptual model of the physical hydrology of the flow-through pools located at the northernmost detailed study site.

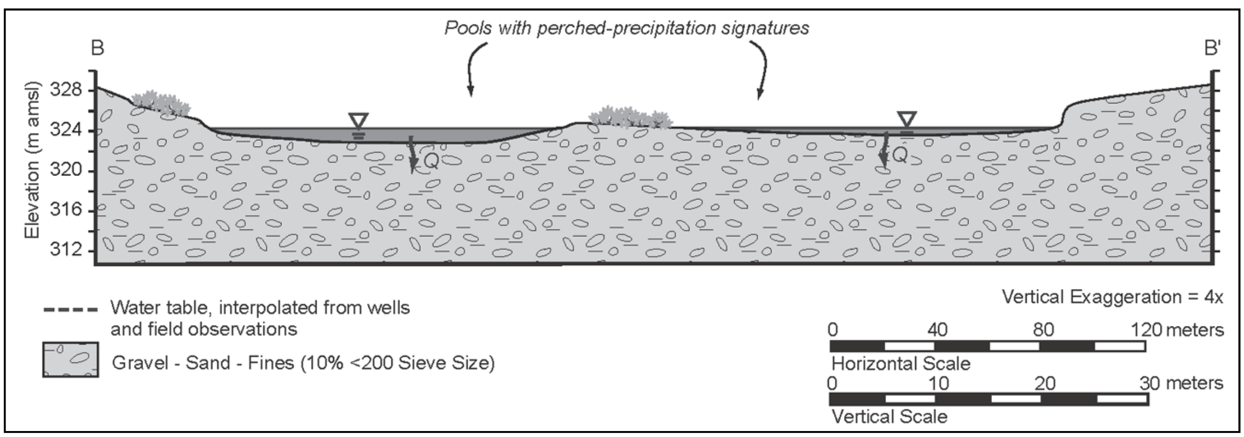

FIGURE 11
Conceptual model of the physical hydrology of the perched-precipitation pools located at the middle detailed study site.

Note:

The cross sections are between A-A' and B-B', as depicted in Figure 1. The vertical units m amsl = meter(s) above mean seal level. Q is used to imply the flow of water in the direction of nearby arrows. Dashed lines with question marks indicate uncertainty due to a lack of measurements.

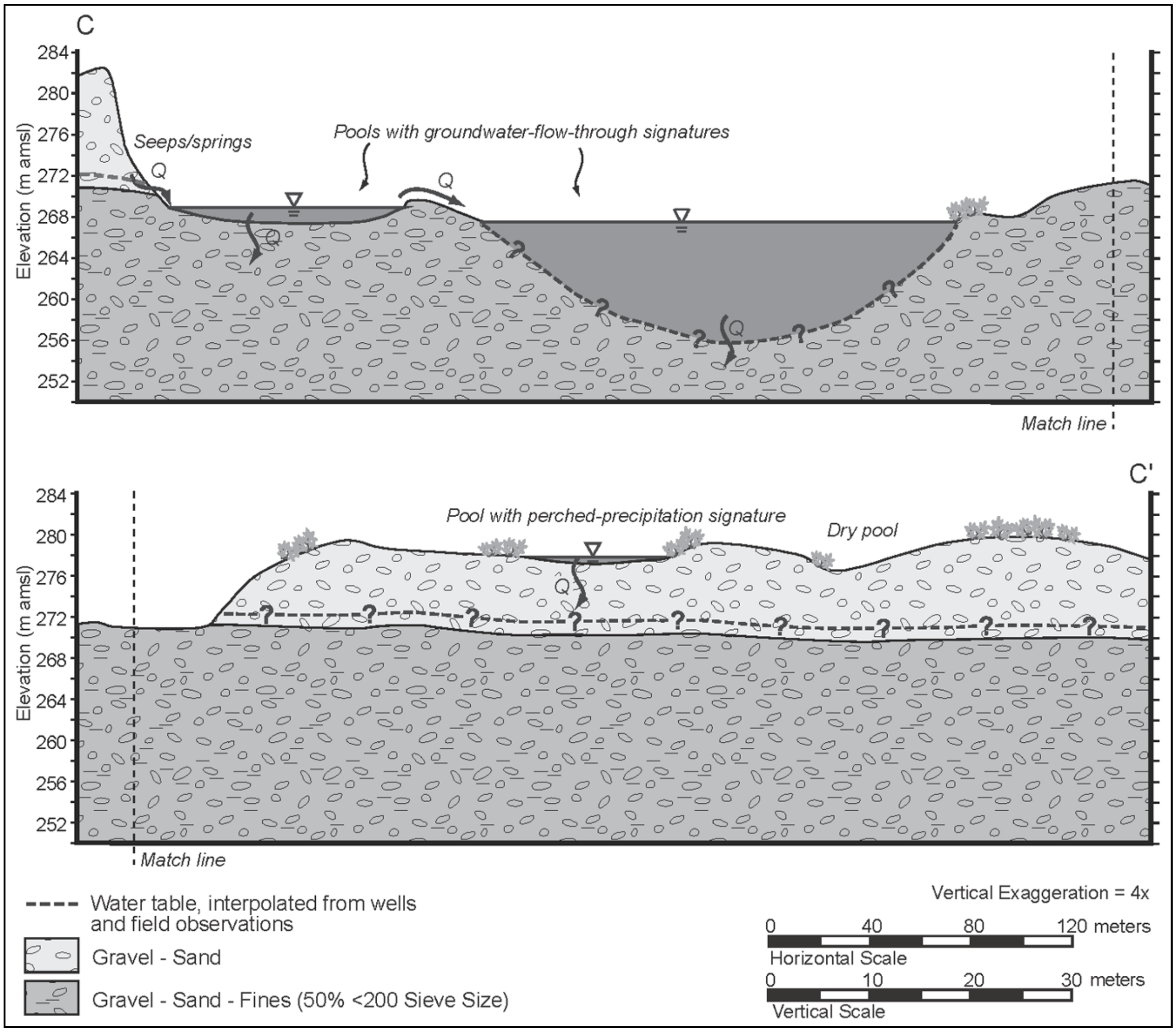

FIGURE 12

Conceptual model of the physical hydrology of the perched-precipitation and flow-through pools located at the southernmost detailed study site.

Note:

The cross section is between C-C', as depicted in Figure 1. The upper and lower cross-sections connect at the match lines. The vertical units m amsl = meter(s) above mean seal level. Q is used to imply the flow of water in the direction of nearby arrows. Dashed lines with question marks indicate uncertainty due to a lack of measurements.

PHOTOGRAPHS

PHOTO 1: Perched-precipitation pool with a wide, unvegetated margin in August 2005.

PHOTO 2: Flow-through pool with a stable, vegetated margin in August 2005.

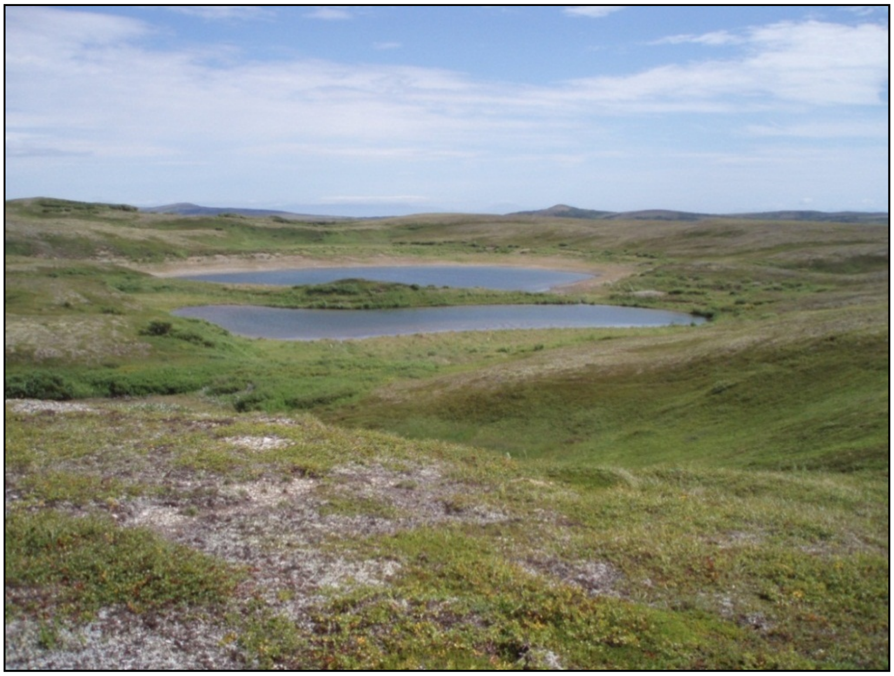

PHOTO 3: Flow-through pool with a stable, vegetated margin (foreground) and flow-through pool with a wide, unvegetated margin at the southernmost detailed study site in August 2006.

PHOTO 4: Flow-through pool with so much accumulated Aeolian-transported snow that the stage gage is below the meltwater level in May 2008.

ATTACHMENTS

ATTACHMENT 1

Laboratory Data

Sample ID	Water Type	Date	SC (μm/cm)	pH	Na (ppm)	K (ppm)	Mg (ppm)	Ca (ppm)	Cl (ppm)	SO4 (ppm)	HCO3 (ppm)	SiO2 (ppm)
NSNOW1	Precipitation	07-Jun-06			1.29	1.39	0.08	0.63	1.68	0.23	4.73	0.10
MSNOW1	Precipitation	07-Jun-06			0.84	0.88	0.10	0.40	1.59	0.26	2.26	0.12
SSNOW1	Precipitation	07-Jun-06			1.20	1.04	0.14	0.63	1.63	0.30	4.24	0.14
NPRCP1	Precipitation	08-Aug-07			0.16	0.37	0.05	0.96	0.38	0.78	2.53	0.05
MPRCP1	Precipitation	08-Aug-07			0.16	0.06	0.04	0.30	0.20	0.51	0.64	0.00
SPRCP1	Precipitation	08-Aug-07			0.15	0.10	0.03	0.21	0.25	0.53	0.24	0.00
NRAIN1	Precipitation	08-Aug-06	13		0.40	0.21	0.28	0.91	0.32	0.80	4.00	0.14
MRAIN1	Precipitation	08-Aug-06	22		0.70	0.20	0.14	0.56	0.47	0.92	2.60	0.08
SRAIN1	Precipitation	08-Aug-06	14		0.28	0.06	0.14	0.71	0.38	1.24	1.47	0.16
Mean			16		0.58	0.48	0.11	0.59	0.77	0.62	2.52	0.09
Stdev			5		0.45	0.50	0.08	0.25	0.66	0.34	1.58	0.06
MPOOL1	P-P Pool SW	07-Jun-06	9	8.7	0.59	0.28	0.16	0.39	0.72	0.50	1.60	0.10
MPOOL2	P-P Pool SW	07-Jun-06	5	8.8	0.48	0.17	0.17	0.64	0.71	0.39	2.62	0.17
SPOOL3	P-P Pool SW	07-Jun-06	6	8.7	0.50	0.34	0.11	0.58	0.97	0.38	2.02	0.16
MPOOL1	P-P Pool SW	08-Aug-06	10		0.87	0.26	0.15	0.33	0.79	0.57	1.87	0.07
MPOOL2	P-P Pool SW	08-Aug-06	12		0.89	0.22	0.10	0.48	0.87	2.03	0.59	0.16
SPOOL3	P-P Pool SW	08-Aug-06	6		0.67	0.35	0.14	0.40	0.81	0.87	1.25	0.25
MPOOL1	P-P Pool SW	09-Aug-07	4	5.8	0.53	0.24	0.11	0.38	0.45	0.31	2.32	0.19
MPOOL2	P-P Pool SW	09-Aug-07	6	6.1	0.96	0.19	0.14	0.25	0.57	0.57	2.60	0.09
SPOOL3	P-P Pool SW	09-Aug-07	5	6.2	0.67	0.42	0.11	0.21	0.70	0.35	1.98	0.07
Mean			7	7.4	0.68	0.27	0.13	0.41	0.73	0.66	1.87	0.14
Stdev			3	1.5	0.18	0.08	0.03	0.14	0.16	0.54	0.65	0.06
WLP04D	P-P Pool GW	07-Jun-06	13	8.5	2.51	0.52	0.41	2.31	1.39	0.97	12.94	5.89
WLP06S	P-P Pool GW	08-Aug-06	17		1.76	0.23	0.29	0.79	0.97	0.76	6.26	3.28
WLS07D	P-P Pool GW	07-Jun-06	9		0.95	0.46	0.20	1.08	1.25	0.56	4.67	0.19
WLS07S	P-P Pool GW	08-Aug-06	22	8.5	2.19	0.68	0.54	2.02	1.10	1.70	11.68	8.56
WLS07S	P-P Pool GW	09-Aug-07	27	5.4	2.02	0.93	0.54	1.74	0.98	1.14	11.69	6.69
Mean			18	7.5	1.89	0.56	0.40	1.59	1.14	1.02	9.45	4.92
Stdev			7	1.8	0.59	0.26	0.15	0.64	0.18	0.44	3.71	3.25
NPOOL1	F-T Pool SW	07-Jun-06	31	8.3	1.10	0.29	0.80	2.94	0.64	2.82	11.65	0.21
NPOOL2	F-T Pool SW	07-Jun-06	24	8.0	1.54	0.65	1.16	4.17	0.76	3.52	17.84	1.59
SPOOL1	F-T Pool SW	07-Jun-06	21	8.0	1.12	0.31	0.64	3.66	0.51	2.48	13.78	2.10
SPOOL2	F-T Pool SW	07-Jun-06	13	8.4	0.82	0.24	0.44	2.48	0.72	1.54	9.11	1.00
NPOOL1	F-T Pool SW	08-Aug-06	22		1.41	0.35	0.93	2.83	0.83	3.57	11.61	0.18
NPOOL2	F-T Pool SW	08-Aug-06	33		2.03	0.51	1.56	4.85	0.63	4.69	21.74	0.73
SPOOL1	F-T Pool SW	08-Aug-06	46		2.31	0.51	1.20	6.35	0.89	3.99	25.68	4.28
SPOOL2	F-T Pool SW	08-Aug-06	24		1.54	0.29	0.73	3.68	0.79	2.74	14.57	2.05
NPOOL1	F-T Pool SW	09-Aug-07	23	7.0	1.51	0.33	1.09	3.34	0.54	2.40	16.19	0.17
NPOOL2	F-T Pool SW	09-Aug-07	30	7.5	2.34	0.40	1.71	5.37	0.42	4.18	25.74	0.90
SPOOL1	F-T Pool SW	09-Aug-07	36	7.3	2.23	0.31	1.13	6.43	0.53	4.12	25.51	0.60
SPOOL2	F-T Pool SW	09-Aug-07	27	7.6	1.43	0.25	0.82	4.23	0.44	2.35	17.44	0.59
Mean			28	7.8	1.61	0.37	1.02	4.19	0.64	3.20	17.57	1.20
Stdev			8	0.5	0.50	0.13	0.37	1.32	0.16	0.95	5.88	1.18
WLS01S	F-T Pool GW	07-Jun-06	45	8.0	3.65	1.25	2.06	6.95	1.09	6.46	33.06	3.71
WLS02S	F-T Pool GW	07-Jun-06	61	7.5	3.29	0.71	1.43	6.96	1.04	4.07	31.25	6.57
WLP01S	F-T Pool GW	07-Jun-06	110	7.7	17.80	1.12	6.38	23.20	0.75	10.60	136.90	5.89
WLP03D	F-T Pool GW	07-Jun-06	132	7.5	18.70	1.68	4.80	20.90	2.70	19.40	110.68	15.70
WLS05D	F-T Pool GW	07-Jun-06	20	8.1	0.93	0.28	0.46	2.53	1.26	2.30	7.83	1.12
WLS06D	F-T Pool GW	07-Jun-06	31	8.1	2.98	0.64	0.78	4.83	2.77	3.03	18.91	3.39
WLS01D	F-T Pool GW	08-Aug-06	37		2.56	1.16	1.36	4.26	1.15	4.15	21.15	1.32
WLS02D	F-T Pool GW	08-Aug-06	48		3.81	0.91	2.44	8.52	0.81	3.76	43.55	5.01

Sample ID	Water Type	Date	SC (μm/cm)	pH	Na (ppm)	K (ppm)	Mg (ppm)	Ca (ppm)	Cl (ppm)	SO4 (ppm)	HCO3 (ppm)	SiO2 (ppm)
WLP01S	F-T Pool GW	08-Aug-06	148		16.30	0.88	5.53	16.70	0.92	12.90	105.27	6.41
WLP03S	F-T Pool GW	08-Aug-06	162		2.64	0.55	1.21	4.47	0.46	1.43	24.94	8.93
WLS05D	F-T Pool GW	08-Aug-06	46		1.98	0.59	0.90	4.70	0.64	2.12	21.21	3.24
WLS06D	F-T Pool GW	08-Aug-06	36		3.23	0.58	0.95	5.26	2.30	3.49	21.87	4.55
WLP01S	F-T Pool GW	09-Aug-07	98	7.2	7.07	0.82	4.92	16.70	0.83	8.98	82.75	6.75
WLS02S	F-T Pool GW	09-Aug-07	64	6.8	2.93	1.36	1.92	7.32	0.72	2.86	36.95	2.73
WLS01S	F-T Pool GW	09-Aug-07	131	7.1	2.98	1.21	2.78	8.47	0.52	2.95	44.90	4.80
WLP03S	F-T Pool GW	09-Aug-07	41	5.7	5.71	1.55	3.13	12.90	1.07	28.10	35.01	10.50
SSPNG1	F-T Pool GW	07-Jun-06	39	7.9	2.34	0.42	1.34	8.17	0.69	6.18	29.43	6.21
SSPNG2	F-T Pool GW	07-Jun-06	27	8.0	1.41	0.31	0.81	4.75	0.56	3.51	17.33	3.21
SSPNG1	F-T Pool GW	08-Aug-06	38		2.60	0.37	1.52	8.04	0.75	6.76	29.71	6.91
SSPNG2	F-T Pool GW	08-Aug-06	41		2.60	0.36	1.54	8.21	0.70	6.52	30.70	6.65
SPRNG1	F-T Pool GW	09-Aug-07	46	6.9	2.56	0.35	1.46	7.91	0.66	6.11	29.85	6.58
Mean			67	7.4	5.15	0.81	2.27	9.13	1.07	6.94	43.49	5.72
Stdev			44	0.7	5.38	0.43	1.71	5.68	0.68	6.44	34.70	3.26

Note:
P-P Pool SW = Perched-precipitation pool surface water
P-P Pool GW = Perched-precipitation pool ground water
F-T Pool SW = Flow-through pool surface water
F-T Pool GW = Flow-through pool ground water
SC = Specific conductance

Sample ID	Pool Type	Date	SC (μm/cm)	pH	Na (ppm)	K (ppm)	Mg (ppm)	Ca (ppm)	Cl (ppm)	SO4 (ppm)	HCO3 (ppm)	SiO2 (ppm)
UTR043	P-P Pool SW	08-Aug-07	3	7.2	0.14	0.07	0.03	0.11	0.18	0.51	0.01	0.04
SFK009	P-P Pool SW	11-Aug-07	4	6.9	0.43	0.14	0.07	0.18	0.56	0.36	0.84	0.07
UTR004	P-P Pool SW	08-Aug-07	5	7.4	0.30	0.16	0.14	0.56	0.20	0.09	1.13	0.51
SFK001	P-P Pool SW	10-Aug-07	5	5.6	0.42	0.14	0.07	0.20	0.42	0.35	3.06	0.10
SFK011	P-P Pool SW	11-Aug-07	5	6.5	0.62	0.11	0.14	0.49	0.44	0.15	3.03	0.14
SFK013	P-P Pool SW	11-Aug-07	5	6.8	0.54	0.14	0.17	0.47	0.49	0.05	3.00	0.13
SFK024	P-P Pool SW	12-Aug-07	6	7.2	0.57	0.37	0.20	0.61	0.51	0.20	3.82	0.09
NFK036	P-P Pool SW	11-Aug-07	7	7.3	0.50	0.18	0.11	0.31	0.44	0.18	2.12	0.10
NFK021	P-P Pool SW	10-Aug-07	7	7.0	0.59	0.15	0.14	0.30	0.26	0.20	2.71	0.13
UTR044	P-P Pool SW	08-Aug-07	7	6.9	0.55	0.32	0.10	0.16	0.61	0.34	1.47	0.15
UTR042	P-P Pool SW	08-Aug-07	8	6.5	0.47	0.28	0.08	0.14	0.58	0.31	1.12	0.11
UTR035	P-P Pool SW	08-Aug-07	8	7.2	0.60	0.22	0.35	2.12	0.31	0.19	9.37	0.12
SFK010	P-P Pool SW	11-Aug-07	8	6.4	0.92	0.23	0.25	0.96	0.63	0.16	5.69	0.37
NFK005	P-P Pool SW	08-Aug-07	8	7.4	0.98	0.43	0.17	0.48	0.59	0.45	4.00	0.17
NFK023	P-P Pool SW	10-Aug-07	8	7.1	0.63	0.27	0.16	0.30	0.30	0.22	3.01	0.15
UTR023	P-P Pool SW	08-Aug-07	9	7.1	0.69	0.14	0.17	0.42	0.52	0.42	2.75	0.39
NFK020	P-P Pool SW	10-Aug-07	9	7.2	0.50	0.31	0.16	0.43	0.25	0.14	3.32	0.13
NFK009	P-P Pool SW	09-Aug-07	9	7.4	0.53	0.30	0.12	0.40	0.52	0.13	2.64	0.19
NFK003	P-P Pool SW	08-Aug-07	9	7.5	0.74	0.10	0.42	0.72	0.29	0.09	5.81	0.44
NFK024	P-P Pool SW	10-Aug-07	9	7.1	0.73	0.21	0.17	0.40	0.32	0.08	3.68	0.16
UTR011	P-P Pool SW	08-Aug-07	10	7.4	0.65	0.17	0.14	0.47	0.59	0.37	2.64	0.13
SFK005	P-P Pool SW	10-Aug-07	10	7.1	0.57	0.23	0.18	1.47	0.42	0.27	6.19	0.30
UTR003	P-P Pool SW	08-Aug-07	11	6.8	1.33	0.33	0.19	0.54	0.90	0.47	4.50	3.77
NFK018	P-P Pool SW	10-Aug-07	11	7.2	0.59	0.28	0.38	1.05	0.21	0.07	6.66	0.18
SFK003	P-P Pool SW	10-Aug-07	11	6.4	0.94	0.11	0.34	1.47	0.43	0.31	7.72	0.07
UTR017	P-P Pool SW	08-Aug-07	12	7.6	0.79	0.22	0.15	0.87	0.44	0.16	4.88	0.19
UTR002	P-P Pool SW	08-Aug-07	13	7.8	0.84	0.18	0.25	1.91	0.47	0.32	8.37	0.82
NFK032	P-P Pool SW	11-Aug-07	13	7.3	0.64	0.54	0.31	0.94	0.57	0.16	5.78	0.22
NFK007	P-P Pool SW	08-Aug-07	14	7.2	0.91	0.31	0.48	1.48	0.53	0.43	8.36	0.31
SFK014	P-P Pool SW	11-Aug-07	14	6.4	0.79	0.40	0.36	1.31	0.53	2.85	3.98	0.13
NFK026	P-P Pool SW	10-Aug-07	14	7.1	0.82	0.37	0.38	1.05	0.52	0.35	6.52	0.46
NFK010	P-P Pool SW	09-Aug-07	14	6.9	1.18	0.11	0.37	1.14	0.09	0.04	8.43	2.51
UTR041	P-P Pool SW	08-Aug-07	14	7.0	0.72	0.25	0.20	1.43	0.42	0.26	6.61	0.66
SFK016	P-P Pool SW	11-Aug-07	15	7.1	1.05	0.33	0.42	1.65	0.46	1.22	8.09	0.43
UTR045	P-P Pool SW	08-Aug-07	15	4.5	0.40	0.60	0.10	0.60	0.27	0.20	3.61	0.11
NFK002	P-P Pool SW	08-Aug-07	16	7.6	1.01	0.26	0.48	1.70	0.27	0.77	9.23	0.17
NFK022	P-P Pool SW	10-Aug-07	16	6.1	0.73	0.27	0.65	1.37	0.46	0.27	8.66	0.62
NFK013	P-P Pool SW	09-Aug-07	16	7.5	0.89	0.15	0.45	1.58	0.17	0.32	8.97	0.40
UTR033	P-P Pool SW	08-Aug-07	16	7.4	0.60	0.27	0.32	1.67	0.30	0.27	7.85	0.39
NFK045	P-P Pool SW	12-Aug-07	18	7.3	0.60	0.21	0.32	1.95	0.30	0.18	8.72	0.09
NFK042	P-P Pool SW	12-Aug-07	18	7.1	1.04	0.16	0.53	1.58	0.37	0.48	9.24	0.19
UTR005	P-P Pool SW	08-Aug-07	19	7.4	1.20	0.15	0.43	3.15	0.49	0.23	14.03	1.61
UTR029	P-P Pool SW	08-Aug-07	19	6.9	1.28	0.15	0.40	1.37	0.50	0.10	8.82	0.40
NFK030	P-P Pool SW	11-Aug-07	20	7.1	1.18	0.51	0.39	1.30	0.41	0.06	9.06	0.13
SFK002	P-P Pool SW	10-Aug-07	20	6.8	1.67	0.14	0.70	3.22	0.46	2.09	14.52	0.36
Mean			11	7.0	0.75	0.24	0.27	1.02	0.42	0.37	5.64	0.41
Stdev			5	0.6	0.30	0.12	0.16	0.74	0.15	0.51	3.35	0.67
NFK025	F-T Pool SW	10-Aug-07	21	7.1	0.92	0.35	0.56	1.70	0.50	0.39	9.62	0.23
SFK004	F-T Pool SW	10-Aug-07	22	6.5	0.99	0.42	0.40	3.90	0.50	0.30	15.92	0.59
SFK008	F-T Pool SW	11-Aug-07	22	7.0	1.35	0.25	0.57	3.16	0.60	0.95	14.22	1.79
NFK039	F-T Pool SW	12-Aug-07	22	7.3	1.10	0.43	0.70	1.81	0.33	0.41	11.53	0.18
NFK047	F-T Pool SW	12-Aug-07	23	7.1	1.36	0.69	0.76	1.60	0.42	0.35	12.21	0.32
NFK046	F-T Pool SW	12-Aug-07	23	7.1	1.23	0.29	0.72	1.97	0.18	0.81	11.99	0.76
SFK012	F-T Pool SW	11-Aug-07	23	6.4	0.88	0.53	0.52	2.69	0.41	5.77	5.92	0.09

Sample ID	Pool Type	Date	SC (μm/cm)	pH	Na (ppm)	K (ppm)	Mg (ppm)	Ca (ppm)	Cl (ppm)	SO4 (ppm)	HCO3 (ppm)	SiO2 (ppm)
NFK033	F-T Pool SW	11-Aug-07	23	7.3	1.59	0.54	0.61	1.93	0.39	0.23	13.04	0.17
NFK041	F-T Pool SW	12-Aug-07	23	7.2	1.19	0.38	0.62	2.42	0.51	0.17	13.14	0.77
UTR022	F-T Pool SW	08-Aug-07	24	7.2	2.33	0.13	1.02	2.17	0.18	0.00	17.81	2.56
NFK014	F-T Pool SW	09-Aug-07	24	7.5	1.66	0.09	0.73	2.09	0.08	0.22	14.16	0.76
SFK006	F-T Pool SW	10-Aug-07	26	6.9	1.44	0.30	0.60	3.65	0.60	0.35	16.94	0.86
NFK035	F-T Pool SW	11-Aug-07	27	7.1	1.77	1.10	0.59	1.96	0.47	0.09	14.42	0.28
NFK019	F-T Pool SW	10-Aug-07	27	7.5	2.14	0.59	0.93	1.81	0.47	0.80	14.96	0.27
UTR012	F-T Pool SW	08-Aug-07	27	7.0	1.21	0.19	0.48	3.53	0.54	0.41	15.22	1.32
NFK044	F-T Pool SW	12-Aug-07	28	7.1	1.01	0.22	0.58	3.47	0.38	0.24	15.54	0.29
NFK011	F-T Pool SW	09-Aug-07	28	7.2	1.75	0.21	0.93	2.67	0.28	0.24	16.98	2.58
UTR009	F-T Pool SW	08-Aug-07	28	8.3	1.02	0.19	0.43	5.25	0.48	0.38	19.84	1.40
UTR036	F-T Pool SW	08-Aug-07	28	7.2	0.96	0.24	0.51	3.05	0.35	0.23	13.88	0.29
UTR010	F-T Pool SW	08-Aug-07	29	7.6	1.12	0.27	0.42	5.02	0.49	0.58	19.21	2.51
UTR007	F-T Pool SW	08-Aug-07	30	7.5	1.22	0.28	0.52	4.97	0.57	0.28	14.41	2.01
SFK007	F-T Pool SW	10-Aug-07	30	7.1	1.82	0.36	0.71	3.48	0.45	3.44	20.08	0.37
SFK021	F-T Pool SW	12-Aug-07	30	7.4	1.55	0.39	1.24	4.12	0.37	2.27	19.97	0.25
UTR001	F-T Pool SW	08-Aug-07	31	7.1	1.57	0.38	0.75	6.56	0.55	0.66	26.71	3.33
UTR008	F-T Pool SW	08-Aug-07	32	7.8	1.36	0.27	0.55	5.14	0.62	0.58	20.64	3.45
UTR006	F-T Pool SW	08-Aug-07	33	7.6	1.32	0.29	0.54	5.50	0.59	0.52	21.74	2.20
UTR016	F-T Pool SW	08-Aug-07	34	7.4	1.47	0.33	0.75	4.35	0.44	0.34	20.24	0.29
UTR049	F-T Pool SW	08-Aug-07	35	6.7	2.86	0.07	0.66	1.47	0.25	0.00	15.06	1.65
SFK018	F-T Pool SW	12-Aug-07	35	7.3	1.45	0.38	1.47	5.89	0.41	1.94	26.59	0.49
UTR031	F-T Pool SW	08-Aug-07	36	7.0	1.80	0.26	0.41	3.47	0.65	3.90	11.73	1.72
UTR026	F-T Pool SW	08-Aug-07	36	6.6	2.32	0.11	0.95	3.60	0.18	0.19	21.51	1.72
NFK016	F-T Pool SW	09-Aug-07	36	7.0	2.35	0.17	1.79	5.26	0.13	0.11	31.14	2.15
NFK037	F-T Pool SW	11-Aug-07	38	7.0	1.66	0.31	1.02	3.79	0.30	0.43	20.49	0.50
UTR040	F-T Pool SW	08-Aug-07	40	7.3	2.04	0.17	1.19	6.43	0.39	0.37	30.09	2.69
UTR024	F-T Pool SW	08-Aug-07	41	7.2	2.78	0.12	0.81	5.83	0.52	3.72	23.76	2.12
UTR018	F-T Pool SW	08-Aug-07	41	7.3	1.90	0.27	0.84	5.29	0.53	0.60	24.11	2.23
SFKR02	F-T Pool SW	11-Aug-07	42	6.7	2.27	0.38	1.27	5.72	0.40	4.95	23.43	3.23
SFK023	F-T Pool SW	12-Aug-07	42	7.7	2.30	0.49	1.76	5.77	0.49	6.34	24.37	1.23
UTR025	F-T Pool SW	08-Aug-07	42	7.3	1.71	0.13	1.07	5.67	0.29	0.39	26.38	0.86
UTR034	F-T Pool SW	08-Aug-07	43	7.1	1.99	0.31	0.78	4.90	0.96	1.06	21.60	1.62
UTR013	F-T Pool SW	08-Aug-07	44	7.5	1.87	0.22	0.99	7.91	0.55	0.84	32.35	3.67
NFK008	F-T Pool SW	09-Aug-07	44	7.3	2.37	0.36	1.19	4.52	0.18	2.04	23.69	1.35
SFKR01	F-T Pool SW	10-Aug-07	44	7.3	2.62	0.25	1.46	5.99	0.36	6.18	24.44	2.88
NFK004	F-T Pool SW	08-Aug-07	46	7.0	0.77	0.07	0.98	3.04	0.00	0.00	16.33	1.76
NFK038	F-T Pool SW	12-Aug-07	46	7.3	1.97	0.52	1.49	5.48	0.26	0.71	28.86	0.70
UTR020	F-T Pool SW	08-Aug-07	48	7.0	2.58	0.08	1.22	5.54	0.61	0.14	28.74	4.03
NFK001	F-T Pool SW	08-Aug-07	48	7.1	2.59	0.23	1.85	5.40	0.37	0.35	31.88	3.91
NFK012	F-T Pool SW	09-Aug-07	49	7.6	2.28	0.42	1.52	5.09	0.29	0.86	28.24	1.58
UTR048	F-T Pool SW	08-Aug-07	50	6.8	1.43	2.28	0.91	3.06	0.76	0.00	19.93	0.11
NFK040	F-T Pool SW	12-Aug-07	51	7.1	2.36	0.52	1.54	5.45	0.20	1.09	29.67	1.68
NFK028	F-T Pool SW	11-Aug-07	53	7.3	2.70	0.47	1.33	5.76	0.50	0.39	30.76	0.20
UTR014	F-T Pool SW	08-Aug-07	53	7.1	2.39	0.20	1.02	9.67	0.45	0.98	39.20	3.08
SFK017	F-T Pool SW	12-Aug-07	54	7.3	1.76	0.28	2.17	9.39	0.21	2.49	41.07	0.88
NFK029	F-T Pool SW	11-Aug-07	55	7.2	2.19	0.30	1.47	5.69	0.31	1.09	29.07	0.12
UTR015	F-T Pool SW	08-Aug-07	56	7.0	1.78	0.25	0.88	7.53	0.50	0.66	30.76	0.63
UTR027	F-T Pool SW	08-Aug-07	57	7.3	2.12	0.19	1.12	6.92	0.40	1.18	30.43	4.12
UTR039	F-T Pool SW	08-Aug-07	57	7.6	2.60	0.30	1.84	6.61	0.21	0.87	35.27	0.37
NFK017	F-T Pool SW	09-Aug-07	58	7.3	2.28	0.03	2.52	6.59	0.13	0.69	37.72	0.47
NFK006	F-T Pool SW	08-Aug-07	59	6.9	3.28	0.39	2.29	6.15	0.39	2.35	35.88	3.75
NFK031	F-T Pool SW	11-Aug-07	59	7.3	2.27	0.71	2.62	5.08	0.52	0.35	34.42	0.78
SFK019	F-T Pool SW	12-Aug-07	59	7.4	2.31	0.87	2.05	11.10	0.43	2.60	47.54	0.80
SFK020	F-T Pool SW	12-Aug-07	61	7.4	2.72	0.49	2.28	9.49	0.45	14.20	29.50	0.62

Sample ID	Pool Type	Date	SC (μm/cm)	pH	Na (ppm)	K (ppm)	Mg (ppm)	Ca (ppm)	Cl (ppm)	SO4 (ppm)	HCO3 (ppm)	SiO2 (ppm)
UTR019	F-T Pool SW	08-Aug-07	64	6.8	3.59	0.12	2.55	6.71	0.22	0.15	42.38	2.52
SFK015	F-T Pool SW	11-Aug-07	66	7.2	2.49	0.69	2.36	10.90	0.38	8.65	41.07	2.96
UTR021	F-T Pool SW	08-Aug-07	66	7.5	3.67	0.16	2.15	7.51	0.43	0.31	42.52	3.73
NFK034	F-T Pool SW	11-Aug-07	67	7.1	2.76	0.54	2.17	7.17	0.39	1.66	38.11	4.27
UTR050	F-T Pool SW	08-Aug-07	67	7.2	4.33	0.06	3.40	7.20	0.00	0.04	50.53	3.22
SFK025	F-T Pool SW	12-Aug-07	71	7.0	3.91	0.50	2.67	9.53	0.35	18.70	29.21	1.10
SFK022	F-T Pool SW	12-Aug-07	78	7.2	3.40	0.56	3.30	12.80	0.40	13.90	47.08	1.31
UTR038	F-T Pool SW	08-Aug-07	79	8.3	4.10	0.07	2.50	9.06	0.15	2.16	48.13	0.56
UTR028	F-T Pool SW	08-Aug-07	80	7.1	2.52	0.38	1.48	11.60	0.52	7.37	39.77	3.02
NFK027	F-T Pool SW	11-Aug-07	80	7.3	2.99	0.35	1.95	9.95	0.50	1.11	46.30	4.83
UTR046	F-T Pool SW	08-Aug-07	86	7.2	3.61	0.05	2.78	11.00	0.04	2.12	54.35	0.23
UTR030	F-T Pool SW	08-Aug-07	88	7.5	2.16	0.34	1.30	12.50	0.68	15.30	30.23	1.69
UTR032	F-T Pool SW	08-Aug-07	91	7.5	2.63	0.24	0.87	11.80	0.68	17.20	24.62	1.69
UTR047	F-T Pool SW	08-Aug-07	108	7.2	3.18	0.08	2.73	12.00	0.14	4.28	53.13	0.85
NFK015	F-T Pool SW	09-Aug-07	112	6.7	3.42	0.46	5.77	13.50	0.26	0.83	78.37	0.44
NFK043	F-T Pool SW	12-Aug-07	159	6.7	4.11	1.55	4.07	15.10	0.66	52.60	11.74	8.64
Mean			48	7.2	2.14	0.36	1.39	5.93	0.40	2.97	26.84	1.68
Stdev			24	0.3	0.85	0.32	0.96	3.22	0.18	6.97	12.88	1.49

Note:
P-P Pool SW = Perched-precipitation pool surface water
F-T Pool SW = Flow-through pool surface water
SC = Specific conductance

ATTACHMENT 2

Precipitation and Pool Stage Data

Date	Precipitation (cm)	West Pool Stage (m)	East Pool Stage (m)
06/01/06			
06/02/06			
06/03/06			
06/04/06			
06/05/06			
06/06/06			
06/07/06			
06/08/06			
06/09/06	0.00	353.93	349.20
06/10/06	0.41	353.92	349.21
06/11/06	1.07	353.94	349.22
06/12/06	0.43	353.93	349.22
06/13/06	0.00	353.93	349.23
06/14/06	0.03	353.92	349.23
06/15/06	1.40	353.92	349.23
06/16/06	1.07	353.95	349.24
06/17/06	0.00	353.95	349.24
06/18/06	0.23	353.94	349.25
06/19/06	0.00	353.93	349.24
06/20/06	0.33	353.92	349.24
06/21/06	0.00	353.91	349.24
06/22/06	1.55	353.91	349.25
06/23/06	0.15	353.93	349.25
06/24/06	0.03	353.92	349.24
06/25/06	0.03	353.91	349.25
06/26/06	0.00	353.91	349.25
06/27/06	0.00	353.90	349.25
06/28/06	0.00	353.89	349.25
06/29/06	0.08	353.89	349.25
06/30/06	0.89	353.90	349.25
07/01/06	0.00	353.90	349.25
07/02/06	0.00	353.88	349.24
07/03/06	0.00	353.88	349.25
07/04/06	0.00	353.87	349.25
07/05/06	0.36	353.87	349.25
07/06/06	0.53	353.87	349.25
07/07/06	0.56	353.88	349.26
07/08/06	0.08	353.88	349.26
07/09/06	0.00	353.88	349.26
07/10/06	0.00	353.87	349.26
07/11/06	0.00	353.86	349.25
07/12/06	0.00	353.85	349.24
07/13/06	0.05	353.85	349.24
07/14/06	0.48	353.85	349.24
07/15/06	0.00	353.85	349.25
07/16/06	0.00	353.85	349.25
07/17/06	0.00	353.85	349.24
07/18/06	0.00	353.84	349.24
07/19/06	0.00	353.84	349.23
07/20/06	0.00	353.82	349.22

Date	Precipitation (cm)	West Pool Stage (m)	East Pool Stage (m)
07/21/06	0.00	353.82	349.22
07/22/06	0.00	353.82	349.22
07/23/06	0.30	353.82	349.22
07/24/06	0.86	353.83	349.24
07/25/06	0.18	353.84	349.25
07/26/06	0.00	353.83	349.25
07/27/06	0.00	353.82	349.25
07/28/06	0.00	353.81	349.24
07/29/06	0.20	353.82	349.24
07/30/06	0.00	353.82	349.24
07/31/06	0.03	353.81	349.24
08/01/06	0.05	353.82	349.24
08/02/06	0.43	353.82	349.25
08/03/06	1.80	353.83	349.26
08/04/06	0.84	353.85	349.28
08/05/06	0.76	353.86	349.28
08/06/06	0.00	353.86	349.27
08/07/06	0.00	353.85	349.27
08/08/06	0.00	353.85	349.26
08/09/06	0.36	353.86	349.27
08/10/06	2.36	353.88	349.29
08/11/06	2.08	353.91	349.29
08/12/06	0.71	353.93	349.29
08/13/06	0.48	353.93	349.29
08/14/06	2.39	353.94	349.30
08/15/06	0.58	353.96	349.31
08/16/06	1.32	353.94	349.30
08/17/06	0.03	353.94	349.30
08/18/06	4.55	353.96	349.31
08/19/06	0.30	353.96	349.31
08/20/06	0.03	353.94	349.30
08/21/06	0.43	353.93	349.30
08/22/06	1.68	353.95	349.30
08/23/06	0.00	353.94	349.29
08/24/06	0.41	353.94	349.30
08/25/06	0.00	353.93	349.30
08/26/06	0.00	353.93	349.30
08/27/06	0.03	353.92	349.30
08/28/06	0.00	353.92	349.30
08/29/06	0.00	353.91	349.30
08/30/06	0.79	353.92	349.31
08/31/06	0.13	353.93	349.30
09/01/06	0.00	353.92	349.30
09/02/06	0.33	353.92	349.30
09/03/06	0.10	353.92	349.30
09/04/06	0.33	353.92	349.30
09/05/06	0.03	353.92	349.30
09/06/06	0.00	353.91	349.29
09/07/06	1.32	353.92	349.30
09/08/06	3.05	353.95	349.32

Date	Precipitation (cm)	West Pool Stage (m)	East Pool Stage (m)
09/09/06	0.00	353.95	349.31
09/10/06	0.00	353.93	349.30
09/11/06	0.00	353.92	349.29
09/12/06	0.00	353.92	349.29
09/13/06	0.00	353.92	349.29
09/14/06	4.65	353.95	349.31
09/15/06	0.15	353.95	349.31
09/16/06	0.00	353.94	349.31
09/17/06	0.00	353.94	349.31
09/18/06	0.20	353.94	349.31
09/19/06	0.58	353.94	349.31
09/20/06	0.20	353.94	349.30
09/21/06	1.37	353.95	349.31
09/22/06	0.36	353.96	349.31
09/23/06	0.53	353.95	349.31
09/24/06	0.00	353.95	349.31
09/25/06	0.00	353.94	349.30
09/26/06	0.94	353.95	349.31
09/27/06	0.25	353.95	349.30
09/28/06	0.18	353.95	349.30
09/29/06	0.00	353.95	349.30
09/30/06	0.00	353.94	349.30
10/01/06	0.41	353.94	349.30
10/02/06	1.42	353.96	349.31
10/03/06	1.37	353.96	349.30
10/04/06	0.99	353.97	349.31
10/05/06	0.66	353.96	349.31
10/06/06			
10/07/06			
10/08/06			
10/09/06			
10/10/06			
10/11/06			
10/12/06			
10/13/06			
10/14/06			
10/15/06			
10/16/06			
10/17/06			
10/18/06			
10/19/06			
10/20/06			
10/21/06			
10/22/06			
10/23/06			
10/24/06			
10/25/06			
10/26/06			
10/27/06			
10/28/06			

Date	Precipitation (cm)	West Pool Stage (m)	East Pool Stage (m)
10/29/06			
10/30/06			
10/31/06			

Date	Precipitation (cm)	North Pool Stage (m)	South Pool Stage (m)
06/01/06			
06/02/06			
06/03/06			
06/04/06			
06/05/06			
06/06/06			
06/07/06			
06/08/06			
06/09/06	0.00	305.00	305.20
06/10/06	0.33	304.97	305.19
06/11/06	0.61	304.95	305.18
06/12/06	0.38	304.93	305.17
06/13/06	0.00	304.91	305.15
06/14/06	0.00	304.88	305.13
06/15/06	1.37	304.86	305.12
06/16/06	1.12	304.87	305.13
06/17/06	0.00	304.85	305.13
06/18/06	0.15	304.83	305.11
06/19/06	0.03	304.80	305.09
06/20/06	0.18	304.78	305.07
06/21/06	0.00	304.75	305.05
06/22/06	1.17	304.73	305.04
06/23/06	0.13	304.73	305.04
06/24/06	0.03	304.71	305.02
06/25/06	0.00	304.69	305.00
06/26/06	0.00	304.67	304.98
06/27/06	0.00	304.65	304.96
06/28/06	0.00	304.63	304.94
06/29/06	0.18	304.62	304.93
06/30/06	1.24	304.61	304.93
07/01/06	0.00	304.60	304.91
07/02/06	0.00	304.58	304.89
07/03/06	0.00	304.56	304.87
07/04/06	0.00	304.55	304.86
07/05/06	0.03	304.53	304.84
07/06/06	0.43	304.51	304.82
07/07/06	0.91	304.51	304.82
07/08/06	0.15	304.50	304.81
07/09/06	0.00	304.49	304.80
07/10/06	0.00	304.48	304.78
07/11/06	0.00	304.46	304.76
07/12/06	0.00	304.44	304.73
07/13/06	0.08	304.42	304.72
07/14/06	0.20	304.42	304.71
07/15/06	0.03	304.41	304.70
07/16/06	0.00	304.40	304.69
07/17/06	0.00	304.38	304.67
07/18/06	0.00	304.37	304.66
07/19/06	0.00	304.36	304.64
07/20/06	0.00	304.34	304.62

Date	Precipitation (cm)	North Pool Stage (m)	South Pool Stage (m)
07/21/06	0.00	304.32	304.61
07/22/06	0.10	304.31	304.60
07/23/06	0.30	304.31	304.59
07/24/06	0.71	304.31	304.59
07/25/06	0.15	304.31	304.59
07/26/06	0.00	304.29	304.57
07/27/06	0.00	304.28	304.55
07/28/06	0.00	304.26	304.54
07/29/06	0.23	304.25	304.53
07/30/06	0.00	304.24	304.52
07/31/06	0.00	304.23	304.51
08/01/06	0.13	304.23	304.50
08/02/06	0.91	304.23	304.50
08/03/06	1.91	304.23	304.50
08/04/06	0.36	304.25	304.51
08/05/06	0.61	304.25	304.51
08/06/06	0.00	304.23	304.50
08/07/06	0.00	304.22	304.49
08/08/06	0.00	304.20	304.47
08/09/06	0.38	304.20	304.47
08/10/06	2.49	304.21	304.48
08/11/06	2.41	304.25	304.51
08/12/06	0.94	304.28	304.53
08/13/06	0.23	304.28	304.52
08/14/06	2.87	304.29	304.53
08/15/06	0.64	304.33	304.56
08/16/06	0.58	304.34	304.56
08/17/06	0.51	304.34	304.55
08/18/06	3.94	304.37	304.58
08/19/06	0.33	304.41	304.62
08/20/06	0.03	304.40	304.61
08/21/06	0.46	304.39	304.61
08/22/06	2.21	304.42	304.65
08/23/06	0.00	304.42	304.66
08/24/06	0.41	304.41	304.66
08/25/06	0.00	304.41	304.66
08/26/06	0.53	304.41	304.67
08/27/06	0.00	304.40	304.66
08/28/06	0.00	304.39	304.66
08/29/06	0.00	304.38	304.65
08/30/06	0.74	304.38	304.65
08/31/06	0.10	304.38	304.65
09/01/06	0.00	304.37	304.64
09/02/06	0.03	304.35	304.63
09/03/06	0.23	304.34	304.62
09/04/06	0.25	304.34	304.62
09/05/06	0.05	304.33	304.61
09/06/06	0.00	304.31	304.60
09/07/06	1.52	304.31	304.60
09/08/06	2.84	304.34	304.63

Date	Precipitation (cm)	North Pool Stage (m)	South Pool Stage (m)
09/09/06	0.03	304.36	304.64
09/10/06	0.00	304.35	304.63
09/11/06	0.00	304.33	304.61
09/12/06	0.00	304.32	304.60
09/13/06	0.03	304.31	304.60
09/14/06	4.95	304.35	304.64
09/15/06	0.18	304.38	304.67
09/16/06	0.00	304.37	304.66
09/17/06	0.00	304.36	304.65
09/18/06	0.08	304.35	304.64
09/19/06	0.48	304.35	304.64
09/20/06	0.94	304.35	304.64
09/21/06	1.55	304.36	304.66
09/22/06	0.86	304.38	304.68
09/23/06	0.23	304.39	304.69
09/24/06	0.58	304.38	304.68
09/25/06	0.00	304.37	304.68
09/26/06	0.84	304.38	304.68
09/27/06	0.25	304.38	304.69
09/28/06	0.15	304.38	304.69
09/29/06	0.00	304.36	304.68
09/30/06	0.00	304.35	304.67
10/01/06	0.56	304.35	304.67
10/02/06	1.60	304.36	304.68
10/03/06	1.12	304.36	304.68
10/04/06	0.91	304.38	304.70
10/05/06	0.15		
10/06/06	0.15		
10/07/06			
10/08/06			
10/09/06			
10/10/06			
10/11/06			
10/12/06			
10/13/06			
10/14/06			
10/15/06			
10/16/06			
10/17/06			
10/18/06			
10/19/06			
10/20/06			
10/21/06			
10/22/06			
10/23/06			
10/24/06			
10/25/06			
10/26/06			
10/27/06			
10/28/06			

Date	Precipitation (cm)	North Pool Stage (m)	South Pool Stage (m)
10/29/06			
10/30/06			
10/31/06			

Date	Precipitation (cm)	North Pool Stage (m)	Middle Pool Stage (m)	South Pool Stage (m)
06/01/06				
06/02/06				
06/03/06				
06/04/06				
06/05/06				
06/06/06				
06/07/06				
06/08/06				
06/09/06	0.00			
06/10/06	0.25			
06/11/06	0.58			
06/12/06	0.25			
06/13/06	0.00			
06/14/06	0.00			
06/15/06	1.30			
06/16/06	1.04			
06/17/06	0.03			
06/18/06	0.03			
06/19/06	0.03			
06/20/06	0.13			
06/21/06	0.00			
06/22/06	1.09			
06/23/06	0.15			
06/24/06	0.03			
06/25/06	0.00			
06/26/06	0.00			
06/27/06	0.00			
06/28/06	0.00			
06/29/06	0.23			
06/30/06	1.70	256.10		277.42
07/01/06	0.00	256.08		277.40
07/02/06	0.00	256.06		277.37
07/03/06	0.00	256.07		277.35
07/04/06	0.00	256.07		277.33
07/05/06	0.05	256.07		277.31
07/06/06	0.33	256.06		277.29
07/07/06	0.71	256.07		277.28
07/08/06	0.10	256.07		277.27
07/09/06	0.00	256.07		277.25
07/10/06	0.00	256.06		277.23
07/11/06	0.00	256.06		277.21
07/12/06	0.00	256.05		277.18
07/13/06	0.05	256.06		277.17
07/14/06	0.23	256.06		277.16
07/15/06	0.00	256.06		277.15
07/16/06	0.00	256.06		277.13
07/17/06	0.00	256.06		277.11
07/18/06	0.00	256.06		277.10
07/19/06	0.00	256.05		277.08
07/20/06	0.00	256.04	251.90	277.06

Date	Precipitation (cm)	North Pool Stage (m)	Middle Pool Stage (m)	South Pool Stage (m)
07/21/06	0.00	256.04	251.88	277.05
07/22/06	0.20	256.05	251.87	277.03
07/23/06	0.36	256.06	251.86	277.03
07/24/06	0.74	256.06	251.85	277.03
07/25/06	0.13	256.06	251.85	277.03
07/26/06	0.00	256.05	251.83	277.01
07/27/06	0.00	256.04	251.80	276.99
07/28/06	0.00	256.04	251.78	276.97
07/29/06	0.28	256.05	251.76	276.97
07/30/06	0.03	256.05	251.74	276.96
07/31/06	0.00	256.04	251.72	276.94
08/01/06	0.30	256.05	*251.71*	276.94
08/02/06	1.12	256.06	*251.70*	276.95
08/03/06	1.73	256.06	*251.69*	276.95
08/04/06	0.48	256.06	*251.68*	276.96
08/05/06	0.79	256.06	*251.67*	276.96
08/06/06	0.00	256.05	*251.66*	276.95
08/07/06	0.00	256.04	*251.65*	276.94
08/08/06	0.00	256.04	251.65	276.92
08/09/06	0.51	256.04	251.63	276.92
08/10/06	2.51	256.06	251.63	276.94
08/11/06	2.46	256.08	251.67	276.99
08/12/06	1.42	256.07	251.69	277.02
08/13/06	0.23	256.06	251.69	277.02
08/14/06	2.95	256.07	251.69	277.03
08/15/06	0.66	256.08	251.71	277.07
08/16/06	0.33	256.06	251.71	277.06
08/17/06	0.03	256.05	251.69	277.05
08/18/06	4.57	256.08	251.71	277.09
08/19/06	0.23	256.08	251.74	277.12
08/20/06	0.05	256.05	251.73	277.11
08/21/06	0.51	256.05	251.71	277.09
08/22/06	2.44	256.08	251.74	277.13
08/23/06	0.00	256.06	251.73	277.12
08/24/06	0.51	256.05	251.72	277.11
08/25/06	0.00	256.05	251.70	277.11
08/26/06	0.61	256.05	251.69	277.10
08/27/06	0.03	256.05	251.68	277.09
08/28/06	0.00	256.05	251.66	277.07
08/29/06	0.00	256.05	251.64	277.06
08/30/06	0.84	256.06	251.63	277.05
08/31/06	0.08	256.06	251.63	277.05
09/01/06	0.03	256.05	251.62	277.04
09/02/06	0.00	256.05	251.60	277.02
09/03/06	0.00	256.05	251.59	277.01
09/04/06	0.05	256.06	251.57	276.99
09/05/06	0.05	256.06	251.57	276.98
09/06/06	0.00	256.06	251.55	276.96
09/07/06	1.42	256.07	251.55	276.96
09/08/06	3.30	256.09	251.59	276.99

Date	Precipitation (cm)	North Pool Stage (m)	Middle Pool Stage (m)	South Pool Stage (m)
09/09/06	0.05	256.08	251.63	277.02
09/10/06	0.00	256.07	251.63	277.01
09/11/06	0.00	256.06	251.62	276.99
09/12/06	0.00	256.06	251.62	276.97
09/13/06	0.03	256.07	251.62	276.96
09/14/06	4.80	256.11	251.68	277.01
09/15/06	0.15	256.09	251.73	277.04
09/16/06	0.00	256.08	251.74	277.03
09/17/06	0.00	256.08	251.74	277.01
09/18/06	0.05	256.09	251.75	277.00
09/19/06	0.43	256.09	251.76	276.99
09/20/06	0.20	256.09	251.78	276.99
09/21/06	1.47	256.11	251.80	276.99
09/22/06	1.02	256.11	251.85	277.01
09/23/06	0.15	256.10	251.88	277.01
09/24/06	0.10	256.10	251.89	277.00
09/25/06	0.00	256.10	251.90	276.98
09/26/06	0.89	256.11	251.93	276.98
09/27/06	0.41	256.11	251.96	276.99
09/28/06	0.20	256.11	251.99	276.98
09/29/06	0.00	256.11	252.01	276.97
09/30/06	0.00	256.11	252.02	276.95
10/01/06	0.36	256.11	252.04	276.95
10/02/06	1.80	256.13	252.09	276.97
10/03/06	1.22	256.12	252.12	276.97
10/04/06	1.09	256.13	252.18	277.00
10/05/06	0.13			
10/06/06	0.13			
10/07/06				
10/08/06				
10/09/06				
10/10/06				
10/11/06				
10/12/06				
10/13/06				
10/14/06				
10/15/06				
10/16/06				
10/17/06				
10/18/06				
10/19/06				
10/20/06				
10/21/06				
10/22/06				
10/23/06				
10/24/06				
10/25/06				
10/26/06				
10/27/06				
10/28/06				

Date	Precipitation (cm)	North Pool Stage (m)	Middle Pool Stage (m)	South Pool Stage (m)
10/29/06				
10/30/06				
10/31/06				

ATTACHMENT 3

Net Groundwater Recharge Data

Date	Precipitation (cm)	ET (cm)	ΔS West Pool (cm)	ΔS East Pool (cm)	ΔGW West Pool (cm)	ΔGW East Pool (cm)
06/01/06						
06/02/06						
06/03/06						
06/04/06						
06/05/06						
06/06/06						
06/07/06						
06/08/06						
06/09/06	0.00	0.20				
06/10/06	0.41	0.14	-0.42	1.04	-0.69	0.77
06/11/06	1.07	0.06	1.07	1.03	0.06	0.02
06/12/06	0.43	0.03	-0.05	0.25	-0.46	-0.15
06/13/06	0.00	0.15	-0.13	0.14	0.02	0.29
06/14/06	0.03	0.14	-0.92	0.05	-0.80	0.17
06/15/06	1.40	0.20	-0.01	0.73	-1.21	-0.47
06/16/06	1.07	0.01	2.38	1.05	1.32	-0.01
06/17/06	0.00	0.13	-0.18	-0.06	-0.04	0.08
06/18/06	0.23	0.15	-0.60	0.36	-0.67	0.28
06/19/06	0.00	0.23	-0.96	-0.29	-0.73	-0.06
06/20/06	0.33	0.18	-1.12	-0.22	-1.27	-0.37
06/21/06	0.00	0.30	-0.45	0.04	-0.15	0.34
06/22/06	1.55	0.12	-0.02	0.34	-1.44	-1.08
06/23/06	0.15	0.14	1.97	0.83	1.95	0.82
06/24/06	0.03	0.26	-1.37	-0.87	-1.13	-0.64
06/25/06	0.03	0.33	-0.70	0.11	-0.39	0.42
06/26/06	0.00	0.32	-0.39	0.34	-0.07	0.66
06/27/06	0.00	0.41	-1.05	-0.29	-0.65	0.11
06/28/06	0.00	0.10	-0.78	-0.12	-0.69	-0.02
06/29/06	0.08	0.16	0.22	0.65	0.30	0.73
06/30/06	0.89	0.07	0.24	0.16	-0.58	-0.66
07/01/06	0.00	0.36	0.00	-0.06	0.36	0.30
07/02/06	0.00	0.44	-1.46	-0.77	-1.02	-0.34
07/03/06	0.00	0.41	-0.30	0.36	0.11	0.77
07/04/06	0.00	0.48	-0.53	-0.20	-0.05	0.27
07/05/06	0.36	0.27	-0.29	0.01	-0.37	-0.07

Date	Precipitation (cm)	ET (cm)	ΔS West Pool (cm)	ΔS East Pool (cm)	ΔGW West Pool (cm)	ΔGW East Pool (cm)
07/06/06	0.53	0.25	-0.07	0.19	-0.35	-0.09
07/07/06	0.56	0.01	0.63	0.74	0.08	0.18
07/08/06	0.08	0.06	0.26	-0.07	0.24	-0.08
07/09/06	0.00	0.35	-0.04	0.36	0.31	0.70
07/10/06	0.00	0.18	-0.64	-0.35	-0.46	-0.16
07/11/06	0.00	0.20	-0.94	-0.65	-0.74	-0.45
07/12/06	0.00	0.40	-1.19	-0.56	-0.79	-0.15
07/13/06	0.05	0.06	-0.27	-0.02	-0.26	-0.01
07/14/06	0.48	0.02	0.04	-0.03	-0.42	-0.50
07/15/06	0.00	0.12	0.27	0.59	0.39	0.71
07/16/06	0.00	0.14	-0.31	-0.08	-0.17	0.06
07/17/06	0.00	0.10	-0.20	-0.30	-0.11	-0.20
07/18/06	0.00	0.12	-0.25	-0.35	-0.13	-0.24
07/19/06	0.00	0.23	-0.64	-0.69	-0.41	-0.46
07/20/06	0.00	0.34	-1.20	-1.10	-0.86	-0.76
07/21/06	0.00	0.20	-0.59	-0.51	-0.39	-0.31
07/22/06	0.00	0.10	-0.02	0.00	0.07	0.10
07/23/06	0.30	0.04	0.44	0.53	0.17	0.26
07/24/06	0.86	0.02	0.83	1.39	-0.02	0.55
07/25/06	0.18	0.21	0.59	1.59	0.62	1.63
07/26/06	0.00	0.12	-0.82	-0.42	-0.69	-0.30
07/27/06	0.00	0.12	-0.59	-0.29	-0.47	-0.17
07/28/06	0.00	0.08	-0.83	-0.74	-0.75	-0.66
07/29/06	0.20	0.08	0.31	0.23	0.18	0.10
07/30/06	0.00	0.02	-0.08	0.04	-0.06	0.06
07/31/06	0.03	0.07	-0.26	-0.06	-0.22	-0.01
08/01/06	0.05	0.04	0.25	0.33	0.24	0.32
08/02/06	0.43	0.06	0.28	0.36	-0.10	-0.02
08/03/06	1.80	0.06	1.06	1.42	-0.68	-0.32
08/04/06	0.84	0.24	1.74	1.32	1.15	0.72
08/05/06	0.76	0.29	1.11	0.07	0.63	-0.41
08/06/06	0.00	0.08	-0.14	-0.68	-0.06	-0.60
08/07/06	0.00	0.00	-0.44	-0.24	-0.44	-0.23
08/08/06	0.00	0.00	-0.44	-0.31	-0.44	-0.30
08/09/06	0.36	0.11	0.66	0.79	0.42	0.55

Date	Precipitation (cm)	ET (cm)	ΔS West Pool (cm)	ΔS East Pool (cm)	ΔGW West Pool (cm)	ΔGW East Pool (cm)
08/10/06	2.36	0.01	2.00	1.44	-0.35	-0.91
08/11/06	2.08	0.00	3.09	0.82	1.01	-1.26
08/12/06	0.71	0.01	2.27	0.00	1.57	-0.70
08/13/06	0.48	0.07	-0.16	0.00	-0.58	-0.41
08/14/06	2.39	0.14	1.45	1.00	-0.80	-1.25
08/15/06	0.58	0.01	1.35	0.21	0.77	-0.36
08/16/06	1.32	0.13	-1.36	-0.51	-2.55	-1.70
08/17/06	0.03	0.18	-0.11	-0.35	0.05	-0.20
08/18/06	4.55	0.14	1.71	1.33	-2.69	-3.07
08/19/06	0.30	0.07	0.03	0.07	-0.20	-0.16
08/20/06	0.03	0.20	-1.71	-0.99	-1.54	-0.82
08/21/06	0.43	0.04	-0.96	-0.44	-1.36	-0.83
08/22/06	1.68	0.20	1.62	0.66	0.15	-0.82
08/23/06	0.00	0.11	-0.87	-0.97	-0.76	-0.86
08/24/06	0.41	0.18	-0.20	0.60	-0.43	0.37
08/25/06	0.00	0.10	-0.51	-0.34	-0.41	-0.24
08/26/06	0.00	0.19	-0.38	0.23	-0.19	0.42
08/27/06	0.03	0.13	-0.64	-0.21	-0.54	-0.11
08/28/06	0.00	0.12	-0.28	0.18	-0.16	0.31
08/29/06	0.00	0.16	-0.42	0.01	-0.26	0.17
08/30/06	0.79	0.15	0.81	0.77	0.17	0.14
08/31/06	0.13	0.14	0.42	-0.27	0.44	-0.25
09/01/06	0.00	0.10	-0.47	-0.22	-0.37	-0.11
09/02/06	0.33	0.19	-0.39	-0.10	-0.53	-0.24
09/03/06	0.10	0.06	-0.04	0.10	-0.08	0.06
09/04/06	0.33	0.01	-0.03	-0.22	-0.35	-0.54
09/05/06	0.03	0.16	0.25	-0.26	0.38	-0.13
09/06/06	0.00	0.14	-0.80	-1.13	-0.66	-0.99
09/07/06	1.32	0.22	0.53	0.93	-0.57	-0.17
09/08/06	3.05	0.25	3.23	1.94	0.43	-0.86
09/09/06	0.00	0.25	-0.25	-0.97	0.00	-0.71
09/10/06	0.00	0.06	-1.45	-0.55	-1.39	-0.49
09/11/06	0.00	0.12	-1.12	-0.62	-1.00	-0.50
09/12/06	0.00	0.09	-0.52	-0.04	-0.43	0.05
09/13/06	0.00	0.05	0.00	0.17	0.05	0.22

Date	Precipitation (cm)	ET (cm)	ΔS West Pool (cm)	ΔS East Pool (cm)	ΔGW West Pool (cm)	ΔGW East Pool (cm)
09/14/06	4.65	0.08	3.64	1.85	-0.93	-2.72
09/15/06	0.15	0.05	-0.24	-0.28	-0.34	-0.37
09/16/06	0.00	0.04	-0.84	-0.27	-0.80	-0.23
09/17/06	0.00	0.00	-0.49	-0.27	-0.49	-0.27
09/18/06	0.20	0.03	-0.08	0.04	-0.26	-0.14
09/19/06	0.58	0.02	0.44	0.08	-0.13	-0.49
09/20/06	0.20	0.07	0.21	-0.21	0.08	-0.35
09/21/06	1.37	0.07	0.96	0.81	-0.33	-0.49
09/22/06	0.36	0.00	0.75	0.24	0.40	-0.11
09/23/06	0.53	0.04	-0.52	-0.24	-1.01	-0.73
09/24/06	0.00	0.02	-0.59	-0.54	-0.57	-0.52
09/25/06	0.00	0.06	-0.65	-0.52	-0.59	-0.46
09/26/06	0.94	0.09	0.73	0.46	-0.12	-0.39
09/27/06	0.25	0.04	0.53	-0.22	0.32	-0.43
09/28/06	0.18	0.01	-0.21	-0.42	-0.37	-0.59
09/29/06	0.00	0.08	-0.53	0.39	-0.44	0.47
09/30/06	0.00	0.01	-0.61	-0.13	-0.60	-0.12
10/01/06	0.41	0.04	0.28	-0.02	-0.09	-0.38
10/02/06	1.42	0.00	1.55	0.70	0.13	-0.72
10/03/06	1.37	0.00	-0.38	-0.97	-1.75	-2.35
10/04/06	0.99	0.06	1.21	1.23	0.28	0.30
10/05/06	0.66	0.07	-0.52	-0.51	-1.11	-1.10
10/06/06						
10/07/06						
10/08/06						
10/09/06						
10/10/06						
10/11/06						
10/12/06						
10/13/06						
10/14/06						
10/15/06						
10/16/06						
10/17/06						
10/18/06						

Date	Precipitation (cm)	ET (cm)	ΔS West Pool (cm)	ΔS East Pool (cm)	ΔGW West Pool (cm)	ΔGW East Pool (cm)
10/19/06						
10/20/06						
10/21/06						
10/22/06						
10/23/06						
10/24/06						
10/25/06						
10/26/06						
10/27/06						
10/28/06						
10/29/06						
10/30/06						
10/31/06						

Note:
ET = Evapotranspiration
ΔS = Change in storage (i.e., change in pool stage)
ΔGW = Net ground-water inflow (i.e., ground-water inflow - ground-water outflow)

Date	Precipitation (cm)	ET (cm)	∆S North Pool (cm)	∆S South Pool (cm)	∆GW North Pool Pool (cm)	∆GW South Pool (cm)
06/01/06						
06/02/06						
06/03/06						
06/04/06						
06/05/06						
06/06/06						
06/07/06						
06/08/06						
06/09/06	0.00	0.20				
06/10/06	0.33	0.14	-2.84	-1.57	-3.03	-1.75
06/11/06	0.61	0.06	-1.93	-0.83	-2.48	-1.39
06/12/06	0.38	0.03	-2.26	-1.35	-2.62	-1.71
06/13/06	0.00	0.15	-2.03	-1.19	-1.88	-1.03
06/14/06	0.00	0.14	-2.84	-2.12	-2.70	-1.98
06/15/06	1.37	0.20	-1.98	-1.16	-3.16	-2.34
06/16/06	1.12	0.01	0.63	1.35	-0.48	0.24
06/17/06	0.00	0.13	-1.50	-0.72	-1.37	-0.59
06/18/06	0.15	0.15	-2.27	-1.50	-2.28	-1.50
06/19/06	0.03	0.23	-2.87	-2.11	-2.66	-1.90
06/20/06	0.18	0.18	-2.77	-2.16	-2.77	-2.16
06/21/06	0.00	0.30	-2.41	-1.79	-2.11	-1.49
06/22/06	1.17	0.12	-1.65	-1.18	-2.70	-2.23
06/23/06	0.13	0.14	-0.17	0.19	-0.16	0.19
06/24/06	0.03	0.26	-2.65	-2.49	-2.42	-2.26
06/25/06	0.00	0.33	-1.87	-1.79	-1.53	-1.46
06/26/06	0.00	0.32	-1.67	-1.52	-1.35	-1.20
06/27/06	0.00	0.41	-2.31	-2.28	-1.91	-1.87
06/28/06	0.00	0.10	-2.07	-1.90	-1.97	-1.80
06/29/06	0.18	0.16	-1.04	-1.08	-1.06	-1.10
06/30/06	1.24	0.07	-0.23	-0.32	-1.41	-1.50
07/01/06	0.00	0.36	-1.17	-1.37	-0.81	-1.01
07/02/06	0.00	0.44	-2.63	-2.76	-2.19	-2.33
07/03/06	0.00	0.41	-1.65	-1.49	-1.24	-1.09
07/04/06	0.00	0.48	-1.49	-1.51	-1.01	-1.04

Date	Precipitation (cm)	ET (cm)	ΔS North Pool (cm)	ΔS South Pool (cm)	ΔGW North Pool Pool (cm)	ΔGW South Pool (cm)
07/05/06	0.03	0.27	-1.70	-1.64	-1.45	-1.39
07/06/06	0.43	0.25	-1.45	-1.57	-1.63	-1.75
07/07/06	0.91	0.01	-0.61	-0.60	-1.52	-1.51
07/08/06	0.15	0.06	-0.41	-0.58	-0.51	-0.68
07/09/06	0.00	0.35	-1.08	-1.46	-0.74	-1.12
07/10/06	0.00	0.18	-1.69	-1.82	-1.50	-1.64
07/11/06	0.00	0.20	-1.78	-1.95	-1.58	-1.75
07/12/06	0.00	0.40	-2.23	-2.54	-1.83	-2.14
07/13/06	0.08	0.06	-1.14	-1.14	-1.16	-1.16
07/14/06	0.20	0.02	-0.81	-0.97	-1.00	-1.16
07/15/06	0.03	0.12	-0.76	-1.15	-0.67	-1.06
07/16/06	0.00	0.14	-1.24	-1.55	-1.10	-1.41
07/17/06	0.00	0.10	-1.44	-1.47	-1.35	-1.37
07/18/06	0.00	0.12	-0.96	-1.14	-0.84	-1.02
07/19/06	0.00	0.23	-1.60	-1.88	-1.37	-1.64
07/20/06	0.00	0.34	-1.93	-2.15	-1.59	-1.80
07/21/06	0.00	0.20	-1.37	-1.49	-1.17	-1.29
07/22/06	0.10	0.10	-1.10	-1.03	-1.11	-1.04
07/23/06	0.30	0.04	-0.61	-0.51	-0.87	-0.77
07/24/06	0.71	0.02	0.30	-0.05	-0.39	-0.74
07/25/06	0.15	0.21	-0.18	-0.45	-0.12	-0.39
07/26/06	0.00	0.12	-1.39	-1.60	-1.27	-1.48
07/27/06	0.00	0.12	-1.62	-1.55	-1.50	-1.43
07/28/06	0.00	0.08	-1.77	-1.85	-1.69	-1.76
07/29/06	0.23	0.08	-0.70	-0.59	-0.85	-0.74
07/30/06	0.00	0.02	-0.93	-1.12	-0.90	-1.10
07/31/06	0.00	0.07	-1.17	-1.29	-1.10	-1.22
08/01/06	0.13	0.04	-0.39	-0.39	-0.47	-0.47
08/02/06	0.91	0.06	0.13	0.16	-0.72	-0.70
08/03/06	1.91	0.06	0.29	0.09	-1.55	-1.75
08/04/06	0.36	0.24	1.52	1.06	1.41	0.94
08/05/06	0.61	0.29	-0.21	-0.47	-0.53	-0.79
08/06/06	0.00	0.08	-1.10	-1.14	-1.02	-1.07
08/07/06	0.00	0.00	-1.31	-1.17	-1.31	-1.16

Date	Precipitation (cm)	ET (cm)	ΔS North Pool (cm)	ΔS South Pool (cm)	ΔGW North Pool Pool (cm)	ΔGW South Pool (cm)
08/08/06	0.00	0.00	-1.79	-1.56	-1.79	-1.56
08/09/06	0.38	0.11	-0.14	-0.18	-0.41	-0.45
08/10/06	2.49	0.01	1.20	1.03	-1.28	-1.44
08/11/06	2.41	0.00	4.03	3.02	1.62	0.61
08/12/06	0.94	0.01	3.09	1.77	2.17	0.84
08/13/06	0.23	0.07	-0.24	-0.36	-0.40	-0.52
08/14/06	2.87	0.14	1.09	0.77	-1.64	-1.97
08/15/06	0.64	0.01	4.05	2.73	3.42	2.10
08/16/06	0.58	0.13	0.27	-0.37	-0.18	-0.82
08/17/06	0.51	0.18	0.05	-0.31	-0.28	-0.64
08/18/06	3.94	0.14	3.72	3.24	-0.08	-0.55
08/19/06	0.33	0.07	3.54	3.22	3.28	2.97
08/20/06	0.03	0.20	-0.76	-0.30	-0.59	-0.14
08/21/06	0.46	0.04	-1.13	-0.41	-1.55	-0.83
08/22/06	2.21	0.20	3.02	4.25	1.01	2.24
08/23/06	0.00	0.11	-0.13	0.98	-0.03	1.09
08/24/06	0.41	0.18	-0.50	0.15	-0.73	-0.08
08/25/06	0.00	0.10	-0.61	0.13	-0.50	0.24
08/26/06	0.53	0.19	-0.26	0.10	-0.60	-0.24
08/27/06	0.00	0.13	-0.79	-0.20	-0.66	-0.07
08/28/06	0.00	0.12	-0.79	-0.53	-0.67	-0.40
08/29/06	0.00	0.16	-1.21	-0.93	-1.05	-0.77
08/30/06	0.74	0.15	-0.31	-0.04	-0.89	-0.62
08/31/06	0.10	0.14	0.04	0.18	0.08	0.22
09/01/06	0.00	0.10	-0.97	-0.89	-0.87	-0.78
09/02/06	0.03	0.19	-1.37	-1.15	-1.20	-0.98
09/03/06	0.23	0.06	-0.94	-0.82	-1.11	-0.99
09/04/06	0.25	0.01	-0.68	-0.58	-0.92	-0.82
09/05/06	0.05	0.16	-0.28	-0.27	-0.17	-0.17
09/06/06	0.00	0.14	-1.84	-1.65	-1.70	-1.51
09/07/06	1.52	0.22	-0.22	0.07	-1.52	-1.24
09/08/06	2.84	0.25	3.18	2.80	0.58	0.20
09/09/06	0.03	0.25	1.28	1.34	1.51	1.57
09/10/06	0.00	0.06	-1.09	-0.94	-1.02	-0.88

Date	Precipitation (cm)	ET (cm)	∆S North Pool (cm)	∆S South Pool (cm)	∆GW North Pool Pool (cm)	∆GW South Pool (cm)
09/11/06	0.00	0.12	-1.63	-1.50	-1.50	-1.38
09/12/06	0.00	0.09	-1.25	-1.05	-1.16	-0.96
09/13/06	0.03	0.05	-1.05	-0.61	-1.03	-0.59
09/14/06	4.95	0.08	4.78	4.64	-0.10	-0.24
09/15/06	0.18	0.05	2.33	2.31	2.21	2.19
09/16/06	0.00	0.04	-0.45	-0.50	-0.41	-0.46
09/17/06	0.00	0.00	-1.02	-0.85	-1.02	-0.85
09/18/06	0.08	0.03	-0.92	-0.92	-0.98	-0.98
09/19/06	0.48	0.02	-0.47	-0.11	-0.94	-0.58
09/20/06	0.94	0.07	0.13	0.09	-0.75	-0.79
09/21/06	1.55	0.07	0.99	1.19	-0.49	-0.29
09/22/06	0.86	0.00	2.40	2.81	1.54	1.95
09/23/06	0.23	0.04	0.07	0.31	-0.11	0.12
09/24/06	0.58	0.02	-0.58	-0.45	-1.14	-1.01
09/25/06	0.00	0.06	-0.68	-0.32	-0.62	-0.26
09/26/06	0.84	0.09	0.31	0.41	-0.43	-0.34
09/27/06	0.25	0.04	0.39	0.57	0.18	0.36
09/28/06	0.15	0.01	-0.29	-0.03	-0.44	-0.17
09/29/06	0.00	0.08	-1.25	-0.76	-1.16	-0.68
09/30/06	0.00	0.01	-1.61	-1.24	-1.60	-1.23
10/01/06	0.56	0.04	-0.18	-0.19	-0.70	-0.71
10/02/06	1.60	0.00	1.32	1.43	-0.28	-0.17
10/03/06	1.12	0.00	0.14	0.24	-0.98	-0.88
10/04/06	0.91	0.06	1.43	1.74	0.57	0.89
10/05/06						
10/06/06						
10/07/06						
10/08/06						
10/09/06						
10/10/06						
10/11/06						
10/12/06						
10/13/06						
10/14/06						

Date	Precipitation (cm)	ET (cm)	ΔS North Pool (cm)	ΔS South Pool (cm)	ΔGW North Pool Pool (cm)	ΔGW South Pool (cm)
10/15/06						
10/16/06						
10/17/06						
10/18/06						
10/19/06						
10/20/06						
10/21/06						
10/22/06						
10/23/06						
10/24/06						
10/25/06						
10/26/06						
10/27/06						
10/28/06						
10/29/06						
10/30/06						
10/31/06						

Note:
ET = Evapotranspiration
ΔS = Change in storage (i.e., change in pool stage)
ΔGW = Net ground-water inflow (i.e., ground-water inflow - ground-water outflow)

Date	Precipitation (cm)	ET (cm)	∆S North Pool (cm)	∆S Middle Pool (cm)	∆S South Pool (cm)	∆GW North Pool (cm)	∆GW Middle Pool (cm)	∆GW South Pool (cm)
06/01/06								
06/02/06								
06/03/06								
06/04/06								
06/05/06								
06/06/06								
06/07/06								
06/08/06								
06/09/06								
06/10/06								
06/11/06								
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06/14/06								
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06/16/06								
06/17/06								
06/18/06								
06/19/06								
06/20/06								
06/21/06								
06/22/06								
06/23/06								
06/24/06								
06/25/06								
06/26/06								
06/27/06								
06/28/06								
06/29/06								
06/30/06	1.70	0.07						
07/01/06	0.00	0.36	-1.63		-1.57	-1.27		-1.22
07/02/06	0.00	0.44	-1.77		-3.28	-1.33		-2.84
07/03/06	0.00	0.41	0.32		-1.98	0.73		-1.57
07/04/06	0.00	0.48	0.05		-1.90	0.53		-1.43
07/05/06	0.05	0.27	-0.06		-2.22	0.16		-2.00

Date	Precipitation (cm)	ET (cm)	ΔS North Pool (cm)	ΔS Middle Pool (cm)	ΔS South Pool (cm)	ΔGW North Pool (cm)	ΔGW Middle Pool (cm)	ΔGW South Pool (cm)
07/06/06	0.33	0.25	-0.25		-2.18	-0.34		-2.27
07/07/06	0.71	0.01	0.70		-0.99	-0.01		-1.70
07/08/06	0.10	0.06	0.11		-1.02	0.07		-1.06
07/09/06	0.00	0.35	-0.75		-1.70	-0.40		-1.36
07/10/06	0.00	0.18	-0.33		-2.11	-0.15		-1.93
07/11/06	0.00	0.20	-0.29		-2.08	-0.09		-1.88
07/12/06	0.00	0.40	-0.88		-2.60	-0.48		-2.20
07/13/06	0.05	0.06	0.51		-1.56	0.51		-1.56
07/14/06	0.23	0.02	0.60		-1.10	0.39		-1.31
07/15/06	0.00	0.12	0.18		-0.91	0.29		-0.80
07/16/06	0.00	0.14	-0.44		-1.64	-0.31		-1.50
07/17/06	0.00	0.10	-0.36		-1.75	-0.26		-1.66
07/18/06	0.00	0.12	0.19		-1.23	0.31		-1.11
07/19/06	0.00	0.23	-0.51		-1.82	-0.28		-1.58
07/20/06	0.00	0.34	-0.81		-2.17	-0.47		-1.83
07/21/06	0.00	0.20	0.09	-1.97	-1.45	0.28	-1.77	-1.25
07/22/06	0.20	0.10	0.36	-1.61	-1.17	0.25	-1.72	-1.28
07/23/06	0.36	0.04	0.91	-0.85	-0.50	0.60	-1.16	-0.81
07/24/06	0.74	0.02	0.58	-0.42	0.04	-0.13	-1.13	-0.68
07/25/06	0.13	0.21	-0.48	-0.55	-0.23	-0.40	-0.46	-0.15
07/26/06	0.00	0.12	-0.98	-1.99	-1.64	-0.86	-1.87	-1.52
07/27/06	0.00	0.12	-0.46	-2.35	-1.77	-0.34	-2.23	-1.65
07/28/06	0.00	0.08	-0.51	-2.67	-1.89	-0.43	-2.59	-1.81
07/29/06	0.28	0.08	0.84	-1.35	-0.69	0.64	-1.55	-0.89
07/30/06	0.03	0.02	-0.04	-2.16	-1.10	-0.04	-2.16	-1.11
07/31/06	0.00	0.07	-0.27	-2.29	-1.26	-0.20	-2.23	-1.19
08/01/06	0.30	0.04	0.84	-0.93	-0.20	0.58	-1.19	-0.46
08/02/06	1.12	0.06	0.91	-0.93	0.38	-0.15	-1.99	-0.68
08/03/06	1.73	0.06	0.15	-0.93	0.32	-1.51	-2.59	-1.35
08/04/06	0.48	0.24	0.13	-0.93	1.56	-0.11	-1.17	1.32
08/05/06	0.79	0.29	-0.70	-0.93	-0.11	-1.20	-1.43	-0.62
08/06/06	0.00	0.08	-1.02	-0.93	-0.85	-0.94	-0.85	-0.77
08/07/06	0.00	0.00	-0.61	-0.93	-1.38	-0.61	-0.92	-1.38
08/08/06	0.00	0.00	-0.47	-0.93	-1.89	-0.47	-0.92	-1.89
08/09/06	0.51	0.11	0.66	-1.46	-0.22	0.26	-1.86	-0.61

Date	Precipitation (cm)	ET (cm)	ΔS North Pool (cm)	ΔS Middle Pool (cm)	ΔS South Pool (cm)	ΔGW North Pool (cm)	ΔGW Middle Pool (cm)	ΔGW South Pool (cm)
08/10/06	2.51	0.01	1.90	0.29	1.75	-0.60	-2.21	-0.75
08/11/06	2.46	0.00	2.11	3.40	5.40	-0.36	0.94	2.93
08/12/06	1.42	0.01	-0.89	2.45	3.30	-2.30	1.04	1.89
08/13/06	0.23	0.07	-1.28	-0.43	-0.34	-1.44	-0.59	-0.50
08/14/06	2.95	0.14	0.84	0.09	0.90	-1.97	-2.72	-1.91
08/15/06	0.66	0.01	0.91	2.62	3.68	0.26	1.96	3.03
08/16/06	0.33	0.13	-1.80	-0.89	-0.34	-2.00	-1.09	-0.54
08/17/06	0.03	0.18	-0.85	-1.70	-1.07	-0.70	-1.55	-0.91
08/18/06	4.57	0.14	3.10	2.48	3.29	-1.33	-1.95	-1.14
08/19/06	0.23	0.07	-0.61	3.12	3.85	-0.76	2.97	3.69
08/20/06	0.05	0.20	-2.40	-1.55	-1.37	-2.26	-1.41	-1.23
08/21/06	0.51	0.04	-0.80	-1.92	-1.56	-1.27	-2.39	-2.03
08/22/06	2.44	0.20	3.05	2.65	3.33	0.81	0.41	1.09
08/23/06	0.00	0.11	-1.93	-0.72	-0.48	-1.82	-0.62	-0.37
08/24/06	0.51	0.18	-0.39	-1.28	-0.94	-0.73	-1.61	-1.27
08/25/06	0.00	0.10	-0.43	-1.31	-0.79	-0.33	-1.20	-0.68
08/26/06	0.61	0.19	0.03	-1.21	-0.76	-0.40	-1.63	-1.19
08/27/06	0.03	0.13	-0.05	-1.45	-1.08	0.05	-1.35	-0.98
08/28/06	0.00	0.12	-0.14	-1.64	-1.35	-0.02	-1.51	-1.22
08/29/06	0.00	0.16	-0.18	-1.97	-1.57	-0.02	-1.81	-1.42
08/30/06	0.84	0.15	1.04	-0.83	-0.70	0.35	-1.51	-1.39
08/31/06	0.08	0.14	-0.01	-0.37	-0.18	0.06	-0.30	-0.11
09/01/06	0.03	0.10	-0.50	-1.28	-1.24	-0.42	-1.21	-1.17
09/02/06	0.00	0.19	-0.04	-1.57	-1.70	0.15	-1.38	-1.51
09/03/06	0.00	0.06	0.33	-1.46	-1.36	0.39	-1.40	-1.30
09/04/06	0.05	0.01	0.25	-1.32	-1.54	0.22	-1.36	-1.58
09/05/06	0.05	0.16	0.28	-0.44	-0.86	0.38	-0.34	-0.76
09/06/06	0.00	0.14	-0.30	-1.70	-2.11	-0.16	-1.56	-1.97
09/07/06	1.42	0.22	1.09	0.18	-0.43	-0.11	-1.03	-1.64
09/08/06	3.30	0.25	2.60	3.70	3.58	-0.45	0.64	0.53
09/09/06	0.05	0.25	-1.17	3.54	2.77	-0.96	3.75	2.97
09/10/06	0.00	0.06	-1.56	0.18	-1.41	-1.50	0.24	-1.35
09/11/06	0.00	0.12	-0.77	-0.69	-2.02	-0.65	-0.56	-1.90
09/12/06	0.00	0.09	-0.06	-0.44	-1.60	0.03	-0.36	-1.51
09/13/06	0.03	0.05	1.02	0.03	-1.36	1.04	0.05	-1.34

Date	Precipitation (cm)	ET (cm)	ΔS North Pool (cm)	ΔS Middle Pool (cm)	ΔS South Pool (cm)	ΔGW North Pool (cm)	ΔGW Middle Pool (cm)	ΔGW South Pool (cm)
09/14/06	4.80	0.08	4.23	6.60	5.45	-0.49	1.88	0.73
09/15/06	0.15	0.05	-1.82	4.60	2.53	-1.91	4.50	2.43
09/16/06	0.00	0.04	-1.00	1.03	-0.86	-0.96	1.07	-0.82
09/17/06	0.00	0.00	0.04	0.63	-1.36	0.04	0.64	-1.36
09/18/06	0.05	0.03	0.60	0.69	-1.46	0.57	0.66	-1.49
09/19/06	0.43	0.02	-0.20	1.30	-0.76	-0.62	0.88	-1.18
09/20/06	0.20	0.07	0.27	1.85	-0.44	0.13	1.72	-0.58
09/21/06	1.47	0.07	1.77	1.94	-0.08	0.37	0.54	-1.47
09/22/06	1.02	0.00	-0.03	4.88	2.46	-1.04	3.86	1.45
09/23/06	0.15	0.04	-0.28	2.63	0.04	-0.39	2.52	-0.07
09/24/06	0.10	0.02	-0.37	1.44	-1.16	-0.45	1.36	-1.24
09/25/06	0.00	0.06	-0.27	1.27	-1.54	-0.21	1.33	-1.48
09/26/06	0.89	0.09	1.14	2.55	-0.03	0.35	1.76	-0.82
09/27/06	0.41	0.04	0.01	3.07	0.30	-0.35	2.71	-0.06
09/28/06	0.20	0.01	-0.05	2.72	-0.34	-0.24	2.52	-0.54
09/29/06	0.00	0.08	-0.05	1.91	-1.27	0.03	1.99	-1.19
09/30/06	0.00	0.01	0.25	1.14	-1.69	0.26	1.15	-1.68
10/01/06	0.36	0.04	0.34	2.30	-0.65	0.03	1.98	-0.96
10/02/06	1.80	0.00	1.50	4.69	2.07	-0.30	2.88	0.27
10/03/06	1.22	0.00	-0.71	3.63	0.44	-1.93	2.41	-0.77
10/04/06	1.09	0.06	0.94	5.50	2.24	-0.09	4.47	1.20
10/05/06								
10/06/06								
10/07/06								
10/08/06								
10/09/06								
10/10/06								
10/11/06								
10/12/06								
10/13/06								
10/14/06								
10/15/06								
10/16/06								
10/17/06								
10/18/06								

Date	Precipitation (cm)	ET (cm)	ΔS North Pool (cm)	ΔS Middle Pool (cm)	ΔS South Pool (cm)	ΔGW North Pool (cm)	ΔGW Middle Pool (cm)	ΔGW South Pool (cm)
10/19/06								
10/20/06								
10/21/06								
10/22/06								
10/23/06								
10/24/06								
10/25/06								
10/26/06								
10/27/06								
10/28/06								
10/29/06								
10/30/06								
10/31/06								

Note:
ET = Evapotranspiration
ΔS = Change in storage (i.e., change in pool stage)
ΔGW = Net ground-water inflow (i.e., ground-water inflow - ground-water outflow)

APPENDIX 7.3A

Gage Station Files, Transportation Corridor Study Area

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ACRONYMS AND ABBREVIATIONS

cfs	cubic feet per second
ddmmss	degree, minute, second
ft	foot (feet)
mi^2	square mile(s)
USGS	United States Geological Survey

GAGE STATION FILES, TRANSPORTATION CORRIDOR STUDY AREA

1. INTRODUCTION

Data were collected at 15 sites on 14 streams within the Bristol Bay drainages. Two of the sites—on Roadhouse Creek and the Iliamna River—are USGS gaging stations. The following is a brief description of each stream at the gage station location. Gaging records, basin characteristic files, and photographs of each stream are included in Attachments 1 through 15.

2. RESULTS

2.1 Gage Station, GS-23 – Chinkelyes Creek

Chinkelyes Creek is a narrow, shallow, higher-velocity river, which is fed from several tributaries of the Chigmit Mountains. Glacial runoff is present, and Summit Lake is a major storage pond for Chinkelyes Creek. The drainage area contributing to this stream is relatively large, with generally steep terrain. However, the gage station is located approximately halfway along the length of the creek, and its drainage represents a small portion of the entire watershed. Several waterfalls exist along the creek where the topography breaks in elevation. Vegetation is low brush, trees, and grasses. Bed materials are generally cobbles with some boulders. The channel banks are steep and show little indication of significant course change. Existing culverts and two small bridges exist along the road that runs parallel to Chinkelyes Creek. The culverts have been washed out on numerous occasions.

2.2 Gage Station, GS-3a – Iliamna River

Gage 3a on the Iliamna River is a continuous-recording gaging station that is maintained by the U.S. Geological Survey (USGS) in cooperation with the Alaska Department of Transportation and Public Facilities (ADOT&PF), as part of their small-streams gaging network. The gaging record indicates that flows in the river respond very rapidly to precipitation inputs, with flows rising rapidly in response to an event and dropping off rapidly almost immediately after the event.

The Iliamna River is one of the larger rivers in the Bristol Bay drainages. The river flows in a broad floodplain. Bed materials range from fine silt to large boulders. The Iliamna River is prone to flooding, and bank erosion in the lower reaches of the drainage areas is most likely to affect the transportation route.

2.3 Gage Station, GS-4a – Pile River

The Pile River is one of the larger drainages in the Bristol Bay drainages. The river is broad, shallow, and moderately swift, but navigable by power boats. Flow response in the river to precipitation events is rapid, consistent with terrain in the drainage basin that includes steep rocky slopes with little vegetation or storage ponds to impede runoff. Bed material is typically gravel with some cobbles. Aerial photography indicates that the stream channel becomes unstable as it enters the broad flat plain near its discharge to Iliamna Lake.

2.4 Gage Station, GS-6a – Unnamed Outlet Creek from Dumbbell Lake

This creek flows from a relatively small drainage area and empties into a series of two ponds several hundred feet downstream of the gaging station. While some steep slopes are present, the basin is generally quite flat where the crest gage was located and has a relatively dense vegetative cover. The stream bed is predominantly cobbles with some sand. Under high runoff events, this stream is likely to flood its banks; however, the channel appears to be relatively stable.

2.5 Gage Station, GS-7a – Unnamed Creek near Pedro Bay Townsite

This creek was often found to be dry. The bed materials are large cobbles and boulders. The drainage basin contributing to this gage station is small but very steep. During runoff events, this creek carries high flows and its flow channel can be highly variable from event to event. The gage station is adjacent to two 24-inch steel culverts that pass the water under a village road. The culverts are partially blocked by large boulders that have been deposited in past events. These culverts are reported to wash out periodically during storm events.

2.6 Gage Station, GS-8a – Knutson Creek

Knutson Creek is a swift, shallow stream. The drainage area contributing to the gaging station is moderate in size compared to other streams in the study area, and is characterized by steep terrain. The stream flows in a braided flood channel. Bed materials are predominantly large cobbles and boulders. Aerial photography and anecdotal information confirm that this stream is highly unstable and routinely changes course during flood events. The stream has jumped its banks and damaged the Pedro Bay airport on several occasions.

2.7 Gage Station, GS-11a – Canyon Creek

Canyon Creek flows in two branches. The streams are shallow, moderate velocity streams. The drainage area contributing to the gaging station is moderate in size compared to other streams in the study area. The upper reaches of the drainage basin are characterized by steep terrain with sparse vegetation, but the terrain flattens out in the vicinity of the gage station into a broad, gently sloping outwash plain. The stream flows in a braided floodplain. Bed materials are predominantly small cobbles. During large runoff events, the channel has been observed to change course slightly, but generally within the existing braided floodplain.

2.8 Gage Station, GS-12a – Chekok Creek

Chekok Creek is a shallow, moderately swift stream. The drainage area contributing to the gage site is slightly larger than that of Canyon Creek or Knutson Creek, but much of the area lies within a gently sloping outwash plain. The area is well vegetated and includes several small ponds. The bed of the stream is predominantly cobbles with incised banks. During high runoff events, flow velocities can become very high.

2.9 Gage Station, GS-14a and GS-14b – Unnamed Creek East of Eagle Bay Creek and Unnamed Creek West of Chekok Creek

This creek is a small, moderate velocity stream. The stream flows in two tributary streams that join into a single stream within the transportation corridor study area. The drainage areas contributing to these two tributary streams are small, well vegetated, and include several small ponds. Bed materials in the stream are sands and medium gravels. The channels are slightly incised in several areas, and vegetation is generally present to the low flow water line. This stream is relatively stable in high runoff events. The 14a tributary is deeper and carries a greater flow than the 14b tributary.

2.10 Gage Station, GS-17a – West Fork, Eagle Bay Creek

This creek is a small, moderate velocity stream. The drainage area tributary to this gage station is small, well vegetated, and includes several small ponds. Bed materials in the stream are sands and medium gravels. The channel is slightly incised in several areas, and vegetation is generally present to the low flow water line. This stream is relatively stable in high runoff events

2.11 Gage Station, GS-18a – Unnamed Creek on South Slope of Roadhouse Mountain

This creek is a small, low velocity stream. The drainage area tributary to this gage station is small, well vegetated, and includes several small ponds. Bed materials in the stream are sands and medium gravels. The channel is incised in several areas, and vegetation is generally present to the low flow water line and overhanging the bank. This stream is stable in high runoff events.

2.12 Gage Station, GS-20 – Roadhouse Creek

The Roadhouse Creek gage station was established in 2004 at the site of the historical USGS crest gage. The USGS established a continuous gage station at this site in 2005.

Roadhouse Creek is a small, low velocity stream fed from several runoff streams of Roadhouse Mountain. The drainage area contributing to this gage station is small, well vegetated, and includes several small ponds. Bed materials in the stream are sands and medium gravels. The channel is incised in several areas, and vegetation is generally present to the low flow water line and overhanging the bank. This stream is stable in high runoff events.

2.13 Gage Station, GS-20a – Upper Roadhouse Creek

The upper reaches of Roadhouse Creek have many small tributaries, and the gage was placed on one of the streams flowing off Old Lake, which was chosen to be representative of smaller tributaries within the transportation corridor study area. Upper Roadhouse Creek is a low velocity stream that has a well incised channel and vegetated banks. The bed material is mostly silty sand with some gravel. This channel meanders through the tundra approximately 4-miles until it intersects the main channel of Roadhouse Creek. The creek responds rapidly to precipitation and overflow from the lake. The topography surrounding the creek is low-lying and therefore the stream banks are often overtopped.

ATTACHMENT 1

GS-23 Chinkelyes Creek

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TABLE 1
GS-23 – Chinkelyes Creek: Basin Characteristic File Data

Parameter	Variable	Unit	Value
Latitude	Lat	ddmmss	59° 43' 10"
Longitude	Long	ddmmss	153° 47' 55"
Drainage area	Da	Square miles	22.55 mi^2
Storage area (lakes and ponds)	St	Square miles	0.42 mi^2
Glacier area	Gl	Square miles	0.60 mi^2
Forested area	Fr	Square miles	7.93 mi^2
Mean basin elevation	El	Feet	1616 feet
Main channel slope	Sl	%	3%
Main channel length	C	Miles	10.50 mi
Mean annual precipitation	Pr	Inches	70 in
Mean minimum January temperature	T	°F	10°F
Stream classification at gage site (Montgomery method)	Level 1	Description	2; Incised; High Velocity

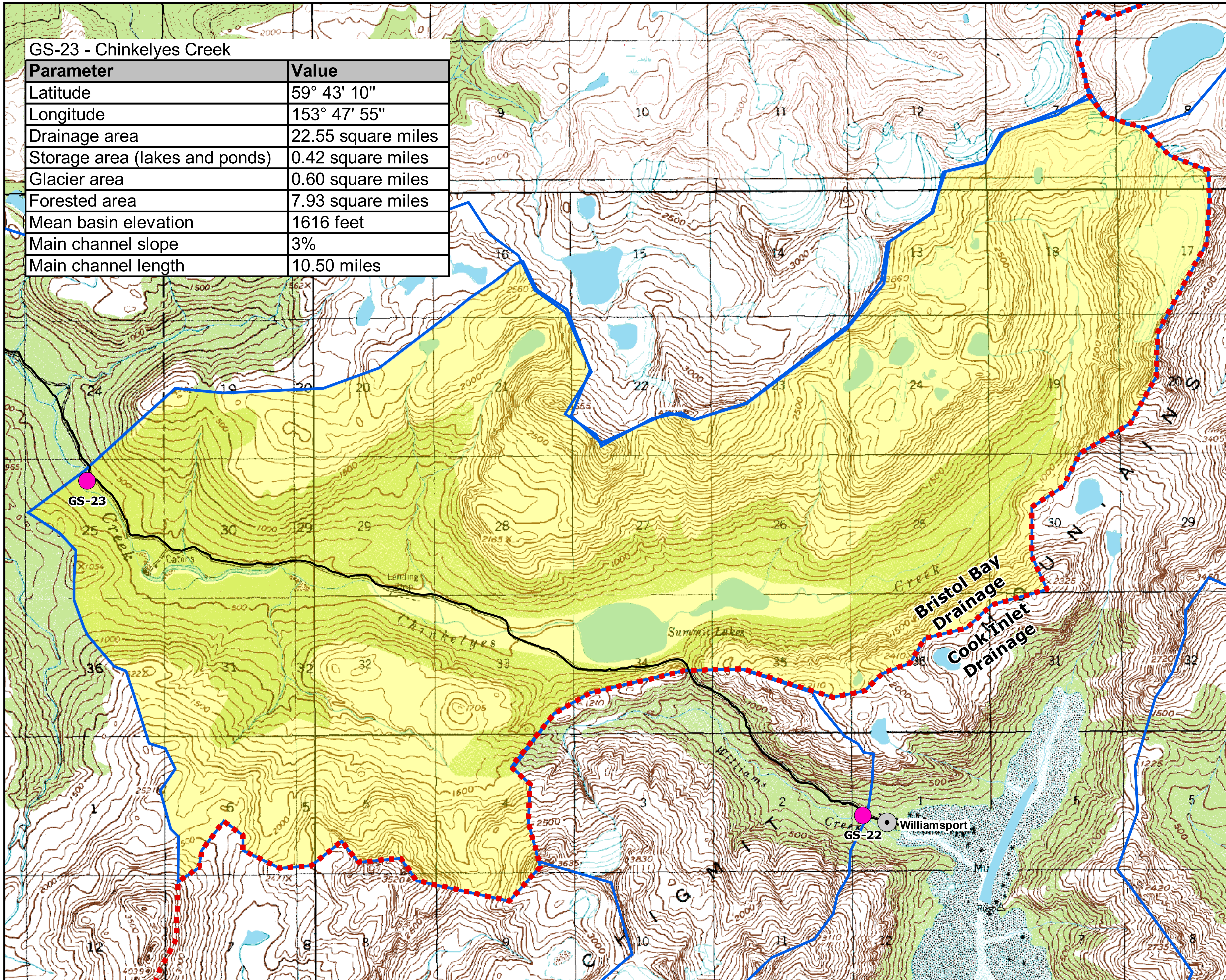
TABLE 2
GS-23 – Chinkelyes Creek: Monthly Discharge

Date	Water Year	Peak Gage Reading	Water Surface Elevation (ft)	Stream Width (ft)	Number of Sections	Total Discharge (cfs)	Comment
14-Jul	2005	New Set	98.75	99	31	295.31	
9-Aug	2005	0	99.26	77.2	21	94.529	
10-Sep	2005	11"	99.30	106	23	467.96	Flooding - swift and high water
6-Oct	2005	11"	98.28	82	19	151.5	

FIGURE

GS-23 - Chinkelyes Creek

Parameter	Value
Latitude	59° 43' 10"
Longitude	153° 47' 55"
Drainage area	22.55 square miles
Storage area (lakes and ponds)	0.42 square miles
Glacier area	0.60 square miles
Forested area	7.93 square miles
Mean basin elevation	1616 feet
Main channel slope	3%
Main channel length	10.50 miles

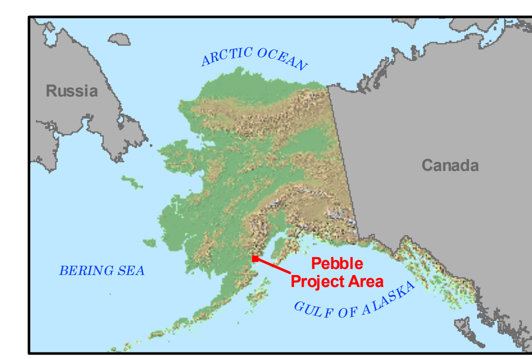


THE pebble PARTNERSHIP

Figure 7.3A1-1
Transportation Corridor
Bristol Bay Drainages
GS-23 Drainage Basin
Chinkelyes Creek

Legend

- Surface Water Gage Station
- Communities
- Existing Roads
- Cook Inlet/Bristol Bay Drainage Boundary
- Drainage Basin
- Drainage Basin GS-23



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0 0.25 0.5 0.75 1 Kilometers

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Scale 1:45,048

Alaska State Plane Zone 5 (units feet)
1983 North American Datum

File: Hydro_EBDaq_V4.mxd	Date: March 28, 2011
Version: 4	Author: BEESC-ME

PHOTOGRAPHS

PHOTO 1: GS-23 Chinkelyes Creek. Aerial View of new gage set, June 19, 2004.

PHOTO 2: GS-23 Chinkelyes Creek. New gage set, May 4, 2005.

PHOTO 3: GS-23 Chinkelyes Creek. View looking upstream during low flows, July 14, 2005.

PHOTO 4: GS-23 Chinkelyes Creek. View looking downstream during low flows, July 14, 2005.

ATTACHMENT 2

GS-3A Iliamna River

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TABLE 1
GS-3a – Iliamna River: Basin Characteristic File Data

Parameter	Variable	Unit	Value
Latitude	Lat	ddmmss	59° 45' 31"
Longitude	Long	ddmmss	153° 50' 41"
Drainage area	Da	Square miles	128 mi^2
Storage area (lakes and ponds)	St	Square miles	1.03 mi^2
Glacier area	Gl	Square miles	3.09 mi^2
Forested area	Fr	Square miles	48.16 mi^2
Mean basin elevation	El	Feet	2236 ft
Main channel slope	Sl	%	1%
Main channel length	C	Miles	25.29 mi
Mean annual precipitation	Pr	Inches	60 in
Mean minimum January temperature	T	°F	10°F
Stream classification at gage site (Montgomery method)	Level 1	Description	3a; Stable; Overbank Flow

TABLE 2
GS-3a – Iliamna River: Monthly Discharge

Date	Water Year	Stream Width (ft)	Number of Sections	Total Discharge (cfs)	Comment
19-Aug	2004	148.00		338.69 [a]	Moving Boat Method
25-Sep	2004	130.00		85.71 [a]	Boat on Tag Line
15-Oct	2004			1,200	USGS Website - Published data
15-Feb	2005	146.90		53.785 [a]	Frozen
14-Jun	2005			2,070	USGS Website - Published data
15-Jul	2005			1,160	USGS Website - Published data
10-Aug	2005			500	USGS Website - Published data
10-Sep	2005			2,530	USGS Website - Published data
6-Oct	2005			565	USGS Website - Published data

Note:

a. Bristol Environmental & Engineering Services Corporation (BEESC) discharge measurements.

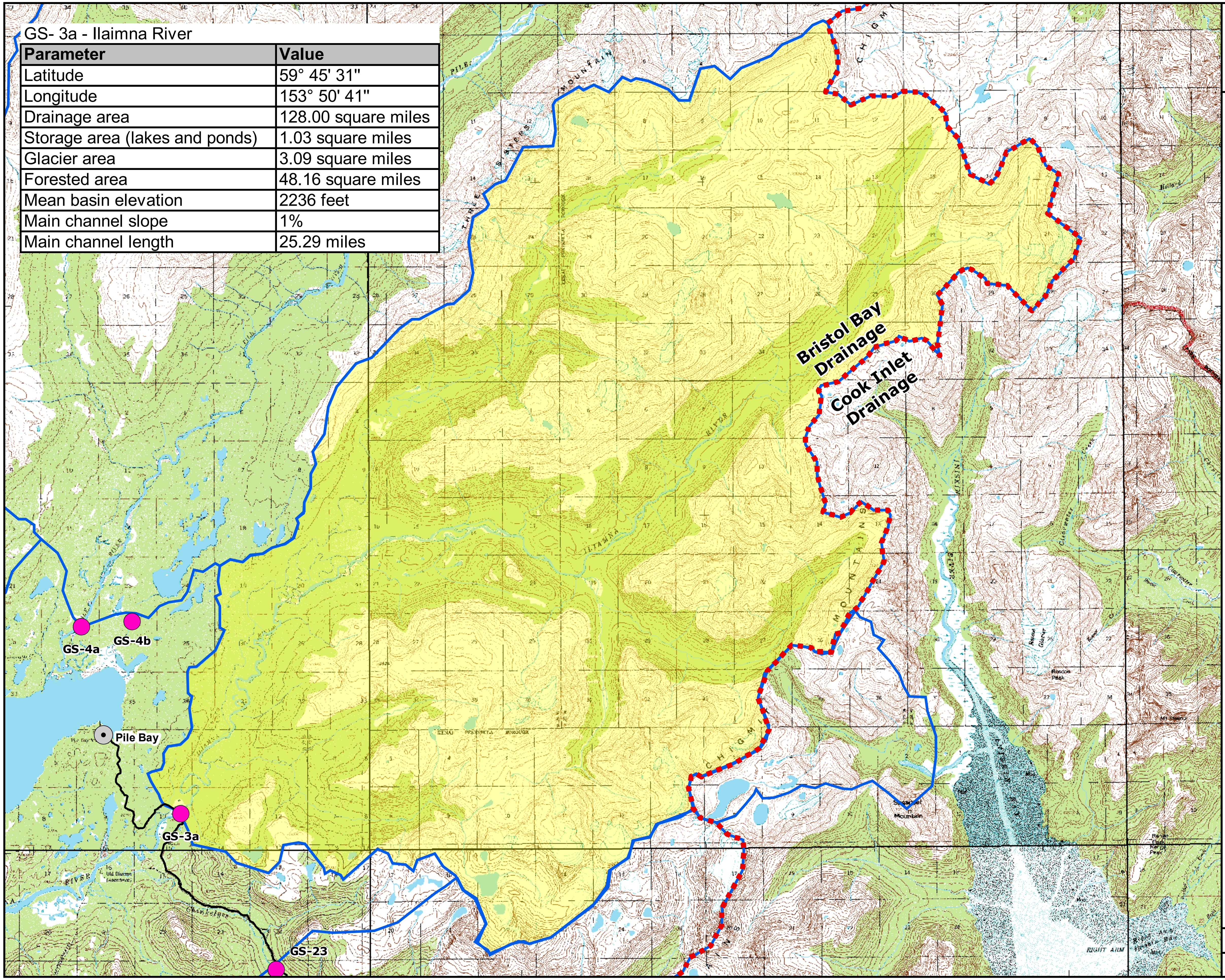
TABLE 3
GS-3a – Iliamna River: Historical USGS Peak Discharge

Date	Water Year	Total Discharge (cfs)	Comment
6/26/96	1996	5,040	USGS Published data
9/9/97	1997	9,300	USGS Published data
6/8/98	1998	22,300	USGS Published data
9/18/99	1999	20,000	USGS Published data
8/2/00	2000	13,700	USGS Published data
7/19/01	2001	14,400	USGS Published data
6/9/02	2002	6,260	USGS Published data
11/6/02	2003	17,400	USGS Published data
10/1/03	2004	53,000	USGS Published data
10/4/04	2005	5,940	USGS Published data

FIGURE

GS- 3a - Ilaimna River

Parameter	Value
Latitude	59° 45' 31"
Longitude	153° 50' 41"
Drainage area	128.00 square miles
Storage area (lakes and ponds)	1.03 square miles
Glacier area	3.09 square miles
Forested area	48.16 square miles
Mean basin elevation	2236 feet
Main channel slope	1%
Main channel length	25.29 miles

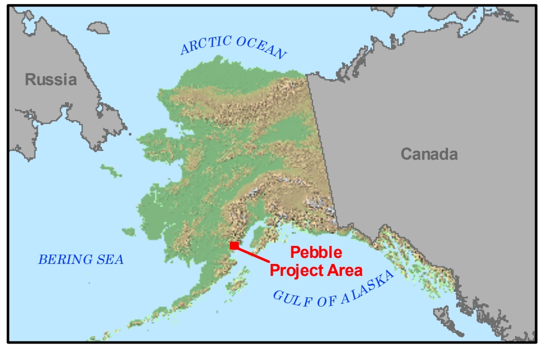


THE pebble PARTNERSHIP

Figure 7.3A2-1
Transportation Corridor
Bristol Bay Drainages
GS-03a Drainage Basin
Iliamna River

Legend

- Surface Water Gage Station
- Communities
- Existing Roads
- Cook Inlet/Bristol Bay Drainage Boundary
- Drainage Basin
- Drainage Basin GS-03a



Miles 0 0.5 1 1.5 2

Kilometers 0 0.5 1 1.5 2

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Scale 1:106,792

Alaska State Plane Zone 5 (units feet)
1983 North American Datum

File: Hydro_EBDaa_V5.mxd	Date: March 28, 2011
Version: 5	Author: BEESC-ME

PHOTOGRAPHS

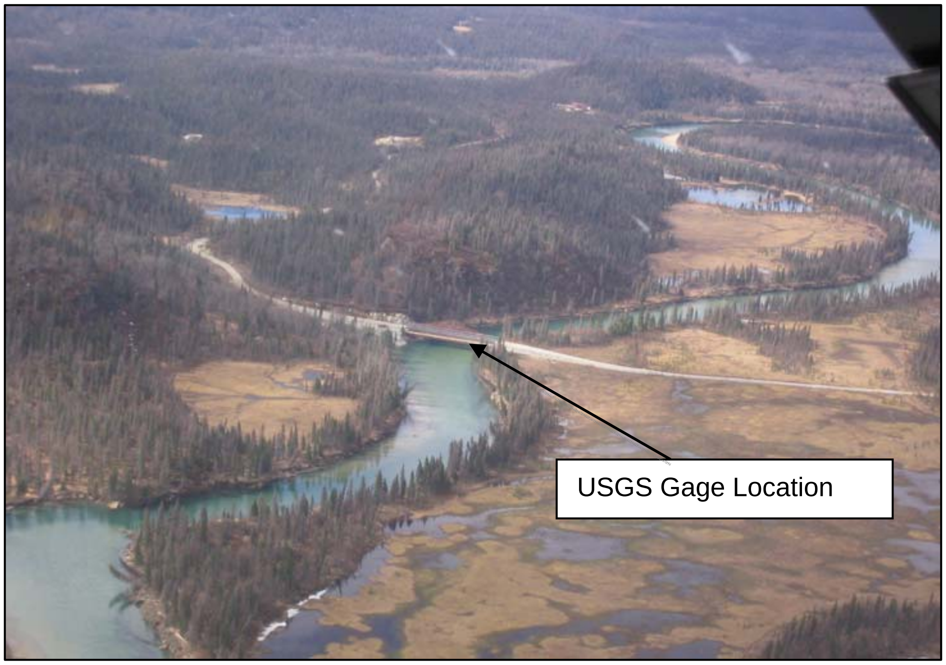

PHOTO 1: GS-3a Iliamna River. Aerial view of site, May 4, 2005.

PHOTO 2: GS-3a Iliamna River. Data taken from small boat using a tag line, July 13, 2005.

PHOTO 3: GS-3a Iliamna River. View looking up river, May 4, 2005.

PHOTO 4: GS-3a Iliamna River. View looking down river, May 4, 2005.

PHOTO 5: GS-3a Iliamna River. View looking up river, April 3, 2005.

PHOTO 6: GS-3a Iliamna River. View looking down river, April 3, 2005.

PHOTO 7: GS-3a Iliamna River. View looking down river, June 13, 2004.

PHOTO 8: GS-3a Iliamna River. View showing new bridge left of the old bridge on the Iliamna River, June 13, 2004.

ATTACHMENT 3

GS-4A Pile River

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TABLE 1
GS-4a – Pile River: Basin Characteristic File Data

Parameter	Variable	Unit	Value
Latitude	Lat	ddmmss	59° 48' 19"
Longitude	Long	ddmmss	153° 53' 42"
Drainage area	Da	Square miles	152.83 mi^2
Storage area (lakes and ponds)	St	Square miles	0.86 mi^2
Glacier area	Gl	Square miles	2.61 mi^2
Forested area	Fr	Square miles	51.84 mi^2
Mean basin elevation	El	Feet	1463 ft
Main channel slope	Sl	%	West-2%/East-2%
Main channel length	C	Miles	West-19.76/East-22.75 mi
Mean annual precipitation	Pr	Inches	60 in
Mean minimum January temperature	T	°F	10°F
Stream classification at gage site (Montgomery method)	Level 1	Description	4; Unstable; Overbank Flow

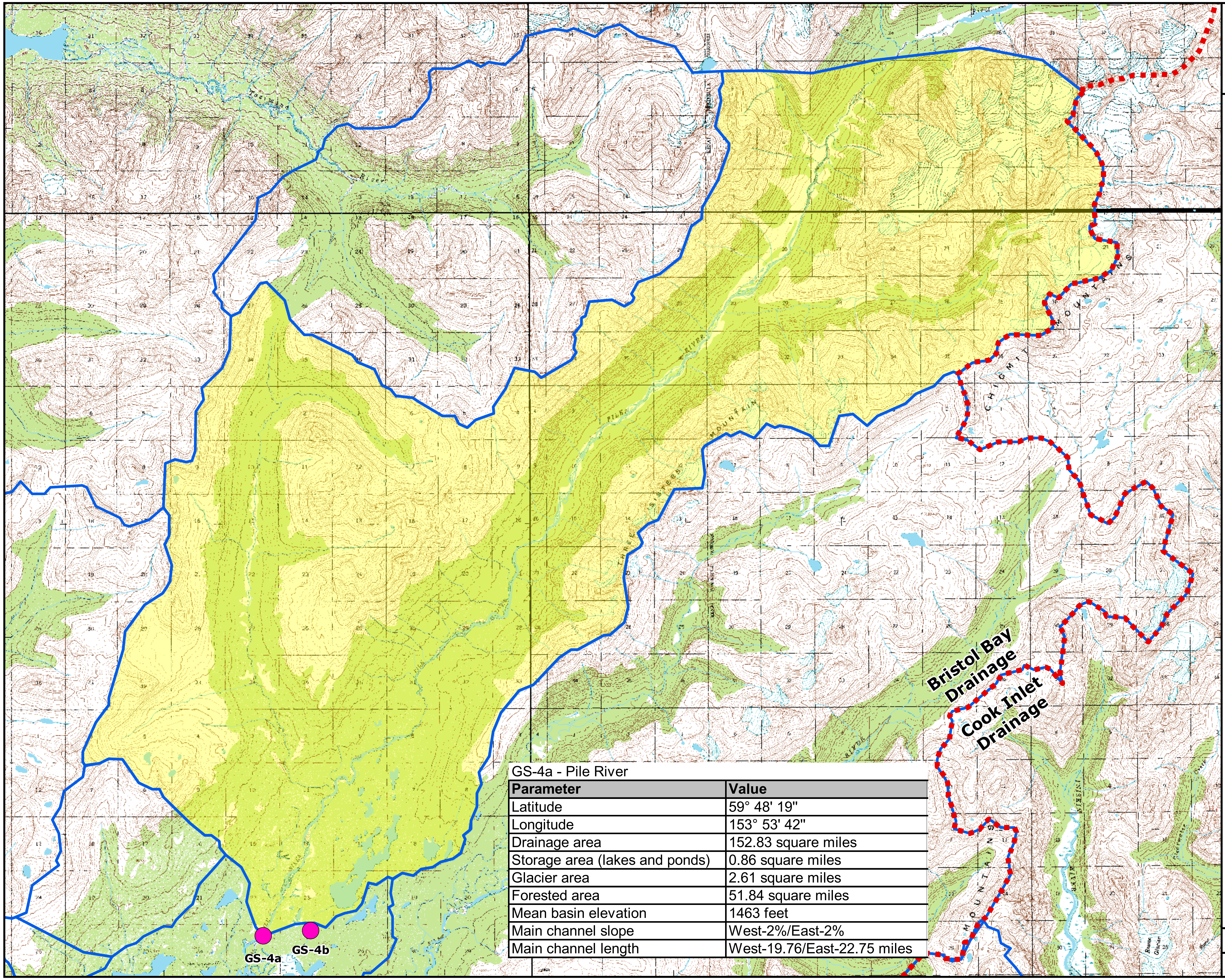
TABLE 2
GS-4a – Pile River: Monthly Discharge

Date	Water Year	Peak Gage Reading	Water Surface Elevation (ft)	Stream Width (ft)	Number of Sections	Total Discharge (cfs)	Comment
2-Aug	2004	New Set	99.03	235	17	1533.095	Moving Boat Method
19-Aug	2004	0	99.20	142.5	17	1375.238	Moving Boat Method
25-Sep	2004	0	98.92	150	17	212.373	Wading
20-Oct	2004	4"	98.82	163	34	763.950	Boat on Tag line
16-Feb	2005	0	-	215.8	18	177.337	Frozen
4-May	2005	0	98.88	136	29	786.129	Boat on Tag line
14-Jun	2005	4.5"	99.83	195	21	1641.135	Boat on Tag line
15-Jul	2005	Down	-	214	39	1522.580	Boat on Tag line
10-Aug	2005	0	98.52	240	26	1272.460	Wading
10-Sep	2005	Down	100.83	-	-	-	No Discharge - Water too Swift
7-Oct	2005	Down	-	152	32	525.380	Wading

FIGURE

THE pebble PARTNERSHIP

Figure 7.3A3-1
Transportation Corridor
Bristol Bay Drainages
GS-04a Drainage Basin
Pile River

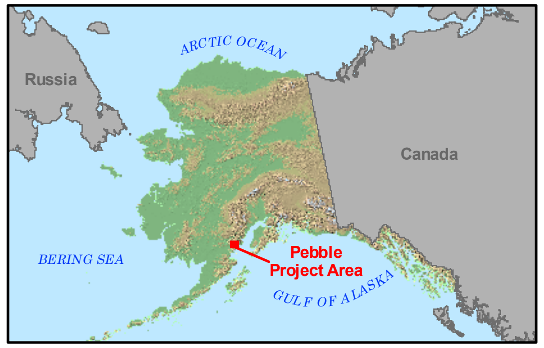


GS-4a - Pile River

Parameter	Value
Latitude	59° 48' 19"
Longitude	153° 53' 42"
Drainage area	152.83 square miles
Storage area (lakes and ponds)	0.86 square miles
Glacier area	2.61 square miles
Forested area	51.84 square miles
Mean basin elevation	1463 feet
Main channel slope	West-2%/East-2%
Main channel length	West-19.76/East-22.75 miles

Legend

- Surface Water Gage Station
- Communities
- Existing Roads
- Cook Inlet/Bristol Bay Drainage Boundary
- Drainage Basin
- Drainage Basin GS-04a



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Kilometers: 0 0.5 1 1.5 2

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Scale 1:114,753

Alaska State Plane Zone 5 (units feet)
1983 North American Datum

File: Hydro_EBDab_V5.mxd	Date: March 28, 2011
Version: 5	Author: BEESC-ME

PHOTOGRAPHS

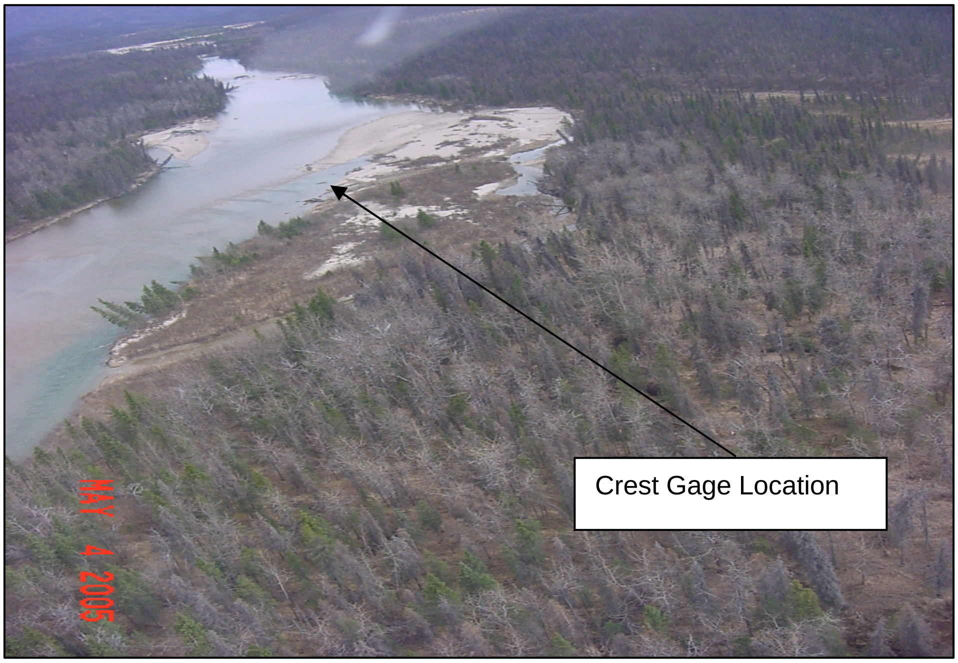

PHOTO 1: GS-4a Pile River. View looking up river, May 4, 2005.

PHOTO 2: GS-4a Pile River. Taking flow measurement by boat method, August 10, 2005.

PHOTO 3: GS-4a Pile River. View looking up river, June 14, 2005.

PHOTO 4: GS-4a Pile River. View looking down river, June 14, 2005.

PHOTO 5: GS-4a Pile River overflow channel View looking up river, June 14, 2005.

PHOTO 6: GS-4a Pile River overflow channel View looking down river, June 14, 2005.

PHOTO 7: GS-4a Pile River. View looking up river, July 31, 2004.

PHOTO 8: GS-4a Pile River. View looking up river, April 2, 2005.

ATTACHMENT 4

GS-4B Unnamed Outlet Creek from Long Lake

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TABLE 1
GS-4b – Unnamed Outlet Creek from Long Lake: Basin Characteristic File Data

Parameter	Variable	Unit	Value
Latitude	Lat	ddmmss	59° 48' 23"
Longitude	Long	ddmmss	153° 52' 11"
Drainage area	Da	Square miles	- [a]
Storage area (lakes and ponds)	St	Square miles	- [a]
Glacier area	Gl	Square miles	0.0 mi^2
Forested area	Fr	Square miles	- [a]
Mean basin elevation	El	Feet	- [a]
Main channel slope	Sl	%	West-4%/East-4%
Main channel length	C	Miles	West-19.76/East-22.75 mi
Mean annual precipitation	Pr	Inches	60 in
Mean minimum January temperature	T	°F	10°F
Stream classification at gage site (Montgomery method)	Level 1	Description	3a; Stable; Overbank Flow

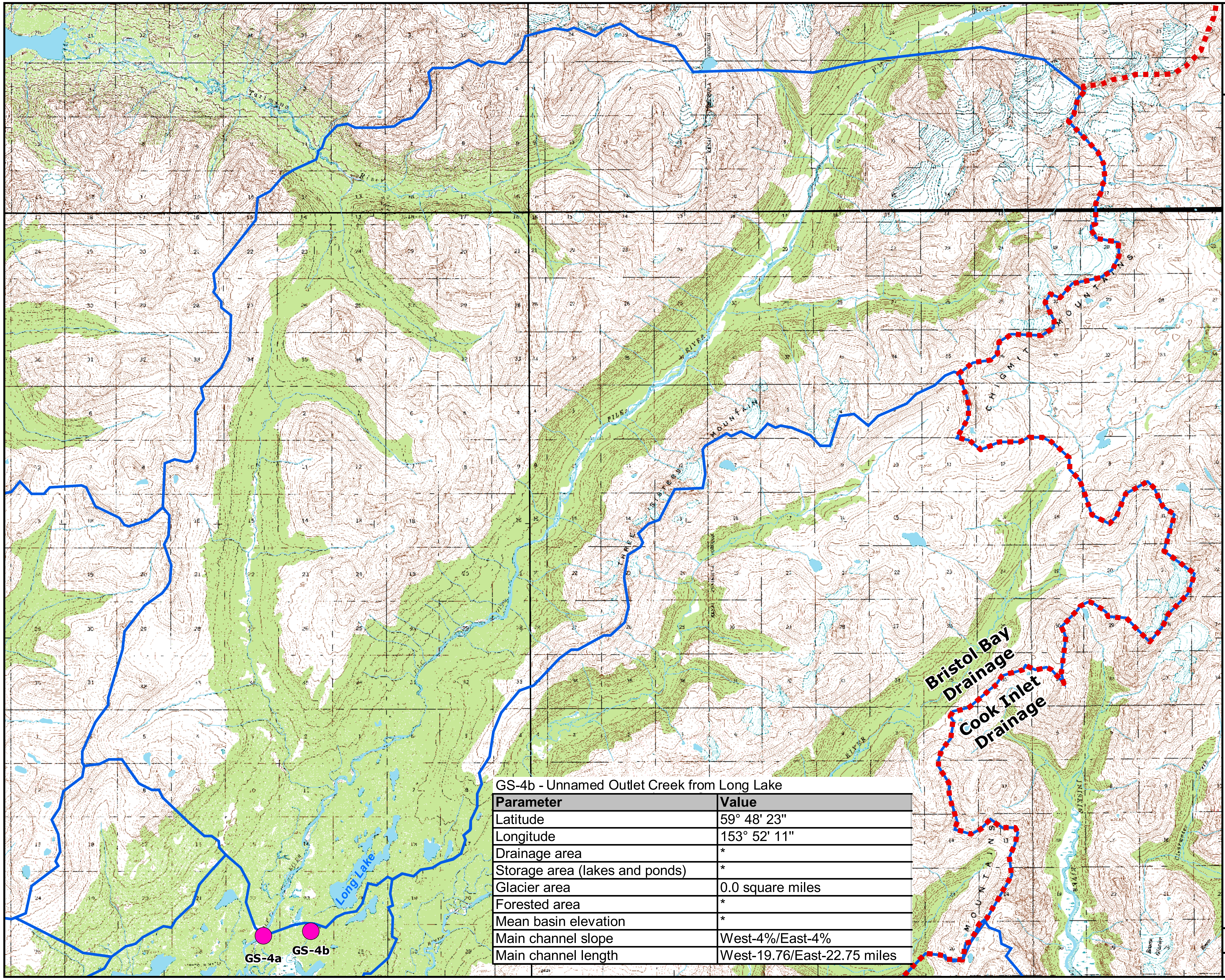
Note:

a. Spatial data not available for this sub-basin of the Pile River (GS-4a).

TABLE 2
GS-4b – Unnamed Outlet Creek from Long Lake: Monthly Discharge

Date	Water Year	Peak Gage Reading	Water Surface Elevation (ft)	Stream Width (ft)	Number of Sections	Total Discharge (cfs)	Comment
25-Sep	2004	New Set	99.97	15	9	0.222	Wading
15-Oct	2004	5.06"	97.06	19	22	20.553	
15-Feb	2005	0.7"	-	-	-	-	Frozen in winter-no data collected

FIGURE



THE pebble PARTNERSHIP

Figure 7.3A4-1
Transportation Corridor
Bristol Bay Drainages
GS-04b Drainage Basin
Unnamed Outlet Creek from Long Lake

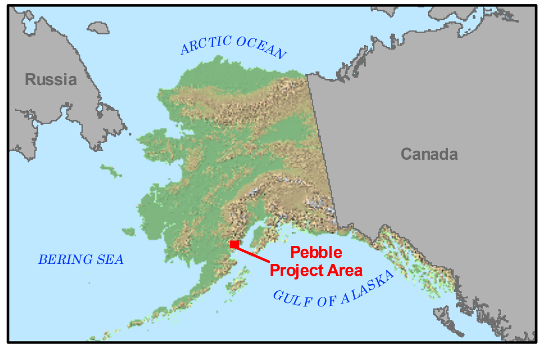
Legend

- Surface Water Gage Station
- Communities
- Existing Roads
- Cook Inlet/Bristol Bay Drainage Boundary
- Drainage Basin

Note
1. The drainage basin for GS-04b has not been delineated

GS-4b - Unnamed Outlet Creek from Long Lake

Parameter	Value
Latitude	59° 48' 23"
Longitude	153° 52' 11"
Drainage area	*
Storage area (lakes and ponds)	*
Glacier area	0.0 square miles
Forested area	*
Mean basin elevation	*
Main channel slope	West-4%/East-4%
Main channel length	West-19.76/East-22.75 miles



Miles 0 0.5 1 1.5 2

Kilometers 0 0.5 1 1.5 2

N

Scale 1:114,626

Alaska State Plane Zone 5 (units feet)
1983 North American Datum

File: Hydro_EBDac_V4.mxd	Date: March 28, 2011
Version: 4	Author: BEESC-ME

PHOTOGRAPHS

PHOTO 1: GS-4b Unnamed Outlet Creek from Long Lake. View looking upstream, October 15, 2004.

PHOTO 2: GS-4b Unnamed Outlet Creek from Long Lake. View looking downstream, October 15, 2004.

PHOTO 3: GS-4b Unnamed Outlet Creek from Long Lake. West view of floodplain and high water marks, October 15, 2004.

PHOTO 4: GS-4b Unnamed Outlet Creek from Long Lake. East View of floodplain and high water marks, October 15, 2004.

ATTACHMENT 5

GS-6A Unnamed Outlet Creek from Dumbbell Lake

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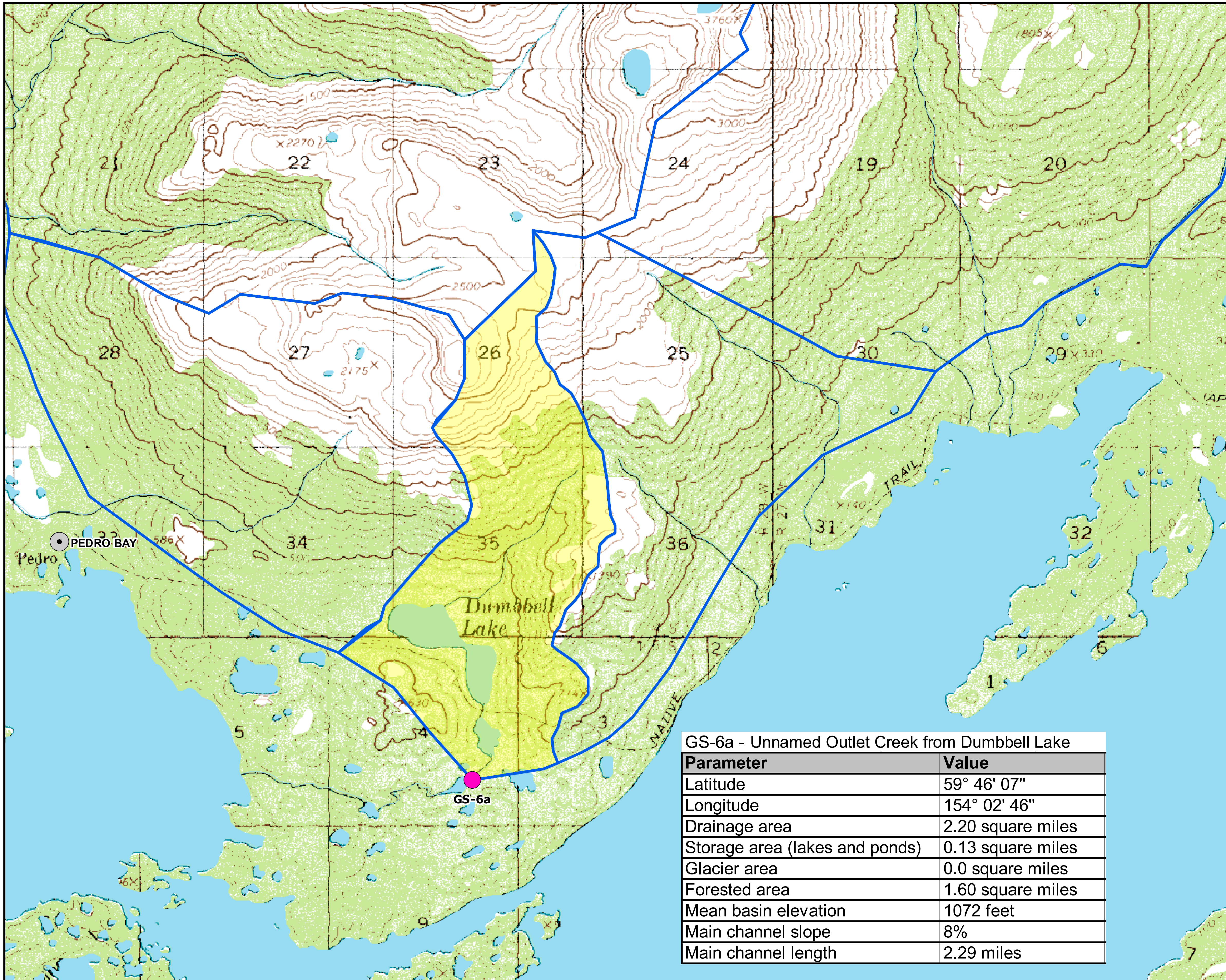
TABLE 1
GS-6a – Unnamed Outlet Creek from Dumbbell Lake: Basin Characteristic File Data

Parameter	Variable	Unit	Value
Latitude	Lat	ddmmss	59° 46' 07"
Longitude	Long	ddmmss	154° 02' 46"
Drainage area	Da	Square miles	2.20 mi^2
Storage area (lakes and ponds)	St	Square miles	0.13 mi^2
Glacier area	Gl	Square miles	0.0 mi^2
Forested area	Fr	Square miles	1.60 mi^2
Mean basin elevation	El	Feet	1072 ft
Main channel slope	Sl	%	8%
Main channel length	C	Miles	2.29 mi
Mean annual precipitation	Pr	Inches	50 in
Mean minimum January temperature	T	°F	10°F
Stream classification at gage site (Montgomery method)	Level 1	Description	2; Stable Overbank Flow

TABLE 2
GS-6a – Unnamed Outlet Creek from Dumbbell Lake: Monthly Discharge

Date	Water Year	Peak Gage Reading	Water Surface Elevation (ft)	Stream Width (ft)	Number of Sections	Total Discharge (cfs)	Comment
21-Jul	2004	New Set	99.83	12.0	9	4.19	
20-Aug	2004	0	100.10	14.7	9	2.24	
24-Sep	2004	0	98.72	12.0	13	2.32	
15-Oct	2004	0	99.22	14.0	15	6.21	
16-Feb	2005	0	99.26	15.5	25	3.56	Open water
3-Apr	2005	0	98.80	11.4	24	3.01	Stopped collecting data after April

FIGURE



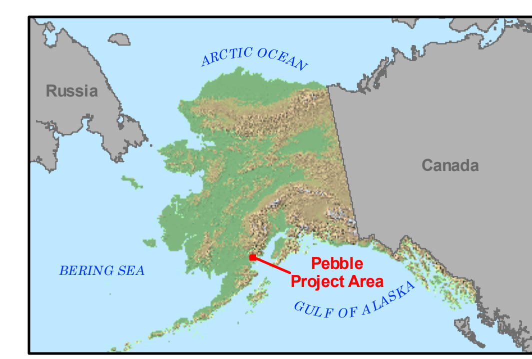
GS-6a - Unnamed Outlet Creek from Dumbbell Lake	
Parameter	**Value**
Latitude	59° 46' 07"
Longitude	154° 02' 46"
Drainage area	2.20 square miles
Storage area (lakes and ponds)	0.13 square miles
Glacier area	0.0 square miles
Forested area	1.60 square miles
Mean basin elevation	1072 feet
Main channel slope	8%
Main channel length	2.29 miles

THE pebble PARTNERSHIP

Figure 7.3A5-1
Transportation Corridor
Bristol Bay Drainages
GS-06a Drainage Basin
Unnamed Outlet Creek
from Dumbbell Lake

Legend

- Surface Water Gage Station
- Communities
- Existing Roads
- Drainage Basin
- Drainage Basin GS-06a



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Kilometers: 0, 0.25, 0.5, 0.75, 1
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Scale 1:32,980

Alaska State Plane Zone 5 (units feet)
1983 North American Datum

File: Hydro_EBDad_V5.mxd	Date: March 28, 2011
Version: 5	Author: BEESC-ME

PHOTOGRAPHS

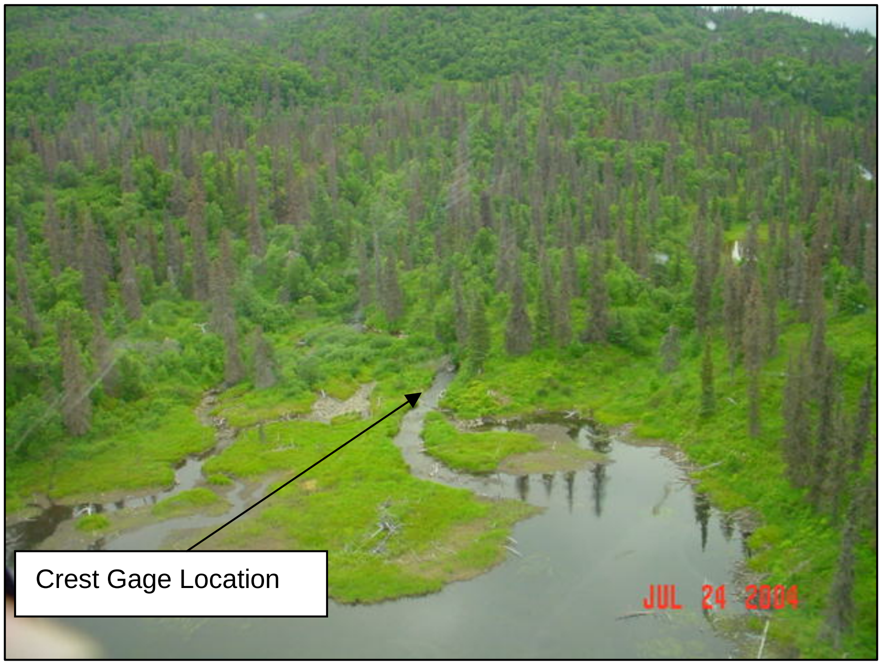

PHOTO 1: GS-6a Unnamed Outlet Creek from Dumbbell Lake. Aerial view looking upstream, July 24, 2004.

PHOTO 2: GS-6a Unnamed Outlet Creek from Dumbbell Lake. Aerial View looking downstream, July 24, 2004.

PHOTO 3: GS-6a Unnamed Outlet Creek from Dumbbell Lake. View looking upstream, July 21, 2004.

PHOTO 4: GS-6a Unnamed Outlet Creek from Dumbbell Lake. View looking downstream, July 21, 2004.

ATTACHMENT 6

GS-7A Unnamed Creek near Pedro Bay Townsite

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TABLE 1
GS-7a – Unnamed Creek near Pedro Bay Townsite: Basin Characteristic File Data

Parameter	Variable	Unit	Value
Latitude	Lat	ddmmss	59° 47' 24"
Longitude	Long	ddmmss	154° 06' 14"
Drainage area	Da	Square miles	3.36 mi^2
Storage area (lakes and ponds)	St	Square miles	0.003 mi^2
Glacier area	Gl	Square miles	0.0 mi^2
Forested area	Fr	Square miles	2.26 mi^2
Mean basin elevation	El	Feet	1176 ft
Main channel slope	Sl	%	19%
Main channel length	C	Miles	2.01 mi
Mean annual precipitation	Pr	Inches	40 in
Mean minimum January temperature	T	°F	10°F
Stream classification at gage site (Montgomery method)	Level 1	Description	2; Unstable; High Velocity

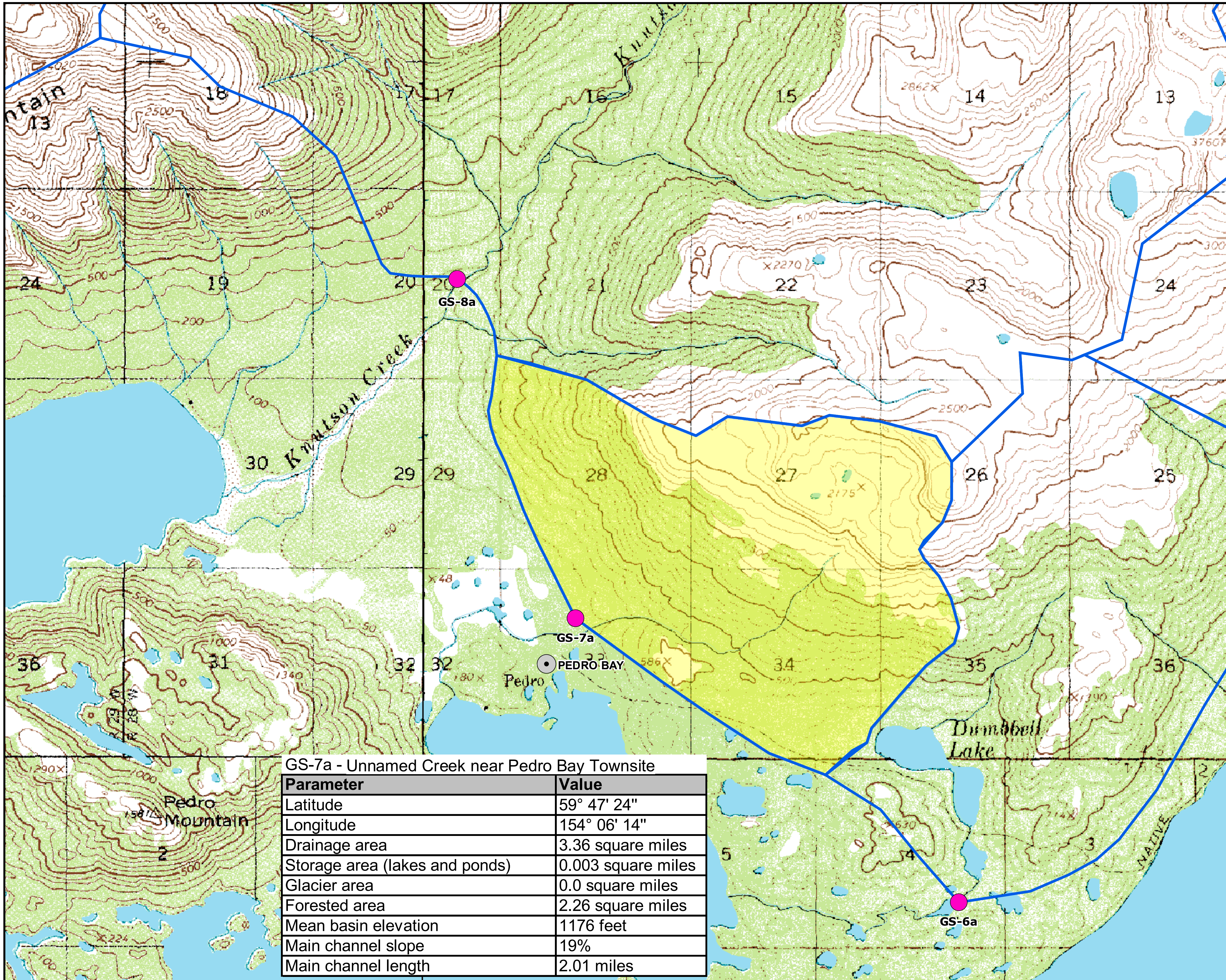
TABLE 2
GS-7a – Unnamed Creek near Pedro Bay Townsite: Monthly Discharge

Date	Water Year	Peak Gage Reading	Water Surface Elevation (ft)	Stream Width (ft)	Number of Sections	Total Discharge (cfs)	Comment
21-Jul	2004	New Set					Dry Creek
19-Aug	2004						Dry Creek
16-Oct	2004	2.5"	98.74	10.0	10	4.67	

FIGURE

THE pebble PARTNERSHIP

Figure 7.3A6-1
Transportation Corridor
Bristol Bay Drainages
GS-07a Drainage Basin
Unnamed Creek near Pedro Bay Townsite

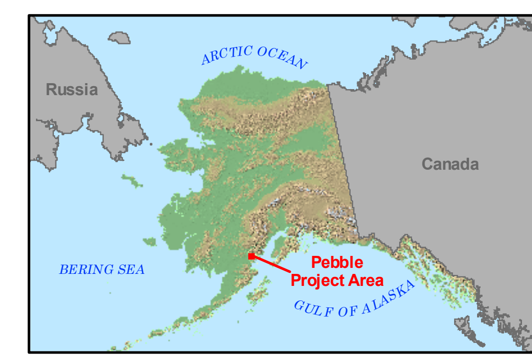


GS-7a - Unnamed Creek near Pedro Bay Townsite

Parameter	Value
Latitude	59° 47' 24"
Longitude	154° 06' 14"
Drainage area	3.36 square miles
Storage area (lakes and ponds)	0.003 square miles
Glacier area	0.0 square miles
Forested area	2.26 square miles
Mean basin elevation	1176 feet
Main channel slope	19%
Main channel length	2.01 miles

Legend

- Surface Water Gage Station
- Communities
- Existing Roads
- Drainage Basin
- Drainage Basin GS-07a



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Kilometers: 0, 0.25, 0.5, 0.75, 1

Scale 1:32,980

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Alaska State Plane Zone 5 (units feet)
1983 North American Datum

File: Hydro_EBDae_V4.mxd	Date: March 28, 2011
Version: 4	Author: BEESC-ME

PHOTOGRAPHS

PHOTO 1: GS-7a Unnamed Creek near Pedro Bay Townsite. View looking upstream, July 24, 2004.

PHOTO 2: GS-7a Unnamed Creek near Pedro Bay Townsite. View looking upstream, October 16, 2004.

PHOTO 3: GS-7a Unnamed Creek near Pedro Bay Townsite. View looking downstream with dry creek,

July 21, 2004.

PHOTO 4: GS-7a Unnamed Creek near Pedro Bay Townsite. View looking downstream during fall precipitation, October 16, 2004.

PHOTO 5: GS-7a Unnamed Creek near Pedro Bay Townsite. View looking downstream with dry creek, July 21, 2004.

PHOTO 6: GS-7a Unnamed Creek near Pedro Bay Townsite. View looking downstream during fall precipitation, October 16, 2004.

ATTACHMENT 7

GS-8A Knutson Creek

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TABLE 1
GS-8a – Knutson Creek: Basin Characteristic File Data

Parameter	Variable	Unit	Value
Latitude	Lat	ddmmss	59° 48' 58''
Longitude	Long	ddmmss	154° 07' 19''
Drainage area	Da	Square miles	35.70 mi^2
Storage area (lakes and ponds)	St	Square miles	0.02 mi^2
Glacier area	Gl	Square miles	0.0 mi^2
Forested area	Fr	Square miles	13.23 mi^2
Mean basin elevation	El	Feet	2300 ft
Main channel slope	Sl	%	5%
Main channel length	C	Miles	9.30 mi
Mean annual precipitation	Pr	Inches	38 in
Mean minimum January temperature	T	°F	10°F
Stream classification at gage site (Montgomery method)	Level 1	Description	5; Unstable; See note below

TABLE 2
GS-8a – Knutson Creek: Monthly Discharge

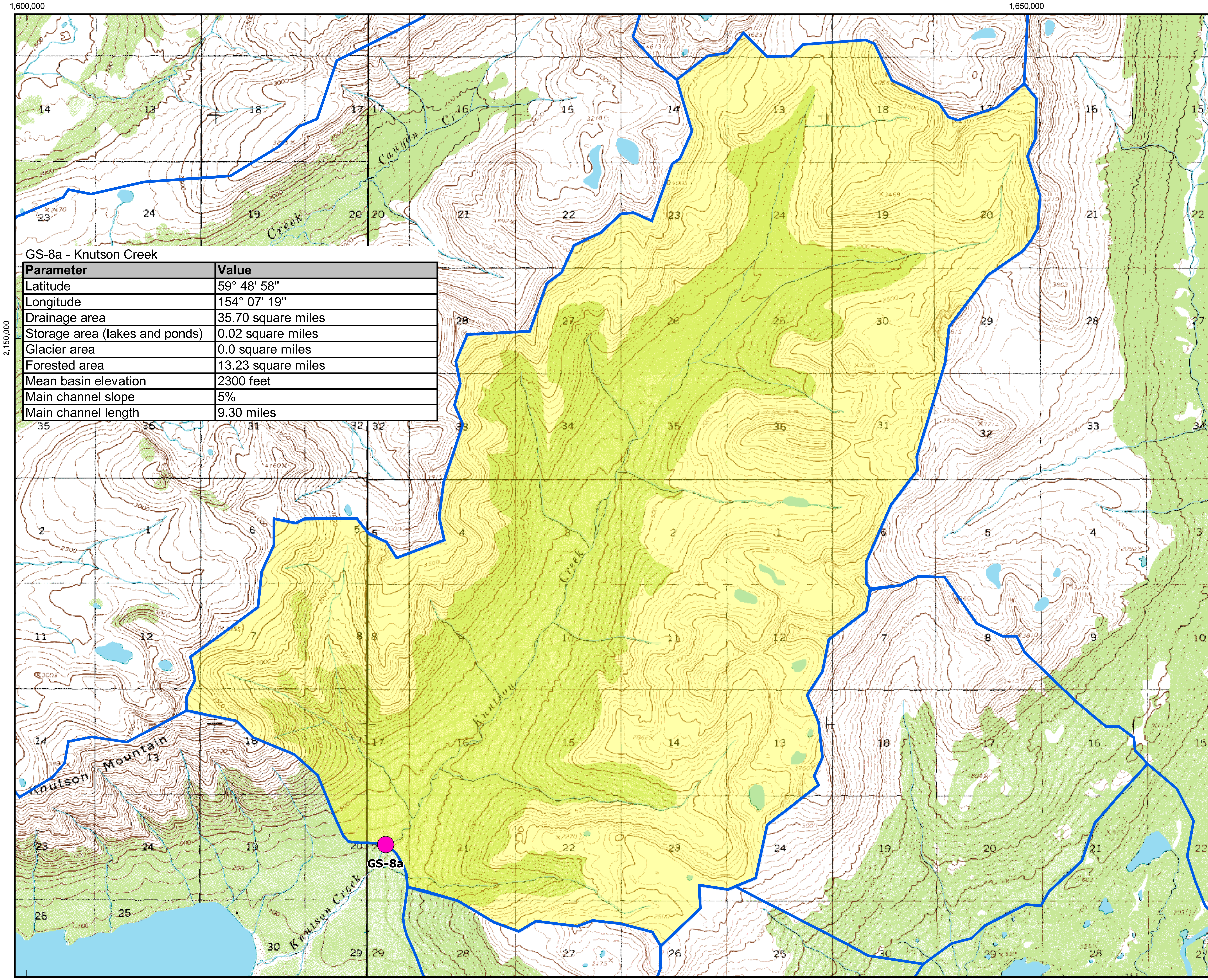
Date	Water Year	Peak Gage Reading	Water Surface Elevation (ft)	Stream Width (ft)	Number of Sections	Total Discharge (cfs)	Comment
Knutson Creek							
21-Jul	2004	New Set	-	49.3	17	128.60	
18-Aug	2004	0	93.15	49.8	17	63.52	
24-Sep	2004	0	-	51.0	12	69.57	
16-Oct	2004	0	96.56	50.0	14	282.35	Too swift - estimated discharge
17-Feb	2005	0	96.60	27.0	29	27.34	Frozen
3-Apr	2005	0	-	12.6		16.03	Frozen
4-May	2005	0	97.30	52.1	12	247.67	
14-Jun	2005	0	97.88	52.0	9	314.31	Too swift - estimated discharge
15-Jul	2005	0	96.50	52.0	16	167.31	Too swift - estimated discharge
9-Aug	2005	0	96.40	51.5	27	116.83	
9-Sep	2005	0	97.66	-	-	-	No Measurement - Dangerous
7-Oct	2005	0	96.36	57.0	27	167.53	
Knutson Creek Eastside Overflow Channel							
14-Jun	2005	0	97.88	9.8	9	2.58	Flooding the east channel

FIGURE

Figure 7.3A7-1
Transportation Corridor
Bristol Bay Drainages
GS-08a Drainage Basin
Knutson Creek

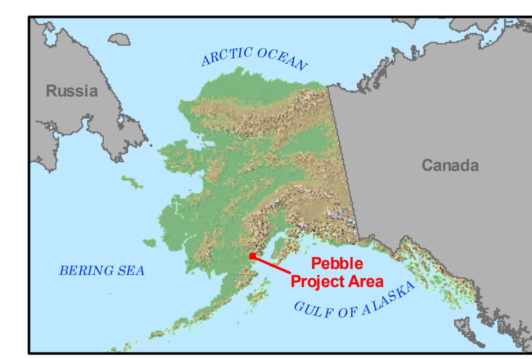
GS-8a - Knutson Creek

Parameter	Value
Latitude	59° 48' 58"
Longitude	154° 07' 19"
Drainage area	35.70 square miles
Storage area (lakes and ponds)	0.02 square miles
Glacier area	0.0 square miles
Forested area	13.23 square miles
Mean basin elevation	2300 feet
Main channel slope	5%
Main channel length	9.30 miles



Legend

- Surface Water Gage Station
- Communities
- Existing Roads
- Drainage Basin
- Drainage Basin GS-08a



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Alaska State Plane Zone 5 (units feet)
1983 North American Datum

File: Hydro_EBDaf_V4.mxd	Date: March 28, 2011
Version: 4	Author: BEESC-ME

PHOTOGRAPHS

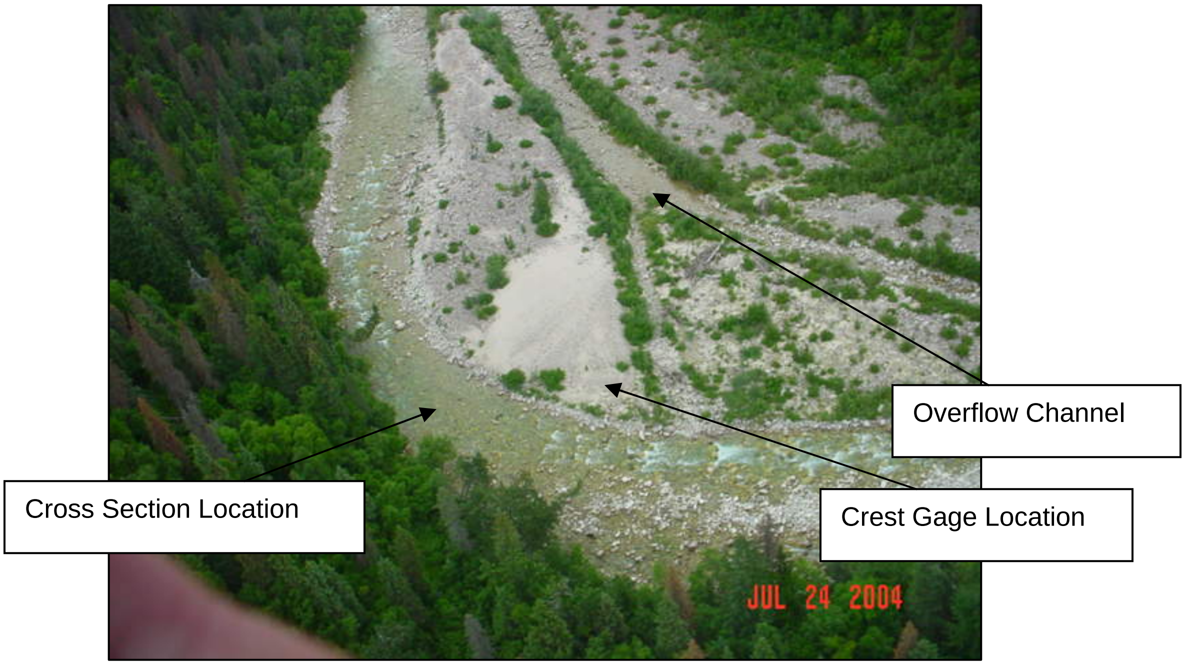

PHOTO 1: GS-8a Knutson Creek. Aerial view looking down at gage location, July 24, 2004.

PHOTO 2: GS-8a Knutson Creek near Pedro Bay Airport. View looking upstream, October 16, 2004.

PHOTO 3: GS-8a Knutson Creek. View looking at cross section location of stream, August 21, 2004.

PHOTO 4: GS-8a Knutson Creek. Bear activity at gage station, August 18, 2004.

PHOTO 5: GS-8a Knutson Creek. View looking upstream with low flow, August 9, 2005.

PHOTO 6: GS-8a Knutson Creek. View looking upstream during fall precipitation September 8, 2005.

PHOTO 7: GS-8a Knutson Creek. View looking downstream during low flow, July 21, 2004.

PHOTO 8: GS-8a Knutson Creek. View looking downstream during fall precipitation, September 9, 2005.

PHOTO 9: GS-8a Knutson Creek. Overflow channel looking upstream, July 21, 2004.

PHOTO 10: GS-8a Knutson Creek. Overflow channel looking downstream, July 21, 2004.

PHOTO 11: GS-8a Knutson Creek. Overflow channel during fall precipitation looking upstream, September 9, 2005.

PHOTO 12: GS-8a Knutson Creek. Overflow channel during fall precipitation looking downstream, September 9, 2005.

ATTACHMENT 8

GS-11A Canyon Creek

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TABLE 1
GS-11a – Canyon Creek: Basin Characteristic File Data

Parameter	Variable	Unit	Value
Latitude	Lat	ddmmss	59° 50' 25"
Longitude	Long	ddmmss	154° 21' 57"
Drainage area	Da	Square miles	36.20 mi^2
Storage area (lakes and ponds)	St	Square miles	0.14 mi^2
Glacier area	Gl	Square miles	0.0 mi^2
Forested area	Fr	Square miles	12.64 mi^2
Mean basin elevation	El	Feet	2257 ft
Main channel slope	Sl	%	4%
Main channel length	C	Miles	13.61 mi
Mean annual precipitation	Pr	Inches	30 in
Mean minimum January temperature	T	°F	9°F
Stream classification at gage site (Montgomery method)	Level 1	Description	3b; Unstable; High Velocity

TABLE 2
GS-11a – Canyon Creek: Monthly Discharge

Date	Water Year	Peak Gage Reading	Water Surface Elevation	Stream Width (ft)	Number of Sections	Total Discharge (cfs)	Comment
Canyon Creek West Channel							
20-Jul	2004	New Set	95.05	26.7	13.0	80.018	
17-Aug	2004	0	96.56	27.0	13.0	36.300	
23-Sep	2004	0	96.86	29.0	16.0	53.352	
16-Oct	2004	0	97.18	31.0	17.0	164.348	
17-Feb	2005	0	97.7	15.0	14.0	7.763	Frozen
1-Apr	2005	0	97	22.2	25.0	7.746	Frozen
3-May	2005	0	93.86	37.4	20.0	183.357	
15-Jun	2005	0	97.24	41.0	23.0	212.241	
16-Jul	2005	0	97	34.7	20.0	143.921	
10-Aug	2005	0	96.64	30.7	22.0	62.522	
8-Sep	2005	0	97.68	45.0	8.0	205.824	Too swift - estimated discharge
7-Oct	2005	Down	-	40.0	20.0	161.301	West channel shifted and cut island
Canyon Creek East Channel							
20-Jul	2004	New Set	95.05	36.0	15.0	27.854	
17-Aug	2004	0	96.56	49.8	13.0	17.930	
23-Sep	2004	0	96.86	46.0	24.0	38.625	
16-Oct	2004	0	97.18	48.0	24.0	96.740	
17-Feb	2005	0	97.7	4.0	4.0	1.055	Frozen
1-Apr	2005	-	-	-	-	-	Frozen solid on east side
3-May	2005	0	93.86	39.5	18.0	63.374	
15-Jun	2005	0	97.24	52.0	20.0	314.310	
16-Jul	2005	0	97	37.0	21.0	52.395	
10-Aug	2005	0	96.64	43.2	29.0	30.673	
8-Sep	2005	0	97.68	44.5	24.0	155.614	
7-Oct	2005	Down	-	43.2	20.0	21.790	

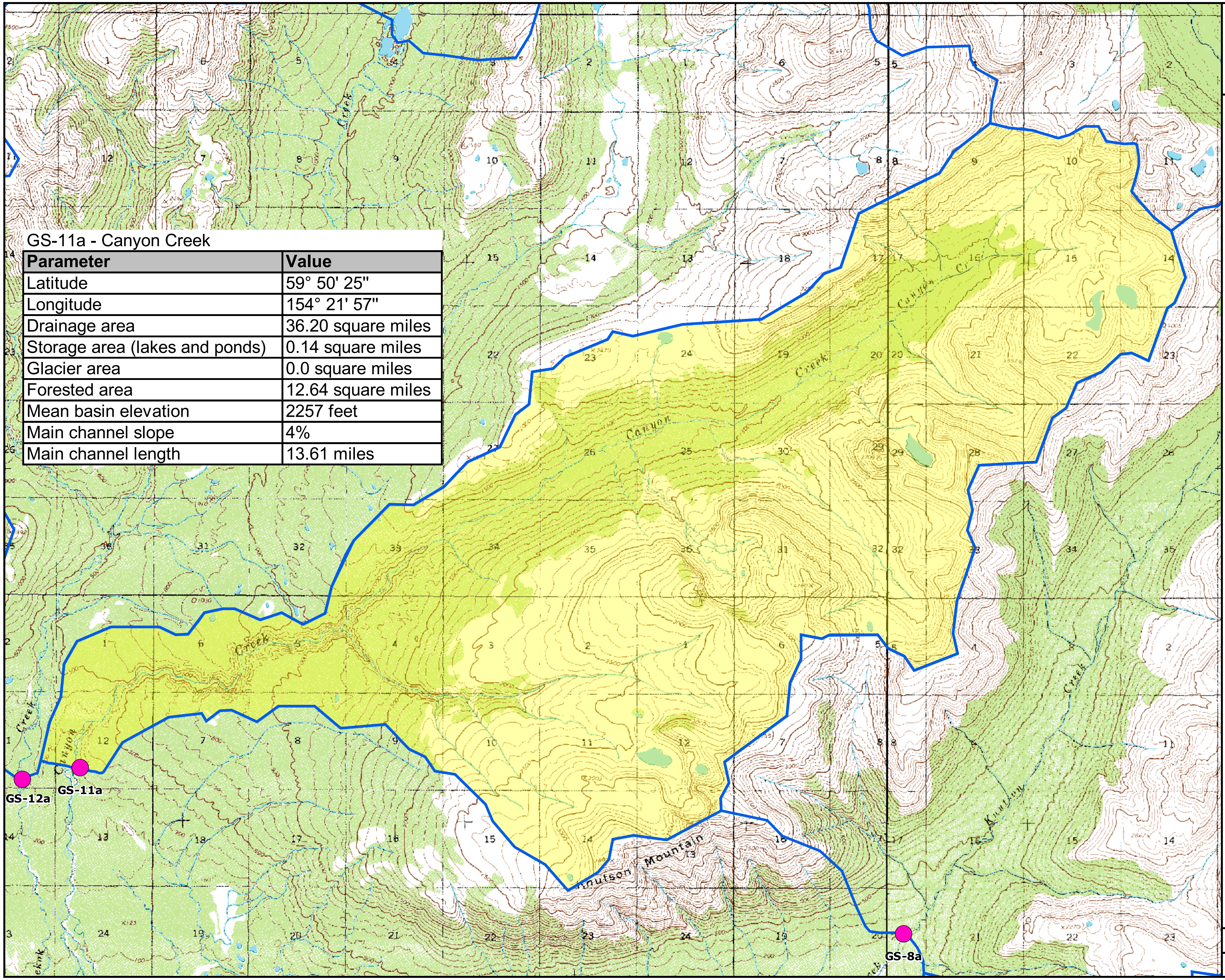
FIGURE

THE pebble PARTNERSHIP

Figure 7.3A8-1
Transportation Corridor
Bristol Bay Drainages
GS-11a Drainage Basin
Canyon Creek

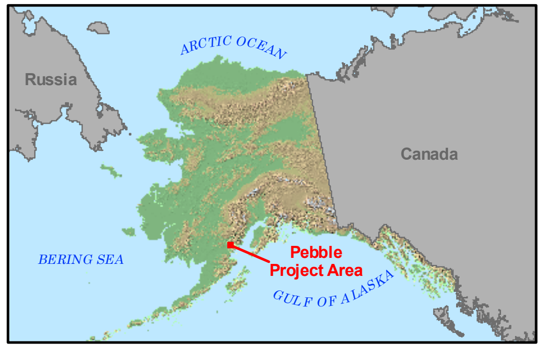
GS-11a - Canyon Creek

Parameter	Value
Latitude	59° 50' 25"
Longitude	154° 21' 57"
Drainage area	36.20 square miles
Storage area (lakes and ponds)	0.14 square miles
Glacier area	0.0 square miles
Forested area	12.64 square miles
Mean basin elevation	2257 feet
Main channel slope	4%
Main channel length	13.61 miles



Legend

- Surface Water Gage Station
- Communities
- Existing Roads
- Drainage Basin
- Drainage Basin GS-11a



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Scale 1:63,621

Alaska State Plane Zone 5 (units feet)
1983 North American Datum

File: Hydro_EBDag_V4.mxd	Date: March 28, 2011
Version: 4	Author: BEESC-ME

PHOTOGRAPHS

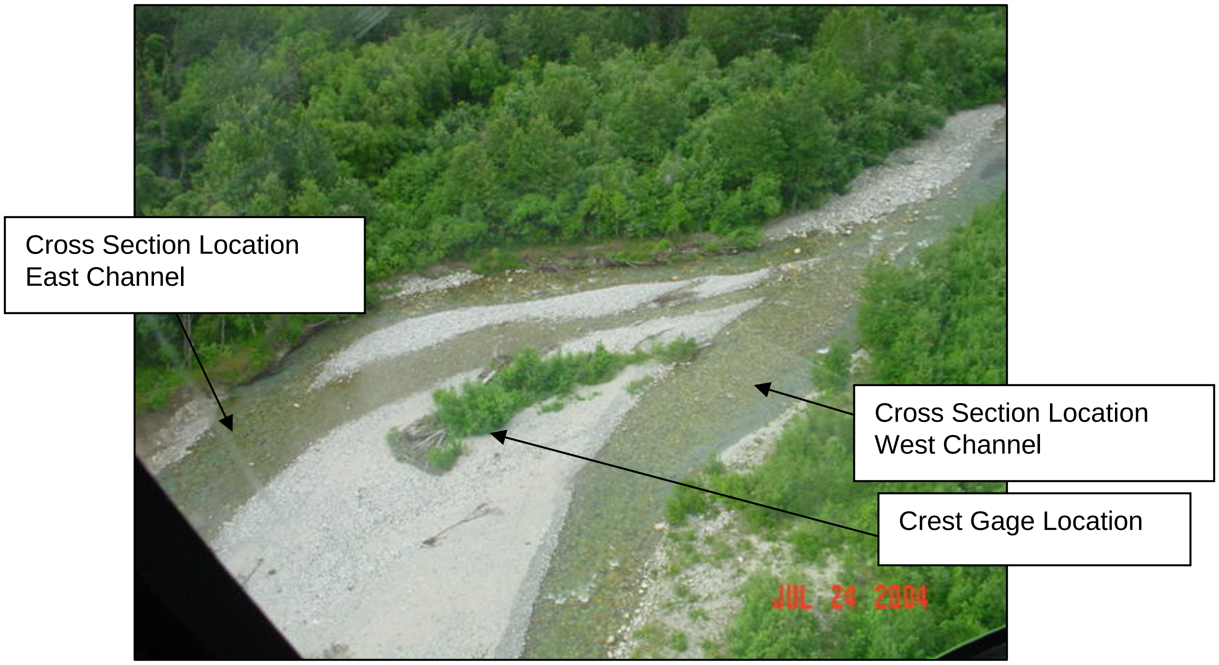

PHOTO 1: GS-11a Canyon Creek. Aerial view looking down at gage location during new set, July 24, 2004.

PHOTO 2: GS-11a Canyon Creek. Aerial view during fall precipitation event. Gage station gone, October 7, 2005.

PHOTO 3: GS-11a Canyon Creek. View looking at gage station near center of gravel island, July 20, 2004.

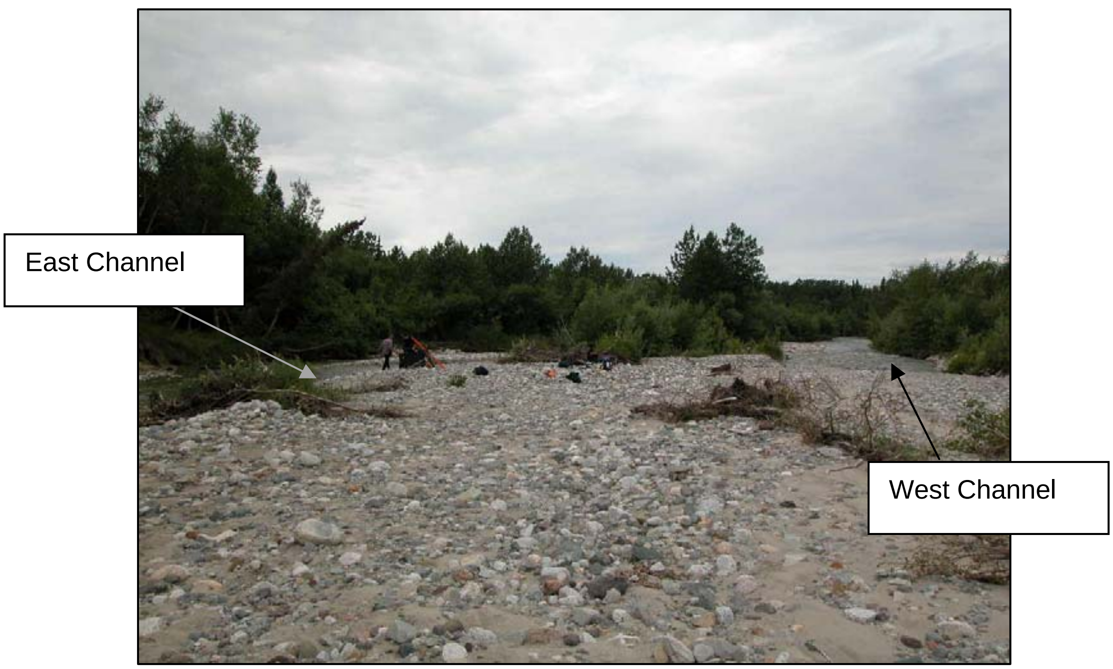

PHOTO 4: GS-11a Canyon Creek. View looking downstream across gravel island toward gage station, July 20, 2004.

PHOTO 5: GS-11a Canyon Creek. East channel, view looking upstream with moderate flow, July 16, 2005.

PHOTO 6: GS-11a Canyon Creek. East channel, view looking downstream with moderate flow, July 16, 2005.

PHOTO 7: GS-11a Canyon Creek. West channel, view looking upstream during low flow, July 20, 2004.

PHOTO 8: GS-11a Canyon Creek. West channel, view looking downstream during low flow. July 20, 2004.

PHOTO 9: GS-11a Canyon Creek. East channel, view looking upstream during fall precipitation, October 7, 2005.

PHOTO 10: GS-11a Canyon Creek. East channel, view looking downstream during fall precipitation, October 7, 2005.

PHOTO 11: GS-11a Canyon Creek. West channel, view looking upstream during fall precipitation, October 7, 2005.

PHOTO 12: GS-11a Canyon Creek. West channel view, looking downstream during fall precipitation, October 7, 2005.

ATTACHMENT 9

GS-12A Chekok Creek

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TABLE 1
GS-12a – Chekok Creek: Basin Characteristic File Data

Parameter	Variable	Unit	Value
Latitude	Lat	ddmmss	59° 50' 19"
Longitude	Long	ddmmss	154° 22' 59"
Drainage area	Da	Square miles	50.48 mi^2
Storage area (lakes and ponds)	St	Square miles	0.34 mi^2
Glacier area	Gl	Square miles	0.0 mi^2
Forested area	Fr	Square miles	32.00 mi^2
Mean basin elevation	El	Feet	1764 ft
Main channel slope	Sl	%	West-6%-East-6%-Main-1%
Main channel length	C	Miles	West-8.49/East-10.27/Main-10.43 mi
Mean annual precipitation	Pr	Inches	30 in
Mean minimum January temperature	T	°F	9°F
Stream classification at gage site (Montgomery method)	Level 1	Description	3b; Unstable; High Velocity

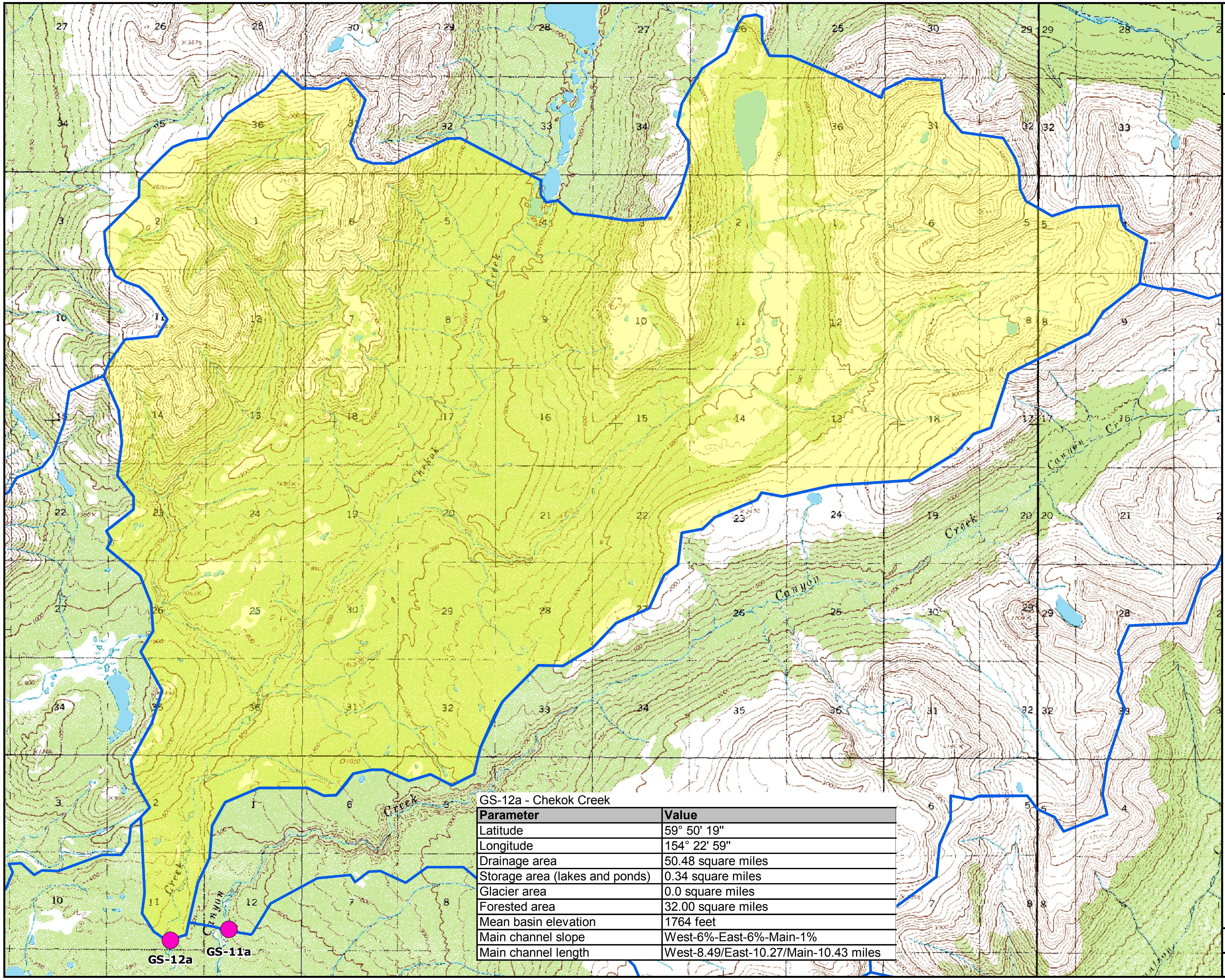
TABLE 2
GS-12a – Chekok Creek: Monthly Discharge

Date	Water Year	Peak Gage Reading	Water Surface Elevation (ft)	Stream Width (ft)	Number of Sections	Total Discharge (cfs)	Comment
1-Aug	2004	New Set	99.20	39.0	14	75.66	
17-Aug	2004	0	98.96	34.3	18	43.08	
22-Sep	2004	Down	99.62	38.0	21	111.94	
16-Oct	2004	Down	99.82	54.0	27	208.95	Reset Gage
19-Feb	2005	Gone	-	19.0	18	16.92	Frozen - Gage missing
1-Apr	2005	Gone	-	34.7	21	14.02	Frozen

FIGURE

THE pebble PARTNERSHIP

Figure 7.3A9-1
Transportation Corridor
Bristol Bay Drainages
GS-12a Drainage Basin
Chekok Creek

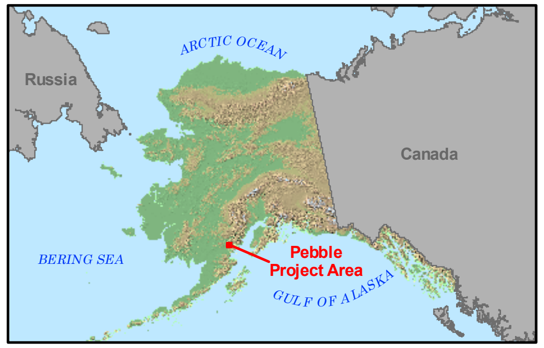


GS-12a - Chekok Creek

Parameter	Value
Latitude	59° 50' 19"
Longitude	154° 22' 59"
Drainage area	50.48 square miles
Storage area (lakes and ponds)	0.34 square miles
Glacier area	0.0 square miles
Forested area	32.00 square miles
Mean basin elevation	1764 feet
Main channel slope	West-6%-East-6%-Main-1%
Main channel length	West-8.49/East-10.27/Main-10.43 miles

Legend

- Surface Water Gage Station
- Communities
- Existing Roads
- Drainage Basin
- Drainage Basin GS-12a



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Kilometers: 0 0.5 1 1.5 2

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Scale 1:63,531

Alaska State Plane Zone 5 (units feet)
1983 North American Datum

File: Hydro_EBDah_V4.mxd	Date: March 28, 2011
Version: 4	Author: BEESC-ME

PHOTOGRAPHS

PHOTO 1: GS-12a Chekok Creek. View looking downstream with during low flow, August 1, 2004.

PHOTO 2: GS-12a Chekok Creek. View looking upstream during low flow, August 1, 2004.

PHOTO 3: GS-12a Chekok Creek. View looking upstream at overflow channel, August 1, 2004.

PHOTO 4: GS-12a Chekok Creek. View looking downstream during fall precipitation, October 15, 2004.

PHOTO 5: GS-12a Chekok Creek. View looking across stream with gage station missing, February 14, 2005.

PHOTO 6: GS-12a Chekok Creek. View looking downstream, February 14, 2005.

ATTACHMENT 10

GS-14A Unnamed Creek East of Eagle Bay Creek

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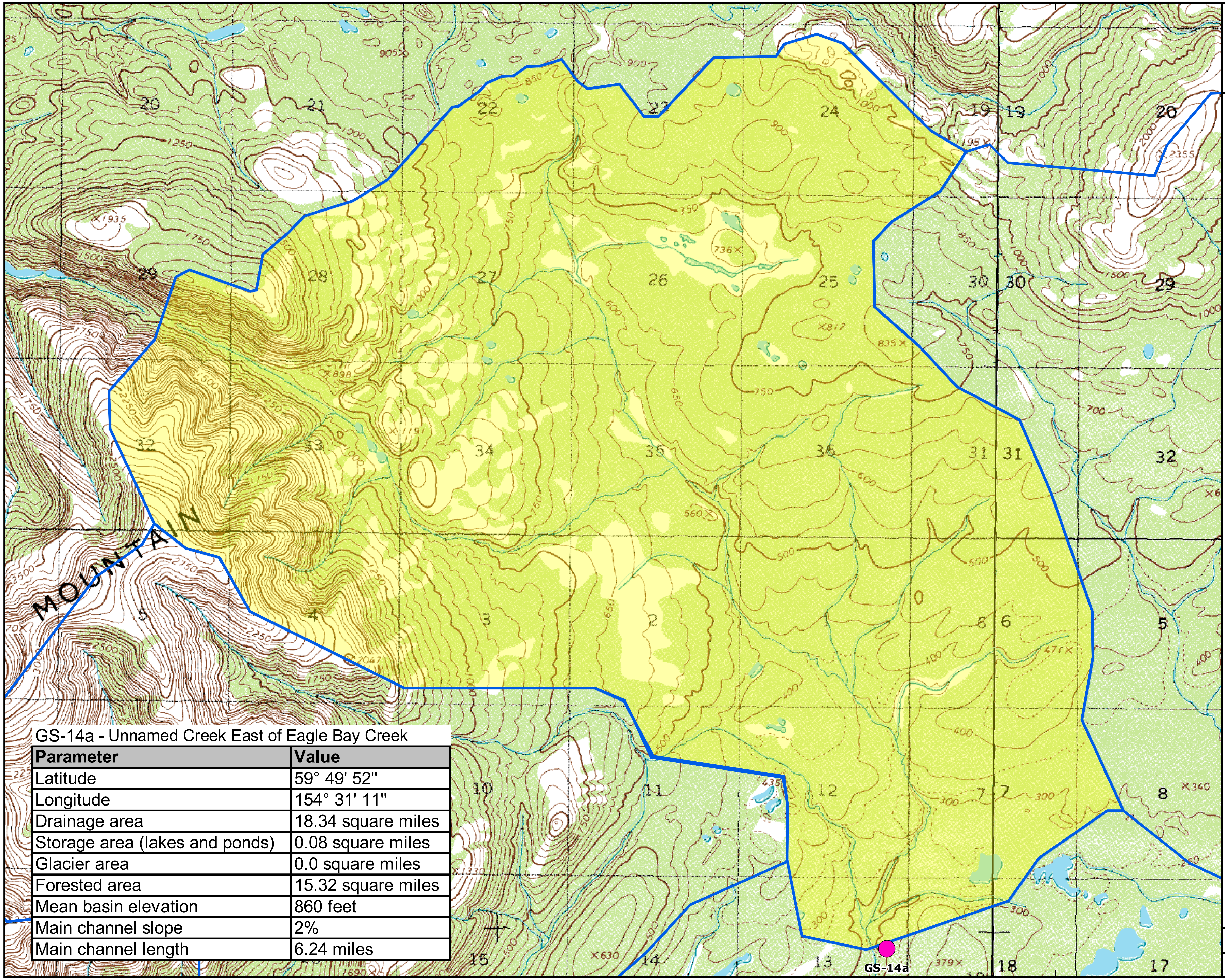
TABLE 1
GS-14a – Unnamed Creek East of Eagle Bay Creek: Basin Characteristic File Data

Parameter	Variable	Unit	Value
Latitude	Lat	ddmmss	59° 49' 52"
Longitude	Long	ddmmss	154° 31' 11"
Drainage area	Da	Square miles	18.34 mi^2
Storage area (lakes and ponds)	St	Square miles	0.08 mi^2
Glacier area	Gl	Square miles	0.0 mi^2
Forested area	Fr	Square miles	15.32 mi^2
Mean basin elevation	El	Feet	860 ft
Main channel slope	Sl	%	2%
Main channel length	C	Miles	6.24 mi
Mean annual precipitation	Pr	Inches	28 in
Mean minimum January temperature	T	°F	9°F
Stream classification at gage site (Montgomery method)	Level 1	Description	2; Unstable; High Velocity

TABLE 2
GS-14a – Unnamed Creek East of Eagle Bay Creek: Monthly Discharge

Date	Water Year	Peak Gage Reading	Water Surface Elevation (ft)	Stream Width (ft)	Number of Sections	Total Discharge (cfs)	Comment
19-Jul	2004	New Set	98.95	22.8	14	19.48	
17-Aug	2004	Down	-	17.5	10	12.30	
22-Sep	2004	0	99.34	24.0	11	86.13	
17-Oct	2004	Down	-	28.0	15	66.39	Gage Down
19-Feb	2005	0	98.43	24.0	20	7.53	Frozen half-way
31-Mar	2005	Down	-	15.5	18	3.87	Frozen half-way

FIGURE

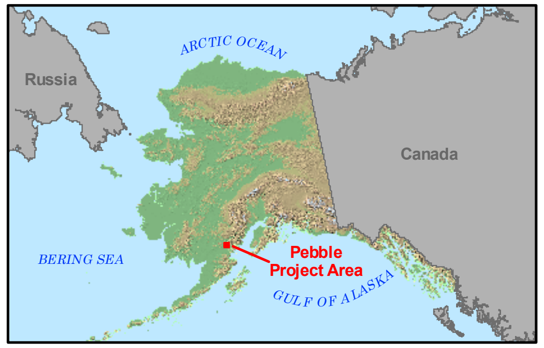


THE pebble PARTNERSHIP

Figure 7.3A10-1
Transportation Corridor
Bristol Bay Drainages
GS-14a Drainage Basin
Unnamed Creek East of Eagle Bay Creek

Legend

- Surface Water Gage Station
- Communities
- Existing Roads
- Drainage Basin
- Drainage Basin GS-14a



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Kilometers: 0, 0.2, 0.4, 0.6, 0.8

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Scale 1:36,258

Alaska State Plane Zone 5 (units feet)
1983 North American Datum

File: Hydro_EBDai_V4.mxd	Date: March 28, 2011
Version: 4	Author: BEESC-ME

GS-14a - Unnamed Creek East of Eagle Bay Creek

Parameter	Value
Latitude	59° 49' 52"
Longitude	154° 31' 11"
Drainage area	18.34 square miles
Storage area (lakes and ponds)	0.08 square miles
Glacier area	0.0 square miles
Forested area	15.32 square miles
Mean basin elevation	860 feet
Main channel slope	2%
Main channel length	6.24 miles

PHOTOGRAPHS

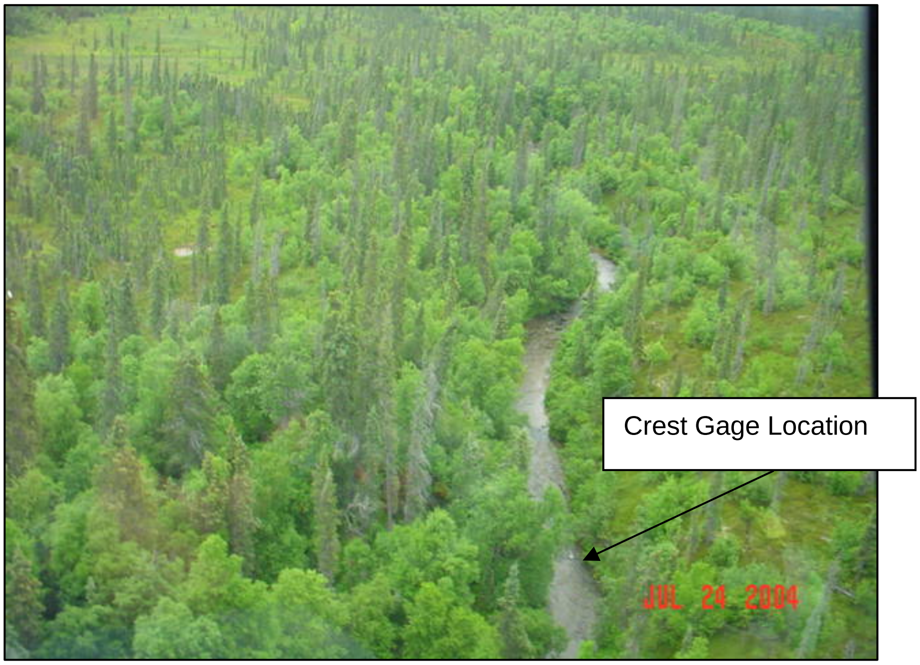

PHOTO 1: GS-14a Unnamed Creek East of Eagle Bay Creek. View looking downstream with during low flow, July 24, 2004.

PHOTO 2: GS-14a Unnamed Creek East of Eagle Bay Creek. View looking down on new set of gage during low flow, July 19, 2004.

PHOTO 3: GS-14a Unnamed Creek East of Eagle Bay Creek. View looking upstream during fall precipitation, October 17, 2004.

PHOTO 4: GS-14a Unnamed Creek East of Eagle Bay Creek. View looking downstream with gage station displaced, October 17, 2004.

PHOTO 5: GS-14a Unnamed Creek East of Eagle Bay Creek. View looking across stream, February 18, 2005.

ATTACHMENT 11

GS-14B Unnamed Creek West of Chekok Creek

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TABLE 1
GS-14b – Unnamed Creek West of Chekok Creek: Basin Characteristic File Data

Parameter	Variable	Unit	Value
Latitude	Lat	ddmmss	59° 50' 03"
Longitude	Long	ddmmss	154° 27' 07"
Drainage area	Da	Square miles	15.91 mi^2
Storage area (lakes and ponds)	St	Square miles	0.29 mi^2
Glacier area	Gl	Square miles	0.0 mi^2
Forested area	Fr	Square miles	13.61 mi^2
Mean basin elevation	El	Feet	973 ft
Main channel slope	Sl	%	4%
Main channel length	C	Miles	8.90 mi
Mean annual precipitation	Pr	Inches	28 in
Mean minimum January temperature	T	°F	9°F
Stream classification at gage site (Montgomery method)	Level 1	Description	3b; Stable; Overbank Flow

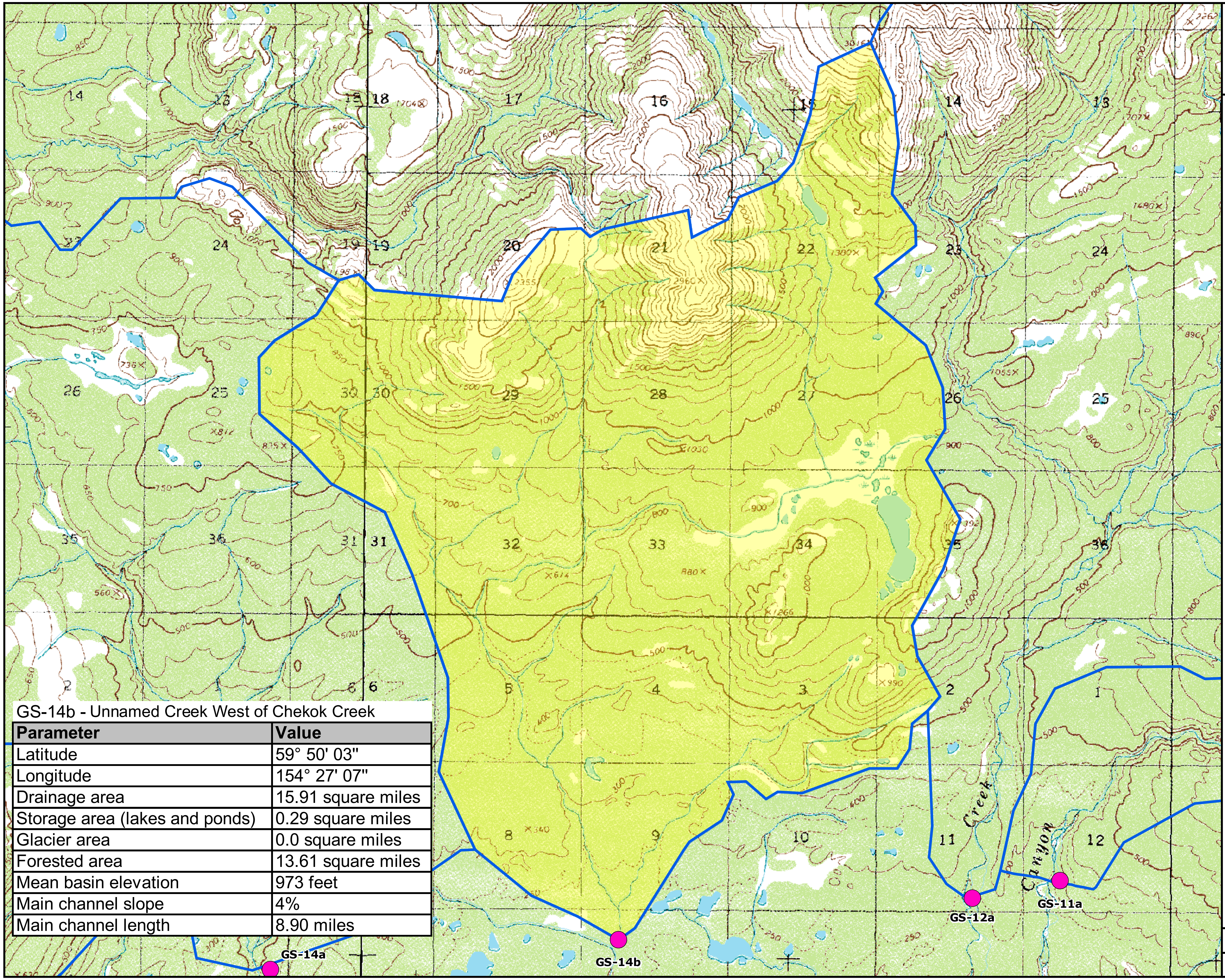
TABLE 2
GS-14b – Unnamed Creek West of Chekok Creek: Monthly Discharge

Date	Water Year	Peak Gage Reading	Water Surface Elevation (ft)	Stream Width (ft)	Number of Sections	Total Discharge (cfs)	Comment
20-Jul	2004	New Set	99.98	16.1	13	7.574	
17-Aug	2004	0	98.86	11.0	8	3.982	
22-Sep	2004	0	99.28	17.0	18	20.327	
16-Oct	2004	0	99.26	17.0	18	27.868	
17-Feb	2005	0	101.30	11.0	22	3.087	Frozen
3-May	2005	0	99.44	15.2	19	45.265	
15-Jun	2005	0	99.02	15.3	18	13.754	
15-Jul	2005	Down	98.90	15.5	17	3.107	Reset Gage
10-Aug	2005	Down	98.88	16.8	31	7.216	
10-Sep	2005	Down	103.66	17.0	18	80.371	Flooded-Water surface at top of bank
7-Oct	2005	Down	99.36	16.0	19	56.581	Reset Gage

FIGURE

THE pebble PARTNERSHIP

Figure 7.3A11-1
Transportation Corridor
Bristol Bay Drainages
GS-14b Drainage Basin
Unnamed Creek West of Chekok Creek

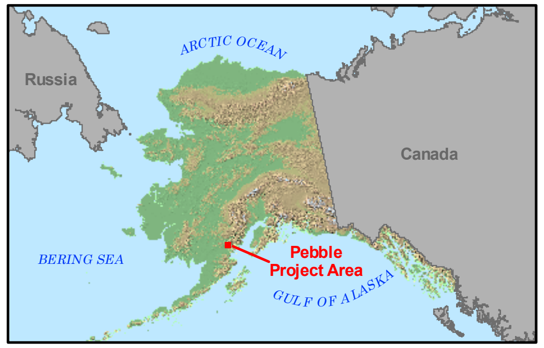


GS-14b - Unnamed Creek West of Chekok Creek

Parameter	Value
Latitude	59° 50' 03"
Longitude	154° 27' 07"
Drainage area	15.91 square miles
Storage area (lakes and ponds)	0.29 square miles
Glacier area	0.0 square miles
Forested area	13.61 square miles
Mean basin elevation	973 feet
Main channel slope	4%
Main channel length	8.90 miles

Legend

- Surface Water Gage Station
- Communities
- Existing Roads
- Drainage Basin
- Drainage Basin GS-14b



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Kilometers: 0 0.25 0.5 0.75 1

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Scale 1:41,927
Alaska State Plane Zone 5 (units feet)
1983 North American Datum

File: Hydro_EBDaj_V4.mxd	Date: March 28, 2011
Version: 4	Author: BEESC-ME

PHOTOGRAPHS

PHOTO 1: GS-14b Unnamed Creek West of Chekok Creek. Aerial view looking upstream, May 4, 2005.

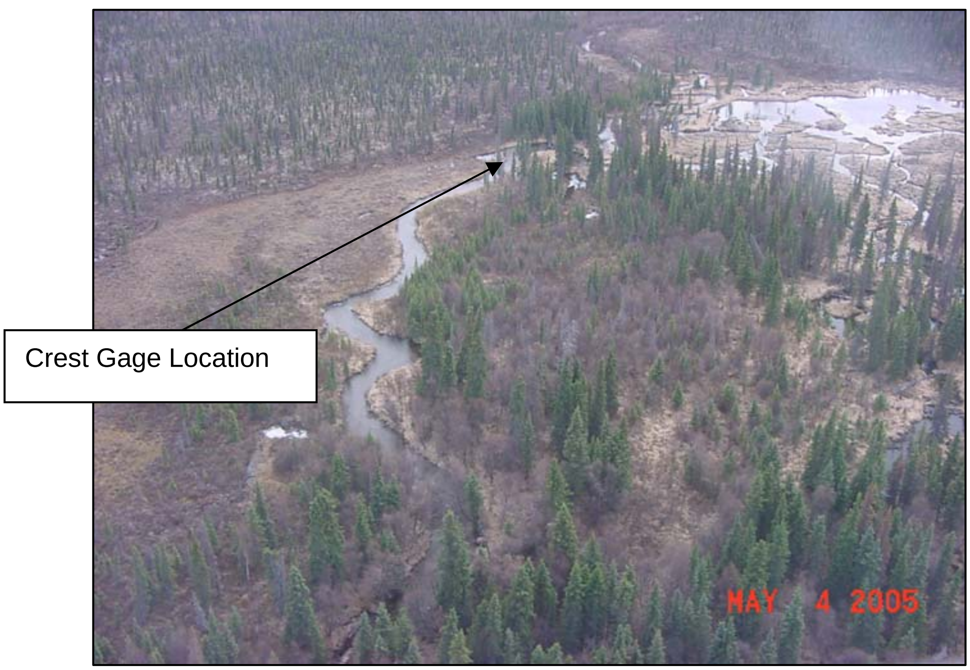

PHOTO 2: GS-14b Unnamed Creek West of Chekok Creek. Aerial view looking downstream, May 9, 2005.

PHOTO 3: GS-14b Unnamed Creek West of Chekok Creek. View looking upstream during low flows, July 20, 2004.

PHOTO 4: GS-14a Unnamed Creek West of Chekok Creek. View looking downstream during low flows, July 20, 2004.

PHOTO 5: GS-14b Unnamed Creek West of Chekok Creek. View looking upstream during fall precipitation, September 9, 2005.

PHOTO 6: GS-14b Unnamed Creek West of Chekok Creek. View looking downstream during fall precipitation, September 9, 2005.

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GS-17A West Fork Eagle Bay Creek

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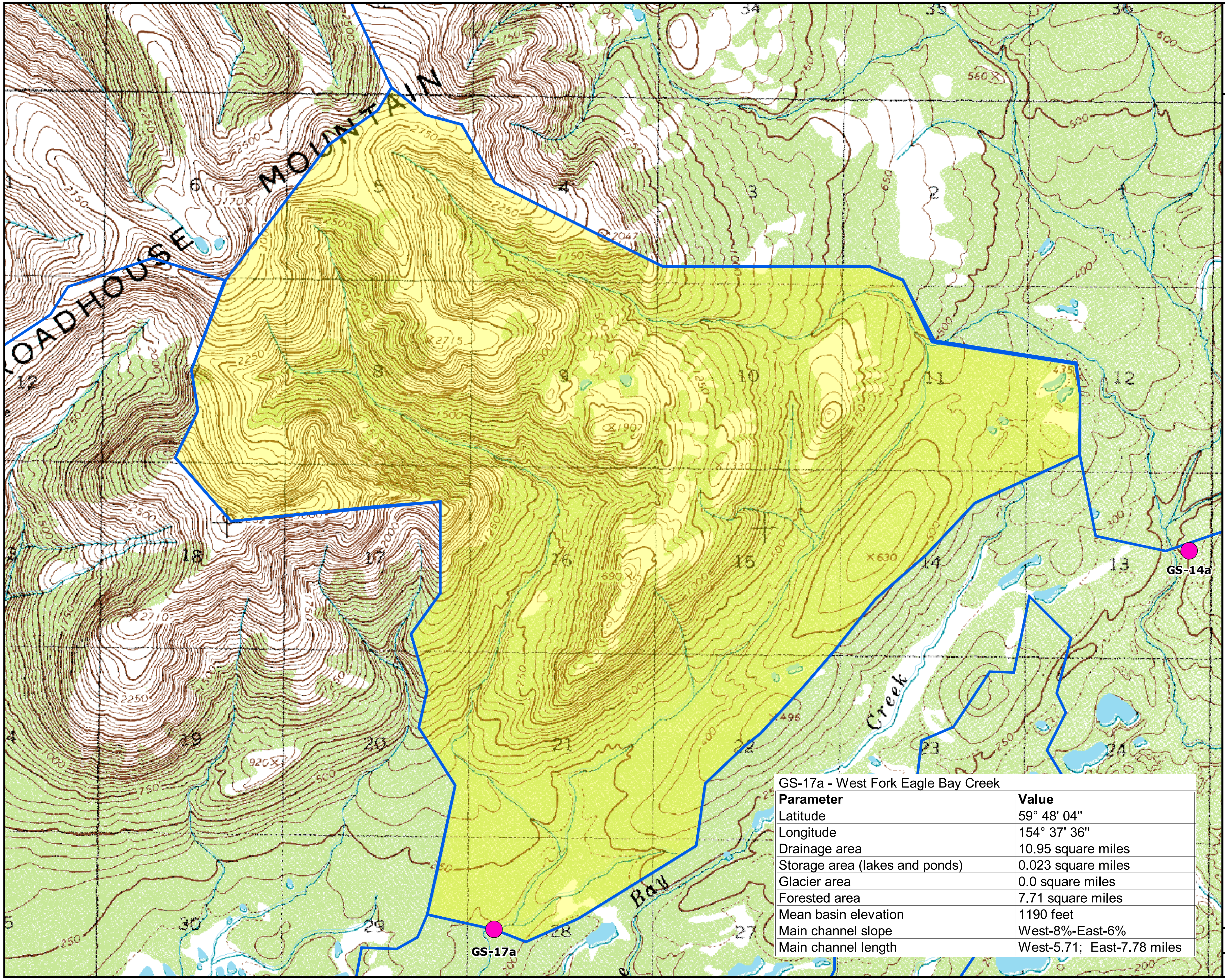
TABLE 1
GS-17a – West Fork Eagle Bay Creek: Basin Characteristic File Data

Parameter	Variable	Unit	Value
Latitude	Lat	ddmmss	59° 48' 04"
Longitude	Long	ddmmss	154° 37' 36"
Drainage area	Da	Square miles	10.95 mi^2
Storage area (lakes and ponds)	St	Square miles	0.023 mi^2
Glacier area	Gl	Square miles	0.0 mi^2
Forested area	Fr	Square miles	7.71 mi^2
Mean basin elevation	El	Feet	1190 ft
Main channel slope	Sl	%	West-8%-East-6%
Main channel length	C	Miles	West-5.71; East-7.78 mi
Mean annual precipitation	Pr	Inches	28 in
Mean minimum January temperature	T	°F	9°F
Stream classification at gage site (Montgomery method)	Level 1	Description	3b; Stable; Overbank Flow

TABLE 2
GS-17a – West Fork Eagle Bay Creek: Monthly Discharge

Date	Water Year	Peak Gage Reading	Water Surface Elevation (ft)	Stream Width (ft)	Number of Sections	Total Discharge (cfs)	Comment
19-Jul	2004	New Set	98.85	14.0	8	6.624	
17-Aug	2004	0	98.42	14.0	8	5.068	
22-Sep	2004	-	98.44	15.0	16	10.839	Gage staff fell down inside pole
16-Oct	2004	-	98.92	17.0	19	28.891	Reset staff
18-Feb	2005	Down	-	13.5	28	1.136	Frozen
31-Mar	2005	0	98.85	14.2	27	0.829	Frozen
5-May	2005	0	99.52	19.0	19	46.512	
15-Jun	2005	Down	97.62	15.3	18	14.236	Elevation measured from rebar
16-Jul	2005	Down	99.94	14.3	30	8.429	Reset Gage
10-Aug	2005	Down	98.83	15.2	18	6.521	Reset Gage
10-Sep	2005	7"	99.24	34.5	28	62.175	Flood-new channel cut on west bank
7-Oct	2005	Down	99.50	16.0	19	30.204	Flooded-new channel cut on east bank. Elevation measured from rebar.

FIGURE



GS-17a - West Fork Eagle Bay Creek

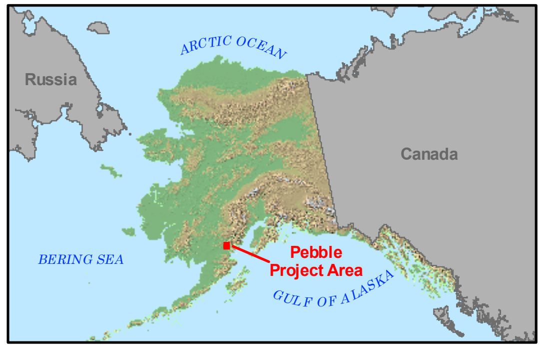
Parameter	Value
Latitude	59° 48' 04"
Longitude	154° 37' 36"
Drainage area	10.95 square miles
Storage area (lakes and ponds)	0.023 square miles
Glacier area	0.0 square miles
Forested area	7.71 square miles
Mean basin elevation	1190 feet
Main channel slope	West-8%-East-6%
Main channel length	West-5.71; East-7.78 miles

THE pebble PARTNERSHIP

Figure 7.3A12-1
Transportation Corridor
Bristol Bay Drainages
GS-17a Drainage Basin
West Fork Eagle Bay Creek

Legend

- Surface Water Gage Station
- Communities
- Existing Roads
- Drainage Basin
- Drainage Basin GS-17a



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0 0.25 0.5 0.75 1 Kilometers

Scale 1:33,313

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Alaska State Plane Zone 5 (units feet)
1983 North American Datum

File: Hydro_EBDak_V4.mxd	Date: March 28, 2011
Version: 4	Author: BEESC-ME

PHOTOGRAPHS

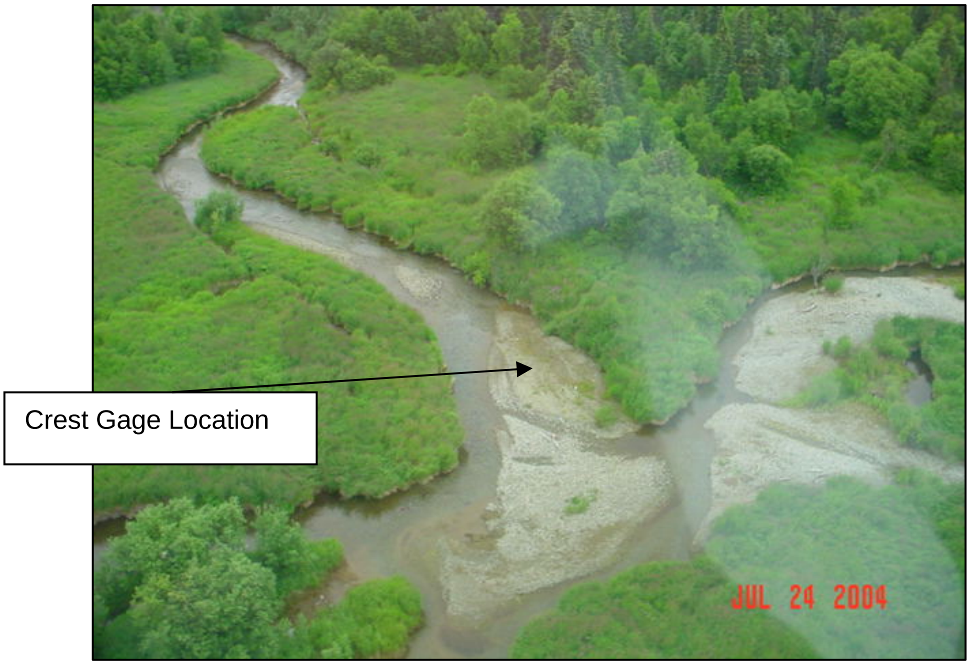

PHOTO 1: GS-17a West Fork Eagle Bay Creek. Aerial View of new gage set, June 19, 2004.

PHOTO 2: GS-17a West Fork Eagle Bay Creek. Aerial view looking across stream during spring runoff, May 4, 2005.

PHOTO 3: GS-17a West Fork Eagle Bay Creek. View looking upstream during low flows, June 19, 2004.

PHOTO 4: GS-17a West Fork Eagle Bay Creek. View looking downstream during low flows, June 19, 2004.

PHOTO 5: GS-17a West Fork Eagle Bay Creek. View looking upstream toward lake during fall precipitation, September 9, 2005.

PHOTO 6: GS-17a West Fork Eagle Bay Creek. View looking downstream during fall precipitation, September 9, 2005.

PHOTO 7: GS-17a West Fork Eagle Bay Creek: New gage set, June 19, 2004

PHOTO 8: GS-17a West Fork Eagle Bay Creek. View looking downstream gage displaced by bears, August 11, 2005.

ATTACHMENT 13

GS-18A Unnamed Creek on South Slope of Roadhouse Mountain

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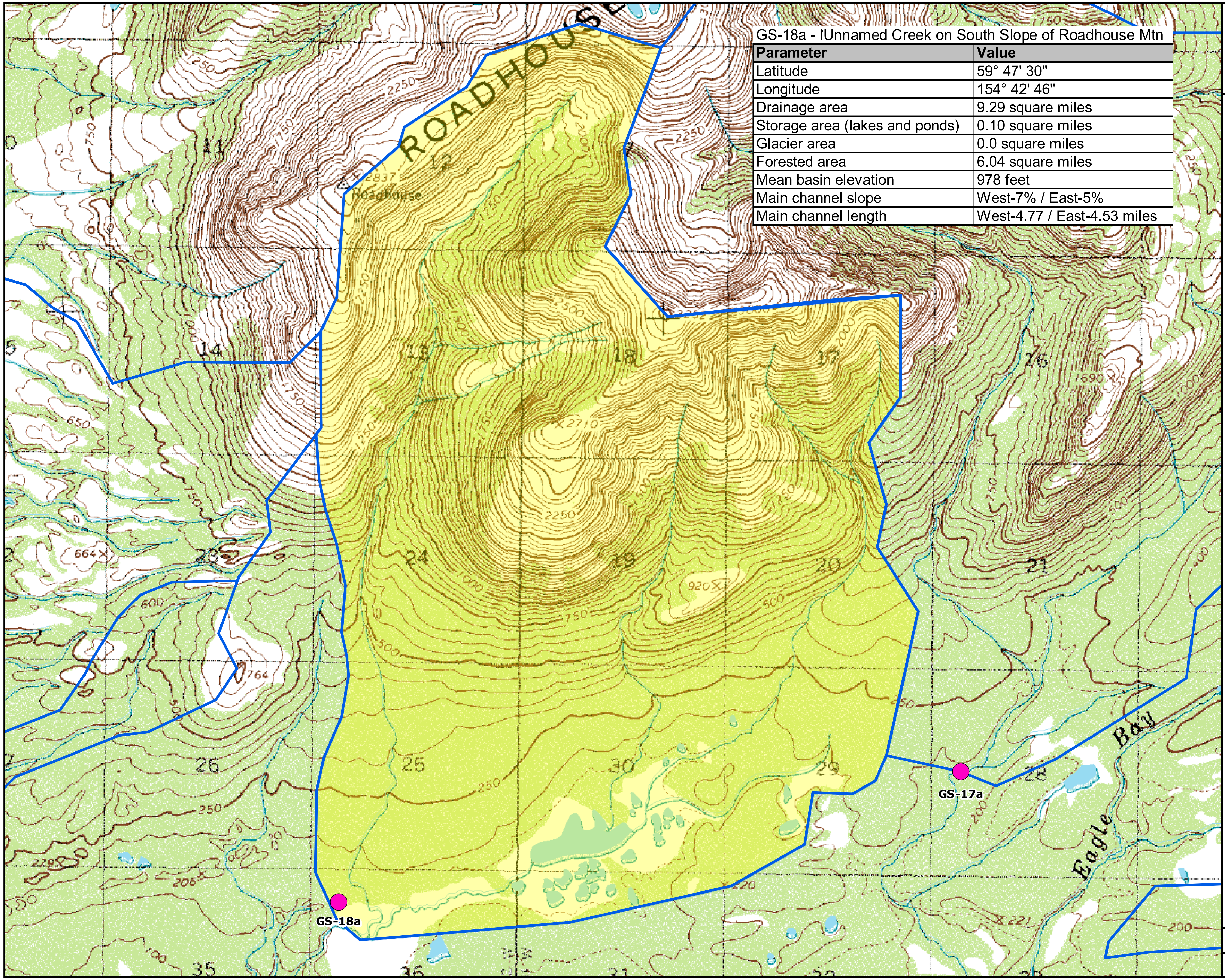
TABLE 1
GS-18a – Unnamed Creek on South Slope of Roadhouse Mountain: Basin Characteristic File Data

Parameter	Variable	Unit	Value
Latitude	Lat	ddmmss	59° 47' 30"
Longitude	Long	ddmmss	154° 42' 46"
Drainage area	Da	Square miles	9.29 mi^2
Storage area (lakes and ponds)	St	Square miles	0.10 mi^2
Glacier area	Gl	Square miles	0.0 mi^2
Forested area	Fr	Square miles	6.04 mi^2
Mean basin elevation	El	Feet	978 ft
Main channel slope	Sl	%	West-7% / East-5%
Main channel length	C	Miles	West-4.77 / East-4.53 mi
Mean annual precipitation	Pr	Inches	25 in
Mean minimum January temperature	T	°F	9°F
Stream classification at gage site (Montgomery method)	Level 1	Description	3a; Stable; Low Velocity

TABLE 2
GS-18a – Unnamed Creek on South Slope of Roadhouse Mountain: Monthly Discharge

Date	Water Year	Peak Gage Reading	Water Surface Elevation (ft)	Stream Width (ft)	Number of Sections	Total Discharge (cfs)	Comment
19-Jul	2004	New Set	99.67	2.6	4	1.487	
21-Sep	2004	0	99.22	2.3	5	0.509	
16-Oct	2004	0	99.24	2.0	7	0.523	
18-Feb	2005	0	99.54	2.5	6	0.116	
31-Mar	2005	0	98.90	2.8	6	0.123	

FIGURE



Parameter	Value
Latitude	59° 47' 30"
Longitude	154° 42' 46"
Drainage area	9.29 square miles
Storage area (lakes and ponds)	0.10 square miles
Glacier area	0.0 square miles
Forested area	6.04 square miles
Mean basin elevation	978 feet
Main channel slope	West-7% / East-5%
Main channel length	West-4.77 / East-4.53 miles

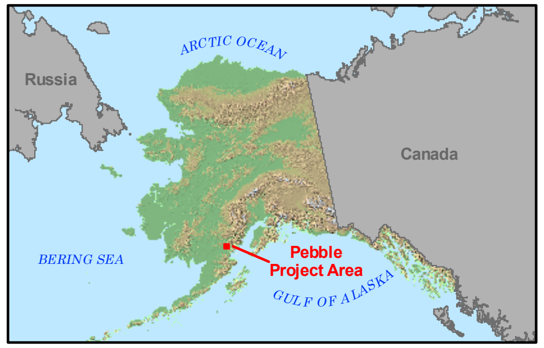
GS-18a - Unnamed Creek on South Slope of Roadhouse Mtn

THE pebble PARTNERSHIP

Figure 7.3A13-1
Transportation Corridor
Bristol Bay Drainages
GS-18a Drainage Basin
Unnamed Creek on South Slope
of Roadhouse Mountain

Legend

- Surface Water Gage Station
- Communities
- Existing Roads
- Drainage Basin
- Drainage Basin GS-18a



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Scale 1:29,873

Alaska State Plane Zone 5 (units feet)
1983 North American Datum

File: Hydro_EBDal_V5.mxd	Date: March 31, 2011
Version: 5	Author: BEESC-ME

PHOTOGRAPHS

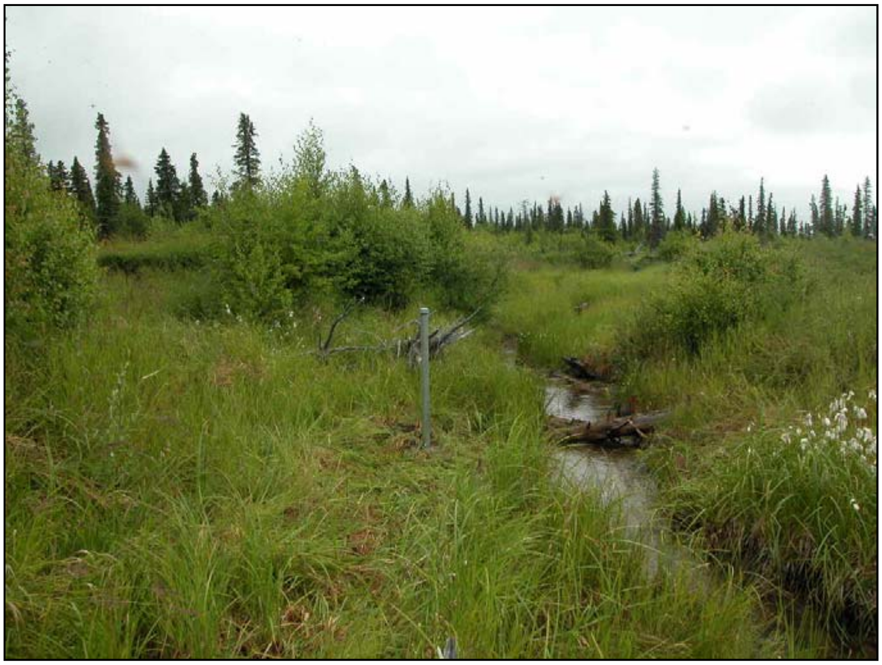

PHOTO 1: GS-18a Unnamed Creek on South Slope of Roadhouse Mountain. View looking upstream during new gage set, June 19, 2004.

PHOTO 2: GS-18a Unnamed Creek on South Slope of Roadhouse Mountain. View looking upstream during low flows, June 19, 2004.

PHOTO 3: GS-18a Unnamed Creek on South Slope of Roadhouse Mountain. View looking upstream toward lake during low flow, July 19, 2004.

PHOTO 4: GS-18a Unnamed Creek on South Slope of Roadhouse Mountain. Winter conditions, April 3, 2005.

ATTACHMENT 14

GS-20 Roadhouse Creek

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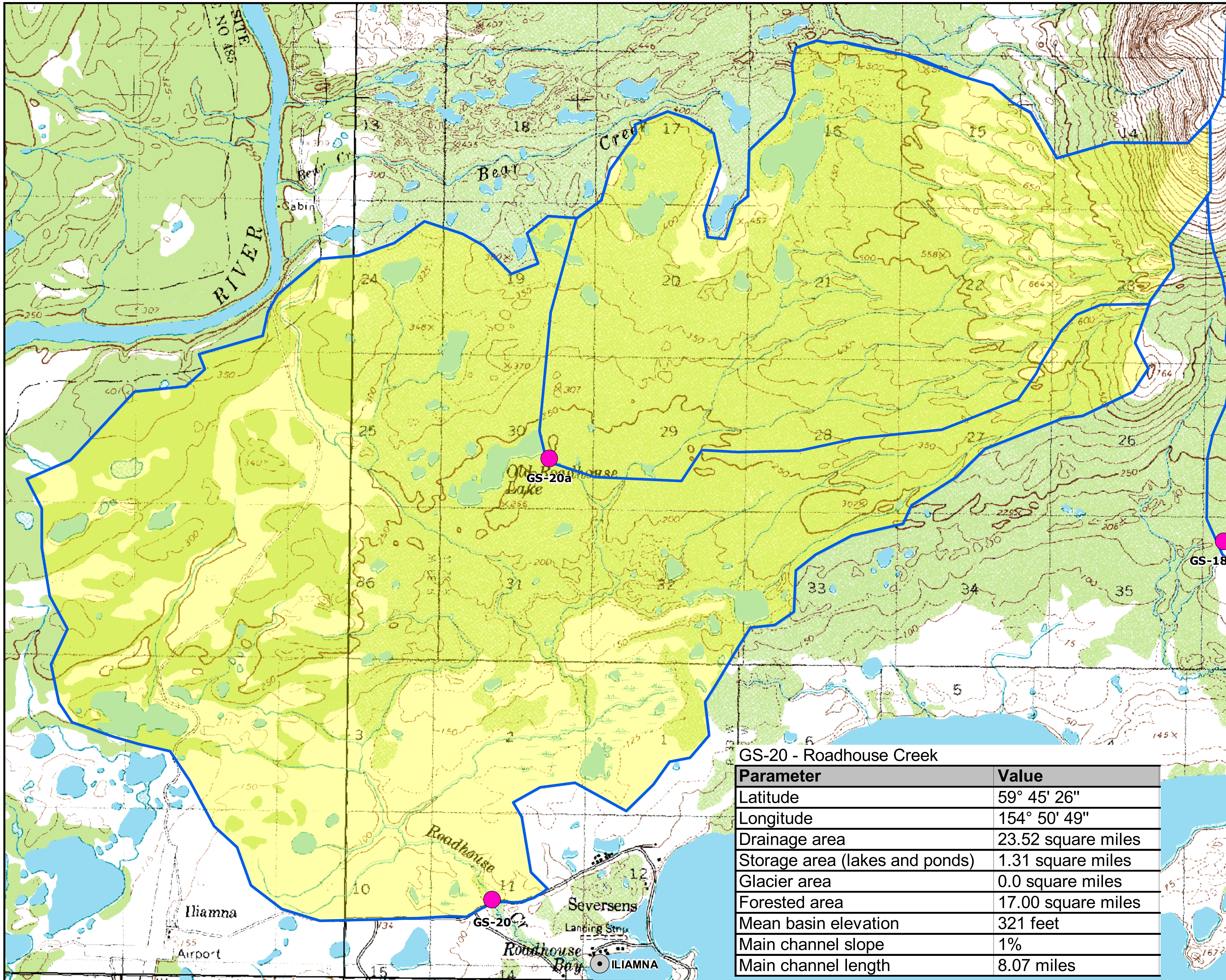
TABLE 1
GS-20 – Roadhouse Creek: Basin Characteristic File Data

Parameter	Variable	Unit	Value
Latitude	Lat	ddmmss	59° 45' 26"
Longitude	Long	ddmmss	154° 50' 49"
Drainage area	Da	Square miles	23.52 mi^2
Storage area (lakes and ponds)	St	Square miles	1.31 mi^2
Glacier area	Gl	Square miles	0.0 mi^2
Forested area	Fr	Square miles	17.00 mi^2
Mean basin elevation	El	Feet	321 ft
Main channel slope	Sl	%	1%
Main channel length	C	Miles	8.07 mi
Mean annual precipitation	Pr	Inches	30 in
Mean minimum January temperature	T	°F	8°F
Stream classification at gage site (Montgomery method)	Level 1	Description	3a; Stable; Low Velocity

TABLE 2
GS-20 – Roadhouse Creek: Monthly Discharge

Date	Water Year	Peak Gage Reading	Water Surface Elevation (ft)	Stream Width (ft)	Number of Sections	Total Discharge (cfs)	Comment
22-Jul	2004	New Set	-	18.0	14	14.989	
3-Aug	2004	0	99.00	14.2	16	8.97	
20-Aug	2004	0	100.04	23.0	11	10.795	
26-Sep	2004	-	-	27.0	23	38.303	Gage staff fell down inside pole
14-Oct	2004	0.5"	99.84	26.0	16	46.426	
18-Oct	2004	0	99.68	28.6	24	48.813	
28-Oct	2004	0	100.40	27.0	23	84.89	
18-Feb	2005	0	100.32	18.0	5	12.964	Frozen
1-Apr	2005	0	99.76	11.2	25	2.771	Frozen
24-May	2005	-	-	-	-	26	USGS Gage reinstalled
18-Jun	2005	-	-	-		45	USGS published peak monthly flow
2-Jul	2005	-	-	-	-	33	USGS published peak monthly flow
24-Aug	2005	-	-	-	-	53	USGS published peak monthly flow
10-Sep	2005	11.88"	-	-	-	282	USGS published peak monthly flow
8-Oct	2005	-	-	-	-	110	USGS published peak monthly flow

FIGURE



GS-20 - Roadhouse Creek

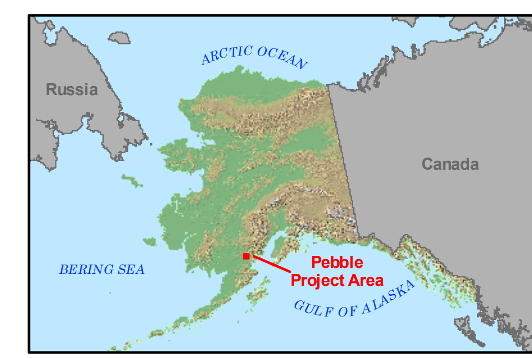
Parameter	Value
Latitude	59° 45' 26"
Longitude	154° 50' 49"
Drainage area	23.52 square miles
Storage area (lakes and ponds)	1.31 square miles
Glacier area	0.0 square miles
Forested area	17.00 square miles
Mean basin elevation	321 feet
Main channel slope	1%
Main channel length	8.07 miles

THE pebble PARTNERSHIP

Figure 7.3A14-1
Transportation Corridor
Bristol Bay Drainages
GS-20 Drainage Basin
Roadhouse Creek

Legend

- Surface Water Gage Station
- Communities
- Existing Roads
- Drainage Basin
- Drainage Basin GS-20



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Scale 1:40,950

Alaska State Plane Zone 5 (units feet)
1983 North American Datum

File: Hydro_EBDam_V4.mxd	Date: March 28, 2011
Version: 4	Author: BEESC-ME

PHOTOGRAPHS

PHOTO 1: GS-20 Roadhouse Creek. New gage set during low flows, July 24, 2004.

PHOTO 2: GS-20 Roadhouse Creek. New set of USGS gage station. View looking upstream, May 24, 2005.

PHOTO 3: GS-20 Roadhouse Creek. View looking downstream during low flows, July 22, 2004.

PHOTO 4: GS-20 Roadhouse Creek. Cross-section view of 8-foot culverts to convey flow under road, June 19, 2004.

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GS-20A Upper Roadhouse Creek

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TABLE 1
GS-20a – Upper Roadhouse Creek: Basin Characteristic File Data

Parameter	Variable	Unit	Value
Latitude	Lat	ddmmss	59° 47' 55"
Longitude	Long	ddmmss	154° 50' 23"
Drainage area	Da	Square miles	8.07 mi^2
Storage area (lakes and ponds)	St	Square miles	0.28 mi^2
Glacier area	Gl	Square miles	0.0 mi^2
Forested area	Fr	Square miles	- [a]
Mean basin elevation	El	Feet	- [a]
Main channel slope	Sl	%	3%
Main channel length	C	Miles	0.14 mi
Mean annual precipitation	Pr	Inches	30 in
Mean minimum January temperature	T	°F	8°F
Stream classification at gage site (Montgomery method)	Level 1	Description	3a; Stable; Low Velocity

Note:

a. Some spatial data not available for this sub-basin of Roadhouse Creek (GS-20).

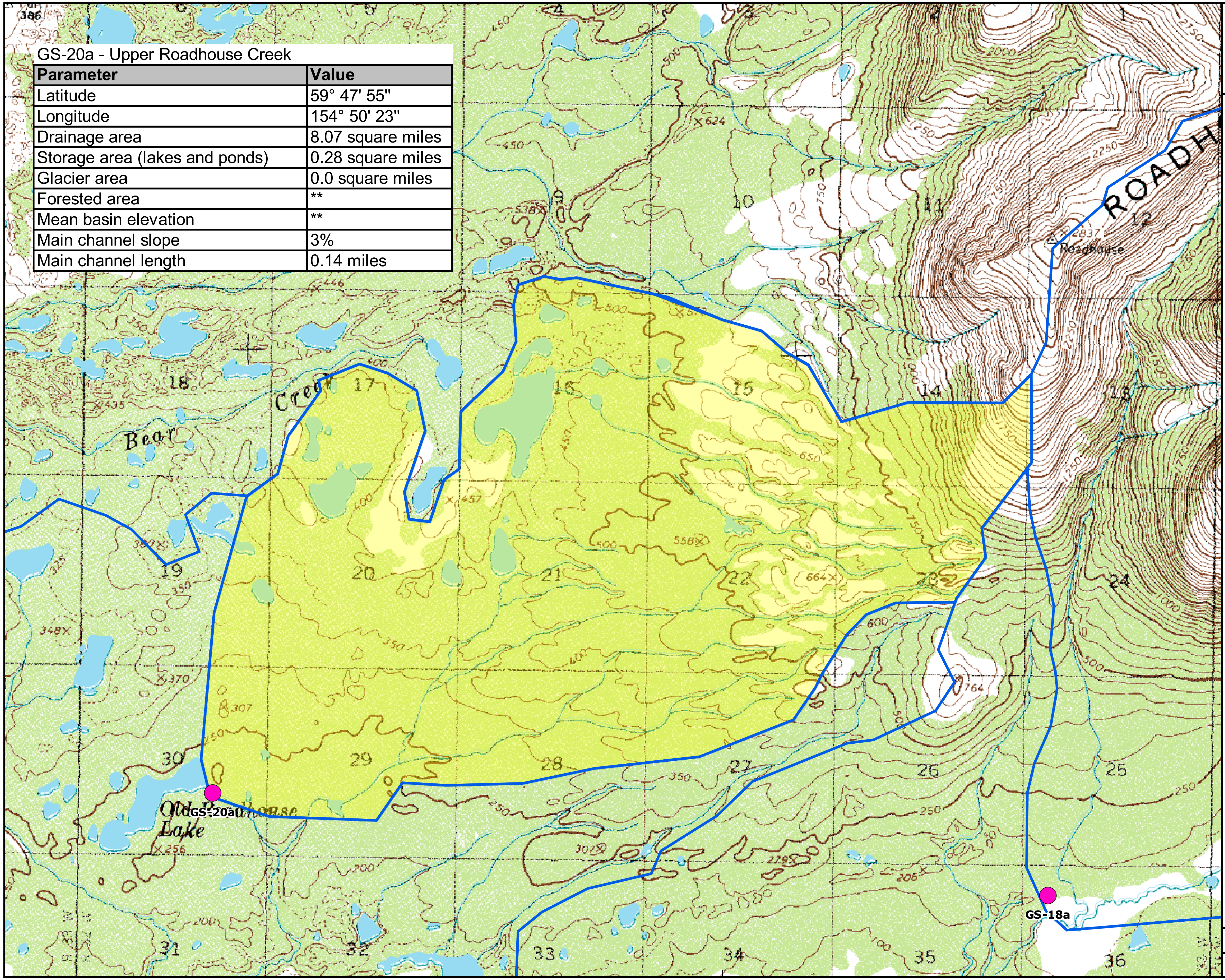
TABLE 2
GS-20a – Upper Roadhouse Creek: Monthly Discharge

Date	Water Year	Peak Gage Reading	Water Surface Elevation (ft)	Stream Width (ft)	Number of Sections	Total Discharge (cfs)	Comment
20-Jul	2004	New Set	99.55	7.1	9	0.677	
20-Aug	2004	0	99.06	10.7	12	0.612	
21-Sep	2004	0.12'	100.13	10.0	11	2.402	
14-Oct	2004	1.9'	100.78	10.5	12	5.805	
18-Feb	2005	0	100.20	2.3	7	0.208	Frozen
30-Mar	2005	0	-	9.7	18	1.781	

FIGURE

GS-20a - Upper Roadhouse Creek

Parameter	Value
Latitude	59° 47' 55"
Longitude	154° 50' 23"
Drainage area	8.07 square miles
Storage area (lakes and ponds)	0.28 square miles
Glacier area	0.0 square miles
Forested area	**
Mean basin elevation	**
Main channel slope	3%
Main channel length	0.14 miles



THE pebble PARTNERSHIP

Figure 7.3A15-1
Transportation Corridor
Bristol Bay Drainages
GS-20a Drainage Basin
Upper Roadhouse Creek

Legend

- Surface Water Gage Station
- Communities
- Existing Roads
- Drainage Basin
- Drainage Basin GS-20a

Miles: 0, 0.25, 0.5, 0.75, 1

Kilometers: 0, 0.25, 0.5, 0.75, 1

Scale 1:32,686

N

Alaska State Plane Zone 5 (units feet)
1983 North American Datum

File: Hydro_EBDan_V4.mxd	Date: March 28, 2011
Version: 4	Author: BEESC-ME

PHOTOGRAPHS

PHOTO 1: GS-20a Upper Roadhouse Creek new gage set, June 19, 2004.

PHOTO 2: GS-20a Upper Roadhouse Creek during low flows, July 20, 2004.

PHOTO 3: GS-20a Upper Roadhouse Creek. View looking upstream during fall precipitation, October 14, 2004.

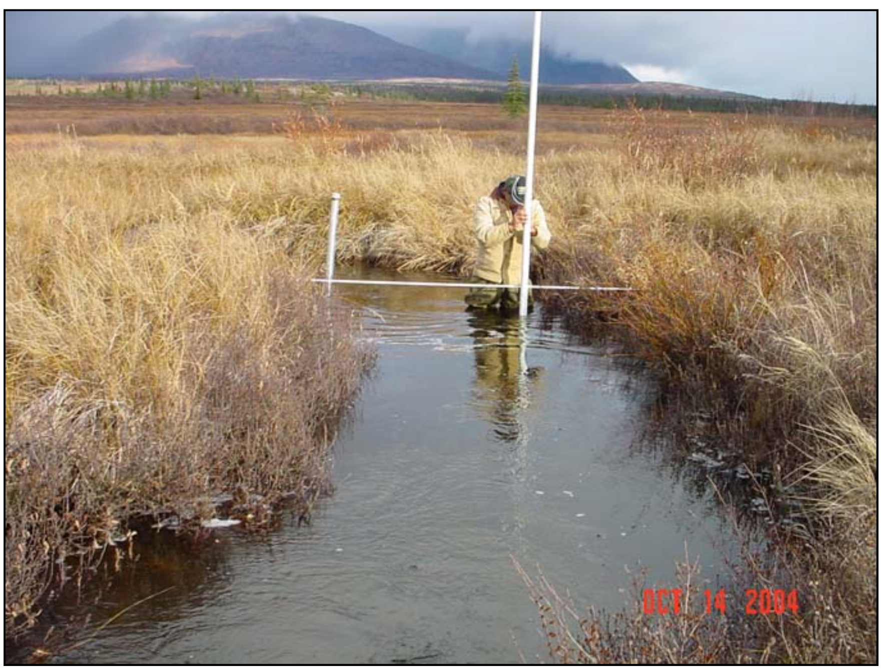


PHOTO 4: GS-20a Upper Roadhouse Creek. View looking downstream during fall precipitation, October 14, 2004.

PHOTO 5: GS-20a Upper Roadhouse Creek. View looking upstream toward lake during fall precipitation, October 14, 2004.

PHOTO 6: GS-20a Upper Roadhouse Creek. View looking downstream during winter, April 3, 2005.

APPENDIX 7.3B

Alternate Peak Flow Estimates
Transportation Corridor Study Area

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ACRONYMS AND ABBREVIATIONS

cfs	cubic feet per second
mi^2	square mile(s)
USGS	U.S. Geological Survey
WRIR	water-resources investigations report

ALTERNATE PEAK FLOW ESTIMATES, TRANSPORTATION CORRIDOR STUDY AREA

1 INTRODUCTION

The eastern part of the study area lies near the boundary between USGS streamflow Analysis Regions 3 and 4. The U.S. Geological Survey (USGS) stations used in the peak streamflow regression analysis for Region 3 may be more representative of the eastern part of the study area than the USGS stations used in the Region 4 regression analysis. Therefore, the peak flow record from the USGS gaging station on the Iliamna River was used to calibrate the Region 3 peak flow equations. These equations provide an alternate set of peak flow estimates for streams in the eastern part of the study area.

1.1 Methods

1.2 Calibration of Regression Equations for Iliamna River Area

The methodology used to calibrate or adjust the equations used in WRIR 03-4188 (Curran et al., 2003) is described in WRIR 78-129 (Lamke, 1979). Using these guidelines, modifications were made to the Region 3 regression equations in WRIR 03-4188 to reflect the Log Pearson Type III analysis results using the expected probability estimate for the Iliamna River as the standard.

2 RESULTS

The calibrated equations are presented in Table 1. The alternate peak flow results for the four largest streams in the eastern part of the study area—Iliamna River, Pile River, Knutson Creek and Canyon Creek—are presented in Table 2.

3 REFERENCES

Curran, J.H., D.F. Meyer, and G.D. Tasker. 2003. Estimating the Magnitude and Frequency of Peak Streamflows for Ungauged Sites on Streams in Alaska and Conterminous Basins. U.S. Geological Survey Water-Resources Investigations Report 03-4188.

Lamke, R.D. 1979. Flood Characteristics of Alaskan Streams. U.S. Geological Survey Water-Resources Investigations Report 78-129.

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