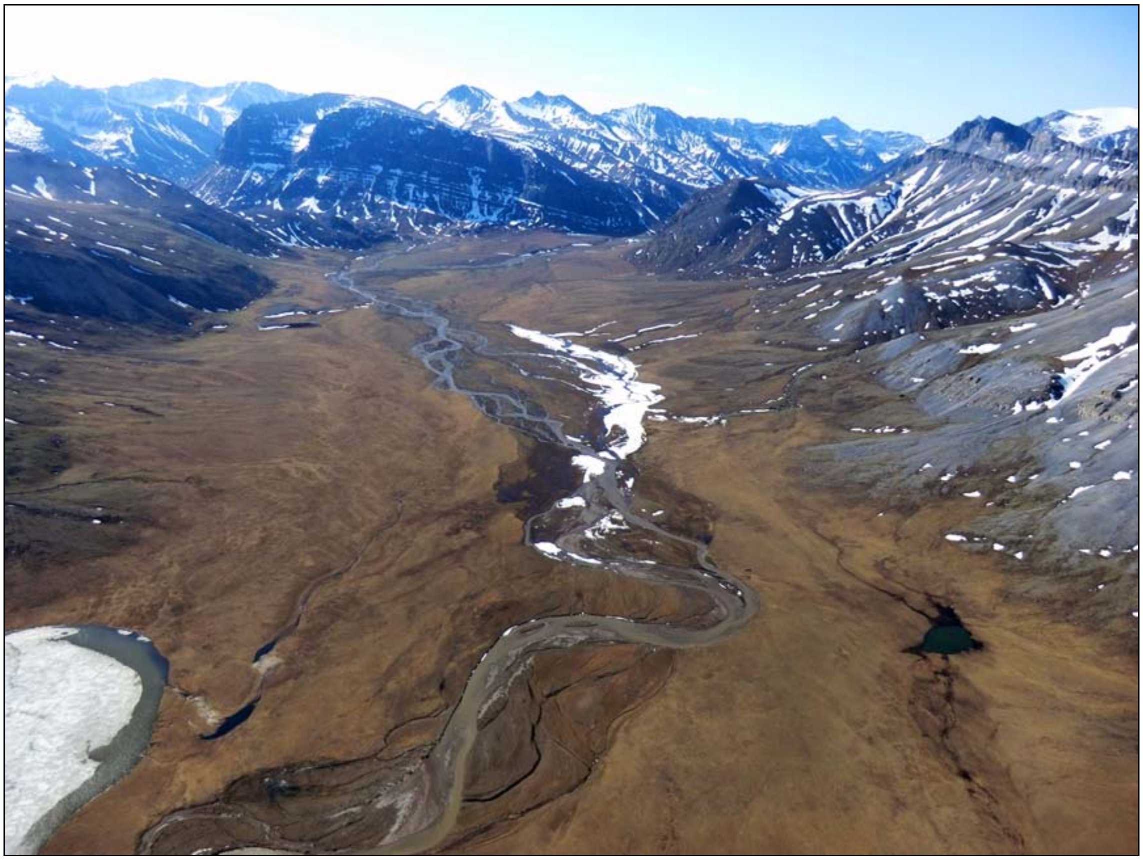
Hydrology and Meteorology of the Central Alaskan Arctic: Data Collection and Analysis

Final Report



D.L. Kane, E.K. Youcha, S.L. Stuefer, G. Myerchin-Tape, E. Lamb,
J.W. Homan, R.E. Gieck, W.E. Schnabel, and H. Toniolo

Prepared for the
Alaska Department of Transportation and Public Facilities

Water and Environmental Research Center
University of Alaska Fairbanks
Fairbanks, AK 99775

Report INE/WERC 14.05

May 2014

Hydrology and Meteorology of the Central Alaskan Arctic: Data Collection and Analysis

Final Report

D.L. Kane, E.K. Youcha, S.L. Stuefer, G. Myerchin-Tape, E. Lamb,
J.W. Homan, R.E. Gieck, W.E. Schnabel, and H. Toniolo

Prepared for the
Alaska Department of Transportation and Public Facilities

Water and Environmental Research Center
University of Alaska Fairbanks
Fairbanks, AK 99775

Report INE/WERC 14.05

May 2014

Front cover photo:

Alapah Creek in the Brooks Range east of the Anaktuvuk River, Alaska.

Back cover photo:

Meteorological station on the Anaktuvuk River near Umiat, Alaska, August 2011.

Recommended citation:

Kane, D.L., Youcha, E.K., Stuefer, S.L., Myerchin-Tape, G., Lamb, E., Homan, J.W., Gieck, R.E., Schnabel, W.E., and Toniolo, H. 2014. Hydrology and Meteorology of the Central Alaskan Arctic: Data Collection and Analysis. Final Report. University of Alaska Fairbanks, Water and Environmental Research Center, Report INE/WERC 14.05, Fairbanks, Alaska.

For additional information, write to:

Publications
Water and Environmental Research Center
University of Alaska Fairbanks
Fairbanks, Alaska 99775
http://ine.uaf.edu/werc/

ABSTRACT

The availability of environmental data for unpopulated areas of Alaska can best be described as sparse; however, these areas have resource development potential. The central Alaskan Arctic region north of the Brooks Range (referred to as the North Slope) is no exception in terms of both environmental data and resource potential. This area was the focus of considerable oil/gas exploration immediately following World War II. Unfortunately, very little environmental data were collected in parallel with the exploration. Soon after the oil discovery at Prudhoe Bay in November 1968, the U.S. Geological Survey (USGS) started collecting discharge data at three sites in the neighborhood of Prudhoe Bay and one small watershed near Barrow. However, little complementary meteorological data (like precipitation) were collected to support the streamflow observations. In 1985, through a series of funded research projects, researchers at the University of Alaska Fairbanks (UAF), Water and Environmental Research Center (WERC), began installing meteorological stations on the North Slope in the central Alaskan Arctic. The number of stations installed ranged from 1 in 1985 to 3 in 1986, 12 in 1996, 24 in 2006, 23 in 2010, and 7 in 2014. Researchers from WERC also collected hydrological data at the following streams: Imnavait Creek (1985 to present), Upper Kuparuk River (1993 to present), Putuligayuk River (1999 to present, earlier gauged by USGS), Kadleroshilik River (2006 to 2010), Shaviovik River (2006 to 2010), No Name River (2006 to 2010), Chandler River (2009 to 2013), Anaktuvuk River (2009 to 2013), Lower Itkillik River (2012 to 2013), and Upper Itkillik River (2009 to 2013). These catchments vary in size, and runoff generation can emanate from the coastal plain, the foothills or mountains, or any combination of these locations. Snowmelt runoff in late May/early June is the most significant hydrological event of the year, except at small watersheds. For these watersheds, rain/mixed snow events in July and August have produced the floods of record. Ice jams are a major concern, especially in the larger river systems. Solid cold season precipitation is mostly uniform over the area, while warm season precipitation is greater in the mountains and foothills than on the coastal plain (roughly 3:2:1, mountains:foothills: coastal plain).The results reported here are primarily for the drainages of the Itkillik, Anaktuvuk, and Chandler River basins, where a proposed transportation corridor is being considered. Results for 2011 and before can be found in earlier reports.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

ACKNOWLEDGMENTS AND DISCLAIMER

The contents of this report reflect the views of the authors, who are responsible for the accuracy of the data presented herein. This research was funded by the Alaska Department of Transportation and Public Facilities (ADOT&PF). Earlier and ongoing work related to this project was funded by the Alaska Department of Natural Resources (ADNR), National Science Foundation, Department of Energy, and U.S. Fish and Wildlife Service. The contents of the report do not necessarily reflect the views or policies of the ADOT&PF, or any other project sponsor. This work does not constitute a standard, specification, or regulation. Authors are appreciative of all of the individuals that helped collect this extensive set of data over the life of the project.

The use of trade and firm names in this document is for the purpose of identification only and does not imply endorsement by the University of Alaska Fairbanks, Alaska Department of Transportation and Public Facilities, or any other sponsors.

CONVERSION FACTORS, UNITS, WATER QUALITY UNITS, VERTICAL AND HORIZONTAL DATUM, ABBREVIATIONS, AND SYMBOLS

Conversion Factors

Multiply	By	To obtain
	Length	
inch (in.)	25.4	millimeter (mm)
inch (in.)	2.54	centimeter (cm)
foot (ft)	0.3048	meter (m)
mile (mi)	1.609	kilometer (km)
	Area	
acre	43560.0	square feet (ft^2)
acre	0.405	hectare (ha)
square foot (ft^2)	3.587e-8	square mile (mi^2)
square mile (mi^2)	2.590	square kilometer (km^2)
	Volume	
gallon (gal)	3.785	liter (L)
gallon (gal)	3785.412	milliliter (mL)
cubic foot (ft^3)	28.317	liter (L)
acre-ft	1233.482	cubic meter (m^3)
acre-ft	325851.43	gallon(gal)
gallon(gal)	0.1337	cubic feet (ft^3)
	Velocity and Discharge	
foot per day (ft/d)	0.3048	meter per day (m/d)
square foot per day (ft^2/d)	0.0929	square meter per day (m^2/d)
cubic foot per second (ft^3/s)	0.02832	cubic meter per second (m^3/sec)
	Water Density	
kilograms per cubic meter (kg/m^3)	1/1000	grams per cubic centimeter (g/cm^3)
grams per cubic centimeter (g/cm^3)	1.94	slugs per cubic foot (slugs/ft^3

Units

In this report, both metric (SI) and English units were employed. The choice of "primary" units employed depended on common reporting standards for a particular property or parameter measured. The approximate value in the "secondary" units may also be provided in parentheses. Thus, for instance, runoff was reported in cubic meters per second (m^3/s) followed by the cubic feet per second (ft^3/s) value in parentheses.

Physical and Chemical Water-Quality Units:

Temperature:

Water and air temperatures are given in degrees Celsius (°C) and in degrees Fahrenheit (°F). Degrees Celsius can be converted to degrees Fahrenheit by use of the following equation:

$$°F = 1.8(°C) + 32$$

Milligrams per liter (mg/L) or micrograms per liter (µg/L):

Milligrams per liter is a unit of measurement indicating the concentration of chemical constituents in solution as weight (milligrams) of solute per unit volume (liter) of water. One thousand micrograms per liter is equivalent to one milligram per liter. For concentrations less than 7000 mg/L, the numerical value is the same as for concentrations in parts per million (ppm).

Horizontal Datum:

The horizontal datum for all locations in this report is the World Geodetic System of 1984 (WGS84).

Vertical Datum:

"Sea level" in the following report refers to either the WGS84 datum (for approximate elevations of station locations) or the GEOID09AK datum for water level elevations. Water level elevations may have arbitrary datums.

ABBREVIATIONS, ACRONYMS, AND SYMBOLS

ADCP	acoustic doppler current profiler
ADNR	Alaska Department of Natural Resources
ADOT&PF	Alaska Department of Transportation and Public Facilities
AUTC	Alaska University Transportation Center
bgs	below ground surface
C	Celsius (°C)
cm	centimeter
d	day
DO	dissolved oxygen
ET	evapotranspiration
F	Fahrenheit (°F)
ft	feet
GPS	Global Positioning System
GWS	Geo-Watersheds Scientific
HDPE	high-density polyethylene
in.	inch
INE	Institute of Northern Engineering
km	kilometers
m	meter
mg/L	milligrams per liter, equivalent to ppm
mi	mile
mm	millimeter
NGVD	National Geodetic Vertical Datum
NRCS	Natural Resources Conservation Service
NSF	National Science Foundation
NTU	nephelometric turbidity units
P-T	Priestley-Taylor
QA	quality assurance
QC	quality control
RTK	real-time kinematic
s	second
SBAS	satellite based augmentation system
SSC	suspended sediment concentration
SWE	snow water equivalent
TDR	time domain reflectometry
TSS	total suspended solids
TT	threshold temperature
UAF	University of Alaska Fairbanks
USGS	U.S. Geological Survey

W	watt
WAAS	Wide Area Augmentation System
WB	water balance
WERC	Water and Environmental Research Center
WGS	World Geodetic System
WWW	World Wide Web

1 INTRODUCTION

The goal of this study was to evaluate hydrological processes of interest along a proposed transportation corridor in Alaska from the vicinity of Umiat on the Colville River to the Dalton Highway (Figure 1), an area mapped as continuous permafrost. Because of the shortage and quality of current data in the field of permafrost hydrology (Woo et al., 2008), studies such as this one need to be executed before action can be taken on any linear transportation structure.

Several potential routings were considered for connecting the area around Umiat to the Dalton Highway/pipeline corridor, with the eastern termination point being the most variable. No matter the route of the proposed transportation corridor, environmental data are meager at best and in most cases totally lacking. The first step (July 2006) in this study was to establish some field meteorological sites; however, there was considerable uncertainty as to the most likely transportation route from Umiat to the Dalton Highway. In 2009, the most likely termination point was on the Dalton Highway near Galbraith Lake. In 2009, five new meteorological stations were added to the Anaktuvuk River basin, and in 2010, five more meteorological stations were added to the Chandler basin. Streamflow measurements commenced in 2009 for the Anaktuvuk River, in 2010 for the Chandler River and Upper Itkillik River, and in 2012 for the Lower Itkillik River. A network of snow survey sites was also established in these basins and the surrounding areas. The sites constituted a set of coordinates used for locating and traveling to stations to take 5 density measurements and 50 snow depth measurements. These measurements were made near the end of winter, and the number of sites varied from year to year (generally around 25 to 30 sites in the Itkillik, Anaktuvuk, and Chandler basins with additional ones in neighboring basins). All measurements and observations ceased in August 2013, as stations were removed.

Table 1 presents a summary of the meteorological stations in or near the Umiat study area where data were collected in this study.

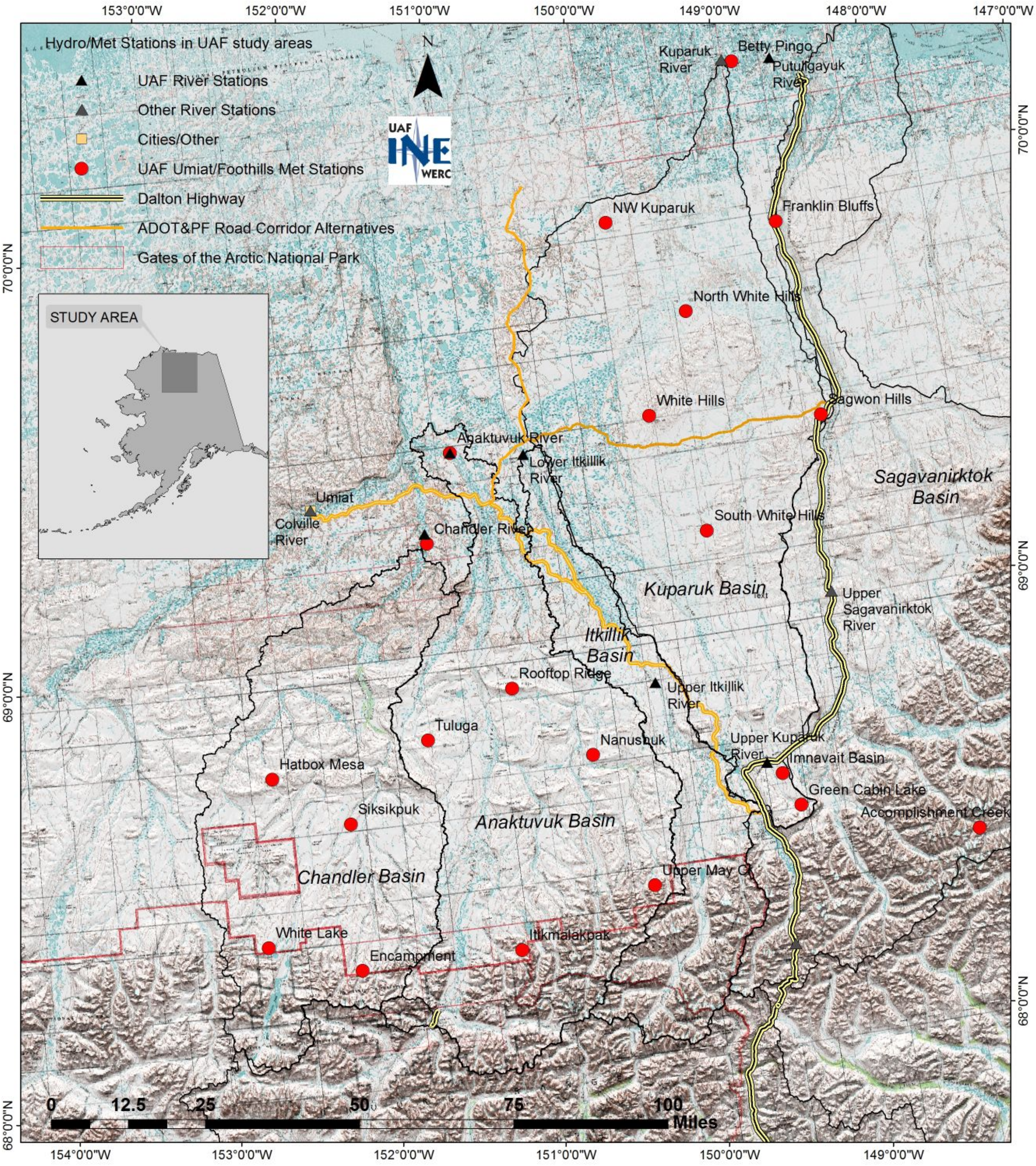


Figure 1. Hydrometeorological study area and location map of field stations for the Kuparuk Foothills/Umiat Corridor study area, North Slope, Alaska.

Table 1. Summary of meteorological, hydrological, and repeater stations in the UAF/WERC network, arranged by elevation from lowest to highest.

Station Name	Station ID	Region	Project	Basin Name	Elevation	Coordinates	Period of Record
West Dock (M)	WD	Coastal Plain	Kuparuk/ NSF	Near Kuparuk	5 m 16 ft	70°22'50" N 148°33'39" W	Jul/1995–Oct/2009
Putuligayuk (H)	Put	Coastal Plain	Kuparuk/ NSF/ USFWS	Putuligayuk	9 m 30 ft	70°16'3.03" N 148°37'48.48"W	Jun/1999–present
Betty Pingo (M)	BM	Coastal Plain	Kuparuk/ NSF	Kuparuk	15 m 49 ft	70°16'46" N 148°53'45" W	Jun/1994–Oct/2011
Franklin Bluffs (M)	FB	Coastal Plain	Kuparuk/ NSF	Sagavanirktok	71 m 234 ft	69°53'32" N 148°46'5" W	Aug/1986–Present
Anaktuvuk River (M,H)	DUS2	Foothills	Umiat/ ADOTPF	Anaktuvuk	81 m 266 ft	69°27'51" N 151°10'07" W	May/2009–Aug/2013
Chandler River Water (H)	DUS3w	Foothills	Umiat/ ADOTPF	Chandler	84 m 276 ft	69°17'00" N 151°24'16" W	May/2011–Aug/2013
North White Hills (M)	DFM3	Coastal Plain	Kuparuk/ ADOTP	Kuparuk	84 m 276 ft	69°42'53" N 149°28'13" W	Jul/2006–present
Chandler River Bluff (M)	DUS3	Foothills	Umiat/ ADOTPF	Chandler	104 m 342 ft	69°15'42.60" N 151°23'45.60" W	May/2009–Aug/2013
Lower Itkillik River (H)	DUS4	Foothills	Umiat/ ADOTPF	Itkillik	111 m 365 ft	68°26'18" N 150°41'16" W	May/2013–Aug/2013
Northwest Kuparuk (M)	DFM4	Coastal Plain	Kuparuk/ ADOTP	Kuparuk	124 m 408 ft	69°56'51" N 149°55'0" W	Jul/2006–Aug/2013
West Kuparuk (M)	WK	Foothills	Kuparuk/ NSF	Kuparuk	159 m 523 ft	69°25'34" N 150°20'25" W	Jul/1995–Jul/2008
Sagwon Hill (M)	SH	Foothills	Kuparuk/ NSF	Sagavanirktok	275 m 905 ft	69°25'28" N 148°41'45" W	Aug/1986–Aug/2013
South White Hills (M)	DFM1	Foothills	Kuparuk/ ADOTPF	Kuparuk	293 m 964 ft	69°12'2" N 149°33'30" W	Jul/2006–present
White Hills (M)	DFM2	Foothills	Kuparuk/ ADOTP	Kuparuk	337 m 1109 ft	69°29'11" N 149°49'17" W	Jul/2006–present
Upper Itkillik River (H&M)	DUS1	Foothills	Umiat/ ADOTPF	Itkillik	420 m 1382 ft	68°51'59"N 150°2'24"W	May/2009–Aug/2013
Siksikpuk River (M)	DUM8	Foothills	Umiat/ ADOTPF	Chandler	463 m 1524 ft	68°37'48"N 152°6'08"W	Sept/2010–Aug/2013
Tuluga (M)	DUM4	Foothills	Umiat/ ADOTPF	Anaktuvuk	497 m 1636 ft	68°48'15" N 151°32'46" W	Jun/2009–Aug/2013
Nanushuk (M)	DUM3	Foothills	Umiat/ ADOTPF	Anaktuvuk	540 m 1777 ft	68°43'15" N 150°30'11" W	Jun/2009–Aug/2013
Hatbox Mesa (M)	DUM7	Foothills	Umiat/ ADOTPF	Chandler	624 m 2053 ft	68°45'16" N 152°34'23" W	Sept/2010–Aug/2013
Rooftop Ridge (R&M)	DUR9	Foothills	Umiat/ ADOTPF	Anaktuvuk	745 m 2444 m	68°54'02" N 150°57'51" W	Jun/2009–Aug/2013
Upper Kuparuk Stream (H)	UKS	Foothills	Kuparuk/ NSF	Kuparuk	747 m 2458 ft	68°38'35" N 149°24'15" W	Aug/1993–present
Upper Kuparuk (M)	UK	Foothills	Kuparuk/ NSF	Kuparuk	778 m 2560 ft	68°38'25" N 149°24'23" W	Aug/1993–present
Imnavait Stream (H)	IHS	Foothills	Kuparuk/ NSF	Kuparuk	881 m 2894 ft	68°37'02" N 149°19'08" W	Aug/1986–present
North Headwaters (M)	NH	Foothills	Kuparuk/ NSF	Kuparuk	904 m 2975 ft	68°36'5" N 149°25'53" W	May/1996–Aug/2010
Green Cabin Lake (M)	GCL	Foothills	Kuparuk/ NSF/ USFWS	Kuparuk	908 m 2988 ft	68°32'01" N 149°13'47" W	May/1996–present
East Headwaters (M)	EH	Foothills	Kuparuk/ NSF	Kuparuk	919 m 3024 ft	68°35'05" N 149°18'22" W	May/1996–Aug/2010
Imnavait Met (M)	IB	Foothills	Kuparuk/ NSF	Kuparuk	937 m 3083 ft	68°36'59" N 149°18'13" W	Aug/1986–present
Upper Headwaters (M)	UH	Foothills	Kuparuk/ NSF	Kuparuk	968 m 3185 ft	68°31'20" N 149°20'18" W	May/1996–Aug/2010
West Headwaters (M)	WH	Foothills	Kuparuk/ NSF	Kuparuk	1027 m 3380 ft	68°33'48" N 149°24'30" W	May/1996–Aug/2010
White Lake (M)	DUM6	Mountains	Umiat/ ADOTPF	Chandler	1081 m 3557 ft	68°21'47"N 152°42'25"W	Sept/2010–Aug/2013
Itikmalakpak (M)	DUM1	Mountains	Umiat/ ADOTPF	Anaktuvuk	1168 m 3844 ft	68°17'24" N 151°6'54" W	Jun/2009–Aug/2013

Station Name	Station ID	Region	Project	Basin Name	Elevation	Coordinates	Period of Record
Encampment Creek (M)	DUM5	Mountains	Umiat/ ADOTPF	Chandler	1224 m 4028 ft	68°17'11.34" N 152°07'55" W	Sept/2010–Aug/2013
Upper May Creek (M)	DUM2	Mountains	Umiat/ ADOTPF	Anaktuvuk	1378 m 4535 ft	68°23'55" N 150°13'40" W	Jun/2009–Aug/2013
Accomplishment Creek (M)	DBM1	Mountains	Bullen/ ADNR	Sagavanirktok	1474 m 4850 ft	68°24'41" N 148°8'11" W	Jul/2006–Aug/2013

M = meteorological, H = hydrological, R = repeater

2 PRIOR RELATED PUBLICATIONS

A list of earlier publications directly related to this study is included in this chapter. These publications are all available on line through the University of Alaska Fairbanks, Water and Environmental Research Center website: (http://ine.uaf.edu/werc/projects/foothills/reports.html).

In 2009 and 2012, we produced reports for the Foothills and Bullen Point projects that included the meteorological and hydrological conditions of those areas and analyses. The Foothills project provided input that could be used on the eastern end of the Umiat transportation corridor. The Bullen Point project provided data quantifying the hydrological and meteorological conditions just east of the Dalton Highway from the Arctic Ocean coast to the continental divide in the Brooks Range. For three years starting in 2006, we produced a report each year on the end-of-winter snow conditions (depth/density/snow water equivalent) for the Kuparuk River basin and Foothills. In 2011, we produced another report detailing preliminary breakup and summer flow conditions in the Umiat corridor.

Stuefer, S.L., Homan, J.W., Kane, D.L., Gieck, R.E., and Youcha, E.K. 2014. Snow Survey Results for the Central Alaskan Arctic, Arctic Circle to Arctic Ocean. University of Alaska Fairbanks, Water and Environmental Research Center, Report INE/WERC 14.01, Fairbanks, Alaska, 96 pp.

Stuefer, S.L., Homan, J.W., Youcha, E.K, Kane, D.L., and Gieck, R.E. 2012. Snow Survey Data for the Central North Slope Watersheds: Spring 2012. University of Alaska Fairbanks, Water and Environmental Research Center, Report INE/WERC 12.22, Fairbanks, Alaska, 38 pp.

Kane, D.L., Youcha, E.K, Stuefer, S.L., Toniolo, H., Schnabel, W.E., Gieck, R.E., Myerchin-Tape, G., Homan, J., Lamb, E., and Tape, K. 2012. Meteorological and Hydrological Data and Analysis Report for the Foothills/Umiat Corridor and Bullen Projects: 2006–2011. University of Alaska Fairbanks, Water and Environmental Research Center, Report INE/WERC 12.01, Fairbanks, Alaska, 260 pp. Appendix.

Stuefer, S.L., Youcha, E.K, Homan, J.W., Kane, D.L., and Gieck, R.E. 2011. Snow Survey Data for the Central North Slope Watersheds: Spring 2011. University of Alaska Fairbanks, Water and Environmental Research Center, Report INE/WERC 11.02, Fairbanks, Alaska, 47 pp.

Youcha, E., Toniolo, H., and Kane, D., 2011. Spring and Summer Runoff Observations 2009–2010, Umiat Corridor Hydrology Project. University of Alaska Fairbanks, Water and Environmental Research Center, Report INE/WERC 11.01, Fairbanks, Alaska, 55 pp.

Berezovskaya, S., Hilton, K., Derry, J., Youcha, E., Kane, D., Gieck, R., Homan, J., and Lilly, M., 2010. Snow Survey Data for the Central North Slope Watersheds: Spring 2010. University of Alaska Fairbanks, Water and Environmental Research Center, Report INE/WERC 10.01, Fairbanks, Alaska, 50 pp.

Berezovskaya, S., Derry, J., Kane, D., Gieck, R., and Lilly, M., 2010. Snow Survey Data for the Central North Slope Watersheds: Spring 2009. University of Alaska Fairbanks, Water and Environmental Research Center, Report INE/WERC 09.01, Fairbanks, Alaska, 21 pp.

Kane, D., White, D., Lilly, M., Toniolo, H., Berezovskaya, S., Schnabel, W., Youcha, E., Derry, J., Gieck, R., Paetzold, R., Trochim, E., Remillard, M., Busey, R., and Holland, K., 2009. Meteorological and Hydrological Data and Analysis Report for Bullen Point and Foothills Projects: 2006–2008. University of Alaska Fairbanks, Water and Environmental Research Center, Report INE/WERC 08.18, Fairbanks, Alaska, 180 pp.

Berezovskaya, S.L., Derry, J.E., Kane, D.L., Gieck, R.E., Lilly, M.R., and White, D.M., 2008. Snow Survey Data for the Kuparuk Foothills Hydrology Study: Spring 2008. June 2008, University of Alaska Fairbanks, Water and Environmental Research Center, Report INE/WERC 08.14, Fairbanks, Alaska, 40 pp. [Amended Figures 3 & 4 Aug. 26, 2008]

Berezovskaya, S.L., Derry, J.E., Kane, D.L., Gieck, R.E., Lilly, M.R., and White, D.M., 2007. Snow Survey Data for the Kuparuk Foothills Hydrology Study: Spring 2007. July 2007, University of Alaska Fairbanks, Water and Environmental Research Center, Report INE/WERC 07.17, Fairbanks, Alaska, 21 pp.

Kane, D.L., Berezovskaya, S., Irving, K., Busey, R., Chambers, M., Blackburn, A.J., and Lilly, M.R., 2006. Snow Survey Data for the Kuparuk Foothills Hydrology Study: Spring 2006. July 2006, University of Alaska Fairbanks, Water and Environmental Research Center, Report INE/WERC 06-06, Fairbanks, Alaska, 12 pp.

3 STUDY AREA

The study area (Figure 1) can be described in general terms as having a low hydraulic gradient (coastal plain) near the Arctic Ocean to having a high hydraulic gradient (mountains) in the headwaters to the south, with a transition through the moderately steep foothills sandwiched in between. The area has an arctic climate, is treeless except for some riparian areas along the north-trending drainages, is mostly vegetated with grasses, sedges, etc., and is underlain by continuous permafrost that is a few to several hundred meters deep.

The study area mainly consists of the north-draining Itkillik, Anaktuvuk, and Chandler River basins. The three rivers originate in the Brooks Range and empty into the Colville River before it drains into the Arctic Ocean. In neighboring watersheds, we have collected hydrological and meteorological data that complement this study. One area is the Kuparuk River basin and its tributaries, which originate in the foothills; another area is the Putuligayuk River catchment that is totally contained on the coastal plain. Both of these rivers drain directly into the Arctic Ocean. These basins lie within in the following latitudes and longitudes: 68° to 70° N and 148° 30′ to 153° W. The northern boundary of the study is dictated by the location of gauging stations, while the southern boundary coincides with the headwater divide. Additional data were collected previously on the eastern side of the Dalton Highway from the Arctic Ocean coast into the Brooks Range (Kane et al., 2012) in the Sagavanirktok, Kadleroshilik, Shaviovik, and No Name watersheds. Logistically, some of these sites can be accessed from the Dalton Highway. In many cases, these observational sites were initiated and maintained using funding from other studies in the area. For example, because we could not get permission to install weather stations in Gates of the Arctic National Park, we maintained a weather station in Accomplishment Creek, our only weather station truly in the middle of the Brooks Range. Our goal was to collect as much environmental data as possible in this area of sparse hydrological and meteorological networks to assist in the evaluation of a constructed roadway from the Umiat area to the Dalton Highway/pipeline corridor.

Permafrost is ubiquitous in the area, with its depth approaching 600 m near the Arctic Ocean and approximately 250 m near the continental divide in the Brooks Range. Permafrost is typically a hydraulic barrier between the suprapermafrost groundwater and the subpermafrost groundwater. Kane et al. (2013) found that in the eastern North Slope, taliks through the permafrost allowed subpermafrost groundwater to discharge through springs at the surface. Large aufeis formations are generally found downstream of these springs (Kane et al., 2013; Yoshikawa et al., 2007), but aufeis does not always form. The aufeis formation on the Kuparuk River, roughly 40 km north of Toolik Lake, is formed by suprapermafrost groundwater (as is the aufeis formation at May Creek in the Upper Anaktuvuk drainage).

Many areas of aufeis and springs were observed from helicopter during snow surveys and spring breakup in the Chandler, Anaktuvuk, and Itkillik basins, most appeared in the middle and upper parts of the basin (foothills and mountains regions). Many of the aufeis areas are visible in aerial photography. The aufeis formations are smaller in comparison with the Kuparuk aufeis. Only one area of aufeis was visible at a proposed crossing; a smaller field of aufeis was observed in the channel (coordinates 69.319874, -151.001519 WGS84) approximately one mile upstream of the Anaktuvuk River crossing.

The maximum depth of the active layer in late August usually averages around 50 cm, with deeper depths in well-drained sites (Hinzman et al., 1991; Hinzman et al., 1998). The active layer generally consists of a surficial porous organic layer underlain by mineral soils. The active layer serves as a small storage reservoir with the capability of storing the equivalent of the annual precipitation volume for one year. However, the active layer is a poor buffer to both flooding and drought, meaning it both wets and dries rapidly. For the small (2.2 km^2) Imnavait Creek, Kane et al. (1989) reported that after 5 to 10 days with minimal antecedent precipitation, runoff from daily precipitation events was equal to or less than 15 mm.

Thermokarst features can be found scattered around the watersheds; they may be the result of climatic warming. Figure 2 shows a thermokarst feature that developed at the weather station site in the Lower Chandler River. The station was installed in 2009 and was instrumented with pressure transducers to monitor stage. The station, because of its high elevation, is protected from floods and ice jams. However, we lost numerous pressure transducers because they were buried at the waterline under thermokarst debris moving downslope.

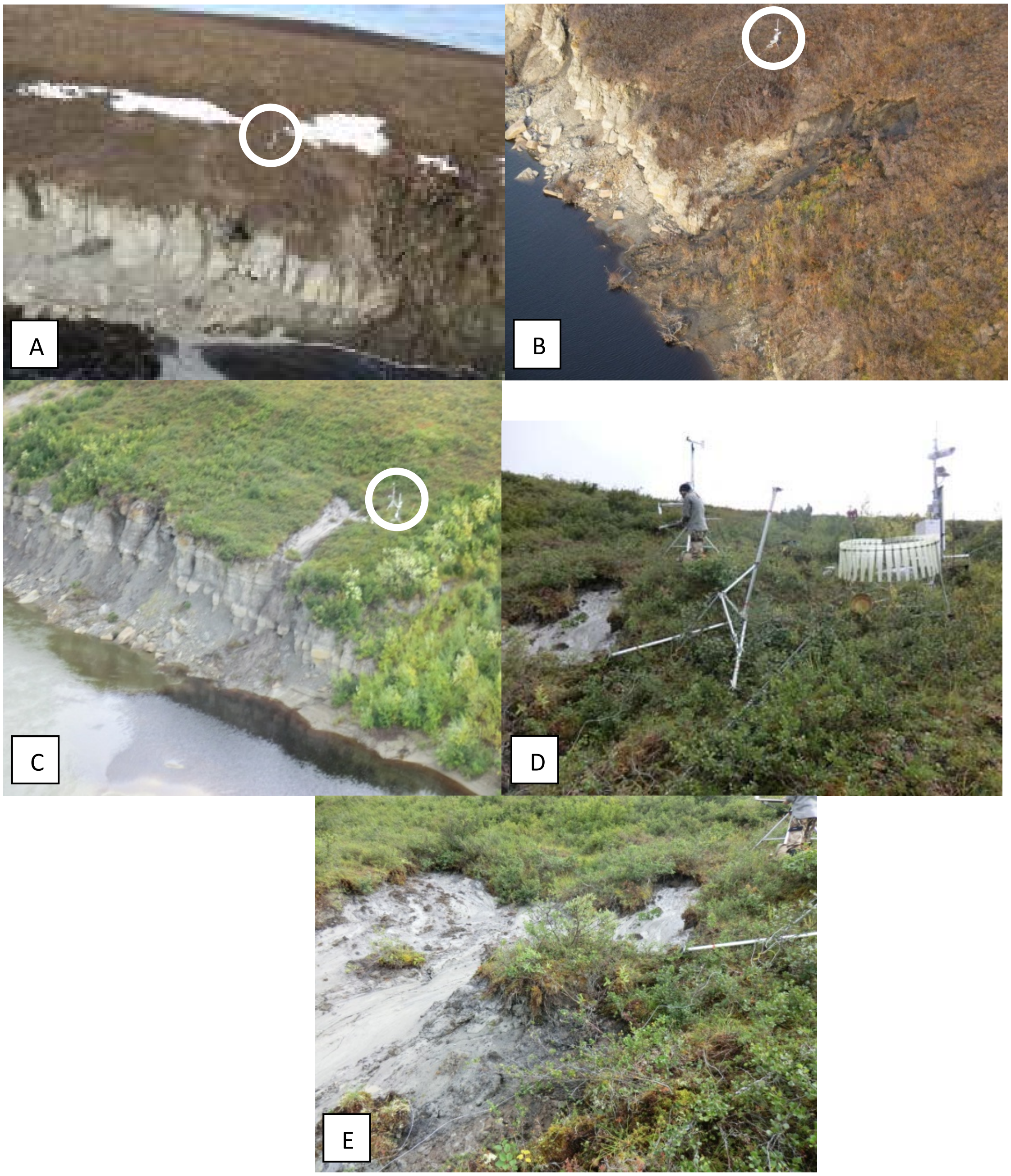


Figure 2. Thermokarst feature on the Lower Chandler River. (A) The bluff in May 2009, when the weather station (center of picture, white open circle) was installed; (B) in September 2009, first landslide to right of circle; (C) in July 2013, newly formed thermokarst (flow in river from right to left) just to the left of the weather station. (D) Replacing the weather station that was tilting and moving downslope. (E) Close-up of thermokarst just downslope of weather station.

4 PREVIOUS STUDIES

While hydrologic activity in the Arctic is limited spatially and temporally, a few data collection efforts and hydrologic studies have been carried out since the early 1970s. The logistical cost of installing, maintaining, and accessing these sites is the main impediment that results in a very sparse hydrologic network. The first sustained data-collection effort on the North Slope of Alaska happened after oil was discovered in Prudhoe Bay in November 1968. The USGS established three stream gauging stations along the Dalton Highway and on the oilfield (Kuparuk, Sagavanirktok, and Putuligayuk Rivers). Unfortunately, additional data (from the coast into the Brooks Range) like precipitation (both solid and liquid) were almost completely lacking and thus deterred precipitation/runoff studies. In the mid-1980s, some small hydrologic research studies were initiated on the North Slope, and this effort expanded during the next two decades. Because of the logistical cost of performing off-road studies, again most of the effort occurred in proximity to the Dalton Highway.

The first detailed study, initiated in 1985, was of a small watershed located in the foothills—Imnavait Creek (2.2 km^2). All facets of the hydrologic cycle were studied. From twenty-five plus years of these continuous studies, we have gained an understanding of the temporal variability of precipitation and runoff for this drainage. For example, the cumulative summer precipitation in the Imnavait basin has ranged from 100 mm in a dry year to almost 350 mm in a wet year (Figure 3). While August is usually the wettest month of the year on average, June and July have had the maximum monthly precipitation in a given year. The two largest runoff events (Kane et al., 2008b) in Imnavait Creek and Upper Kuparuk (142 km^2) River catchments were due to a rain event in July 1999 and a mixed rain/snow event in August 2002; generally, the peak runoff event for the year is due to snowmelt. Early in the warm season, convective precipitation is common; later in the summer, frontal systems are more common.

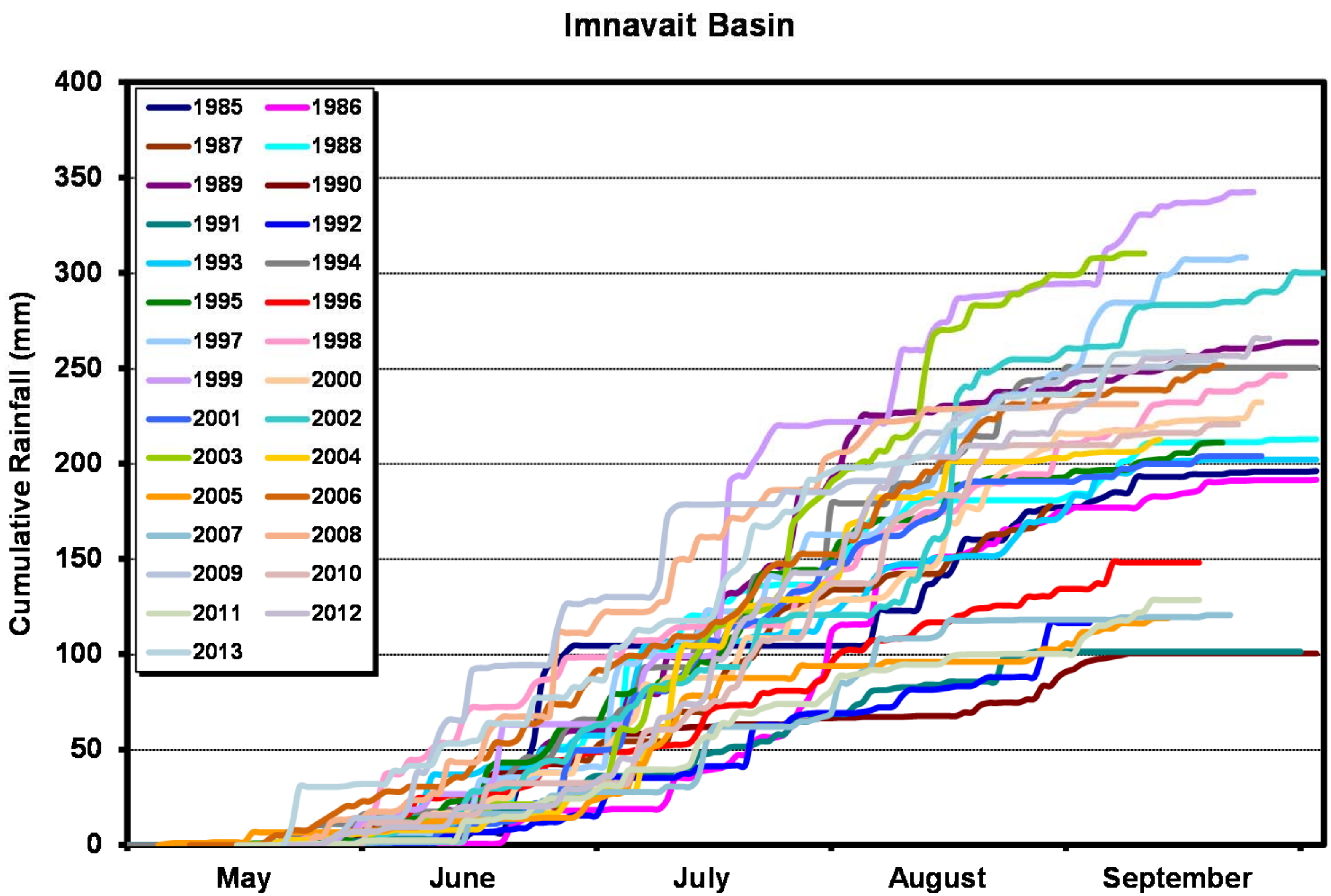


Figure 3. Cumulative summer precipitation (29 years) at Imnavait Creek from 1985 to 2013 (data for 2006 taken from USDA NRCS Wyoming snow gauge located next to our gauge).

For comparison, over an approximately eight-month cold period, the average snow water equivalent (SWE) for the Imnavait catchment ranged from 69 to 185 mm, averaging about 120 mm/yr. Relatively long-term discharge measurements on streams like Imnavait Creek, Upper Kuparuk River, Kuparuk River, and Putuligayuk River show that the snowmelt runoff event is a significant hydrologic event each year (Kane et al., 2008b). However, the highest runoff events observed for small, moderate to steep watersheds are from rainfall. Generally, for smaller headwater catchments like Imnavait and Upper Kuparuk basins, the maximum floods are rainfall-generated, while for larger watersheds, the maximum floods are snowmelt-generated (Kane et al., 2008b; Kane et al., 2003). There are two reasons for this phenomenon: (1) the maximum rate of rainfall is greater than the maximum rate of snowmelt; and (2) low-pressure systems that produce rainfall cover smaller watersheds in their entirety, whereas they cover only a fraction of the area of larger watersheds. For larger basins, the entire area is covered with snow, which potentially contributes to runoff. Although possible, the likelihood of the flood of record in large watersheds being from rainfall is rather low. The storm would need to simultaneously track directly over the watershed and cover a large majority of its area.

In the foothill watersheds of the Imnavait Creek area, an almost equal amount of water exits the catchments by runoff and evapotranspiration (Kane et al., 2004). The runoff ratio is higher in steeper-gradient watersheds, such as those in the Brooks Range. Surprisingly, the runoff ratio on the low-gradient coastal plain is relatively high during the snowmelt runoff process (Kane et al., 2008a), partially due to the extensive area of lakes and wetlands there and because the system is frozen (permafrost and seasonal frost) during breakup.

Eventually, through funding from several sources, the Imnavait Creek study was expanded to the Upper Kuparuk River, the whole of the Kuparuk River, and the Putuligayuk River on the coastal plain. This effort involved installing several meteorological and hydrological gauging stations. The Kuparuk River has been gauged by the USGS since the early 1970s. The USGS started gauging the Putuligayuk River then, too, but stopped doing so in 1983. We reinitiated measurements in 1999 on the Putuligayuk River, since we were collecting complementary meteorological data. In spring 2000, we began end-of-winter snow surveys across the whole of the Kuparuk basin and tributary and neighboring streams. This work included 50 snow depth measurements along an L-shaped transect every 1 m with 5 density measurements at each site.

The number of sites varied from year to year depending upon what research projects were funded (2000 – 65 sites, 2001 – 85, 2002 – 85, 2003 – 87, 2004 – 56, 2005 – 81, 2006 – 118, 2007 – 150, 2008 – 106, 2009 – 143, 2010 – 104, 2011 – 77, 2012 – 73, and 2013 – 79). The goal when picking these sites was to pick ones that were representative of large areas. Since 2006, we have produced annual reports on the snow data collected, including data on snow depth accumulation, end-of-winter snow surveys of SWE, and ablation curves. The snow survey reports by Kane et al. (2006), Berezovskaya et al. (2007, 2008, 2010a, 2010b), and Stuefer et al. (2011, 2012, 2013) are listed in Chapter 2.

From the meteorological stations, we were able to quantify the spatial distribution of summer precipitation. A substantial increase in warm season precipitation occurs with increasing elevation; the coastal plain receives an average of 100 mm of cumulative precipitation, the foothills about 200 mm, and the Brooks Range about 300 mm. Interestingly, we did not find much difference in SWE distribution across the three landscapes (coastal plain, foothills, and mountains). However, note that measuring SWE in the Brooks Range is quite challenging, as these surveys are done with a helicopter, and landing sites are limited.

In 2006, we initiated a new hydrologic study (Kane et al., 2009; Kane et al., 2012) east of the Dalton Highway in the Sagavanirktok, Shaviovik, Kavik, No Name, and Kadleroshilik River basins, along with the ongoing work in the Kuparuk River basin. Essentially no prior hydrometeorological studies had been done in this region of the Alaska Arctic; this study terminated in 2010. Also in 2006, meteorological studies were initiated in the foothills area, from the Dalton Highway at Sagwon towards Umiat. In 2009, this study was expanded to include hydrological observations in the Itkillik, Chandler, and Anaktuvuk River basins; the field data collection terminated in August 2013.

5 METHODOLOGY AND EQUIPMENT

While some environmental data are being collected in/near the area of study (USGS and USDA NRCS), most data reported and analyzed in this report have been collected by our group. The first equipment installed in the field was that associated with meteorological sites. Each site was instrumented to measure the following (Table 2): warm season rainfall, continuous winter snow depth, air temperature, relative humidity, wind speed and direction, net radiation, and some soil properties. We installed thermistors and time domain reflectometry (TDR) probes at most stations to measure shallow near-surface soil temperatures and volumetric soil moisture contents, respectively (the TDR probes only measure the unfrozen water content). Generally, we take readings every minute to get an average hourly value, which is recorded. Detailed information on the makeup of meteorological stations was presented in Kane et al. (2012).

The next step in the overall effort was to install hydrological stations. The purpose of these stations was to obtain estimates of stream discharge (and water stage) in the near vicinity of stream crossings along the proposed transportation corridor. The standard approach, which is to develop a stream stage-discharge relationship at the stream crossing of interest, involves installing pressure transducers in the stream to get a continuous record of river stage and making discharge measurements that can be related to the stage at the time of the observations (equipment used listed in Table 2). Ideally, discharge measurements are made over a wide range of water levels—something that is much easier to say than to accomplish. These sites are in remote areas, and usually observers are not present when high flows (and high stages) occur, especially for summer rainfall events. We generally have people in the area (staying in nearby camps [Umiat, Toolik Lake, or Prudhoe Bay]) throughout breakup and attempt to gauge each day. However, weather is still a problem for accessing remote field sites.

Table 2. Details of equipment used on the Umiat study.

Category	Item	Model	Accuracy	Remarks
Met	Wind Direction	RM Young 05103	± 3 degrees	
Met	Wind Speed	RM Young 05103	± 0.3 m/s	
Met	Air Temperature	HMP45C	± 0.5 °C at −40 °C	
Met	Air Relative Humidity	HMP45C	± 3 % at 20 °C	
Met	Snow Depth	SR50 or SR50A	± 1 cm	
Met	Soil Moisture	CS616	± 2.5 % VWC	
Met	Barometric Pressure	CS106	± 1.5 mb @ −40 to +60 °C	
Met	Net Radiation	NR-Lite		
Met	Rainfall	Tipping Bucket TE525MM or TE525WS	± 1 % up to 10 mm/hr (and 1 in/hr)	
Met	Soil, Water Temperature, also Air Temperature backup	Alpha or YSI Thermistor		
Hydro	Water Level	INW AquiStar SDI-12	± 0.5 cm (5 psi), ± 1.6 cm (15 psi)	vented to atmosphere
Hydro	Water Level, backup	Hobo U20	± 0.6 cm	absolute pressure, barometric corrections required
Hydro	Turbidity	OBS500, OBS3+		
Hydro	Suspended Sediment	ISCO 3700, Rickly DH76		
Hydro	ADCP, shallow	RDI StreamPro		
Hydro	ADCP	RDI Rio Grande WHRZ1200		
Hydro	ADCP	Sontek River Surveyor S5		
Hydro	ADCP Software	WinRiver II and RiverSurveyor Live		
Hydro	ADCP GPS Reference	Novatel Smart-V1		
Hydro	ADCP Manned Boat	Achilles 11-foot inflatable		15 HP motor, Kentucky-type mount
Hydro	ADCP Manned Boat	Cataraft		15 HP motor, tethered riverboat, StreamPro
Hydro	ADCP Manned Boat	Kayak inflatable 1-person		StreamPro in well
Hydro	ADCP Trimaran	Oceanscience Riverboat		
Hydro	Computer	Panasonic Toughbook CF19		
Station	Datalogger	CR1000		
Station	Camera	CC640 or PlantCam		
Station	Radio	FreeWave FGR or DGR		
Station	Solar Panel	Sharp 85 W, typical		
Station	Batteries	Concorde 104 AH		4 batteries per station, 3 for repeaters
Station	Charge Controller	SunSaver 10 or 12		
Station	Tripod	CM110		

5.1 Acoustic Doppler Current Profiler

Discharge measurements were conducted at or near the station on each river using the acoustic doppler current profiler (ADCP) technique. Measurements are made by driving a motorized boat or paddling a non-motorized boat slowly across the river along a transect. A minimum of four transects are made per measurement (or a total measurement duration of 720 seconds in steady-state conditions), and an average discharge is calculated from the multiple transects. At times of high flow, the transects may be at an oblique angle (diagonal and downstream direction) across the river. Transects were made from both the left-to-right-bank and the right-to-left-bank directions in order to calculate river discharge and determine any directional bias. When the coefficient of variation (standard deviation/mean) of the measurements is less than 5%, an average discharge is calculated. If the coefficient of variation is greater than 5%, additional transects/measurements are made or the length of time spent measuring during the transect is increased.

5.2 Discharge Measurements

Both ADCP bottom tracking and ADCP GPS options were used as the reference to measure river velocity. Usually, the GPS is preferred, but if technical problems occur with it, bottom tracking may be used. If bottom tracking is the reference, a test is conducted to determine if there is a moving bed and correct the discharge for the moving bed. The GPS model used during measurements is the Novatel Smart V1-2US-L1. Typically, a base station is set up and a real-time kinematic (RTK) GPS is used, but satellite-based augmentation system (SBAS or WAAS) differential correction is also used and is considered acceptable (Wagner and Mueller, 2011). The horizontal position accuracy of the RTK is 0.2 m and 1.2 m when using SBAS/WAAS with the Novatel units.

The ADCPs used during the study period were the RDI StreamPro, RDI Rio Grande, and Sontek River Surveyor S5 unit. The StreamPro and River Surveyor S5 are most useful in shallow water (less than 5 m), and the Rio Grande is used if the water depth is greater than 5 m.

A stage-discharge relationship (rating curve) was developed to calculate the discharge for a range of stages at each river. The stage is plotted against the discharge, and a best-fit curve is fitted through the points (and represented by an equation) on both normal and logarithmic scales. We attempted to collect discharge measurements at various river stages in order to have a good relationship at all river stages. Extrapolation for low and high flows is necessary because measurements in these ranges of the curve are lacking. Caution is used in extrapolating the discharges at high stages due to changes in the control at high stage. Once the stage increases above the banks (over bankfull conditions) onto the floodplain, the channel geometry changes, and the stage-discharge relationship developed for the channel is no longer valid. Also, since the geometry of the channel controls the relationship, we tried to make the measurements in the same location each time. However, due to a dynamic river channel during breakup, it was not always possible to measure the same river location each time. Changes in water flow paths at low versus high stage, multiple channels during high stage, and due to ice in the channel made it problematic to measure discharge at exactly the same location each day. Additionally, it is common to have a shifting control, and therefore, many measurements need to be made, along with adjustment to the rating curve. Shifts are applied to the rating curve when there is a change in channel shape or a change in the control. Channel shape can change during spring breakup when the river is affected by ice or during periods of sediment aggradation and degradation. We applied shifts to the rating curves for the Anaktuvuk and Chandler Rivers because of changes in the channel geometry. Our rating curves and continuous discharge estimates are still considered preliminary because we only have a limited number of measurements to use on the rating curve.

The biggest challenge associated with making a good quality ADCP discharge measurement is locating a single straight parabolic cross section of the river with steady and uniform flow to perform the measurement. A bad measurement section usually results in poor data quality. This is primarily a problem during the spring flood when ice is present in the channels, flows may be high and unsteady, and the river consists of multiple channels.

Technical problems and limitations of the ADCP and associated equipment are other factors that degrade the quality of the measurement. Technical problems may include improper configuration of the ADCP, GPS problems, radio communication failures, and incorrect baud rates. Typical ADCP limitations include turbulent water, too much or too little sediment in the water column, a moving bed, or insufficient water depth for use of a particular ADCP. However, we believe that ADCP measurements are far superior to traditional current meter measurements, because the number of ADCP velocity measurements through the cross section is so much greater than could be measured with a conventional current meter.

The following field procedures occur before the ADCP discharge measurement:

- ADCP diagnostic and quality tests
- Compass calibration for GPS
- Assessment/description of the river reach characteristics for suitability of ADCP measurement
- Moving bed test

The following are reviewed during both quality assurance and control of the data:

- Measurement reach characteristics
- ADCP configuration
- Each transect and set of velocity contours for bad/lost velocity data
- Determination of percentage of flow that is measured vs. estimated
- Moving bed test and discharge, adjusting as needed
- Assessment of GPS quality if GPS is used
- Each transect, checking for consistency (discharge, area, width, boat speed, water speed, flow direction, measurement duration, etc.)
- The transect coefficient of variation, checking for discharge that is within 5% of other measurements
- Quality of the river stage data

After the measurement at a site is reviewed, a quality rating that is both qualitative and quantitative is assigned to that measurement. The quality rating is based on both the transect coefficient of variation (i.e., measurement repeatability) and the overall general quality of the measurement (such as the river reach characteristics, ADCP limitations, transect consistency). The quality rating given to each measurement is either excellent (2%), good (5%), fair (8%), or poor (10% or more). These quality ratings are carried over to the rating curve.

Errors in water level and discharge measurements propagate to the rating curve. We assign quality indicators to each measurement and use these during the rating curve development. The complex and dynamic nature of these river channels adds additional uncertainty to the rating curve. Changes in the discharge measurement location may occur due to changes in stage that result in river access problems (i.e., too shallow to drive a boat), braiding of the river channel, and even safety issues. The change in the measurement cross section is not ideal and results in more uncertainty (and shifts) in the rating curve; however, there is probably little measurable change in flow between the measurement sites (typically they are all within a kilometer of the station).

Additional errors may occur during the extrapolation of the rating curve beyond the highest or lowest measured discharge. It is typical that none of the measurements or few occur at the highest flows (either for safety reasons or because we are not present during the high flows), so we extend the rating curve to these higher stage discharges. However, the rating curve may not be extended too high without consideration of the river cross section and changing controls.

5.3 Suspended Sediments

Sediment concentration is a key hydraulic parameter when considering the overall character of a river. While fairly extensive research has been done on the sediment transport regimes of gravel rivers in temperate climates (Parker et al., 2007), our understanding of these processes is less complete in arctic systems. For larger rivers in the Arctic, spring breakup is the major annual hydrologic event (Kane et al., 2003). The presence of snow and ice for almost eight months of the year, coupled with rivers that may freeze to the bed, clearly differentiates the sediment transport regimes of arctic rivers from the sediment transport regimes of rivers in temperate regions. The impact of bed ice on bedload transport has been studied on the Kuparuk River (Oatley, 2002; Best et al., 2005; McNamara et al., 2008), where it was observed that the presence of ice on the bed during the spring flood significantly reduced bedload transport. The occurrence of ice during spring melt will also affect suspended sediment transport in a river. In the Canadian Arctic, this effect was seen to vary between rivers, depending on channel size and discharge rates (Forbes and Lamoureux, 2005).

As part of a smaller, complementary study, the sediment dynamics of the Chandler, Anaktuvuk, and Itkillik Rivers were studied, including suspended sediment monitoring that began in 2011 during spring breakup. In 2012, the summer flow season was captured, and in 2013 spring breakup and the summer flow season were again monitored through August, with the addition of sediment measurements on the new station at Lower Itkillik River.

5.3.1 River Sediment

In each of the rivers, the suspended sediment flux was quantified, as well as other key indicators of sediment transport. Limited sediment transport studies have been performed on major rivers in this part of the world due to challenging accessibility and environmental conditions. In this study, methods used to monitor suspended sediment transport included the collection of suspended sediment samples through both automatic pump devices and depth-integrated samplers. In the calculation of suspended sediment discharge, we utilized suspended sediment rating curves, turbidity measurements, bed sediment grain-size distributions, and observations of suspended sediment grain-size distributions.

5.3.2 Suspended Sediment Observations

Suspended sediment samples were taken with an Isco 3700 Portable Autosampler on the Anaktuvuk, Chandler, and Itkillik (Upper and Lower) Rivers. Grab samples were also taken on all rivers when staff were on-site stream gauging, with the majority of these taken during breakup when autosamplers could not be deployed because of ice conditions. During spring breakup, Isco samples were taken every 6 hours; from early June to September, a sample was taken with the autosampler once daily at 15:00 AST. The samplers were moved multiple times throughout spring breakup, but were installed in permanent locations from June through September. During this time, the intake hose was clamped to rebar and located roughly 6 inches (~15 cm) above the riverbed. Because during the summertime we only visit the sites twice (~middle July and end of August), the intake for sediment sample collection is placed low in the water column to ensure it stays below the water surface during low flows.

Several problems occurred with the autosamplers in the unpredictable environment of the North Slope. It is unfeasible to suspend the intake at a constant height above the bed during breakup due to the debris and ice carried by the river, the frozen nature of the bed, and the high water levels. Large gaps occurred in the data sets throughout the period of this study. The Iscos, which were disturbed by animals and knocked over by high flows, malfunctioned for various reasons. In 2012 and 2013, two Iscos were deployed at each site, with each Isco taking a sample every 48 hours, staggered to have one sample per day. With this method, 48 days of continuous data could be collected without a site visit, and if one sampler was disrupted, the density of sampling would be reduced, but a broad picture of sediment load could still be achieved with samples collected every other day.

Depth-integrated suspended sediment samples were also taken along the main channels using a Rickly Hydrological depth-integrating sampler (Model DH76), with a ¼ inch nozzle. By taking an average of two samples per day during breakup with the integrated sampler, a representation of sediment load throughout the water column can be achieved. This method also addresses the problem of the Isco hose being on the riverbed during breakup, allowing for a comparison between the Isco and the integrated samples to ensure that the Isco samples accurately represent the sediment load in the rivers. The goal was to establish a relationship between the Isco and the depth-integrated samples with a rating curve for each river.

Samples taken by the Iscos and the integrated sampler are analyzed in the lab to determine suspended-sediment concentration (SSC). Following ASTM Standard 3977-97, the samples are vacuum filtered through Whatman GF/C glass microfiber filters, with a particle retention of 1.2 µm. The percentage of organic matter in each sample is then determined using ASTM Standard 2974 (Test Method C), in which samples are placed in a muffle furnace at 440°C for 12 hours. For this study, only the inorganic contribution to the SSC was considered.

5.3.3 Suspended Sediment Discharge

Suspended sediment discharge (qs) is a frequent value used to quantify the total suspended sediment being transported over a specific period; qs is defined as SSC multiplied by discharge at the same point in time. The value used for SSC was taken in this case from the suspended sediment rating curves developed from the estimated discharge and the depth-integrated samples, while discharge was taken from the 15-minute discharge record available for the flow period on each river. Finally, the values for qs were calculated at 15-minute intervals for the entire flow season, and these values were then used to calculate the annual suspended sediment load.

5.3.4 Turbidity

Campbell Scientific OBS-3+ turbidity sensors were also installed at the Anaktuvuk, Chandler, and Upper Itkillik River gauging sites. These sensors have optics on the side of the body, which emit a near-infrared light to detect turbidity levels in the water. Operating at wavelengths of 850 nanometers (±5 nm), these sensors are capable of measuring turbidity levels from 0 to 4000 NTUs (nephelometric turbidity units). Turbidity readings have an accuracy of 2% of the reading or 0.5 NTU, whichever is greater. Installation involved mounting the sensor on rebar driven into the streambed, with the optics facing the middle of the channel and 180° away from the rebar. The sensor was installed roughly 6 inches (15 cm) above the channel bed on all three rivers, and in proximity to the intake of the Isco sampler. At each river, each turbidity sensor was electrically connected to the surface-water observation station datalogger to record readings at 15-minute intervals. Data were then transmitted via radio telemetry and internet capabilities to UAF/WERC.

It was unknown how these sensors would perform in a remote arctic environment. In 2011, turbidimeters were installed without wipers (which were an additional and costly component), because it was felt that growth on the window would not be a problem in this nutrient-poor environment. However, the data showed clearly that after just 7 to 10 days, the turbidity readings were erroneous (turbidity readings increased while the flow was decreasing). For the field seasons of 2012 and 2013, wipers were installed on all turbidity sensors, but issues with fouling persisted.

5.3.5 Bed Sediment Distribution

The bed sediment distribution was calculated for each river using a taped grid of 1 m by 1 m on exposed gravel bars near the end of the spring fieldwork. Photographs of each grid were taken, with the sediments later measured and separated into size intervals. In the photographs, only those sediments large enough to be seen without magnification and unobscured by other sediments were measured. Nine rocks were brought back from each grid to precisely weigh and measure in a lab.

5.3.6 Suspended Sediment Grain-Size Distribution

A selection of depth-integrated samples collected throughout the 2013 field season were sent to Particle Technology Labs for total suspended solids (TSS) and grain-size analysis. The volume weighted D_{50} was reported back in micrometers (μm) for each sample.

6 RESULTS

This chapter presents a summary of the hydrological and meteorological data collected on this and related projects that contribute to the Umiat study. Sometimes it is not obvious why we collect all of the data that we do, and some data like relative humidity (used in evapotranspiration [ET] estimates) are collected at very little expense because we already have the infrastructure in place and are already visiting the sites. A variable like air temperature is important in numerous hydrologic processes such as sublimation, snowmelt, ET, soil freezing and thawing, and formation and decay of ice (surface water bodies). All of the data collected on this project can be found in electronic form on a DVD in the back of this report and at: http://ine.uaf.edu/werc/projects/umiat_corridor/stations.html

Selected data can be found in graphical form in this chapter or in the appendices at the end of this report. The results presented here are an update of information reported in Kane et al. (2012).

6.1 Air Temperature and Relative Humidity

Mean monthly air temperature is plotted in Figure 4 for selected mountains, foothills, and coastal plain stations. The clearest message in this figure is the long "cold season" for all three physiographic regions: October through April with the seasonal transition occurring in September and May. In summer, air temperatures are the warmest in the foothills, less warm on the coastal plain, and on average, coolest in the mountains. During the cold season, the coastal plain is the coldest, followed by the foothills. The mountains are warmest. The amplitude (Figure 4) of the average temperature plot is greater for the coastal plain, followed by the foothills, with the mountains having the lowest amplitude (mostly due to effect of altitude on summer temperatures). Generally, the air temperature decreases both with elevation and at higher latitudes. The northern foothills are at the optimum location (both elevation and latitude) for having the highest annual air temperature. The size of shrub vegetation found at the northern fringes of the foothills is evidence that the temperatures are higher.

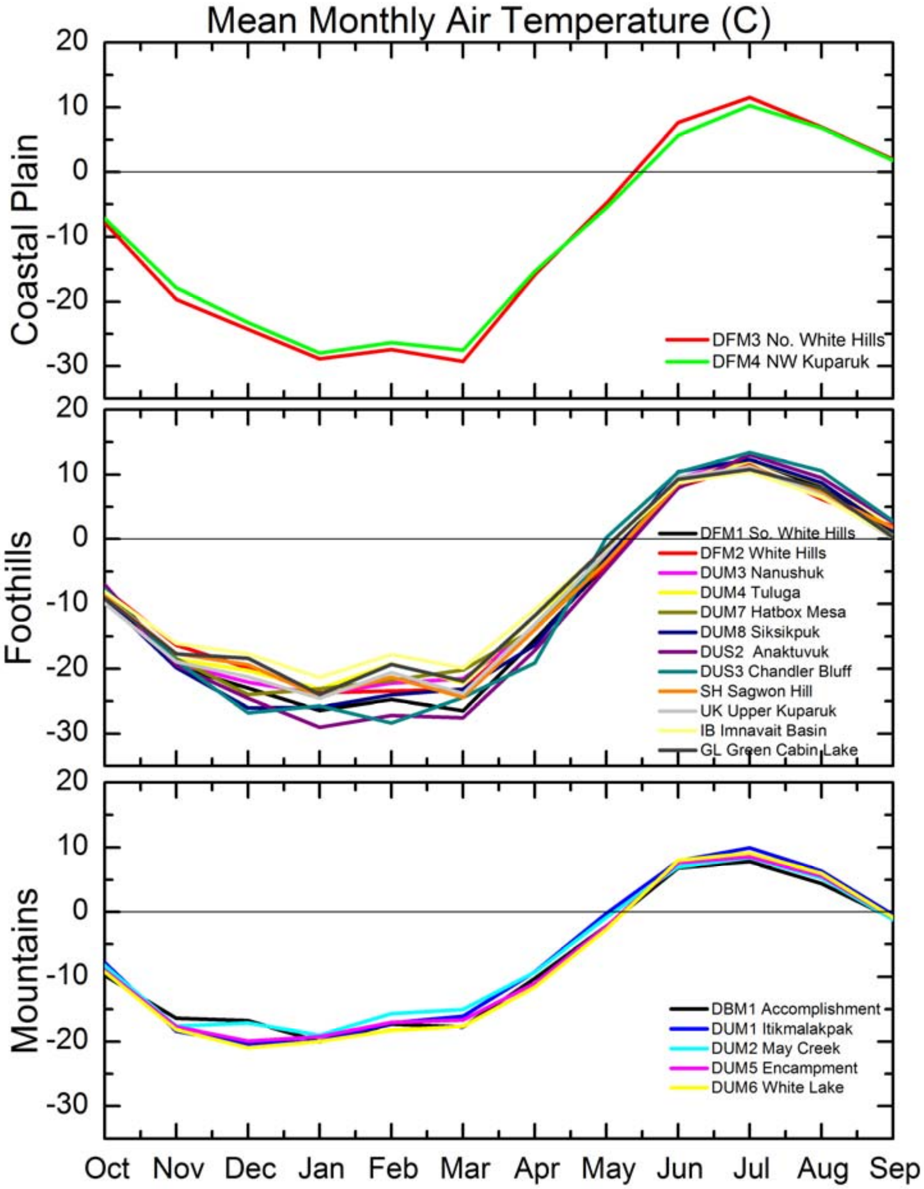


Figure 4. Monthly mean air temperature for meteorological stations in the mountain, foothills, and coastal plain regions of the Kuparuk Foothills/ Umiat Corridor project area.

Within the study area, the July monthly average temperature at the stations varies from 7.8°C (46.1°F) to 13.4°C (56.1°F); this month has the highest monthly air temperatures. March, one of the coldest months along with January and February, has average temperatures over the study area that vary from -29.3°C (-20.7°F) to -15.0°C (4.9°F). The extreme temperatures for the study area are -48.4°C (-55.1°F) at the Anaktuvuk meteorological station on January 24, 2012. The warmest temperature that we observed was 29.7°C (85.5°F) at the Chandler meteorological station on June 20, 2013. Both of these stations are at the transition from the coastal plain to the foothills. The climate here is more continental, in that the winters are cold and the summers are warm. Most of the warmest temperatures occur in June; some occur in July. The coldest temperatures measured occur in January as a rule, but occasionally some occur in February.

Appendix A contains a table of mean, maximum, and minimum monthly air temperatures for each station ($n = 19$) as well as an annual plot of updated hourly values of air temperature and relative humidity for each station. Again, the data used for the plots of air temperature and relative humidity in Appendix A can be found in the attached DVD or at; http://ine.uaf.edu/werc/projects/umiat_corridor/stations.html

Relative humidity, which is an important factor in evapotranspiration, is generally higher in the warm season than in the cold season, although more variability occurs during the warm season (probably due to the daily variation in air temperature—near saturation when air temperature cools in the evenings and lower during the day when air temperature warms). Table 3, Table 4, and Table 5 show the monthly variation of relative humidity in the Kuparuk, Anaktuvuk, and Chandler River basins. The annual pattern of monthly relative humidity is similar in each basin; the values are high (at or near 90%) in September and October, with the lowest values in March, April, and May. The monthly average relative humidity at typical stations representing mountains (DFM4 Northwest Kuparuk), foothills (DUM4 Tuluga), and coastal plain (DUM5 Encampment) regions are presented in Figure 5. Monthly mean relative humidity is lowest in the mountains region, followed by the foothills and coastal plain regions. Data show an annual cycle with relative humidity correlating closely to temperature, except during the summer months. It should be noted that high relative humidity in winter months can be misleading, because at very cold temperatures, below -35°C (-31°F), little moisture is contained in the air at saturation (100%). Occasional bumps occur in the data (Figure 5) in April, May, and June.

Table 3. Mean monthly relative humidity (%) at Kuparuk Foothills stations, 2006–2013.

Month	Mean Monthly Relative Humidity (%)							
	DBM1 Accomplish-ment	DFM1 S White Hills	DFM2 White Hills	DFM3 N White Hills	DFM4 NW Kuparuk	Sagwon	Imnavait Basin	Upper Kuparuk
Oct	75	86	90	89	93	89	80	83
Nov	69	80	84	83	86	83	74	77
Dec	64	75	77	77	80	76	70	74
Jan	65	73	74	73	76	73	70	73
Feb	63	74	75	74	77	74	68	72
Mar	60	70	73	72	76	71	63	68
Apr	64	77	80	79	85	80	70	74
May	69	82	85	85	89	84	73	76
Jun	72	73	76	76	82	75	71	70
Jul	78	75	77	77	79	75	73	73
Aug	79	81	84	83	86	83	77	77
Sep	78	86	86	88	91	86	80	82

Table 4. Mean monthly relative humidity (%) at Umiat Corridor (Anaktuvuk basin) stations, 2009–2013.

Month	Mean Monthly Relative Humidity (%)				
	DUM1 Itikmalakpak	DUM2 Upper May Creek	DUM3 Nanushuk	DUM4 Tuluga	DUS2 Anaktuvuk
Oct	81	78	85	88	78
Nov	75	76	80	86	76
Dec	69	70	72	74	70
Jan	67	66	72	71	66
Feb	67	65	74	77	65
Mar	58	57	67	67	57
Apr	61	61	77	79	61
May	63	64	82	78	64
Jun	75	74	75	75	74
Jul	68	67	69	71	67
Aug	74	76	77	78	76
Sep	81	81	84	87	81

Table 5. Mean monthly relative humidity (%) at Umiat Corridor (Chandler basin) stations, 2009–2013.

Month	Mean Monthly Relative Humidity (%)				
	DUM5 Encampment	DUM6 White Lake	DUM7 Hat Box Mesa	DUM8 Siksikpuk	DUS3 Chandler
Oct	83	85	90	90	90
Nov	78	79	86	84	83
Dec	73	74	78	76	75
Jan	69	70	75	76	78
Feb	70	71	77	76	71
Mar	63	65	70	72	75
Apr	65	66	75	77	73
May	68	70	76	77	80
Jun	74	73	75	72	70
Jul	79	77	80	76	74
Aug	78	78	82	78	79
Sep	84	86	90	88	88

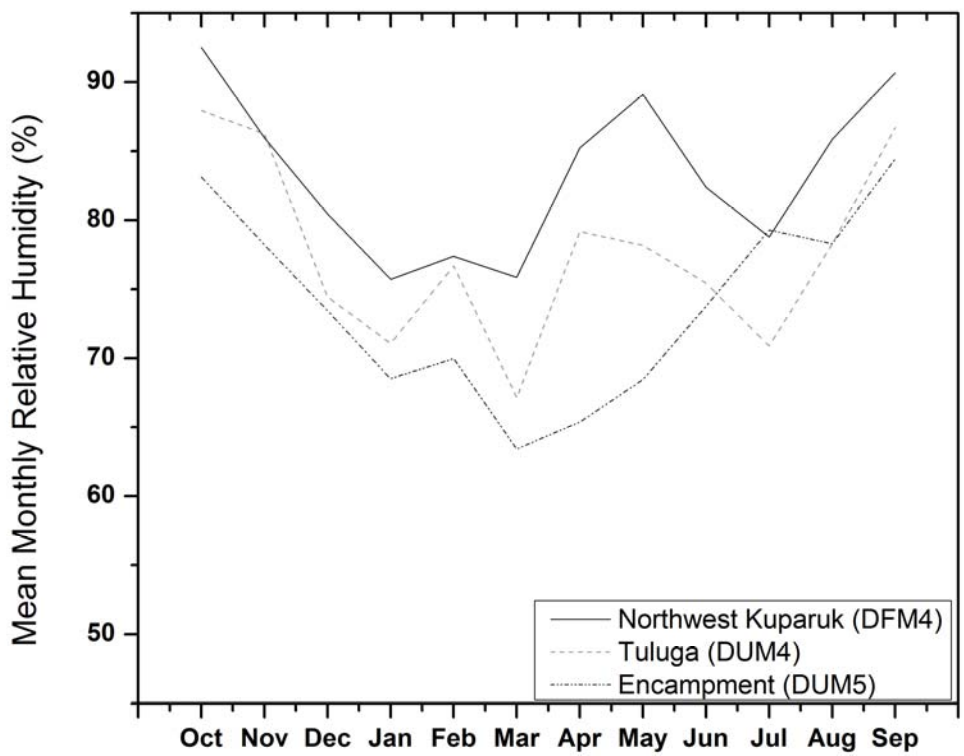


Figure 5. Mean monthly relative humidity at three select stations. Northwest Kuparuk is representative of coastal plain region, Tuluga is representative of the foothills region, and Encampment is representative of the mountains region.

6.2 Wind Speed and Direction

Wind conditions on the North Slope generally depend upon the pathway of low- and high-pressure systems. Low-pressure systems typically are generated where surface water is available, like the North Pacific; they then track eastward over various parts of Alaska. High-pressure systems often enter Alaska traveling east from Siberia (land mass), where there is little available water. High-pressure systems generally result in clear skies, and in the winter, with little solar radiation, cold air temperatures. Low-pressure systems are able to moderate the cold winter temperatures and provide solid precipitation. Low-pressure systems during the warm season provide liquid precipitation. High-elevation terrain like the Alaska Range and Brooks Range is capable of redirecting and/or stripping precipitation from low-pressure systems. Strong storm systems that push over the Brooks Range from the south can produce Chinook conditions. A lack of snow (viewed from satellite images) in the mountain passes demonstrates that Chinook winds in the Brooks Range passes are a common event.

Recall that this data are collected at unmanned, remote sites where observers cannot monitor what is happening at the site. Rime ice is a significant problem in the winter at these sites and is apparent when wind speeds are at zero for extended periods. High winds often break the anemometers free.

Although we have captured some wind profile data (1.5, 3, and 10 m), most of our sites are instrumented with anemometers at 3 m. In the following text, figures, and tables, we will present updated 3 m wind data for the central North Slope of the Alaska Arctic. In the Kuparuk River basin, where we have the most hydrological and meteorological data (9 meteorological stations at the end of the project), the highest average winds generally occur in winter (Table 6). In this basin, it is also clear that the highest winds can be found at the transition from the coastal plain to the foothills. The highest mean monthly wind speeds in the Kuparuk basin were 5 m/s at White Hills (DFM2) and Northwest Kuparuk (DFM4), two neighboring sites.

Mean monthly wind speeds in the Anaktuvuk and Chandler basins are also shown in Table 7 and Table 8. The mean monthly wind speeds are not as high in these two basins as in the Kuparuk. Itikmalakpak (DUM1) in the mountains has the lowest mean monthly wind speeds; however, although it is at high elevation, it is in a protected spot (low depression surrounded by mountains). The highest measured mean monthly wind speeds are in the mountains for Chandler basin and in the foothills for Anaktuvuk basin.

Table 6. Mean monthly wind speed at Kuparuk Foothills stations, 2006–2013.

Month	Mean Monthly Wind Speed (m/s)								
	DBM1 Accomplish-ment	DFM1 S White Hills	DFM2 White Hills	DFM3 N White Hills	DFM4 NW Kuparuk	Sagwon	Imnavait Basin	Upper Kuparuk	Green Cabin Lake
Oct	2.8	2.4	4.6	3.0	3.9	3.4	2.9	2.7	1.9
Nov	3.4	2.9	4.4	3.2	3.4	3.0	3.2	3.0	2.3
Dec	3.4	3.1	5.0	3.2	3.4	3.9	3.2	2.9	2.0
Jan	3.4	3.1	4.6	4.2	4.2	3.5	3.1	2.8	2.1
Feb	3.7	3.5	4.7	3.7	5.0	4.9	3.9	3.6	2.2
Mar	3.2	2.7	4.4	3.5	4.9	3.3	2.5	2.2	1.6
Apr	3.1	2.9	4.3	3.4	4.2	4.1	2.8	2.6	2.0
May	2.3	2.8	4.5	3.8	4.4	3.8	3.0	2.6	2.1
Jun	2.7	3.0	4.6	3.7	4.5	4.5	3.4	2.9	2.8
Jul	2.6	2.7	4.0	3.0	3.7	4.2	3.2	2.7	2.6
Aug	2.5	2.6	3.8	2.9	3.3	3.8	3.3	2.7	3.7
Sep	2.5	2.4	3.6	2.8	3.5	3.6	2.8	2.5	2.2

Table 7. Mean monthly wind speed at Umiat Corridor (Anaktuvuk basin) stations, 2009–2013.

Month	Mean Monthly Wind Speed (m/s)				
	DUM1 Itikmalakpak	DUM2 Upper May Creek	DUM3 Nanushuk	DUM4 Tuluga	DUS2 Anaktuvuk
Oct	1.8	2.0	2.1	2.2	2.0
Nov	1.5	2.6	2.6	3.0	2.6
Dec	1.7	2.5	2.2	2.7	2.5
Jan	1.0	2.8	2.0	2.6	2.8
Feb	1.2	2.6	2.3	3.2	2.6
Mar	0.7	1.9	1.9	1.9	1.9
Apr	1.0	2.3	2.0	2.9	2.3
May	1.2	2.1	2.3	2.7	2.1
Jun	1.8	2.6	3.1	3.0	2.6
Jul	1.6	2.6	2.6	2.7	2.6
Aug	1.8	2.5	2.8	3.3	2.5
Sep	1.3	2.2	2.4	2.7	2.2

Table 8. Mean monthly wind speed at Umiat Corridor (Chandler basin) stations, 2009–2013.

Month	Mean Monthly Wind Speed (m/s)				
	DUM5 Encampment	DUM6 White Lake	DUM7 Hat Box Mesa	DUM8 Siksikpuk	DUS3 Chandler
Oct	3.8	3.1	2.1	1.8	1.3
Nov	3.2	3.2	2.8	2.0	2.4
Dec	3.3	3.0	2.4	1.6	2.3
Jan	3.3	3.0	2.7	1.5	1.6
Feb	4.4	3.8	3.1	2.1	2.5
Mar	2.8	2.5	2.6	1.2	1.6
Apr	2.6	2.5	2.7	1.6	1.8
May	3.6	3.1	2.6	1.9	1.6
Jun	3.1	2.9	3.1	2.6	2.0
Jul	3.8	3.1	2.7	2.3	1.7
Aug	4.6	3.6	2.9	2.4	1.8
Sep	3.4	2.9	2.4	1.9	1.5

A summary of wind data at each of the 15 operational meteorological stations in 2013 for the three major basins is presented in Table 9. In the Kuparuk basin, the average hourly wind speeds are higher in the cold season (September 15 to May 14); in the Anaktuvuk and Chandler basins, the average hourly wind speeds are higher in the warm season (May 15 to September 14). This area experiences calm conditions about 5% of the time, except Itikmalakpak (DUM1), which is protected, and Siksikpuk (DUM8), which is not obviously protected. As mentioned before, riming of the anemometers is a significant problem at these stations. The last two columns show the total data count in hours for the period of record and the total hours of missing data during this record. At some stations, the percentage of missing data is high, particularly during the winter months.

Another way of showing wind data, including direction, is wind roses. Four wind roses (Figure 6, Figure 7, Figure 8, and Figure 9) illustrate conditions from the coastal plain to the mountains. The wind roses show both the distribution of selected wind speeds (calm 0.5 to 2.1 m/s, 2.1 to 3.6 m/s, 3.6 to 5.7 m/s, 5.7 to 8.8, 8.8 to 11.1 m/s, and >11.1 m/s) and the predominant directions, including the percent of time that calm conditions prevail. To convert m/s to miles per hour (MPH), multiply the wind speed in m/s by 2.237. In Figure 10 for the Northwest Kuparuk, the predominant wind directions are the WSW and ENE. Winds from the WSW correspond to low-pressure systems (precipitation); winds from the ENE correspond to high-pressure systems (clear skies). A similar wind rose can be seen in Figure 7 for North White Hills (DFM3); however, the direction of the prevailing winds has shifted slightly. This is probably due to topography. For example, the wind rose for Accomplishment Creek (DBM1) (Figure 8) shows a totally different pattern, with the prevailing winds from the ESE and NNW. Finally, Figure 9 shows the wind pattern over the foothills (White Hills, DFM2), an exposed site. The prevailing winds are similar to the Northwest Kuparuk (Figure 6), but the percentage of time with high winds has increased from the ENE.

Table 9. Summary of WRPLOT wind rose analysis for the period of record for July 2006 through September 2013. Summer period is May 15 through September 15, and winter period is September 16 through May 14.

Station	Overall Average Hourly Wind Speed (m/s)	Summer Average Hourly Wind Speed (m/s)	Winter Average Hourly Wind Speed (m/s)	Overall Calm Winds (%)	Summer Calm Winds (%)	Winter Calm Winds (%)	Total Data Count (hr)	Missing Data (hr)
Accomplishment (DBM1)	3.0	2.5	3.2	2.8	1.6	2.9	54042	8206
South White Hills (DFM1)	2.8	2.7	2.9	2.8	0.9	3.8	60378	3404
White Hills (DFM2)	4.4	4.2	4.5	1.7	0.2	2.2	39703	23515
North White Hills (DFM3)	3.4	3.2	3.5	3.4	1.0	4.5	60480	3044
Northwest Kuparuk (DFM4)	4.0	3.8	4.1	2.1	0.4	2.9	50837	10627
Itikmalakpak (DUM1)	1.2	1.7	0.9	27.8	10.1	37.6	35428	1526
Upper May Creek (DUM2)	2.4	2.6	2.3	10.1	4.0	13.5	35876	1028
Nanushuk (DUM3)	2.4	2.8	2.1	7.1	1.2	10.5	35281	1528
Tuluga (DUM4)	2.8	3.0	2.5	4.4	0.7	6.4	29219	7779
Anaktuvuk River (DUS2)	2.8	2.9	2.8	2.7	0.5	3.8	30448	6429
Encampment Creek (DUM5)	3.5	3.9	3.3	5.3	1.5	7.0	25184	1020
White Lake (DUM6)	3.1	3.2	3.0	5.7	1.8	7.4	23997	2179
Hatbox Mesa (DUM7)	2.7	2.8	2.7	5.8	1.6	7.5	21818	4332
Siksikpuk (DUM8)	1.9	2.3	1.7	13.0	0.8	18.2	23682	2383
Chandler River Bluff (DUS3)	1.9	1.8	2.0	5.0	2.4	4.9	16453	9430

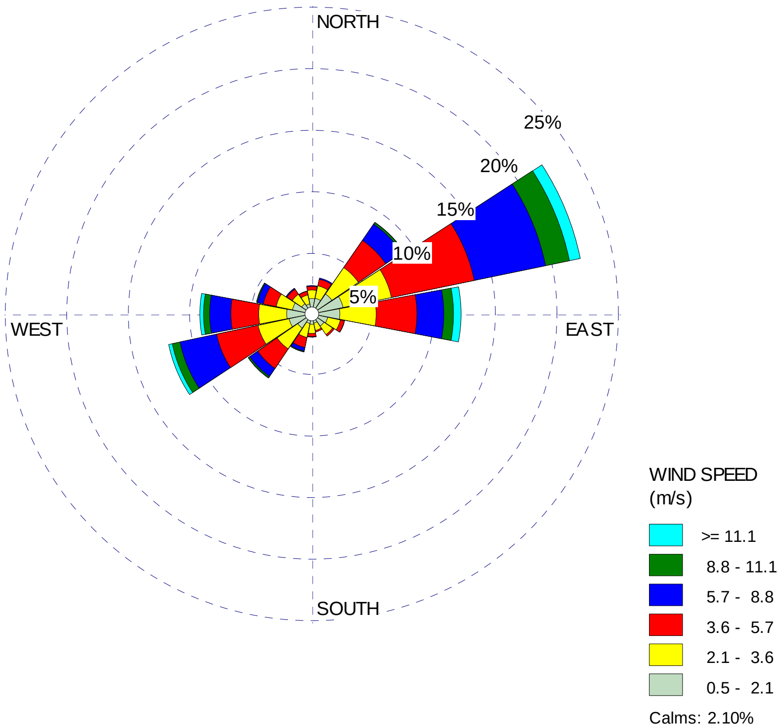


Figure 6. Wind rose from average annual wind record for Northwest Kuparuk station (DFM4).

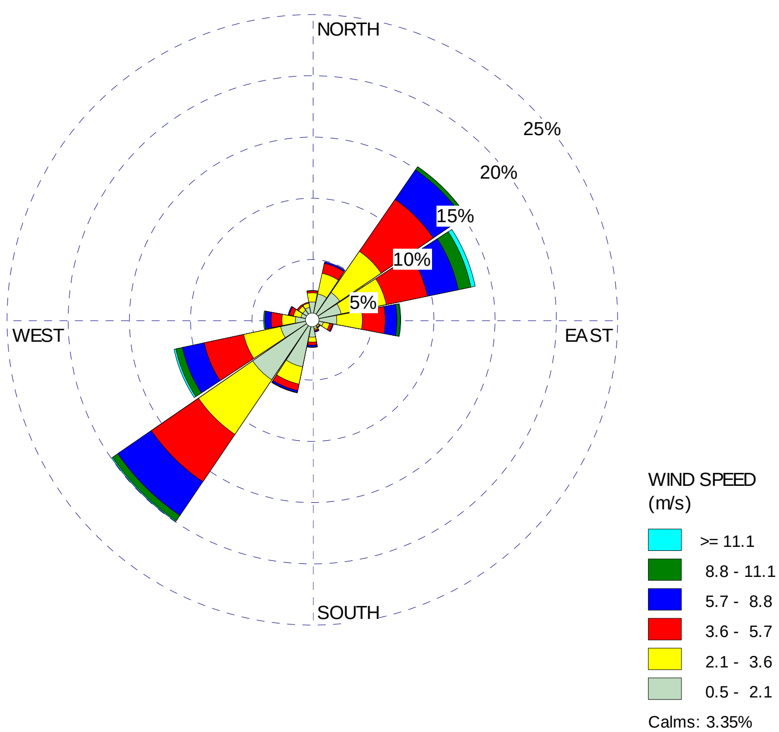


Figure 7. Wind rose from average annual wind record for North White Hills station (DFM3).

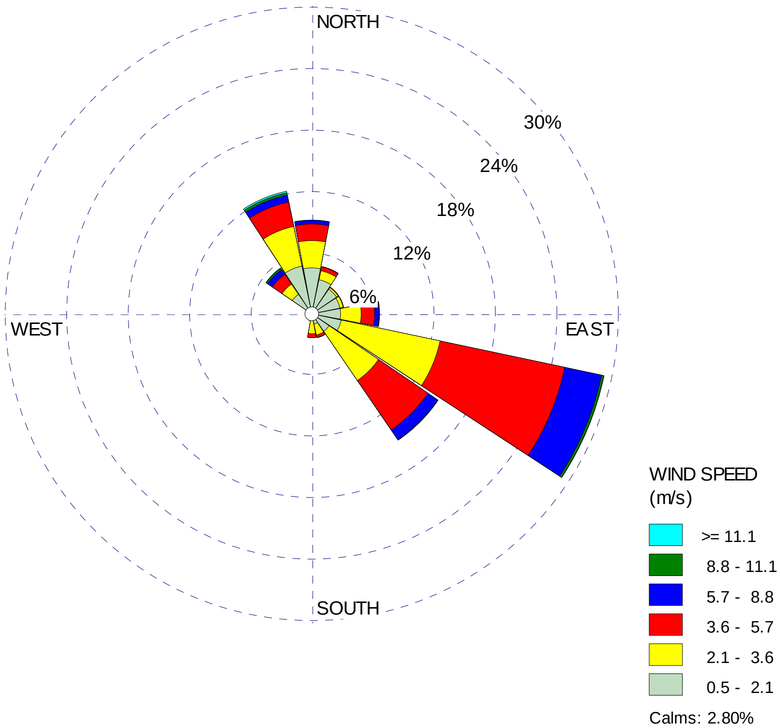


Figure 8. Wind rose from average annual wind record for Accomplishment Creek station (DBM1).

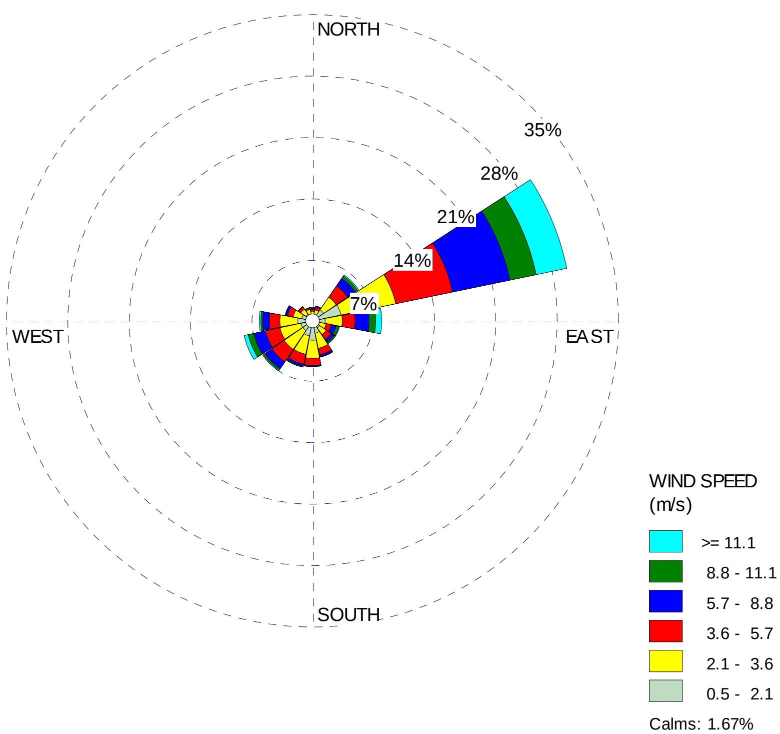


Figure 9. Wind rose from average annual wind record for White Hills station (DFM2).

Figure 10 shows the total number of hours that the wind speed has exceeded 8 m/s (18 mph) at a coastal plain, foothills, and mountains site from June 2009 and August 2013. The Northwest Kuparuk meteorological station adjacent to the coastal plain shows the highest occurrence of winds exceeding the 8 m/s threshold. Also, it is more likely that these winds will occur in the cold season rather than in the warm season.

In Appendix B are wind roses for all of the meteorological stations in the Kuparuk, Anaktuvuk, and Chandler basins that were operational in 2013. The analysis includes three wind roses for each station: annual – January 1 through December 31, warm season – May 15 through September 15, and cold season – September 16 through May 14.

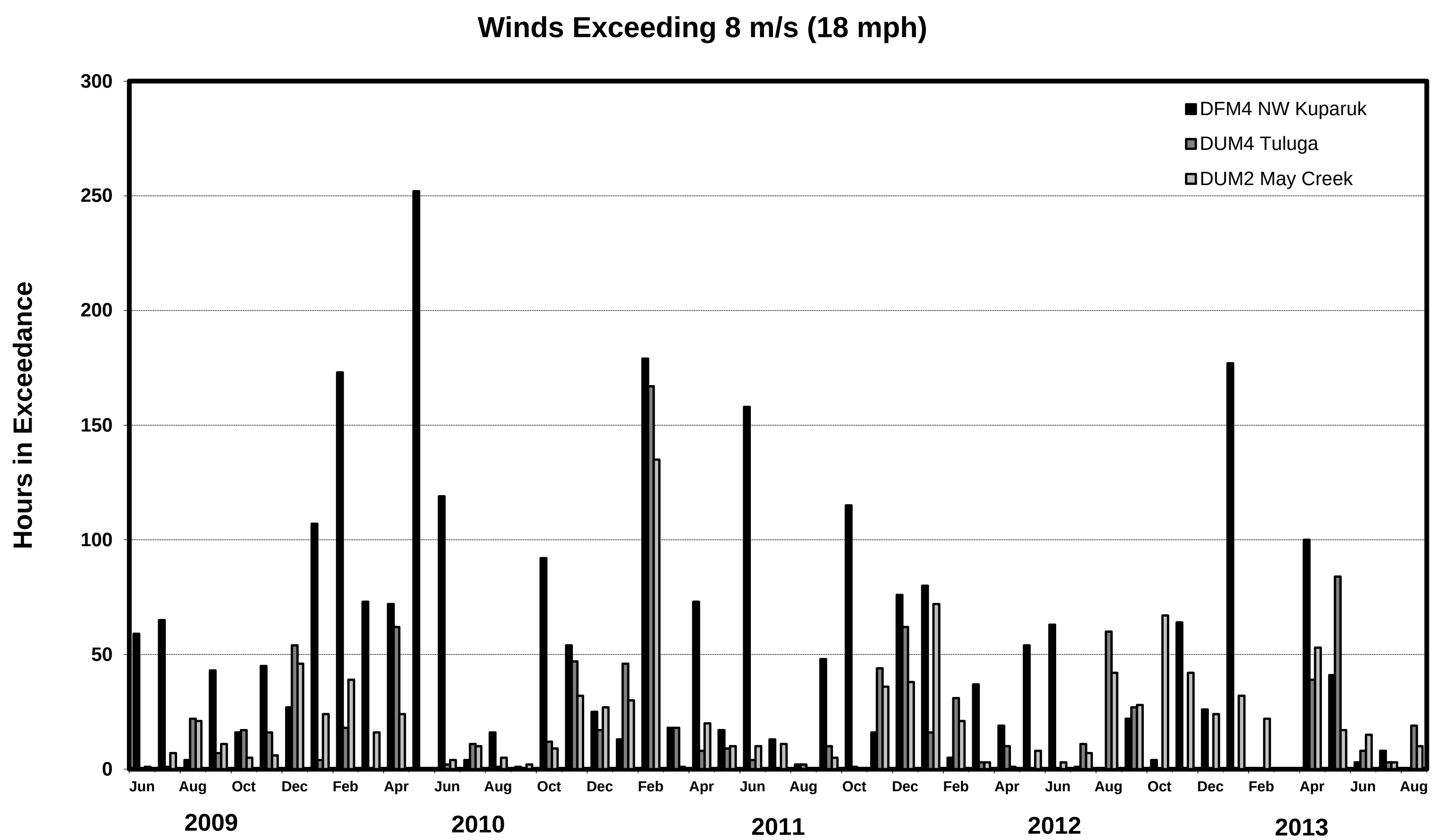


Figure 10. Hours of wind speed exceeding 8.0 m/s by month for Northwest Kuparuk (DFM4, coastal plain), Tuluga (DUM4, foothills), and May Creek (DUM2, mountains) for June 2009 through September 2013.

6.3 Net Radiation

Net radiation is equivalent to the amount of incoming radiation (positive) minus the outgoing radiation (negative) for both short-wave and long-wave radiation. The following is a summary of updated net radiation data collected on the North Slope in the Kuparuk, Anaktuvuk, and Chandler catchments (Table 10–Table 12). The data displayed here are for the warm season; during the cold season, ice and snow collect on the radiation sensors and compromise the quality of the data. Also, since the sites are unmanned, there is no way to occasionally clean the sensor surface. Net radiation data are shown here for the months of May through September. Some years during the shoulder seasons of spring and fall data are not available in May and September because of late breakup or early freeze-up. Net radiation plays a significant role in many phase change processes like soil freezing and thawing, snowmelt, formation and decay of ice on surface water bodies, etc.

A transition from a negative net radiation balance to a positive radiation balance occurs in May; the reverse of that process occurs in September. A positive net radiation value means that more radiation is received at the surface than is lost. In all three physiographic regions, the maximum positive net radiation occurs in June. This is not surprising, as the solstice (the sun at a maximum distance above the equator) is around June 21. In Table 13, the mean monthly net radiation for stations in each of the three physiographic regions (coastal plain, foothills, and mountains) is given. The seasonal (May through September) mean is also provided. During June, July, and August, as well as seasonally (Table 13), the coastal plain has the greatest positive net radiation followed by the foothills and the mountains. The mean monthly net radiation during the warm season for the three stations representing the physiographic regions—Northwest Kuparuk (coastal plain), Tuluga (foothills), and May Creek (mountains)—is shown in Figure 11. This figure and Table 13 show that the net radiation transitions from negative to positive in May and transitions in the reverse in September. Measured average monthly fluxes in June exceed 125 W/m^2 on the coastal plain, 110 W/m^2 in the foothills, and 95 W/m^2 in the mountains.

Table 10. Monthly mean net radiation (W/m^2) during the warm season for meteorological stations in the Kuparuk Foothills project area, 2006–2013.

Month	Mean Monthly Net Radiation (W/m^2)							
	DBM1 - Accomplish-ment	DFM1 S White Hills	DFM2 White Hills	DFM3 N White Hills	DFM4 NW Kuparuk	Sagwon	Imnavait Basin	Upper Kuparuk
May	18.9	36.8	68.5	53.6	7.0	n/a	n/a	n/a
Jun	93.7	131.7	121.6	127.1	123.5	146.8	129.2	122.4
Jul	70.6	97.9	80.9	94.8	98.7	130.4	115.1	104.7
Aug	38.2	58.0	47.9	53.9	53.1	74.7	72.0	74.1
Sep	-4.0	16.6	8.6	14.5	15.3	n/a	n/a	n/a

Table 11. Monthly mean net radiation (W/m^2) during the warm season for meteorological stations in the Umiat Corridor project area (Anaktuvuk River basin), 2009–2013.

Month	Mean Monthly Net Radiation (W/m^2)				
	DUM1 Itikmalakpak	DUM2 Upper May Creek	DUM3 Nanushuk	DUM4 Tuluga	DUS2 Anaktuvuk
May	17.9	43.2	30.5	28.5	43.2
Jun	81.7	82.9	111.8	116.5	82.9
Jul	78.8	73.0	95.3	100.5	73.0
Aug	35.8	35.2	50.1	55.8	35.2
Sep	-4.6	-1.5	10.8	12.0	-1.5

Table 12. Monthly mean net radiation (W/m^2) during the warm season for meteorological stations in the Umiat Corridor project area (Chandler River basin), 2009–2013.

Month	Mean Monthly Net Radiation (W/m^2)				
	DUM5 Encampment	DUM6 White Lake	DUM7 Hat Box Mesa	DUM8 Siksikpuk	DUS3 Chandler
May	51.4	27.8	6.7	19.5	90.4
Jun	100.6	106.7	110.3	117.1	127.1
Jul	76.3	78.7	84.1	87.1	94.8
Aug	40.8	45.8	46.5	54.0	58.7
Sep	-1.4	-1.3	3.7	11.1	9.1

Table 13. Mean monthly net radiation for the coastal plain, foothills, and mountains regions stations.

Month	Mean Monthly Net Radiation (W/m^2)		
	Coastal Plain	Foothills	Mountain
May	30.3	40.5	31.8
Jun	125.3	119.8	93.1
Jul	96.7	96.7	75.5
Aug	53.5	57.0	39.2
Sep	14.9	8.5	-2.5
Seasonal Mean	64.2	64.5	47.4

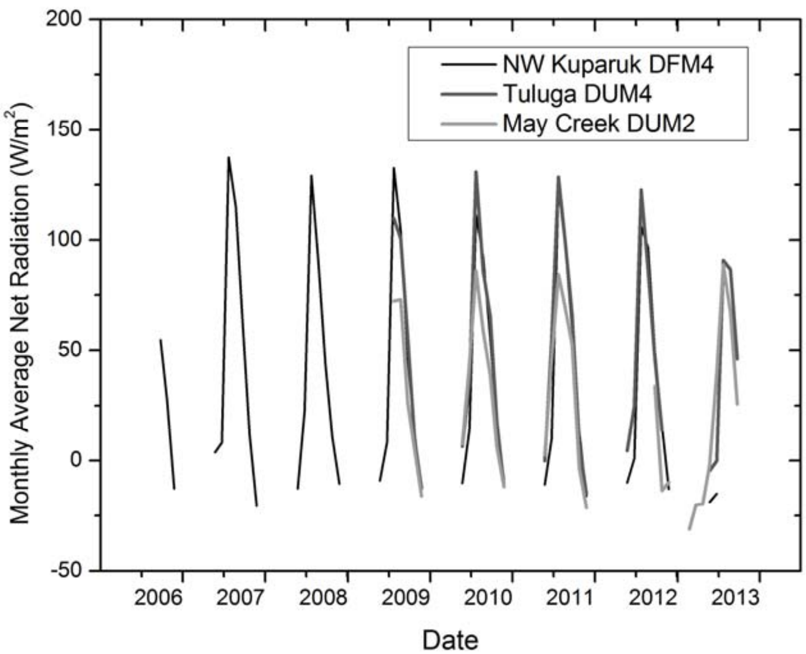


Figure 11. Mean monthly average net radiation for three meteorological stations representing the coastal plain, foothills, and mountains regions.

6.4 Warm Season Precipitation

During the data collection period since the last report (Kane et al., 2012), we have collected two additional years of warm season precipitation data from 21 stations (5 stations below elevation of 125 m [410 ft, coastal plain], 11 stations in the foothills (elevation of 125 m [410 ft] to 1000 m [3280 ft], and 5 stations in the mountains (above elevation of 1000 m [3280 ft]). The standard NOAA/NWS 8-inch-orifice tipping bucket gauges are used for measuring liquid precipitation, and they generally performed well except for occasional periods when either the weather (solid precipitation or wind) or wildlife (mostly bears) caused the gauges to be inoperable for a time. It was our intent to measure all precipitation from the end of spring ablation to fall freeze-up, generally from mid-May into September, with the warm season being shorter during the shoulder seasons farther north. The mean warm season precipitation covering a period of record that ranges from 2 to 29 years is shown in Table 14.

Table 14. Mean warm season precipitation (and duration of data collection) for North Slope sites, ordered by lowest to highest elevation.

		Period of Record	Mean Annual Rainfall	
Station Name	**Station ID**	**Years**	**(mm)**	**(in)**
Betty Pingo	**BM**	16	78.3	3.1
Franklin Bluffs	**FR**	26	81.3	3.2
Anaktuvuk River	**DUS2**	5	112.4	4.4
North White Hills	**DFM3**	5	80.5	3.2
Chandler River Bluff	**DUS3**	3	105.0	4.1
Northwest Kuparuk	**DFM4**	7	77.9	3.1
Sagwon Hill	**SH**	27	111.3	4.4
South White Hills	**DFM1**	8	131.3	5.2
White Hills	**DFM2**	6	122.0	4.8
Siksikpuk River	**DUM8**	3	144.9	5.7
Tuluga	**DUM4**	5	178.7	7.0
Nanushuk	**DUM3**	5	131.3	5.2
Hatbox Mesa	**DUM7**	3	208.9	8.2
Rooftop Ridge	**DUR9**	2	248.7	9.8
Upper Kuparuk	**UK**	19	210.2	8.3
Imnavait Basin	**IB**	29	211.3	8.3
Green Cabin Lake	**GCL**	18	204.8	8.1
White Lake	**DUM6**	3	251.4	9.9
Itikmalakpak	**DUM1**	5	135.3	5.3
Encampment Creek	**DUM5**	3	275.2	10.8
Upper May Creek	**DUM2**	5	298.5	11.8
Accomplishment Creek	**DBM1**	5	197.3	7.8

Figure 12 shows that the cumulative mean warm season precipitation ranges from 70.9 mm (2.8 in.) on the coastal plain to 298.5 mm (11.8 in.) in the Brooks Range. Also, the orographic effect on warm season precipitation is demonstrated in Table 14 and more clearly in Figure 12.

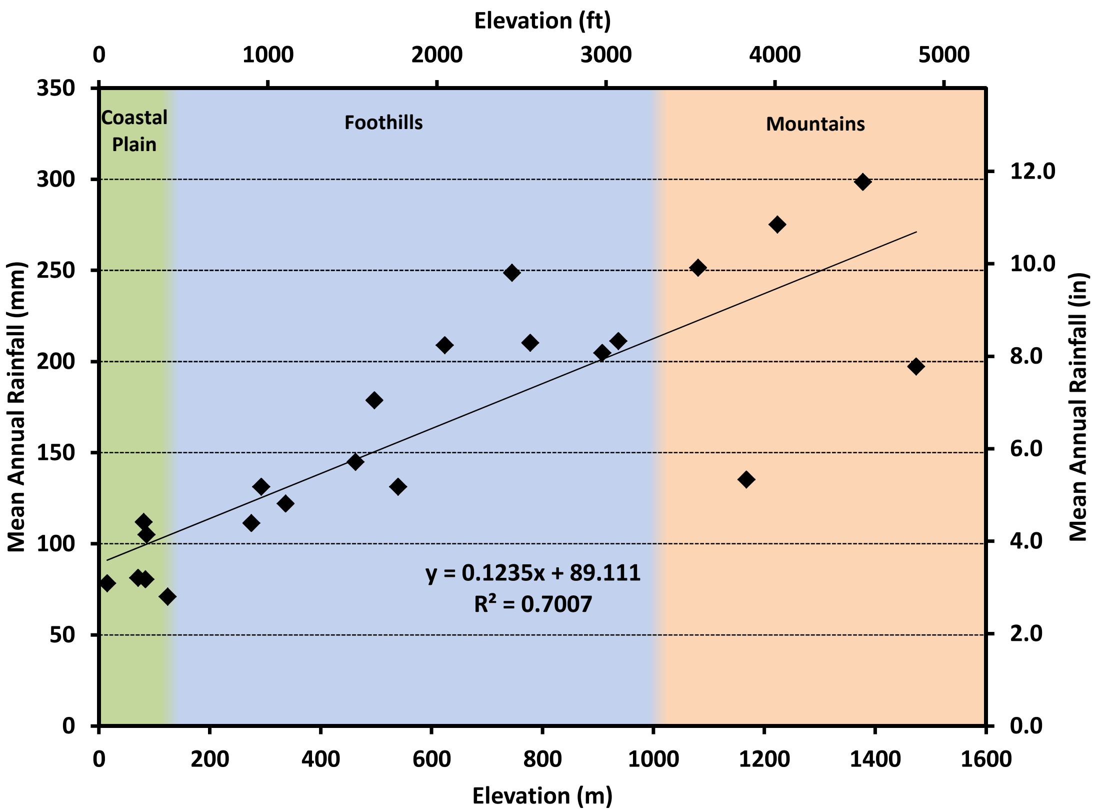


Figure 12. Plot of measured cumulative mean annual warm season precipitation versus elevation in the central Alaskan Arctic.

With the earlier, more limited liquid precipitation data record, a strong trend towards greater warm season precipitation at higher elevations was evident. This orographic relationship remained the same for the new data (Table 15) from 2012 and 2013. In contrast, this relationship did not remain the same for solid precipitation (discussed later). In Table 15, we show the station name and abbreviation, elevation, period of record, and minimum and maximum accumulated precipitation for the warm season record, with the year of the extreme event (both minimum and maximum). Stations are arranged from lowest to highest elevation. Note that the period of record ranges from just 2 years (Rooftop Ridge Repeater) to 29 years (Imnavait basin met); those stations with a longer record give a clearer picture of what can be expected hydrologically in this area. Cumulative warm season precipitation ranged from 8.8 mm (0.35 in.) to 362.6 mm (14.28 in.). Not surprisingly, the minimum cumulative precipitation occurred on the coastal plain (Franklin Bluffs in 2007), and the maximum cumulative precipitation occurred in the mountains (Upper May Creek in 2012). Across the whole of the North Slope, 2007 was a fairly dry season; it was also the year of the largest recorded tundra fire on the North Slope, the area between the

Itkillik and Anaktuvuk Rivers. Other years that were dry in this area include 1990, 1991, 2005, 2007, and 2011. Very high years of precipitation occurred in 1999 and 2002, particularly in the headwaters of the Kuparuk River. A rainfall event occurred in 1999 (July), and a mixed rain/snow event occurred in 2002 (August). Both produced the highest runoff events measured for the Upper Kuparuk River (n = 20 years; 142 km^2) and Imnavait Creek (n = 28 years, 2.2 km^2), including snowmelt-generated events (Kane et al., 2003; Kane et al., 2008b).

The cumulative summer precipitation for the last two years of observation is shown in the last two column sets in Table 15. Several of the cumulative warm season precipitation values are record highs and lows for 2012 and 2013. However, the record length of these events at these stations is short, ranging from two to seven years. If Imnavait basin Met (IB), Green Cabin Lake (GCL), and Upper Kuparuk (UK) with durations of 18 to 29 years are examined, the cumulative warm season precipitation for these two years appears to be average, neither very dry nor wet. However, the cumulative warm season precipitation can be several small events, a few large events, or some combination of the two. So, even for years with relatively low precipitation amounts, it is possible to have significant runoff events if this precipitation is concentrated into one or two storms.

In Appendix C is a series of graphs that show the cumulative warm season precipitation at each station for each year from 2007 to 2013. A second set of graphs in that appendix shows for each individual station all of the cumulative warm season precipitation data collected at that site. During this period of study (2007 to 2013), the number of meteorological stations where warm season precipitation was measured varied, as some old stations were removed and new ones added (in new locations).

A contoured map of warm season precipitation over the central Alaskan Arctic is presented in Figure 13. A strong north–south pattern in warm season precipitation is evident. The average annual precipitation varies from 60 mm along the Arctic Ocean coast to 240 mm along the northern fringe of the Brooks Range.

Table 15. Record duration in years for meteorological stations with rain gauges and the year of both minimum and maximum cumulative precipitation. The last two columns show cumulative summer precipitation that can be compared to the cumulative summer minimum and maximum in earlier columns. Stations are ordered from lowest elevation to highest elevation.

Station Name (Code)	Elevation		Record Duration/ Number of Years	MIN Cumulative Summer Precipitation			MAX Cumulative Summer Precipitation			Cumulative Summer Precipitation - 2012		Cumulative Summer Precipitation - 2013	
	m	ft		Year	mm	in	Year	mm	in	mm	in	mm	in
Franklin Bluffs (FB)	71	232.94	1987-2013/ 27	2007	8.8	0.35	2002	138.9	5.47	96.2	3.79	109.6	4.31
Anaktuvuk River (DUS2)	81	265.74	2009-2013/ 5	2010	86.5	3.41	2012	145.2	5.72	145.0	5.71	115.0	4.53
North White Hills (DFM3)	84	275.59	2006-2013/ 7	2007	18.0	0.71	2013	133.4	5.25	84.0	3.31	133.4	5.25
Chandler River Bluff (DUS3)	86	282.15	2011-2013/ 3	2011	66.1	2.60	2012	130.3	5.13	130.3	5.13	118.7	4.67
Northwest Kuparuk (DFM4)	124	406.82	2006-2013/ 7	2007	20.8	0.82	2009	97.5	3.84	67.0	2.64	89.0	3.50
Sagwon (SH)	275	902.22	1987-2013/ 27	2007	26.8	1.06	2002	157.2	6.19	150.6	5.93	122.9	4.84
South White Hills (DFM1)	293	961.27	2006-2013/ 8	2007	47.5	1.87	2009	198.1	7.80	154.7	6.09	178.4	7.02
White Hills (DFM2)	337	1105.6	2006-2013/ 8	2007	35.6	1.40	2008	179.1	7.05	**	**	**	**
Siksikpuk (DUM8)	463	1519	2011-2013/ 3	2013	119.6	4.71	2011	174.5	6.87	174.5	6.87	119.6	4.71
Tuluga (DUM4)	497	1630.6	2009-2013/ 5	2012	152.9	6.02	2011	211.5	8.33	152.9	6.02	208.0	8.19
Nanushuk (DUM3)	540	1771.6	2009-2013/ 5	2012	125.8	4.95	2010	162.2	6.39	125.8	4.95	91.6	3.6
Hatbox Mesa (DUM7)	624	2047.2	2011-2013/ 3	2011	188.9	7.44	2012	232.7	9.16	232.7	9.16	205.2	8.08
Rooftop Ridge (DUR8)	745	2444.2	2012-2013/ 2	2013	230.4	9.07	2012	267.0	10.51	267.0	10.51	230.4	9.07
Upper Kuparuk (UK)	778	2552.5	1994-2013/ 15	2007	100.0	3.94	1997	263.9	10.39	236.1	9.30	233.2	9.18
Imnavait Basin Met (IB)	937	3074.1	1985-2013/ 29	1990	100.3	3.95	1999	342.3	13.48	265.7	10.46	258.7	10.19
Green Cabin Lake (GCL)	908	2979	1996-2013/ 18	2011	121.7	4.79	1999	322.9	12.71	236.7	9.32	222.6	8.76
White Lake (DUM6)	1081	3546.5	2011-2013/ 3	2013	189.8	7.47	2012	302.7	11.92	302.7	11.92	189.8	7.47
Itikmalakpak (DUM1)	1168	3832	2009-2013/ 5	2011	117.1	4.61	2009	154.0	6.06	123.8	4.87	147.3	5.80
Encampment Creek (DUM5)	1224	4015.7	2011-2013/ 3	2013	200.3	7.89	2012	356.5	14.04	356.5	14.04	200.3	7.89
Upper May Creek (DUM2)	1378	4520.9	2009-2013/ 5	2011	227.5	8.96	2012	362.6	14.28	362.6	14.28	306.0	12.05
Accomplishment Creek (DBM1)	1474	4835.9	2006-2013/ 5	2012	152.1	5.99	2009	275.6	10.85	152.1	5.99	**	**

** missing data

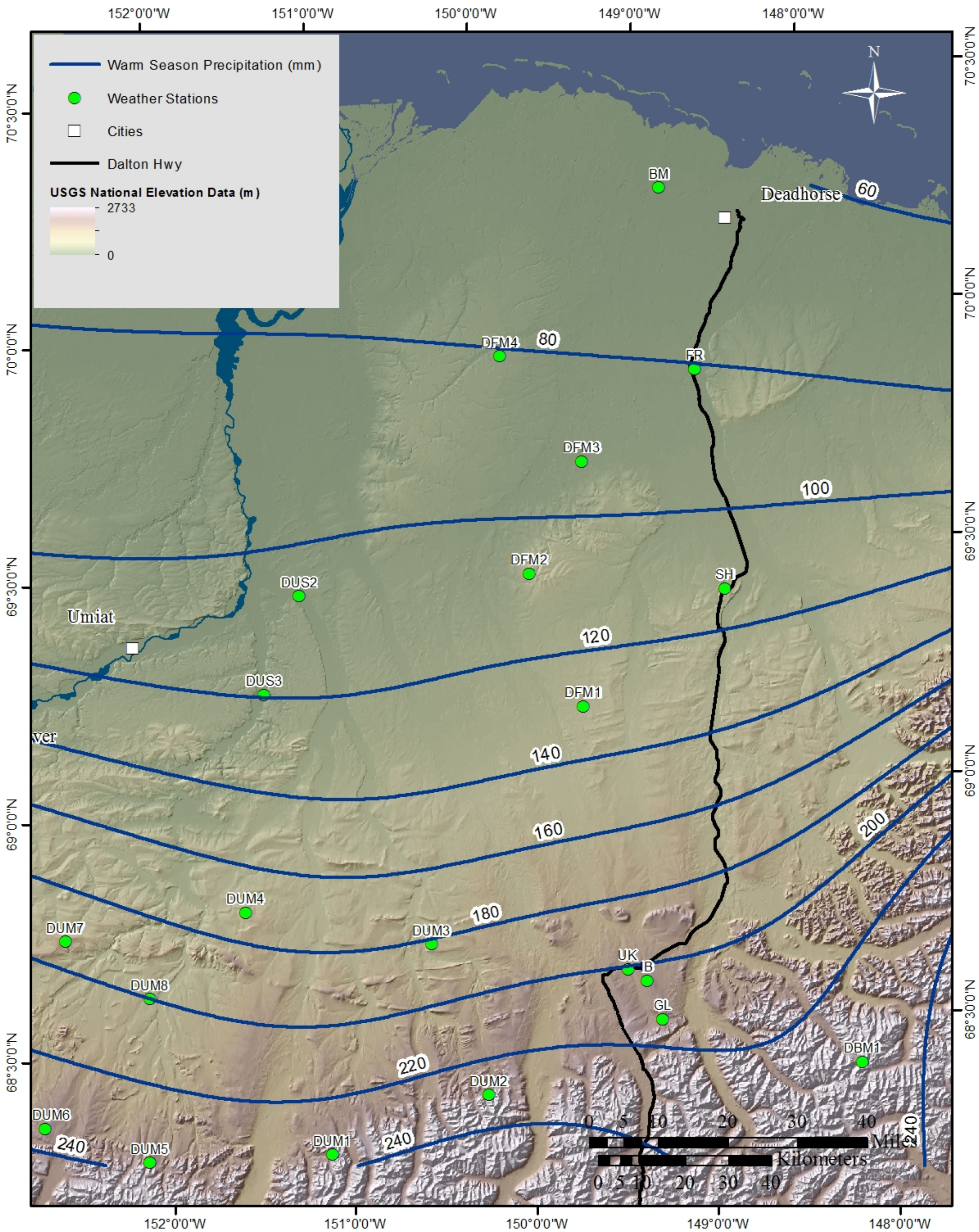


Figure 13. Contoured map of warm season precipitation in the central Alaskan Arctic. Point data were interpolated with Barnes interpolation method.

6.5 Cold Season Precipitation

It has already been mentioned that the amount of solid precipitation at winter's end does not vary much over the study area from the Arctic Ocean to the continental divide in the Brooks Range. At winter's end, there is considerable variation at the scale of a few kilometers or less. This results from the local redistribution of snow in this windy, treeless environment. In contrast to spatial distribution, there is considerable temporal variation in SWE (snow water equivalent) from year to year over the study area. In addition to redistribution of snow by wind, there is the potential for sublimation. Finally, we have not designed a gauge for solid precipitation that captures the actual amount falling (Goodison et al., 1998; Yang et al., 1998, 1999, and 2000). Thus, measurement results from gauges do not give a clear picture of the distribution of snow on the ground at winter's end.

All of these reasons influenced how we eventually attempted to quantify cold season precipitation. What evolved was a method to measure at winter's end the SWE, density, and depth of snow on the ground at selected locations (Figure 14). It was intended that the selected sites would be representative of the snow on the ground for a much larger surrounding area. We attempted to avoid areas where scouring removed much of the snow and drifts. We were not always successful in accomplishing this, as one year the selected sites may look representative but not in neighboring years. We have evaluated each site in comparison with other nearby sites. The details of earlier field snow surveys are described in the annual snow survey reports cited in Chapter 2.

Starting in 2000 for the Kuparuk River basin, a number of end-of-winter snow survey sites were established. Since then, we have maintained a fairly large site network with shifting emphasis on the river basins monitored. The number of sites each year is indicated in Figure 15 with the range being about 50 (2004) to 150 (2007). This figure shows the spatial distribution of the snow surveys sites and an indication (color of markers) of the duration of observations at each site. First (in 2000) observations were initiated in the Kuparuk River basin. Around 2006, several snow survey sites were added east of the Dalton Highway, plus a few more strategically placed in the Kuparuk River basin. Finally, in 2009 several sites were established in the Itkillik, Anaktuvuk, and Chandler River basins. Again, when stations were installed and deleted depended primarily on research funding on various projects.

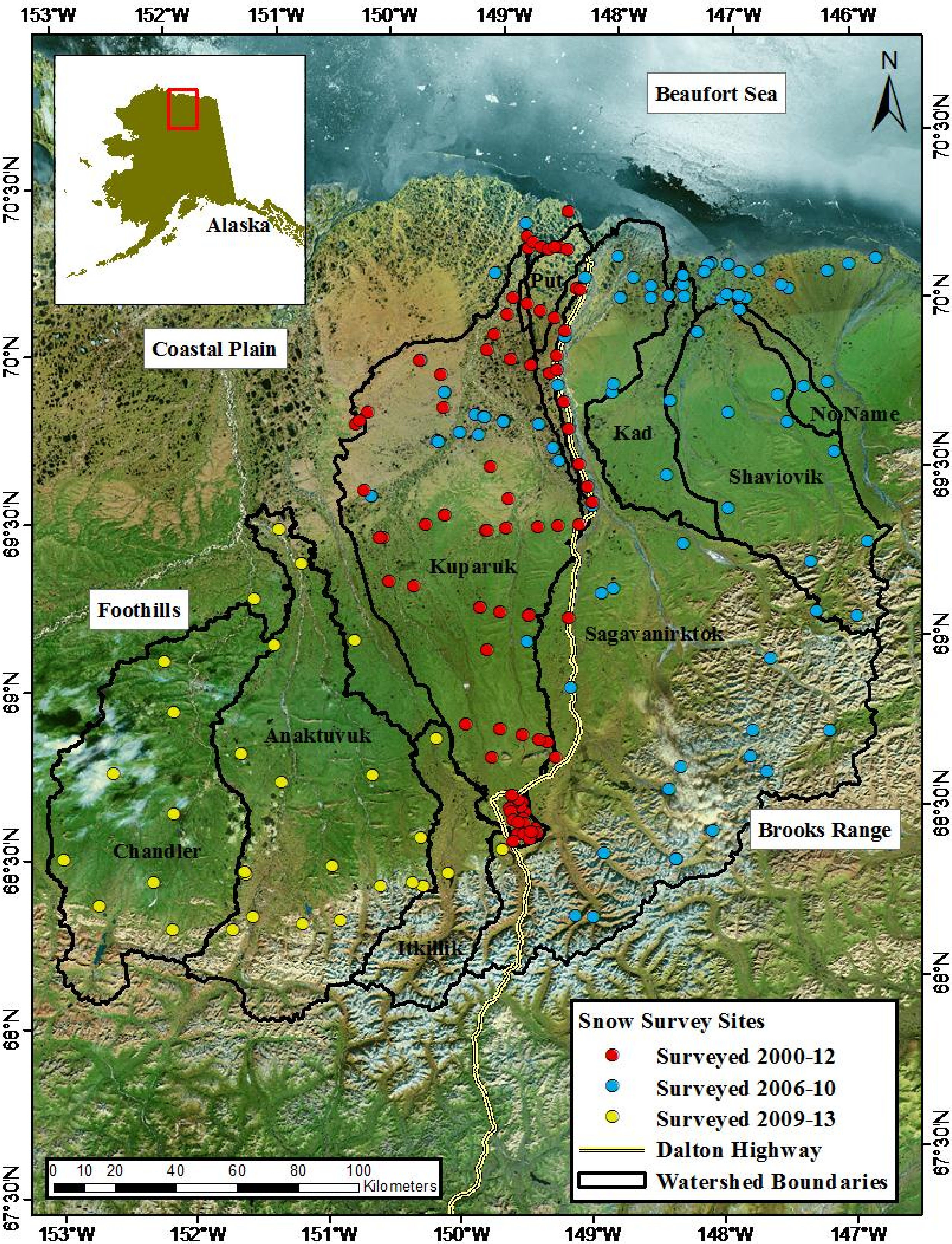


Figure 14. Distribution of end-of-winter snow survey sites in the central Alaskan Arctic.

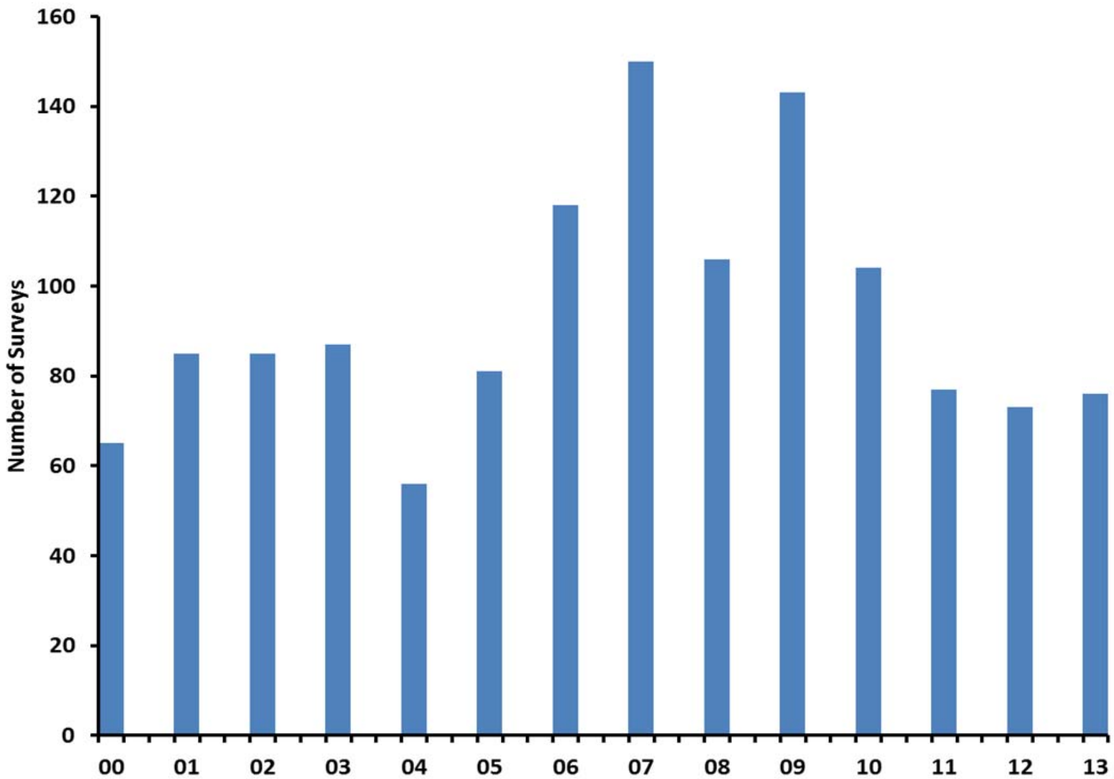


Figure 15. The number of snow survey sites where measurements were taken each year from 2000 through 2013.

Snow bulk density, snow depth, and SWE from all of the end-of-winter measurements from 2000 through 2013 are plotted versus elevation in the three panels of Figure 16. The top panel shows that there is a slight decrease in bulk density with elevation (as the elevation contours on average run east–west, it can also be described as decreases in latitude). The top panel shows that bulk density generally ranges from 0.14 to 0.4 g/cm^3 (0.27 to 0.78 slugs/ft^3) with an average of 0.26 gm/cm^3 (0.50 slugs/ft^3) along a north–south elevational transect (from sea level to 1400 m; sea level to 4593 ft). This decrease in bulk density with elevation is probably due to the wind patterns in the exposed environment of the coastal plain. Both snow depth and SWE values show very little change with elevation for the period of record.

Table 16 is a summary of SWE at each meteorological station in the study area from 2006 through 2013. During the short study period, the majority of stations (13 out of 20) had high SWE in 2011 or 2013. The station SWEs ranged from 0–27.4 cm, with an overall mean of 11 cm and a median of 10.4 cm, similar to what is plotted in Figure 16.

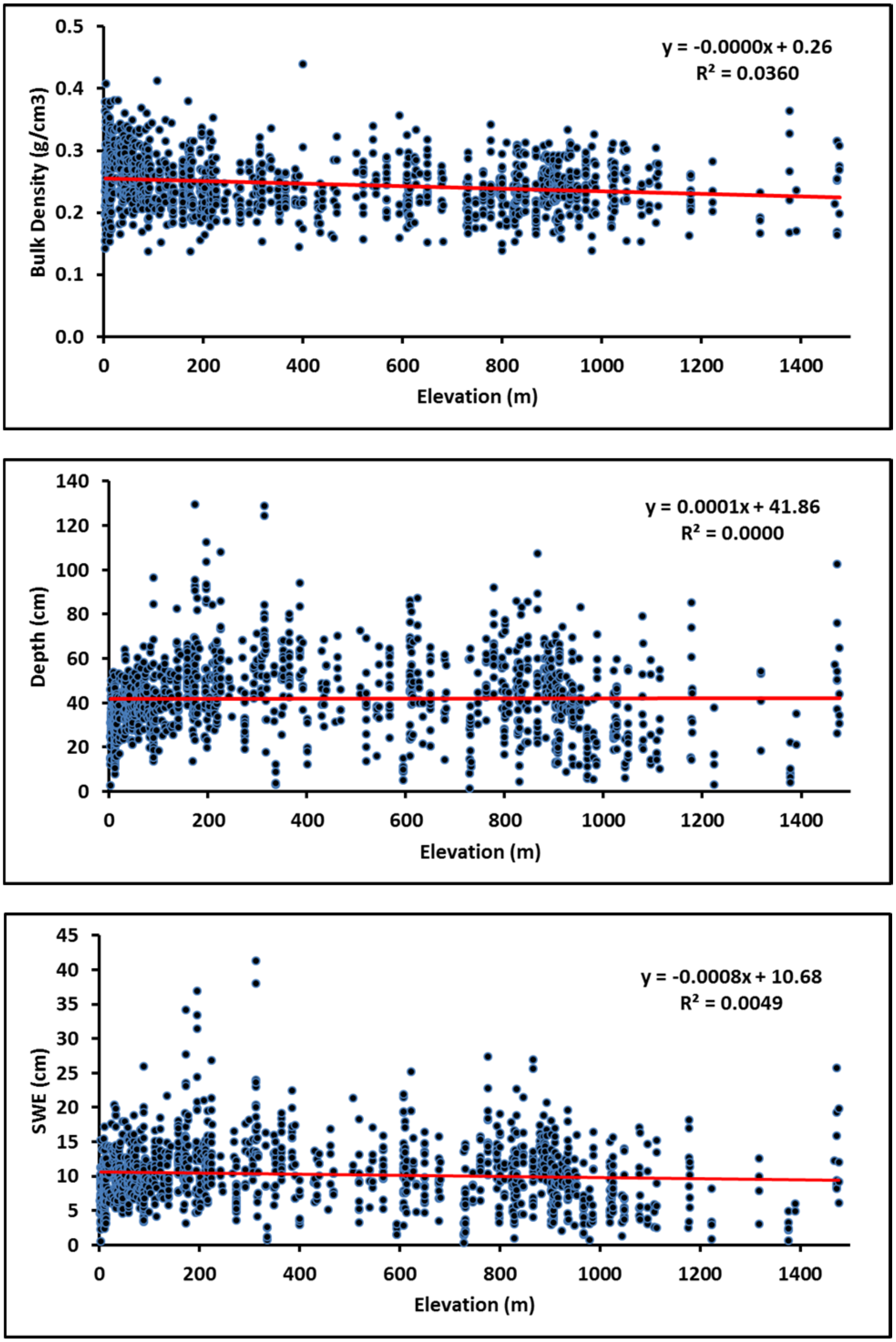


Figure 16. All end-of-winter snow measurements (2000–2013) of bulk density, depth, and SWE plotted versus elevation.

Table 16. Summary of SWE (cm) at stations in the study region for each year, in order of lowest elevation to highest elevation.

Station Name	Station ID	2006	2007	2008	2009	2010	2011	2012	2013
Franklin Bluffs	FB	10.3	6.6	9.7	16	13.3	12.1	13.9	9.3
Anaktuvuk River	DUS2					10.6	8.3	8.2	10.7
North White Hills	DFM3		16.7	9.1	15.2	16.6	6.6	9	12.9
Chandler River Bluff	DUS3					11.5	11.3	n/a	10.4
Northwest Kuparuk	DFM4		11.6	7.1	13.8	16.8	12.7	12.2	12.9
West Kuparuk	WK	7.5	7.8	10.3	13.1	n/a	12.7	15.1	15.2
Sagwon Hill	SH	5.9	7.5	3.6	8.8	4.7	8.6	8.6	8.8
South White Hills	DFM1		10.4	8.8	17.5	8.4	10.9	14.6	19.1
White Hills	DFM2		0.8	0	2.4	0	2.7	0	5.3
Siksikpuk River	DUM8/CHA6					8.8	13.2	13.3	18.5
Tuluga	DUM4/GUN4				10.3	9.3	13.1	10.3	27.1
Nanushuk	DUM3/GUN2				12.2	17	8.3	12.4	16.6
Hatbox Mesa	DUM7/CHA4					19.4	9.8	18.4	27.1
Upper Kuparuk	UK	11.9	11.9	10.4	14.1	14.6	27.4	15.6	18.1
White Lake	DUM6/CHA2					3.7	5.5	8.1	16.3
Itikmalakpak	DUM1/MTN5				6.8	11.4	5.4	12.5	12.9
Encampment Creek	DUM5/CHA1					3.3	2.9	0.6	9.4
Upper May Creek	DUM2/MTN2				2.1	3.3	2.3	1.3	7.6
Accomplishment Creek	DBM1		9.4	8.4	8.9	15.9	25.7	6.4	24.1

A contoured plot of SWE for the central Alaskan Arctic is presented in Figure 17. As can be seen, there is very little variation in the SWE values over the study area, with values ranging only from 80 mm to 120 mm.

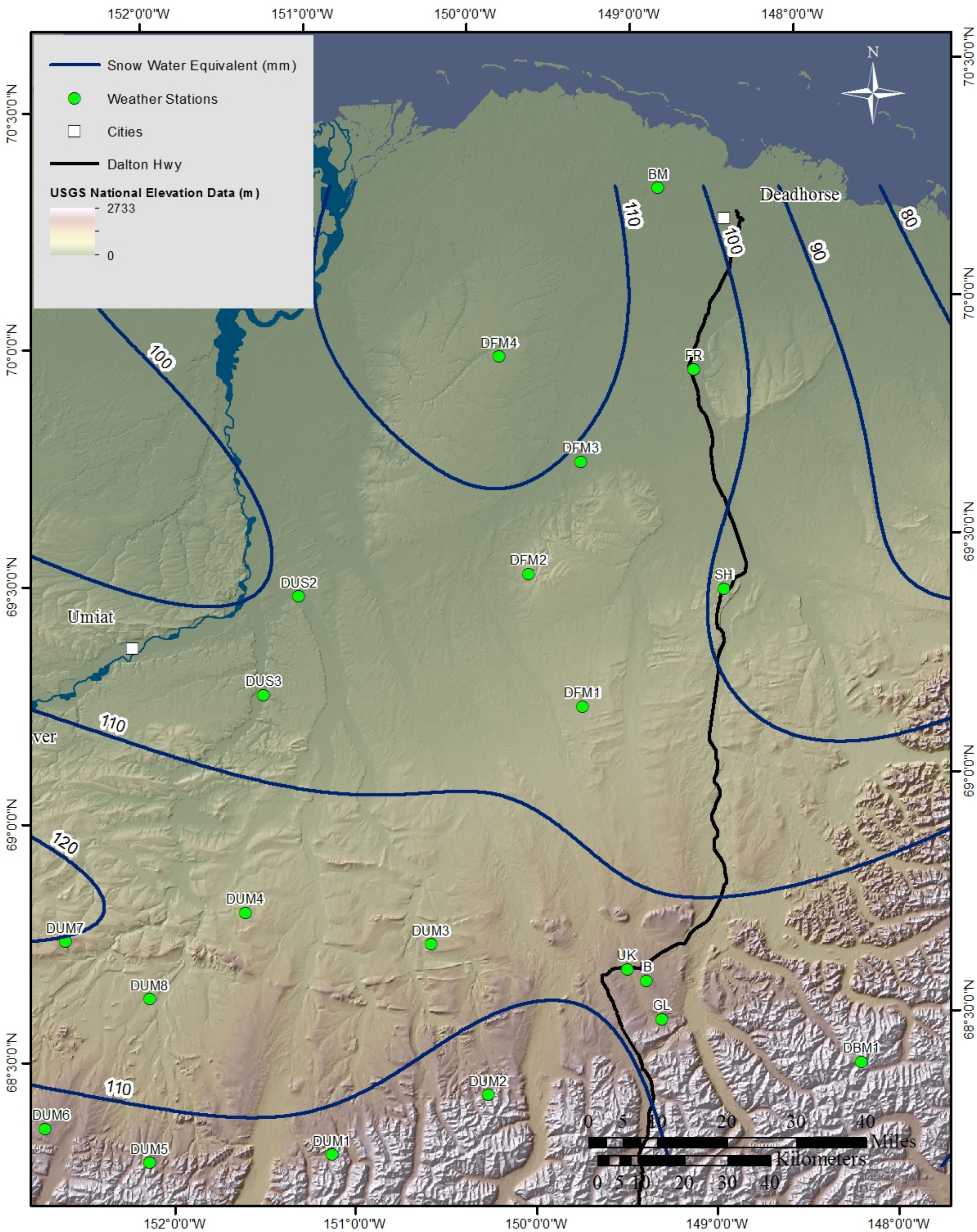


Figure 17. Contoured map of cold season precipitation from the central Alaskan Arctic. Point data were interpolated with Barnes interpolation method.

6.6 Annual Precipitation

To understand the hydrology of the North Slope of Alaska, we need good precipitation data, both solid and liquid. Through all of our studies on the North Slope, we have tried to capture the spatial distribution of precipitation throughout the year. This goal is challenging at the North Slope not only because the location is remote, but also because from eight to nine months of the year, the precipitation there is in solid form and extensively redistributed in the windy environment. In addition, sublimation can significantly reduce the snow water equivalent (SWE) on the ground at the end of winter. Our approach to quantifying SWE on the ground at winter's end is to measure both the depth and density at widely scattered and representative sites within the watersheds being studied. This task is accomplished by snow machine, helicopter, and walking (skiing and snowshoeing) to sites along the road system. The main problem with this approach is that the snow surveys can be performed too early, with the possibility of additional snowfall before ablation. The idea behind this approach is to capture the spatial distribution of the SWE after redistribution by the wind and most of the sublimation has taken place. Of course, the major concern is whether the measurement sites picked are truly representative of the general snow conditions of the surrounding area.

Rainfall precipitation was measured at the meteorological stations using a tipping bucket rain gauge. We have used these gauges since 1985 on the North Slope, and they have performed fairly well for liquid precipitation events. When we get solid precipitation during the summer (and it can and has happened), these gauges may not perform so well. During small events, the solid precipitation is collected in the 8-inch (~20 cm) orifice; however, this captured precipitation is not recorded until later when it melts. For large events like the August 2002 event (Kane et al., 2008b), the orifice is overwhelmed by the amount of solid precipitation and spills down to the ground around the orifice. The main problems with these gauges are wildlife and the environment.

Annual precipitation varies temporally and spatially over the North Slope. In the higher elevations of foothills and mountains, annual precipitation is made up of approximately 33% solid precipitation and 67% liquid precipitation (Kane et al., 2004). On the coastal plain, the total contribution from rainfall increases to slightly more than 50%. In general, rainfall precipitation increases with elevation, while solid precipitation SWE on average is fairly constant from the Arctic Ocean to the continental divide in the Brooks Range.

In the two previous sections, we presented contoured maps of warm season and cold season precipitation with a strong north–south increasing trend in warm season trend and no pattern for the cold season precipitation. For the average annual precipitation total (Figure 18), there is also a strong north-to-south increasing trend, mainly because warm season precipitation is usually greater than cold season precipitation. Along the coast, annual precipitation averages around 140 to 160 mm, and along the northern fringe of the Brooks Range, the average is 340 mm.

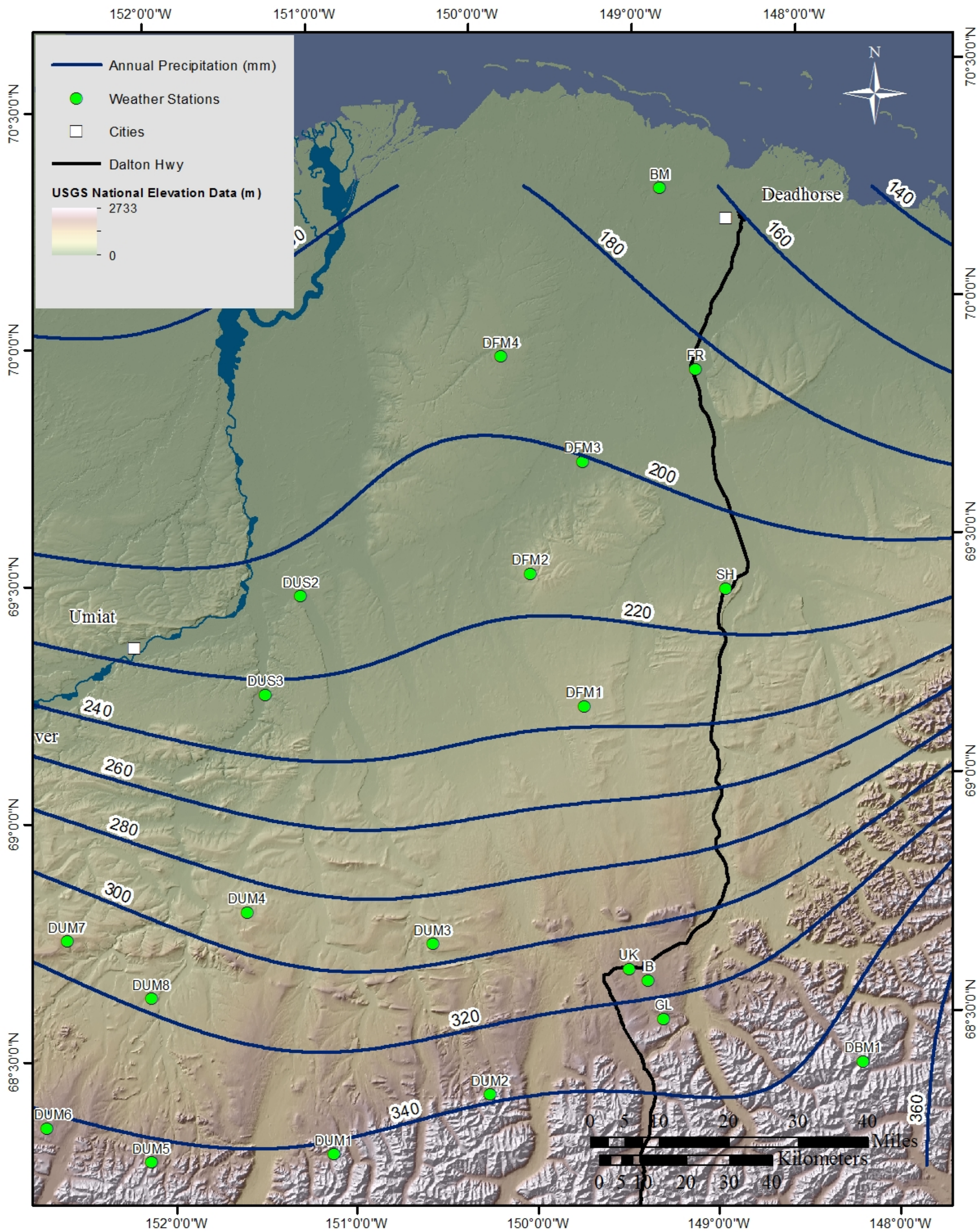


Figure 18. Contoured map of average annual precipitation for the central Alaskan Arctic. Point data were interpolated with Barnes interpolation method.

6.7 Soil

Improving our understanding of soil conditions throughout the year is necessary to interpret the hydrologic response of arctic watersheds. Soil temperature is needed for certain hydrologic or energy-balance models, geotechnical applications, winter tundra-travel requirements, and climate studies. Soil moisture content is an important part of the hydrologic cycle. The presence of either well-drained or poorly drained soil conditions, such as those found at foothills or coastal plain stations, respectively, will impact feasibility and costs of road construction.

As part of the Kuparuk Foothills/Umiat Corridor projects, soil pits are dug at nearly all meteorological stations in order to describe the soil conditions at the station and install soil moisture and temperature sensors. The study area extends from the Kuparuk River basin in the east to the Chandler River basin in the west. An explanation of how soil descriptions were obtained can be found in the previous project data and analysis report by Kane et al. (2012). A brief summary of the soil properties of each station are included in Table 17.

Table 17. Soil description for each station.

Station Name	Max Depth of Soil Temp. Sensor	Site Description	Soil Description
DBM1 - Accomplishment Creek	N/A	Mountainous	Large rocks and weathered bedrock at surface.
DFM1 - South White Hills	150	Upland with small rolling hills	Thin organic layer (0-5 cm) underlain by dense, homogenous grey mineral soil. One vein of organic soil within pit. Bottom of soil pit at 50 cm is dry.
DFM2 - White Hills	150	Foothills, located at the flat ridgetop of a large hill	Weathered bedrock at surface. Poorly consolidated mineral soil with pebbles. No organic layer.
DFM3 - North White Hills	120	Boundary of Foothills/Coastal Plain with small rolling hills. Poorly drained, fairly flat, tussock tundra with small shrubs.	Organic layer (0-20 cm) underlain by mineral soil. Gradual transition to mineral with some mixing.
DFM4 - Northwest Kuparuk	150	Coastal Plain, flat, tussock tundra.	Organic layer (0-10 cm) underlain by mineral soil. Water accumulation at bottom of pit at ~75 cm bgs.
DUM1 - Itikmalakpak	80	Rocky mountain site with tundra at surface in vicinity of station. Pass saddle.	Coarse-loamy, mixed, pergelic Ruptic Histoturbel. Organic layer (0-15 cm), and mineral soil at 15-50+ cm bgs.
DUM2 - Upper May Creek	N/A	Mountainous region, flat rocky ridgetop	Fragmental, mixed pergelic Lithic Eutrogelepts. Weathered bedrock at surface. Mineral and rocky soil from 0-35 cm bgs. Large gravel and cobbles up to 25 cm width.
DUM3 - Nanushuk	100	Foothills region, tundra. Moraine, upper part of ridge.	Fragmental, mixed, pergelic Lithic Eutrogelepts; Rocky for first 1-15cm; Organic layer (0-20 cm) underlain by mineral soil 20-100+ cm bgs.

Station Name	Max Depth of Soil Temp. Sensor	Site Description	Soil Description
DUM4 - Tuluga	100	Foothills region, site on a rocky ledge, sparse tundra in area. Moraine. Upper shoulder/ridge of hill.	Organic layer 0-20 cm bgs, Mineral soil ~20-120 cm bgs.
DUM5 - Encampment Creek	N/A	Mountainous ridge up against high mountains	Large rocks and boulders at surface.
DUM6 - White Lake	60	Upland mountainous site with sedges, mosses, lichen and many boulders. 100 m from crest of ridge.	Thin organic layer above weathered bedrock.
DUM7 - Hatbox Mesa	60	Foothills region, at the edge of wide water track. Very broad area of grass/sedge. Wet between tussocks. Slightly sloping to the south.	~10 cm of organic layer at surface.
DUM8 - Siksikpuk	60	Foothills region, Upland tundra, sedge, mosses, lichens.	N/A
DUS2 - Anaktuvuk River	80	On boundary between foothills and Coastal Plain. Thaw-lake basin within Anaktuvuk River floodplain, sedge, tussocks, mosses. Polygons 6 m diameter	Coarse-silty, euic, pergelic Terric Sapristel. Organic layer (0-20 cm) and mineral soil to 85 cm bgs. Frozen rocky mineral soil below 85 cm.
DUS3 - Chandler River	N/A	Adjacent to river on bluff above floodplain. Frost/mud boils with nearby thermokarst feature causing erosion. At depth bedrock is present (based on observations of river cut bank)	N/A

6.7.1 Soil Temperature

The soil temperature profile (0 to up to 150 cm below ground surface [bgs] depending upon local conditions) over the period of record for the South White Hills station (DFM1) is shown in Figure 19 as an example to aid in the general understanding of soil temperatures within the study area. Although a few shallow sensor data are removed because of sensor drift, updated soil temperature data through 2013 support observations from the previous 2012 report. For instance, soil temperatures at each depth below ground surface rise rapidly in the spring, while fall season freezing is a slower process. In the fall, the soil temperatures remain near 0°C during the water-to-ice phase change (known as the zero curtain). The deeper soil is warmer in the winter and cooler in the summer. The deeper soils (~> 50 cm) warm significantly during the spring, but soil temperatures never rise above 0°C. Soil temperature variability decreases with increasing depth from the ground surface.

Phase changes during freezing and thawing are evident in Figure 19. The figure shows that the freezing phase change during fall takes longer than the thawing phase change in spring; the time for this phase-change cycle to occur is directly related to soil type and soil moisture content. Soils typical of this location (South White Hills) generally have a shallow layer of organic material at the surface (15–20 cm), resulting in low soil moisture content except following snowmelt and significant rain events. The deeper mineral soils are generally near saturation. When frozen, these soils have a low hydraulic conductivity. Deeper mineral soils do not show rapid warming in spring, which implies that water does not migrate beyond the shallow soils during ablation.

6.7.1.1 Results

Surface soil-temperature (temperature at the ground surface) statistics (averages, maximum, and minimum) for each station by month are included in Appendix D. Soil surface temperature and soil temperature at depth as time series plots are also available for all stations for the period of record in Appendix D. Maximum periods of record length span from October 1, 2006, to October 21, 2013. Period of records for each station are indicated on the table in Appendix D.

Average monthly soil temperature through the soil profile at the three reference stations for selected months can be found in the previous project data and analysis report by Kane et al. (2012). In summary, the soil temperature profiles showed that the coldest temperatures occurred near the surface during the coldest spring months and, as temperatures warm during summer, the active layer thickness reaches its maximum in late August and early September.

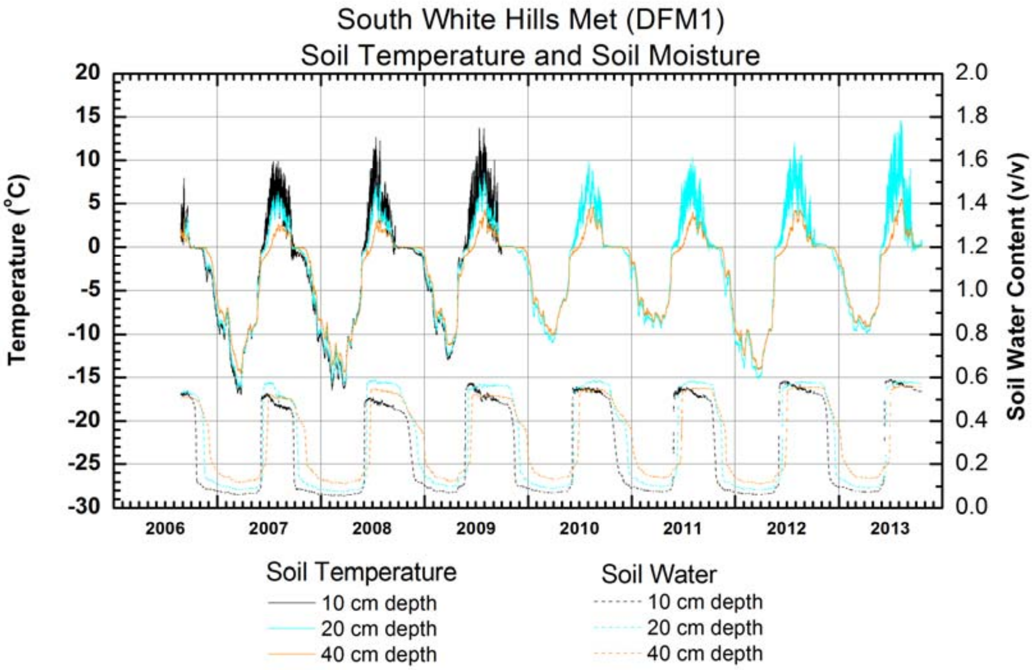


Figure 19. Soil temperatures and soil moisture at the South White Hills (DFM1) station as a function of depth for the period of record.

Average soil temperatures are again compared by year and by region by examining the average soil temperature at each station. Table 18 shows the average soil temperatures for 2007 through 2013 water years (October 1 through September 30) at depths of 60 cm and 100 cm bgs. Temperature sensor depths vary for each station and range from 0 to 150 cm bgs. The two depths are selected based on availability of data. The measurement duration of each site varies because of funding for ongoing research and lack of data due to faulty equipment (environment, animal damage, etc.). Averages are not presented in Table 18 for stations with incomplete or absent data sets for the 60 cm or 100 cm depths below ground surface.

Compilation of the recent data with that of the 2012 report showed similar and consistent regional results. The coastal plain region and the higher latitude foothills region have the coldest regional soil temperatures, and the mountains (or the most southern foothills stations) region has the warmest regional soil temperatures. The average annual soil temperature in the profiles ranges from about -0.1°C at Tuluga (DUM4, 2011) to -7.2°C at North White Hills (DFM3, 2008). One southern Foothills region station in the Anaktuvuk basin, Tuluga (DUM4), produced consistent results with only slightly below-freezing average annual soil temperatures. In general, we observe the warmest annual average soil temperature in the south and the coolest soil temperature in the north. Based on limited available data, water year 2010 (October 1, 2009, through September 30, 2010) appears to be the warmest year during the study period of 2007 through 2013. But this can vary spatially as does the depth and distribution of the winter snow cover.

Table 18. Average annual soil temperature at 60 and 100 cm bgs (generally listed from south to north in latitude).

Station	Average Soil Temperature (°C) by water year (Oct 1 – Sept 30)													
	2007		2008		2009		2010		2011		2012		2013	
	60 cm bgs	100 cm bgs	60 cm bgs	100 cm bgs	60 cm bgs	100 cm bgs	60 cm bgs	100 cm bgs	60 cm bgs	100 cm bgs	60 cm bgs	100 cm bgs	60 cm bgs	100 cm bgs
Itikmalakpak (DUM1)[m]							-1.21		-0.62		-1.23			
Nanushuk (DUM3)[f]							-0.86	-1.03	-1.11	-1.21	-2.55	-2.54		
Tuluga (DUM4)[f]							-0.67	-0.86	-0.56	-0.08	-1.41			
S. White Hills (DFM1)[f]	-4.22		-4.52		-2.41		-0.13		-2.11		-4.13		-2.22	
White Hills (DFM2)[f]	-5.80	-5.89				-2.89								
Anaktuvuk River (DUS2)[f]							-5.92		-4.27					
N. White Hills (DFM3)[f]			-7.23		-6.34		-2.20		-5.03		-6.73		-6.14	
Northwest Kuparuk (DFM4)[c]	-6.12	-6.16	-6.22	-6.36	-4.13	-4.53	-1.08	-1.05	-2.43	-3.15	-4.11	-4.48		

m = Mountain, f = Foothills, c = Coastal Plain, bgs = below ground surface

The depth at which maximum annual soil temperature is always less than 0°C is a good indicator of the maximum thaw depth for that year, or the active layer thickness. Maximum soil temperatures and minimum active layer thickness are generally reached during late August or early September. Results and further discussion on active layer delineation of the three referenced stations can be found in the previous project data and analysis report by Kane et al. (2012).

6.7.2 Soil Moisture

At each of the permanent meteorological and hydrological stations, soil moisture observations were made. The only exceptions were where the ground was too rocky to install time domain reflectometry (TDR) probes. The methodology of using TDR probes developed in the last 30 years for measuring unfrozen water content by examining the di-electric properties of the soil (Stein and Kane, 1983). Different soils, such as organic and mineral, have different relationships between the di-electric properties and soil water content; therefore, they must be calibrated. It is clear when freezing and thawing of the active layer is ongoing. During winter months, the unfrozen moisture content drops to single digits, while during the warm season, it can reach as high as saturation (especially following snowmelt). Organic soils have a high porosity, but typically drain readily. Mineral soils have higher porosities than would be expected; this is due to repeated freezing and thawing each year and the development of ice lenses.

Each location where soil moisture measurements were made had its own distinct soil characteristics that included the active layer thickness throughout the summer, the thickness off the surficial organic layer, bulk density, and other properties such as aspect, slope, and elevation. In this area of continuous permafrost, a layer of organic soil is generally over the mineral soil. The thickness of the organic soil layer can vary substantially from 10 cm or less to greater than 1 m over relatively short distances. The active layer, that layer that freezes and thaws each year, can vary from 30 to 40 cm to greater than 1 m in well-drained sites (areas of deeper thaw generally have lower soil moisture ice contents at winter's end; thus they thaw deeper, since less energy is needed for phase change). The presence of ground squirrels is a good indication of a deeper active layer, as they like to excavate their burrows as deep as possible to avoid bears without digging into the permafrost.

Generally, areas with low topographically controlled hydraulic gradients (coastal plain) have higher moisture contents throughout the soil profile. In the foothills and mountains, the soils drain better and the organic layer has lower volumetric soil moisture content. The mineral soils stay near saturation (Hinzman et al., 1991) at all physiographic settings, except during extended periods of minimal or no warm season precipitation, which is common immediately following snowmelt. Then an onset of decline in soil moisture occurs in the top of the mineral soil.

6.7.2.1 Results

In Figure 20, Figure 21, and Figure 22, the typical unfrozen water content by volume is shown for several years at a mountain, foothills, and coastal plain site in the study region. As shown in Figure 20, at the mountain site (Itikmalakpak Met, DUM1), the top 15 cm of soil is organic with the soil moisture content by volume being the lowest of all depths during the summer. The sensor at the 40 cm depth is located near the bottom of the active layer at summer's end. This sensor shows early upward freezing in the fall, probably due to freeze-back from the underlying permafrost. Throughout summer, the soil moisture content increased with depth. During the warm season, a gradual decline in soil moisture content occurred at all depths, with the highest moisture contents early in the warm season. The range of soil moisture values measured at this mountain site is typical of other similar sites.

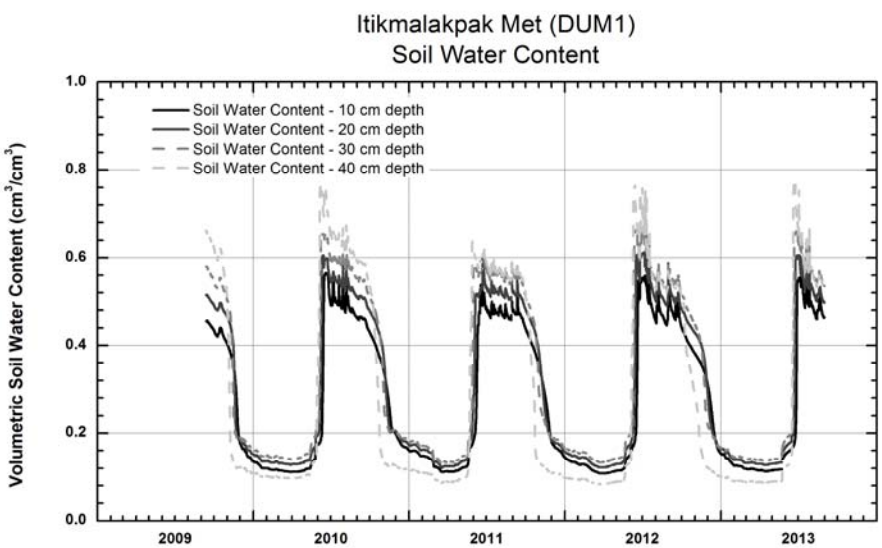


Figure 20. Soil moisture at Itikmalakpak (DUM1) station, 2006–2013.

Observed soil moisture values for a foothill site in the Kuparuk basin (South White Hills Met, DFM1) are shown in Figure 21 for 2006 to 2013. The variation each year is quite similar with the exception of 2007 and 2008, when moisture levels were slightly lower due to drought conditions those years. Except for a bit of variation from year to year, this plot of soil water content is quite typical.

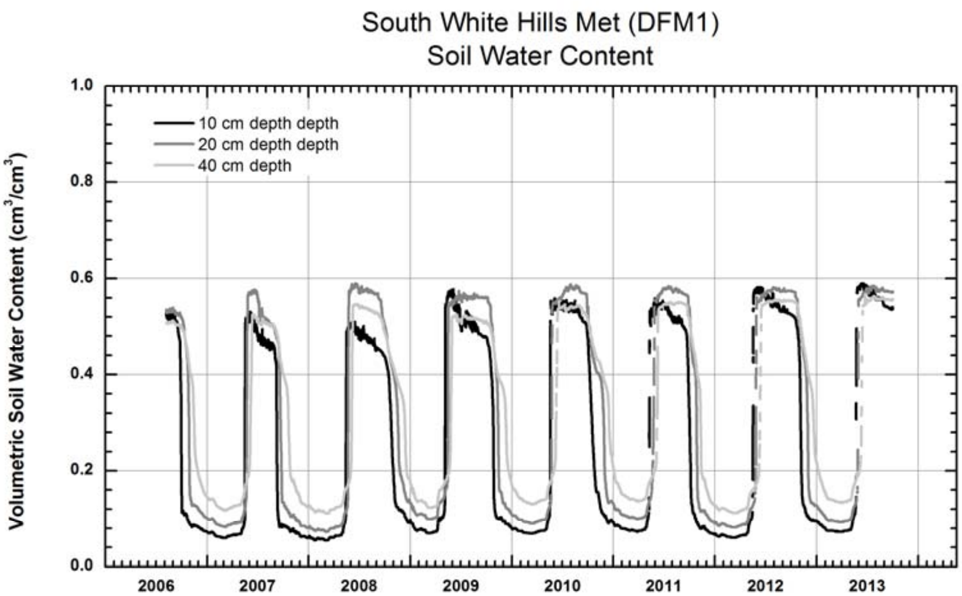


Figure 21. Soil moisture at South White Hills (DFM1) station, 2006–2013.

The final soil water content plot is of a site near the outlet of the Anaktuvuk basin (Figure 22). Sensors are installed at 10, 20, 30, and 40 cm depths, with the 20 cm probe at the interface of the organic and mineral soils. The site is the wettest of the three as would be expected for low hydraulic gradient terrain. The 40 cm probe is installed just above the permafrost; during some years (such as 2010), thawing of the 40 cm depth is only partial. The surficial organic soils dry out each summer, and in 2012, rewetting of the surficial organic soils due to warm season precipitation is evident.

The three soil water content curves show some of the variation that exists over the three main physiographic areas (mountains, foothills, and coastal plain). While there are some exceptions to the above graphs, in general they are representative of what would be found in each physiographic region.

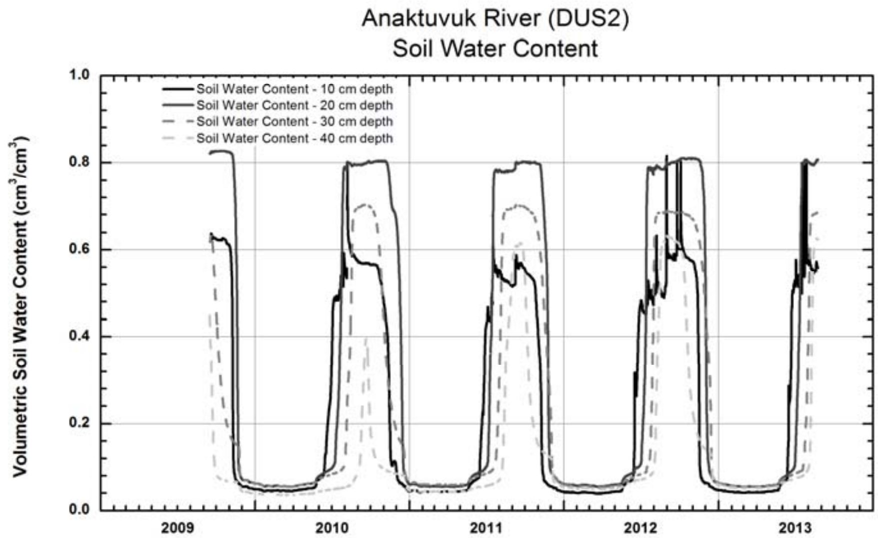


Figure 22. Soil moisture at Anaktuvuk River (DUS2) station, 2006–2013.

6.8 North Slope Climatology

6.8.1 Air Temperature

The presence of continuous permafrost is an indication of below-freezing air temperatures throughout the area of study. Mean annual air temperatures at the meteorological stations for the period of record are shown in Table 19; only years with a complete data set are used. The number of years with complete records varies from 2 to 27 years. The stations with the longest record are all in the Kuparuk River basin (Franklin Bluffs, 24 years; Sagwon Hill, 19 years; Upper Kuparuk, 14 years; Imnavait, 27 years; and Green Cabin Lake, 14 years). Stations in the Itkillik, Anaktuvuk, and Chandler River basins all have relatively short periods of air temperature measurements (2 to 6 years). There is a north-to-south pattern of lower-to-higher mean annual air temperatures (Figure 23) in the Kuparuk watershed as well as the three watersheds to the west with shorter records. Some local variation occurs, attributed to the local topography in the vicinity of the stations. Some stations are located in drainages, while others are located higher, on ridges or plateaus. For example, the Anaktuvuk meteorological station is located next to the river, and although some distance from the coast, it has fairly low air temperatures (~10°C, 14°F).

Table 19. Average annual air temperature at stations in study area.

Station Name	ID	Annual Average Air Temperature (°C)	Annual Average Air Temperature (°F)	No. of Complete Years in Record
Franklin Bluffs	FB	-10.5	13.2	24
Anaktuvuk River	DUS2	-10.2	13.7	3
Northwest Kuparuk	DFM4	-10.5	13.1	6
Sagwon Hills	SH	-8.2	17.3	19
South White Hills	DFM1	-9.8	14.3	6
North White Hills	DFM3	-10.8	12.6	6
White Hills	DFM2	-8.6	16.5	4
Siksikpuk	DUM8	-9.3	15.2	2
Tuluga	DUM4	-7.5	18.5	2
Nanushuk	DUM3	-8.3	17.1	4
Hatbox Mesa	DUM7	-8.5	16.7	2
Upper Kuparuk	UK	-8.8	16.2	14
Imnavait	IB	-7.7	18.2	27
Green Cabin Lake	GCL	-6.2	20.9	14
White Lake	DUM6	-7.8	17.9	2
Itikmalakpak	DUM1	-7.4	18.6	2
Encampment Dr	DUM5	-7.5	18.5	2
Upper May Creek	DUM2	-6.8	19.7	3
Accomplishment Creek	DBM1	-7.9	17.7	6

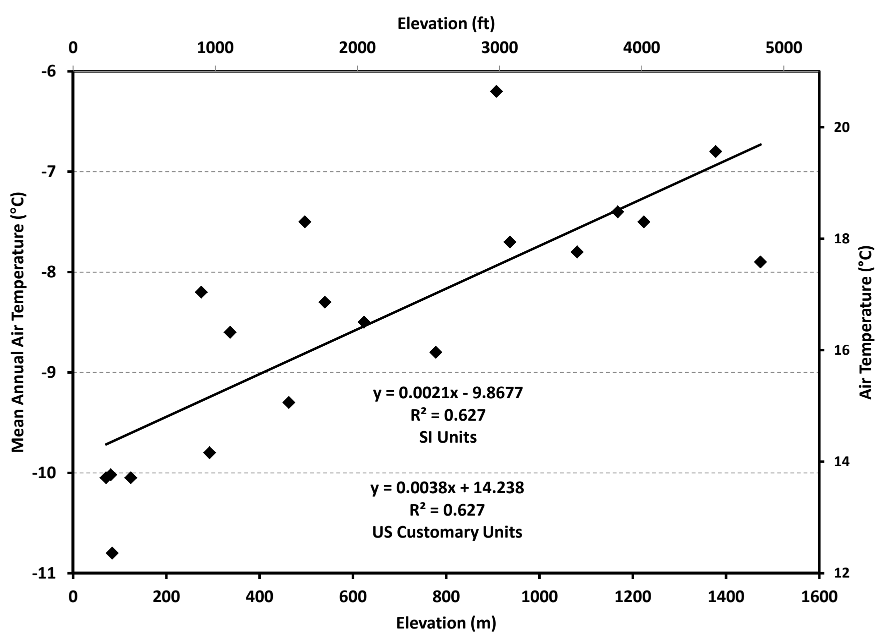


Figure 23. Mean annual air temperature as a function of elevation for meteorological stations in the central North Slope.

The northern stations, in the transition from the coastal plain to the foothills, have mean annual temperatures below -10°C (15°F). General warming occurs as one travels south through the foothills, with mean annual air temperatures in the ~ -7 to -9°C (~19 to 16°F) range. The warmest mean annual air temperatures are at higher elevations (Figure 23) in the northern Brooks Range. The mean annual mountain air temperatures are in the -6 to -7°C (21 to 19°F) range. A comparison of mean annual air temperatures for stations with a long record and stations with a short record in the three physiographic areas yields similar results.

We have not found any trends in our air temperature data that would indicate a change in climate. The fact that most of our stations have quite short records limits this analysis. Only Imnavait Creek has a relatively long record, but we do not see any trend in the data that would indicate climate change.

6.8.2 Precipitation

6.8.2.1 Warm Season Precipitation

As stated earlier in this report, cumulative warm season precipitation increases from lower elevations to higher elevations; so as elevations increase southward, greater precipitation is expected during the summer months. Summarized in Table 20 and Table 21 is cumulative annual precipitation for each summer, the average warm season precipitation, along with the statistics of maximum, minimum, and standard deviation for the period of record. We have six stations that could be considered relatively long-term stations (for research installations): Betty Pingo (n = 16 years), Franklin Bluffs (n = 27), Sagwon Hill (n = 27), Upper Kuparuk (n = 18), Imnavait (n = 29), and Green Cabin Lake (n = 18). While stations on the North Slope that were established earlier on other projects had a longer history, data collected on this project at newly established stations had a maximum life of eight years, with the shortest (Rooftop Ridge) having only two years of data collection.

Like most environments, considerable spatial and temporal variation occurs in precipitation. In this study area, most of the precipitation variation occurs during the warm season. If one examines the column of average annual precipitation in Table 20 and Table 21 (arranged by elevation from left to right), the increase in precipitation with elevation is clear. Both wet and dry years have been documented in the data set.

Table 20. Total annual rainfall measured at each meteorological station along with statistics on the average, maximum, minimum, and standard deviation (stations arranged from lowest to highest elevation). (Part one of two-part table; see Table 21).

Year	Total Annual Rainfall by Station - mm (in)										
	Betty Met	Franklin Bluffs	Anaktuvuk River	N White Hills	Chandler Bluff	NW Kuparuk	Sagwon Hill	S White Hills	White Hills	Siksikpuk River	Tuluga
1985											
1986											
1987		48 (1.9)					60 (2.4)				
1988		65 (2.6)					93 (3.7)				
1989		130 (5.1)					131 (5.2)				
1990		93 (3.7)					105 (4.1)				
1991		73 (2.9)					96 (3.8)				
1992		74 (2.9)					130 (5.1)				
1993		74 (2.9)					79 (3.1)				
1994		98 (3.9)					120 (4.7)				
1995		84 (3.3)					135 (5.3)				
1996	53 (2.1)	94 (3.7)					138 (5.4)				
1997	92 (3.6)	98 (3.9)					120 (4.7)				
1998	57 (2.3)	66 (2.6)					37 (1.5)				
1999	104 (4.1)	62 (2.4)					131 (5.2)				
2000	59 (2.3)	99 (3.9)					103 (4.1)				
2001	76 (3.0)	93 (3.7)					137 (5.4)				
2002	137 (5.4)	139 (5.5)					162 (6.4)				
2003	108 (4.2)	86 (3.4)					152 (6.0)				
2004	112 (4.4)	113 (4.4)					135 (5.3)				
2005	50 (2.0)	52 (2.0)					67 (2.6)				
2006	104 (4.1)	100 (3.9)					153 (6.0)	94 (3.7)	106 (4.2)		
2007	15 (0.6)	9 (0.4)		18 (0.7)		21 (0.8)	27 (1.1)	47 (1.9)	36 (1.4)		
2008	82 (3.2)	74 (2.9)		79 (3.1)		93 (3.7)	127 (5.0)	131 (5.2)	179 (7.0)		
2009	93 (3.6)	19 (0.7)	101 (4.0)	109 (4.3)		98 (3.8)	129 (5.1)	199 (7.8)	178 (7.0)		163 (6.4)
2010	54 (2.1)	62 (2.4)	86 (3.4)	46 (1.8)		80 (3.1	64 (2.5)	127 5.0)	84 (3.3)		158 (6.2)
2011	56 (2.2)	54 (2.1)	115 (4.5)	84 (3.3)	66 (2.6)	77 (3.0)	102 (4.0)	119 (4.7)		140 (5.5)	211 (8.3)
2012		96 (3.8)	145 (5.7)	84 (3.3)	130 (5.1)	67 (2.6)	151 (5.9)	155 (6.1)	149 (5.9)	174 (6.9)	153 6.0)
2013		110 (4.3)	115 (4.5)	133 (5.2)	119 (4.7)	89 (3.5)	123 (4.8)	178 (7.0)		120 (4.7)	208 (8.2)
Max	137 (5.4)	139 (5.5)	145 (5.7)	133 (5.2)	130 (5.1)	98 (3.9)	162 (6.4)	199 (7.8)	179 (7.0)	174 (6.9)	211 (8.3)
Min	15 (0.6)	9 (0.4)	86 (3.4)	18 (0.7)	66 (2.6)	21 (0.8)	27 (1.1)	47 (1.9)	36 (1.4)	140 (5.5)	153 (6.0)
Average	78 (3.1)	80 (3.2)	112 (4.4)	79 (3.1)	105 (4.1)	75 (3.0)	111 (4.4)	131 5.2)	122 (4.8)	157 (6.2)	179 (7.0)
Std Dev	30.0 (1.2)	29.0 (1.1)	19.5 (0.8)	35.2 (1.4)	27.9 (1.1)	24.1 (0.9)	35.1 (1.4)	44.7 (1.8)	52.0 (2.0)	17.0 (0.7)	25.4 (1.0)

Table 21. Total annual rainfall measured at each meteorological station along with statistics on the average, maximum, minimum and standard deviation (stations arranged from lowest to highest elevation). (Part two of two-part table; see Table 20).

Year	Total Annual Rainfall by Station - mm (in)										
	Nanushuk	Hatbox Mesa	Rooftop Ridge	Upper Kuparuk	Imnavait Basin	Green Cabin Lake	White Lake	Itikmal-akpak	Encamp-ment Creek	Upper May Creek	Accomp-lishment Creek
1985					196 (7.7)						
1986					191 (7.5)						
1987					178 (7.0)						
1988					213 (8.4)						
1989					264 (10.4)						
1990					100 (3.90)						
1991					101 (4.0)						
1992					116 (4.6)						
1993					202 (16.6)						
1994				283 (11.1)	250 (9.9)						
1995				298 (11.7)	211 (8.3)						
1996				221 (8.7)	148 (5.8)	243 (9.6)					
1997				359 (14.1)	308 (12.1)	189 (7.4)					
1998				219 (8.6)	246 (9.7)	215 (8.5)					
1999				296 (7.1)	342 (13.5)	323 (12.7)					
2000					232 (9.1)	209 (8.2)					
2001					204 (8.0)	160 (6.3)					
2002				256 (10.1)	300 (11.8)	222 (8.7)					
2003				147 (5.8)	310 (12.2)	271 (10.7)					
2004				62 (2.4)	213 (8.4)	189 (7.4)					
2005				145 (5.7)	119 (4.7)	127 (5.0)					
2006				203 (8.0)	252 (9.9)	226 (8.9)					
2007				100 (3.9)	121 (4.7)	130 (5.1)					182 (7.2)
2008				237 (9.3)	231 (9.1)	166 (6.5)					217 (8.5)
2009	147 (5.8)			243 (9.6)	255 (10.0)	214 (8.4)		154 (6.1)		234 (9.2)	276 10.9)
2010	162 (6.4)			245 (9.6)	221 (8.7)	220 (8.7)		134 (5.3)		362 (14.3)	160 (6.3)
2011	130 (5.1)	189 (7.4)		114 (4.5)	129 (5.1)	122 (4.8)	262 (10.3)	117 (4.6)	269 (10.6)	227 (8.9)	
2012	126 (5.0	233 (9.2)	267 (10.5)	236 (9.3)	266 (10.5)	237 (9.3)	303 (11.9)	124 (4.9)	357 (14.1)	363 (14.3)	152 (6.0)
2013	92 (3.6)	205 (8.1)	230 (9.1)	233 (9.2)	259 (10.2)	223 (8.8)	190 (7.5)	147 (5.8)	200 (7.9)	306 (12.0)	
Max	162 (6.4)	233 (9.2)	267 (10.5)	359 (14.1)	342 (13.5)	323 (12.7)	303 (11.9)	154 (6.1)	357 (14.1)	363 (14.3)	276 (10.9)
Min	92 (3.6)	189 (7.4)	230 (9.1)	62 (2.4)	100 (3.9)	122 (4.8)	190 (7.5)	117 (4.6)	200 (7.9)	227 (8.9)	152 (6.0)
Average	131 (5.2)	209 (8.2)	249 (9.8)	217 (8.5)	213 (8.4)	205 (8.1)	252 (9.9)	135 (5.3)	275 (10.8)	298 (11.7)	197 (7.8)
Std Dev	23.5 (0.9)	18.2 (0.7)	18.5 (0.7)	74.5 (2.9)	64.9 (2.6)	49.9 (2.0)	46.7 (1.8)	13.8 (0.5)	64.3 (2.5)	59.2 (2.3)	45.3 (1.8)

The maximum warm season precipitation exceeded 350 mm (13.8 in.) at three stations (Upper May Creek and Encampment in the mountains and Upper Kuparuk at the southern edge of the foothills), generally fitting the pattern of precipitation increasing at higher elevations. Upper May

Creek in the mountains, with only five years of rainfall data, has the two highest wet years (363 and 362 mm, 14.3 in.) and the highest station average (298 mm, 11.7 in.).

The lowest seasonal rainfall on the central Alaskan Arctic happened over the summer of 2007. Only 9 mm (0.35 in.) fell at Franklin Bluffs on the coastal plain over the whole of the summer. Other stations with minimal rainfall were Betty Pingo (15 mm, 0.59 in.), North White Hills (18 mm, 0.71 in.), and Northwest Kuparuk (21 mm, 0.83 in.), all on or very close to the coastal plain. In general, it was dry over all three physiographic regions; the largest recorded tundra fire burned that summer between the Itkillik and Anaktuvuk Rivers.

Using the three stations with the longest records (Franklin Bluffs on the coastal plain, Sagwon Hill at the transition from coastal plain to foothills, and Imnavait Creek close to the mountains), we can analyze the warm season rainfall statistics. At Franklin Bluffs, the average warm season precipitation is 80 mm (3.15 in.), with the maximum of 139 mm (5.47 in.), minimum of 9 mm (0.35 in.), and standard deviation of 29 mm (1.14). The two driest years were 2007 and 2009; the two wettest years were 1989 and 2002. The same statistics for Sagwon Hill were an average of 111 mm (4-37 in.), a maximum of 162 mm (6.38 in.), a minimum of 27 mm (1.06 in.), and a standard deviation of 35 mm (1.38 in). At Imnavait Creek, with 29 years of data, the statistics were an average of 213 mm (8.38 in.), a maximum of 342 mm (13.46 in.), a minimum of 100 mm (3.94 in.), and a standard deviation of 64.9 mm (2.56 in.). All of these statistics increase from north to south. Similar statistics are shown for all stations, but because of the short length of record for these stations, the results should be used with caution.

6.8.2.2 Cold Season Precipitation

At four sites, we have collected twenty years or more of end-of-winter data of snow on the ground. Reported in Table 22 is the average depth, density, and snow water equivalent (SWE) for four sites in the Kuparuk River basin on a south-to-north transect: Imnavait Creek, Sagwon Hills, Franklin Bluffs, and Betty Pingo; the first two are in the foothills and the last two are on the coastal plain. As these measurements are snow on the ground, some snow has sublimated and some has been repositioned by wind. We attempt to make measurements at maximum SWE, but during some years, additional precipitation occurs in the window between measurements and ablation. We do try to make corrections for this if possible (Stuefer et al., 2014). Also, these estimates are based on 5 density and 50 snow depth measurements at each site.

Snow depth (Table 22) has the greatest variation, and density has the least, with SWE in the middle. The maximum depth observed at winter's end was 70 cm (28 in.) at Franklin Bluffs in 1989. The shallowest snow depth was 11 cm (4 in.) at Sagwon Hills in 1988. Both of these observations are probably influenced by wind. The other two measurements in 1989 were 51 and 46 cm (20 and 18 in.) and in 1988, 30 and 27 cm (12 and 11 in.). The average snow depths, for the period of record, at each site were 43, 30, 36, and 37 cm (17, 12, 14, and 15 in.). The standard deviation between the four sites varied little, with a range of only 10 to 11 cm (~4 in.).

Average snow densities varied from 0.23 to 0.30 g/cm^3 (0.46 to 0.58 slugs/ft^3), with the highest densities on the coastal plain. The standard deviations for density varied from 0.02 to 0.06 g/cm^3 (0.04 to 0.12 slugs/ft^3).

Snow water equivalent values for the four sites averaged 11.1, 7.1, 10.3, and 9.7 cm of water (4.4, 2.8, 4.0, and 3.8 in. of water). Sagwon Hill site has the lowest SWE; it also has the lowest depth and density of snow. The standard deviations of the SWEs are all consistently around 3 cm (1.2 in.).

Generally, the overall average snowpack conditions are fairly uniform on the North Slope from the Arctic Ocean to the continental divide in the Brooks Range. However, when there is a near record high or low event at one site, it is not likely to be repeated at the remaining sites. Occasionally, two sites will have either a high or low snow event year, but the sites may not be adjacent.

Table 22. Long-term snow survey data (depth, density, and SWE) for four stations along the Dalton Highway from Imnavait Creek to Betty Pingo.

Year	Imnavait Creek (n = 26)			Sagwon Hills (n = 27)			Franklin Bluffs (n = 27)			Betty Pingo (n = 20)		
	Depth	Density	SWE	Depth	Density	SWE	Depth	Density	SWE	Depth	Density	SWE
	cm	g/cm3	cm	cm	g/cm3	cm	cm	g/cm3	cm	cm	g/cm4	cm
1985	41	0.24	9.9									
1986	41	0.27	11.2	32	0.16	5.1	21	0.23	4.9			
1987	44	0.23	10.2	25	0.21	5.3	30	0.28	8.3			
1988	30	0.25	7.3	11	0.23	2.6	27	0.35	9.5			
1989	51	0.25	12.5	46	0.33	15.0	70	0.32	22.2			
1990	42	0.28	11.7	19	0.26	5.0	18	0.31	5.6			
1991	48	0.23	11.0	25	0.22	5.6	42	0.27	11.2			
1992	62	0.29	17.9	38	0.22	8.4	27	0.29	7.8			
1993	47	0.26	12.5	17	0.36	5.9	35	0.39	13.7	16	0.33	5.2
1994	22	0.23	5.2	23	0.17	3.9	23	0.27	6.2	26	0.43	10.9
1995	32	0.29	9.3	15	0.24	3.6	29	0.30	8.6	27	0.41	11.2
1996	46	0.29	13.6	39	0.26	10.2	20	0.38	7.5	14	0.41	5.9
1997	43	0.27	11.3	39	0.30	11.6	32	0.28	9.0	50	0.34	17.0
1998												
1999			6.9			7.7			9.1			9.9
2000	44	0.24	10.8	33	0.21	6.8	42	0.24	10.2	52	0.30	15.4
2001	56	0.23	12.6	32	0.20	6.4	43	0.27	11.4	29	0.26	7.7
2002	42	0.23	9.6	51	0.24	12.2	35	0.24	8.5	30	0.25	7.4
2003	47	0.29	13.6	30	0.27	8.1	39	0.31	12.0	38	0.19	7.2
2004	44	0.26	11.5	41	0.28	11.3	43	0.33	14.1	33	0.31	10.1
2005	20	0.28	5.7	25	0.22	5.5	38	0.31	11.5	28	0.26	7.1
2006	41	0.23	9.4	33	0.18	6.0	45	0.23	10.2	38	0.32	12.0
2007	45	0.26	12.0	31	0.24	7.5	28	0.24	6.6	29	0.22	6.5
2008	36	0.22	7.7	19	0.19	3.6	38	0.26	9.7	38	0.30	11.4
2009	56	0.29	16.9	40	0.22	8.8	48	0.33	16.0	27	0.29	8.0
2010				23	0.21	4.7	43	0.31	13.3	41	0.29	11.8
2011				44	0.20	8.6	44	0.28	12.1	40	0.27	10.6
2012	47	0.29	14.0	30	0.20	6.1	47	0.24	11.3	37	0.28	10.3
2013	59	0.26	15.4	27	0.20	5.2	32	0.22	7.2	39	0.24	9.3
Average	43	0.26	11.1	30	0.23	7.1	36	0.29	10.3	33	0.30	9.7
Max	62	0.29	17.9	51	0.36	15.0	70	0.39	22.2	52	0.43	17.0
Min	20	0.22	5.2	11	0.16	2.6	18	0.22	4.9	14	0.19	5.2
Stdev	10	0.02	3.1	10	0.05	3.0	11	0.05	3.6	10	0.06	3.0

6.8.2.3 Annual Total Precipitation

We have between 14 and 27 years of both solid and liquid precipitation measurements at 4 meteorological stations (Table 23): Betty Pingo, Franklin Bluffs, Sagwon Hill, and Imnavait Creek. The values in Table 23 should not be accepted as true annual precipitation, as we do not account for precipitation that falls during winter and sublimates. Also, we probably miss some precipitation during the shoulder seasons (transitions from warm season to cold and then back again to the warm season), so it might be better to refer to this precipitation as “effective” precipitation. Most years, very little precipitation falls during March/April/May, so accurate measurements are not a significant problem, but there are years when considerable precipitation falls during this period. During the fall transition, considerable precipitation can occur.

Annual precipitation generally increases from north to south (increases with elevation). The yearly average at Betty Pingo (coastal plain) is 174 mm (6.9 in.), with the maximum, minimum, and standard deviation being 227 mm (8.9 in.), 100 mm (3.9 in.), and 43.5 mm (6.9 in.), respectively. At Franklin Bluffs (coastal plain), the average annual precipitation per year increases to 193 mm (7.4 in), with the maximum, minimum, and standard deviation equaling 353 mm (13.9 in.), 96 mm (3.8 in.) and 59.8 mm (2.4 in.). At Sagwon Hill—the transition from coastal plain to the foothills—the results are very similar to Franklin Bluffs. Finally, Imnavait Creek (basin in the foothills) has a much higher annual precipitation value of 334 mm (13.1 in.) for total precipitation; in 2003, the annual maximum was 495 mm (19.5 in.), and in 1991, the annual minimum was 183 mm (7.2 in.) with a standard deviation of 77 mm (3.0 in.).

The ratio of snowfall precipitation to rainfall precipitation varies over the area. Along the north–south transect from Betty Pingo to Imnavait Creek, the amount of rainfall goes from ~45% to 64% of annual precipitation. While most of the area gets similar amounts of snowfall, a significant increase in rainfall precipitation occurs at the higher elevations during the warm season.

Table 23. Table of annual precipitation (warm season rainfall, cold season solid precipitation, and annual) for four locations with a relatively long record of data.

Year	Betty n=14			Franklin Bluffs n=25			Sagwon n=24			Imnavait Basin n=27		
	Rainfall	SWE	Total	Rainfall	SWE	Total	Rainfall	SWE	Total	Rainfall	SWE	Total
	mm (in)	mm (in)	mm (in)	mm (in)	mm (in)	mm (in)	mm (in)	mm (in)	mm (in)	mm (in)	mm (in)	mm (in)
1985										196 (7.7)	106 (4.2)	302 (11.9)
1986										191 (7.5)	114 (4.5)	305 (12.0)
1987				48 (1.9)	85 (3.3)	133 (5.2)	60 (2.4)	52 (2.0)	112 (4.4)	178 (7.0)	100 (3.9)	278 (10.9)
1988				65 (2.6)	93 (3.7)	158 (6.2)	93 (3.7)	84 (3.3)	177 (7.0)	213 (8.4)	75 (3.0)	288 (11.3)
1989				130 (5.1)	223 (8.8)	353 (13.9)	131 (5.2)	91 (3.6)	222 (8.7)	264 (10.4)	130 (5.1)	394 (15.5
1990				93 (3.7)	56 (2.2)	149 (5.9)	105 (4.1)	44 (1.7)	149 (5.9)	100 (3.90)	99 (3.9)	199 (7.8)
1991				73 (2.9)	113 (4.4)	186 (7.3)	96 (3.8)	60 (2.4)	156 (6.1)	101 (4.0)	82 (3.2)	183 (7.2)
1992				74 (2.9)	80 (3.1)	154 (6.1)	130 (5.1)	74 (2.9)	204 (8.0)	116 (4.6)	153 (6.0)	269 (10.6)
1993		100 (3.9)		74 (2.9)	140 (5.5)	214 (8.4)	79 (3.1)	56 (2.2)	135 (5.3)	202 (16.6)	101 (4.0)	303 (11.9)
1994		73 (2.9)		98 (3.9)	61 (2.4)	159 (6.3)	120 (4.7)	109 (4.3)	229 (9.03)	250 (9.9)	80 (3.1)	330 (13.0)
1995		76 (3.0)		84 (3.3)	70 (2.8)	154 (6.1)	135 (5.3)	51 (2.0)	186 (7.3)	211 (8.3)	140 (5.5)	351 (13.8)
1996	53 (2.1)	47 (1.9)	100 (3.9)	94 (3.7)	69 (2.7)	163 (6.4)	138 (5.4)	83 (3.3)	221 (8.7)	148 (5.8)	102 (4.0)	250 (9.8)
1997	92 (3.6)	128 (5.0)	220 (8.7)	98 (3.9)	229 (9.0)	327 (12.9)	120 (4.7)	115 (4.5)	235 (9.3)	308 (12.1)	125 (4.9)	433 (17.0)
1998	57 (2.2)	78 (3.1)	135 (5.3)	66 (2.6)	65 (2.6)	131 (5.2)	37 (1.5)	17 (0.7)	54 (2.1)	246 (9.7)	95 (3.7)	341 (13.4)
1999	104 (4.1)	99 (3.9)	203 (8.0)	62 (2.4)	96 (3.8)	162 (6.4)	131 (5.2)	58 (2.3)	189 (7.4)	342 (13.5)	69 (2.7)	411 (16.2)
2000	59 (2.3)	128 (5.0)	187 (7.4)	99 (3.9)	147 (5.8)	246 (9.7)	103 (4.1)	100 (3.9)	203 (8.0)	232 (9.1)	112 (4.4)	344 (13.5)
2001	76 (3.0)	83 (3.3)	159 (6.3)	93 (3.7)	134 (5.3)	227 (8.9)	137 (5.4)	64 (2.5)	201 (7.9)	204 (8.0)	140 (5.5)	344 (13.5)
2002	137 (5.4)	90 (3.5)	227 (8.9)	139 (5.5)	85 (3.3)	224 (8.8)	162 (6.4)	100 (3.9)	262 (10.3)	300 (11.8)	126 (5.0)	426 (16.8)
2003	108 (4.3)	109 (4.3)	217 (8.5)	86 (3.4)	195 (7.7)	281 (11.1)	152 (6.0)	81 (3.2)	233 (9.2)	310 (12.2)	185 (7.3)	495 (19.5)
2004	112 (4.4)	81 (3.2)	193 (7.6)	113 (4.4)	91 (3.6)	204 (8.0)	135 (5.3)	110 (4.3)	245 (9.6)	213 (8.4)	120 (4.7)	333 (13.1)
2005	50 (2.0)	108 (4.3)	158 (6.2)	52 (2.0)	128 (5.0)	180 (7.1)	67 (2.6)	55 (2.2)	122 (4.8)	119 (4.7)	120 (4.7)	239 (9.4)
2006	104 (4.1)	120 (4.7)	224 (8.8)	100 (3.9)	100 (3.9)	200 (7.9)	153 (6.0)	60 (2.4)	213 (8.4)	252 (9.9)	96 (3.8)	348 (13.7)
2007	15 (0.6)	93 (3.7)	108 (4.3)	9 (0.4)	87 (3.4)	96 (3.8)	27 (1.1)	75 (3.0)	102 (4.0)	121 (4.7)	124 (4.9)	245 (9.6)
2008	82 (3.2)	91 (3.6)	172 (6.8)	74 (2.9)	92 (3.6)	166 (6.5)	127 (5.0)	80 (3.1)	207 (8.1)	231 (9.1)	88 (3.5)	319 (12.6)
2009	93 (3.7)	80 (3.1)	173 (6.8)	19 (0.7)	91 (3.6)	110 (4.3)	129 (5.1)	73 (2.9)	202 (8.0)	255 (10.0)	174 (6.9)	429 (16.9)
2010	54 (2.1)	111 (4.4)	165 (6.5)	62 (2.4)	92 (3.6)	154 (6.1)	64 (2.5)	51 (2.0)	115 (4.5)	221 (8.7)		
2011	56 (2.2)	106 (4.2)	162 (6.4)	54 (2.1)	139 (5.5)	193 (7.6)	102 (4.0)	86 (3.4)	188 (7.4)	129 (5.1)		
2012		55 (2.2)		96 (3.8)	130 (5.1)	226 (8.9)	151 (5.9)	70 (2.8)	221 (8.7)	266 (10.5)	138 (5.4)	404 (15.9)
2013				110 (4.3)			123 (4.8)			259 (10.2)	193 (7.6)	452 (17.8)
Max	137 (5.4)	128 (5.0)	227 (8.9)	139 (5.5)	229 (9.0)	353 (13.9)	162 (6.4)	120 (4.7)	262 (10.3)	342 (13.5)	193 (7.6)	495 (19.5)
Min	15 (0.6)	47 (1.9)	100 (3.9)	9 (0.4)	56 (2.2)	96 (3.8)	27 (1.1)	17 (0.7)	54 (2.1)	100 (3.9)	69 (2.7)	183 (7.2)
Average	78 (3.1)	93 (3.7)	174 (6.9)	80 (3.2)	113 (4.4)	193 (7.4)	111 (4.4)	73 (2.9)	184 (7.1)	213 (8.4)	118 (4.6)	334 (13.1)
Std Dev	30.2 (1.2)	21.4 (0.8)	43.5 (1.5)	29.0 (1.1)	45.4 (1.8)	59.8 (2.4)	35.1 (1.4)	23.1 (0.9)	50.5 (2.0)	64.9 (2.6)	31.3 (1.2)	77.0 (3.0)

6.9 Surface Water Hydrology

Hydrology data were collected at the three major proposed river crossings on the foothills route. The proposed road would cross the Itkillik, Anaktuvuk, and Chandler Rivers. Water levels are monitored in the three watersheds during most of the spring breakup period and summer. Since 2009, point discharge measurements are made several times during snowmelt and a few times during summer on the Anaktuvuk River. Beginning in summer 2010, the same measurements have been taken on the Upper Itkillik and Chandler Rivers and, since fall of 2012, on the Lower Itkillik. To document the hydrologic activity more completely, we also have cameras, pointed at the river, at all hydrological stations.

The purpose of this section is to summarize the water level and discharge results of the spring and summer runoff period for 2009 through 2013 on the rivers studied for the Umiat Corridor. Preliminary hydrologic results for the Itkillik, Anaktuvuk, and Chandler Rivers were presented in a data report (Youcha et al., 2011) and in Kane et al. (2012) to ADOT&PF. This report provides updated data and the most recent findings.

6.9.1 Itkillik River

The Itkillik River is a long, narrow basin that originates at a few small glaciers in the Endicott Mountains (up to 2000 m elevation). Two gauge sites were established on the Itkillik River to observe the conditions at two river crossing alternatives. In early May 2009, UAF installed an observation station approximately 5.5 km to the south (upstream) of the ADOT&PF proposed foothills route bridge crossing. In fall 2013, UAF established a new downstream gauging station called the Lower Itkillik Station, located near the Meltwater/Pump Station route proposed bridge crossing, approximately 77 km north of the Upper Itkillik station. The Upper Itkillik has a basin area of approximately 1900 km^2 and is 153 km long (above the Upper Itkillik gauging site). The Lower Itkillik (above the lower gauge site) has a basin area of 2944 km^2 and is 245 km long. The Itkillik River eventually flows into the Colville River near the Colville delta on the coastal plain. The maximum elevation of the basin is approximately 2300 m in the mountains; the lowest elevation is around 90 m at the Lower Itkillik station.

Both stations record water levels every 15 minutes. In fall 2010, UAF began making discharge measurements on the river near the Upper Itkillik station. In fall 2013, UAF began measuring discharge at the lower station. The previous data reports (Youcha et al., 2011; Kane et al., 2012) summarize the early results of the project and provide more details on the breakup events of 2009–2011. This section includes updated stage and discharge data through 2013, and summarizes spring breakup in 2013 at the Upper and Lower Itkillik stations.

6.9.2 Upper Itkillik River

The Upper Itkillik station is approximately 8 km upstream from the proposed bridge crossing for the Foothills route. The Upper Itkillik is gauged at the proposed crossing. Extensive ice was present at both the station (Figure 24) and gauging site prior to flow on the Upper Itkillik River. Midday on May 24, 2013, a channel at the gauging site opened (Figure 25), but the meteorological station remained completely ice covered for two additional days (Figure 26). At the gauging site, little to no anchor ice was present midchannel, but grounded ice was common in shallow parts of the river and along edges. Aufeis was visible in the upper and middle sections of the Itkillik basin during April snow surveys and just prior to spring breakup in mid-May.

Flow gradually increased and remained steady and high throughout breakup, even as ice was removed from the channel. Breakup on the Upper Itkillik River began May 24 and continued beyond June 6 (high flows continued after this date when cold weather delayed the melt in the mountains). Shore ice and snow persisted along edges for many days after flow initiation. Most of the floating river ice in the Itkillik River consisted of smaller chunks due to high velocities and a rocky streambed, which mechanically broke the ice. Initially, ice chunks can be large, with pieces up to a few meters in length being observed. Low-lying fog interrupted access to the Upper Itkillik River for many days during breakup and prevented stream discharge measurements during the rise and recession of the river, but measurements near peak flow conditions were obtained on June 2 (Figure 27). During peak flow, which occurred on June 3, nearly all of the snow and shore ice was gone.

Figure 28 shows the water level elevations at the Upper Itkillik station from 2009–2013. The datum for the station is GEOID09AK, and establishment of the temporary benchmarks was in 2009 and 2010 with survey grade GPS, as described in Kane et al. (2012). Peak water levels are shown in Table 24, with the highest recorded stage over the short period of record occurring in 2013. The maximum difference in water levels since we began observations occurred in 2011 (from lowest to highest stage difference) was 2.1 m (~7ft).

Figure 24. Upper Itkillik River on May 23, 2013. Channel is ice covered, and no flowing water is visible. Red star indicates Upper Itkillik meteorological station location; yellow arrow shows flow direction.

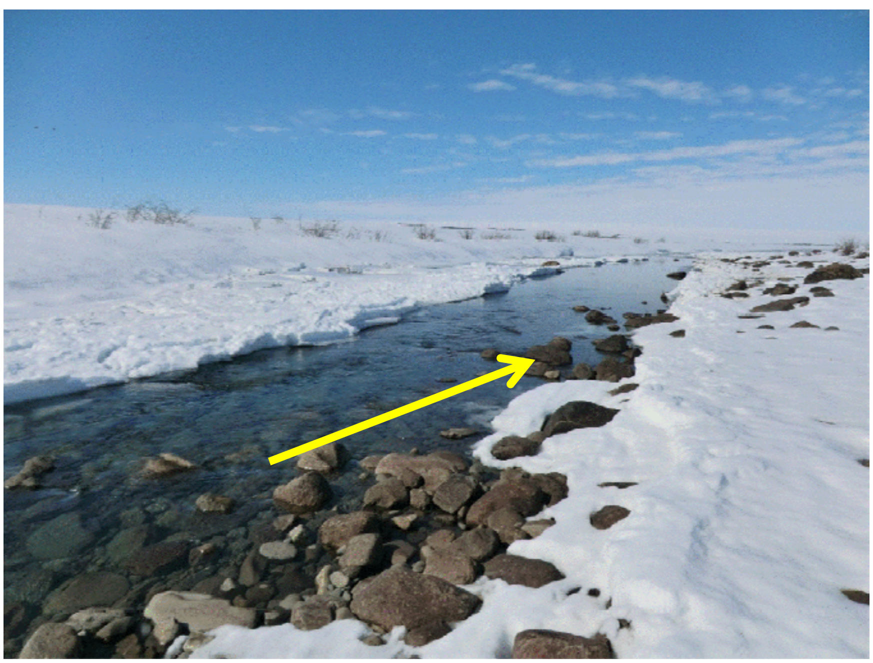


Figure 25. Upper Itkillik River on May 24, 2013 showing channel opening at Upper Itkillik gauging site, clear waters, a cobble/boulder streambed with some anchor ice, and snow-covered shorelines. Yellow arrow illustrates flow direction.

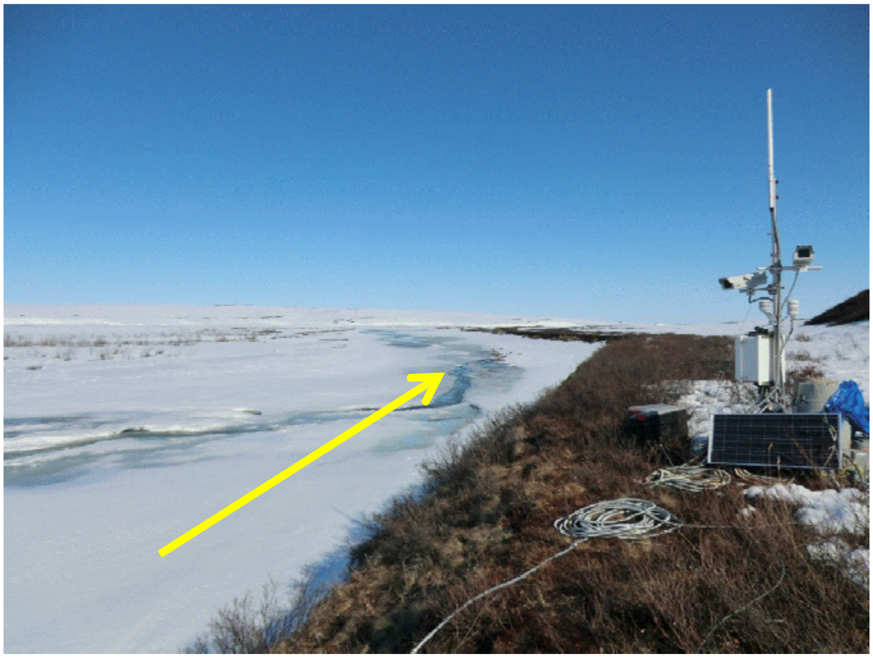


Figure 26. Upper Itkillik River on May 25, 2013. Little to no open flow at the meteorological station. Yellow arrow illustrates flow direction.

Figure 27. Upper Itkillik River on June 2, 2013. Water levels are high, but within bankfull. There is little floating ice and high velocities (~2.5 m/s). Discharge measurements were made using a cataraft (lower left circle) and an ADCP. Yellow arrow illustrates flow direction.

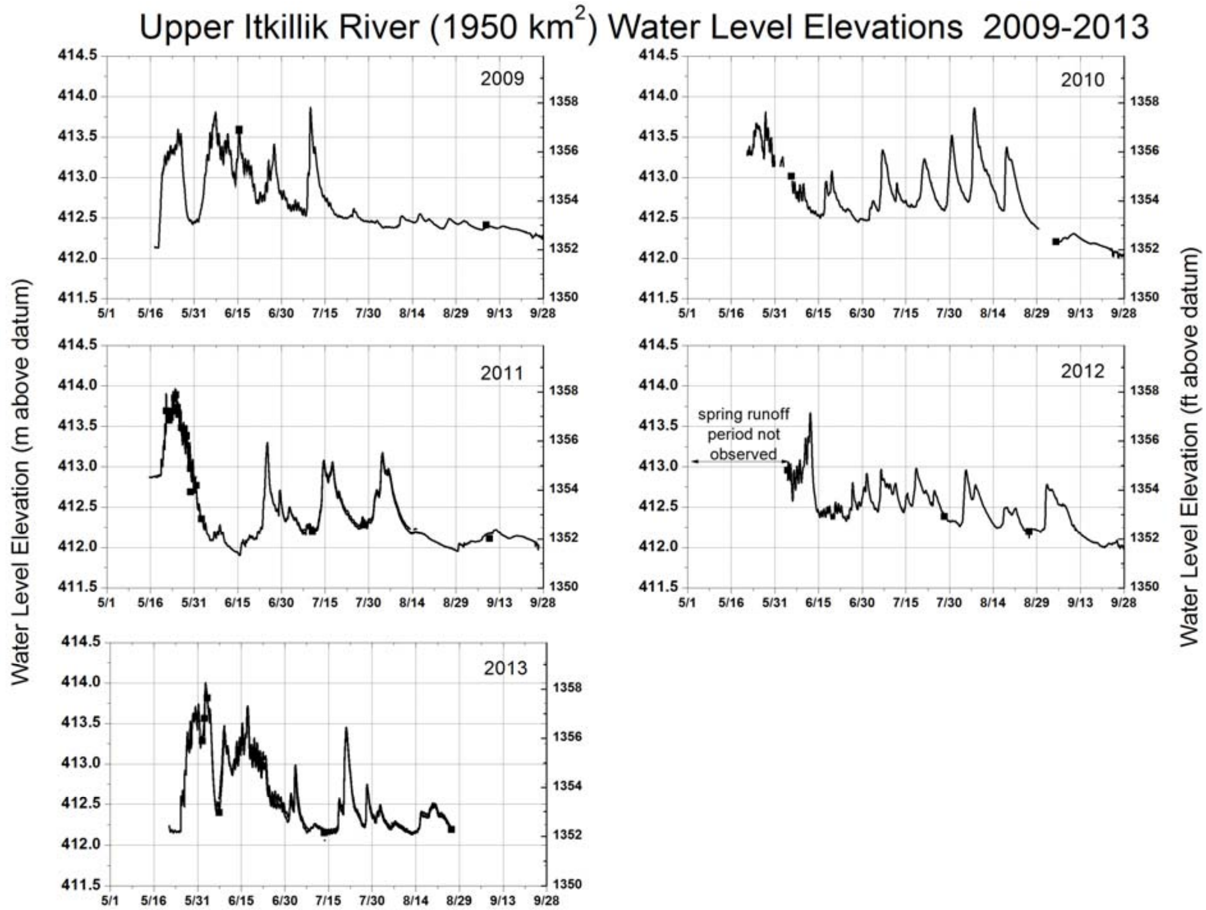


Figure 28. Continuous and manual measurements of water level at Upper Itkillik River station from 2009–2013. The datum is GEOID09AK.

Table 24. Estimated peak spring breakup and summer water-level events for the Upper Itkillik River 2009–2013. The stage is reported in units above the datum (GEOID09AK).

Date	Peak Water Level Elevation (m)	Peak Water Level Elevation (ft)
Spring: May 25, 2009	413.60	1356.95
Summer: July 10, 2009	413.87	1357.84
Spring: May 27, 2010	413.81	1357.64
Summer: August 7, 2010	413.86	1357.80
Spring: May 24, 2011	413.96	1358.13
Summer: June 25, 2011	413.30	1355.97
Spring 2012 not measured	N/A	N/A
Summer: June 12, 2012	413.66	1357.15
Spring::June 2, 2013	414.00	1358.26
Summer::June 17, 2013	413.69	1357.26

Table 25 presents all ADCP discharge measurements by UAF at the Upper Itkillik River. Most measurements were made near the bridge-crossing location. Experiments with dye trace measurements to estimate discharge during ice-affected conditions are presented in the next section (Section 6.9.1.2). A rating curve was developed for the Upper Itkillik River (Appendix E) based on individual discharge (using an ADCP) and stage measurements collected by UAF from 2010 through 2013. The rating curve was then applied to continuous stage readings to estimate continuous discharge (Figure 29). This rating curve was shifted beginning in 2012 due to the change in curve for the majority of rating points at lower flows. Higher uncertainty is associated with the estimated continuous discharge, particularly at highest stage (due to the lack of rating points) and during spring, when early on, the channel may be somewhat ice-affected. Appendix E contains the expanded rating table and all measurements.

The Upper Itkillik River hydrograph (Figure 29) shows the estimated discharge for 2009–2013. Note that the 2009 record has no ADCP discharge measurements to verify the estimated flow; this is because measurements began in 2010. The spring runoff event is a large event each year in terms of peak and total volume of water. Large events may also occur during summer months, as observed in 2009 and 2010, when several rain events produced high discharges that probably equaled the snowmelt peak discharge. However, these events are of shorter duration (and less total water volume) than the annual snowmelt event.

Peak flows were obtained from the continuous discharge data (Table 26) and have some error due to the uncertainty in the rating curve at high stage and the possibility of ice affecting the stage measurements. The maximum flow measured with an ADCP on the Upper Itkillik is 270 m^3/s (9530 ft^3/s) in 2013; however, higher stages occurred in both 2011 and 2013 that likely resulted in flows greater than 300 m^3/s (10,590 ft^3/s). Summer flows of 268 m^3/s (9460 ft^3/s) have been recorded in response to summer rain events. The low flow discharge on the Upper Itkillik River for each year is around 25 m^3/s (882 ft^3/s).

Table 25. Discharge measurements for the Itkillik River, 2010–2013. The stage is reported in units above the datum (GEOID09AK).

Date	No	Discharge (m^3/s)	Discharge (ft^3/s)	Stage (m)	Stage (ft)	Quality (%)	Mean Velocity (m/s)	Mean Depth (m)	Approx. Width (m)	Location
7/15/2010 14:00	1	38	1,360	412.65*	1353.8*	10	1.4	0.78	35	Nr. bridge crossing
9/4/2010 13:00	2	20	710	412.21	1352.40	5	0.9	0.73	32	Station
5/25/2011 18:30	5	230	8,120	413.75	1357.44	20	2.5	1.55	61	Bridge crossing
5/26/2011 14:15	6	170	6,000	413.51	1356.66	10	2.3	1.31	78	Bridge crossing
5/27/2011 15:00	7	169	5,970	413.47	1356.52	10	2.0	1.22	71	Bridge crossing
5/28/2011 13:00	9	156	5,510	413.43	1356.39	10	1.9	1.15	70	Bridge crossing
5/29/2011 20:10	10	111	3,920	413.26	1355.83	10	1.6	1.04	65	Bridge crossing
5/31/2011 12:15	11	70	2,470	412.87	1354.56	10	1.3	0.85	70	Bridge crossing
7/6/2011 16:15	12	29	1,020	412.65	1353.83	5	0.9	0.68	50	Bridge crossing
9/9/2011 17:22	13	26	918	412.11	1352.06	5	0.8	0.65	50	Bridge crossing
6/4/2012 18:30	14	94	3,320	413.00	1354.64	10	1.5	1.07	59	Bridge crossing
7/28/2012 11:50	15	39	1,380	412.39	1352.64	5	0.9	0.84	51	Bridge crossing
8/26/2012 12:30	16	25	865	412.19	1352.34	8	0.8	0.73	43	Bridge crossing
6/1/2013 13:45	17	152	5,330	413.27	1352.06	5	2.0	1.36	56	Bridge crossing
6/2/2013 14:25	18	243	8,580	413.76	1357.12	8	2.3	1.48	70	Bridge crossing
6/3/2013 12:30	19	271	9,570	413.78	1357.21	8	2.3	1.64	72	Bridge crossing
7/11/2013 12:00	20	36	1,270	412.23	1352.11	5	0.9	0.83	49	Bridge crossing
8/26/2013 15:10	21	36	1,270	412.20	1352.01	8	0.9	0.89	45	Bridge crossing

* Stage based on pressure transducer data, no stage available at time of measurement

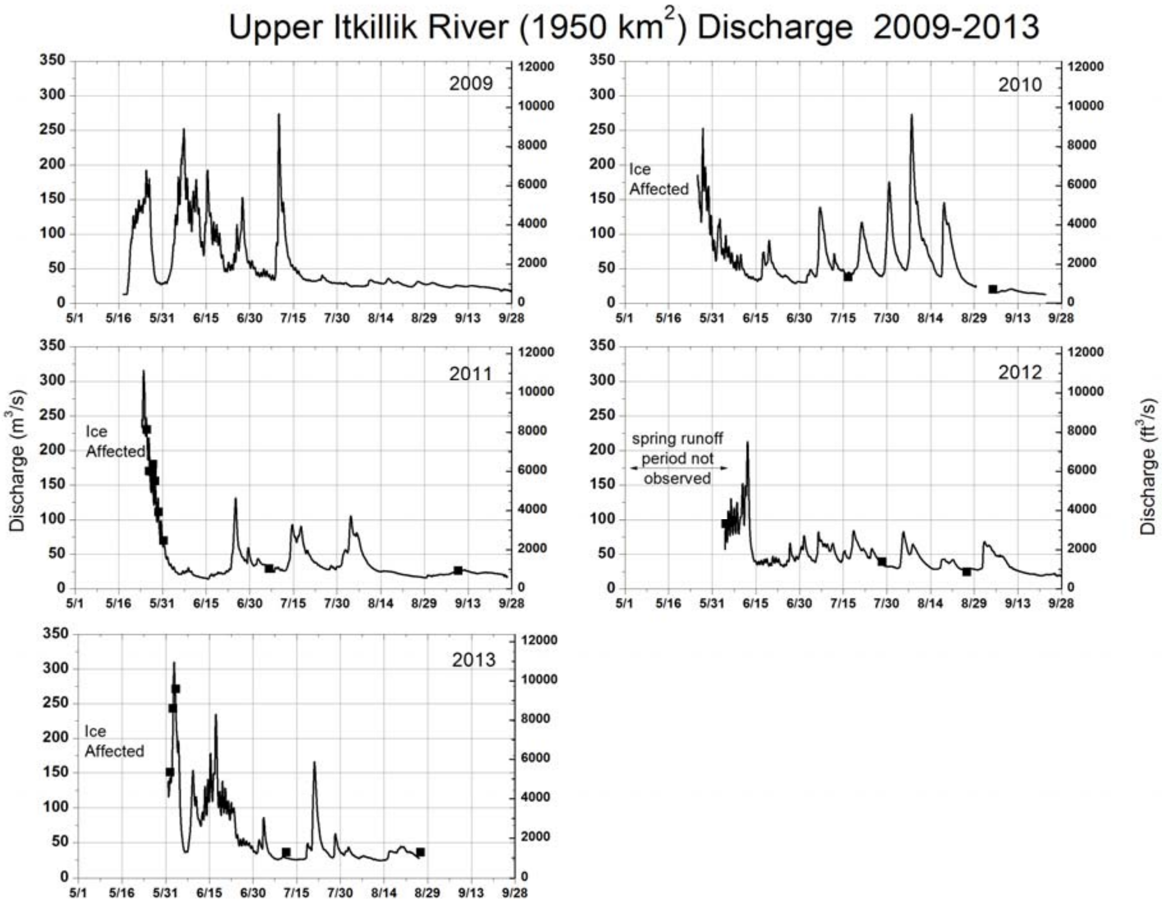


Figure 29. Continuous and manual measurements of discharge at Upper Itkillik River station from 2009–2013. Units of m^3/s is on the left axis and ft^3/s is the right axis.

Table 26. Estimated peak runoff for the Upper Itkillik River.

Date	Peak Runoff (m^3/s)	Peak Runoff (ft^3/s)
Spring: May 25, 2009	183	6,462
Summer: July 10, 2009	268	9,464
Spring: May 27, 2010	250*	8,829
Summer: August 7, 2010	268	9,464
Spring: May 24, 2011	300*	10,594
Summer: June 25, 2011	120	4,237
Spring: Not measured	N/A	N/A
Summer: June 12, 2012	208	7,345
Spring: June 2, 2013	310	10,947
Summer: June 17, 2013	234	8,263

* Higher uncertainty due to possibility of channel ice affecting rating curve

6.9.2.1 Dye Trace Results, Upper Itkillik River

During the original 2011 tests, the rhodamine WT did not accurately predict Itkillik River breakup discharge (Kane et al., 2012). In nearly every test, only a fraction of dye was recovered relative to the amount expected, resulting in an overestimation of flow compared with the ADCP measurements. This diminished dye recovery was attributed to high concentrations of total suspended solids in the flow.

The 2012 tests were intended to ascertain whether uranine dye would be more appropriate than rhodamine WT for measuring breakup discharge. The tests were conducted primarily in the Upper Kuparuk River, as the smaller stream allowed for better experimental control. However, a single test was run in the Itkillik during summer 2012 to verify Upper Kuparuk results on a larger stream.

Dye injection background and methods are presented in our previous report (Kane et al., 2012). In 2012, we modified our previously reported methods by incorporating uranine as a second dye, and by employing an Albillia FL24 fluorometer to collect real-time, continuous measurements of in-stream fluorescence at the recovery site.

As illustrated in Figure 30, dyes were injected into the Upper Kuparuk by hand. During the initial portion of breakup, flows were minimal and allowed us to inject at midstream. During higher flows, the dyes were injected from the right bank. The dyes were injected sequentially, with a slug of rhodamine WT followed one minute later by an equal quantity of uranine.

A graph of typical fluorescence results is depicted in Figure 31. As the total dye recovered is calculated using the area under each curve, the results clearly indicate that recovery of the uranine was higher than that of the rhodamine WT in the test run depicted. This result was similar for all trials. The calculated flow is inversely related to the concentration of dye recovered, as described previously (Kane et al., 2012). Thus, the flows measured by uranine were consistently lower than the flows measured by rhodamine WT. As illustrated by the Figure 32 bar graph, the discharge values measured by uranine were consistent with the complementary acoustic Doppler measurements.

Figure 30. A researcher injects uranine dye into the Upper Kuparuk River, May 19, 2012.

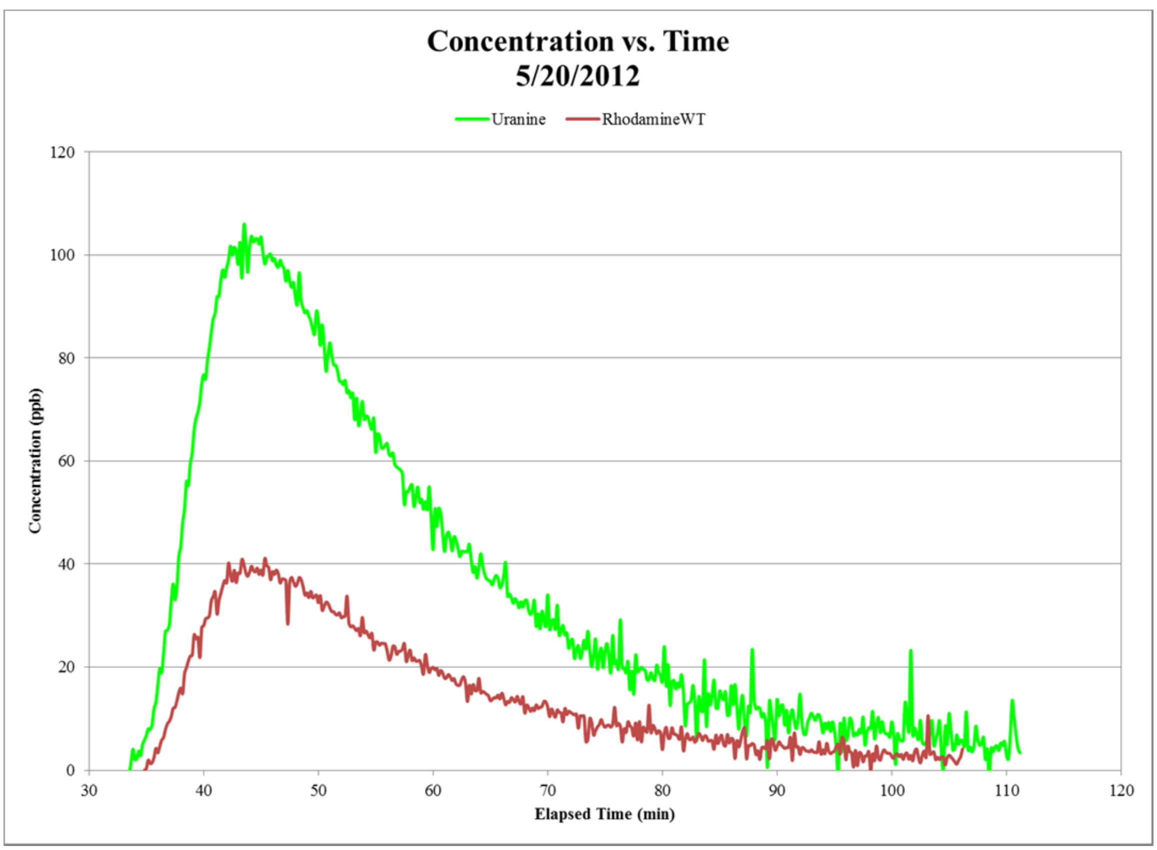


Figure 31. Plot of concentration versus time of uranine (green) and rhodamine WT (red) at the Upper Kuparuk River sampling site. Equal masses of both dyes were injected on any given test run.

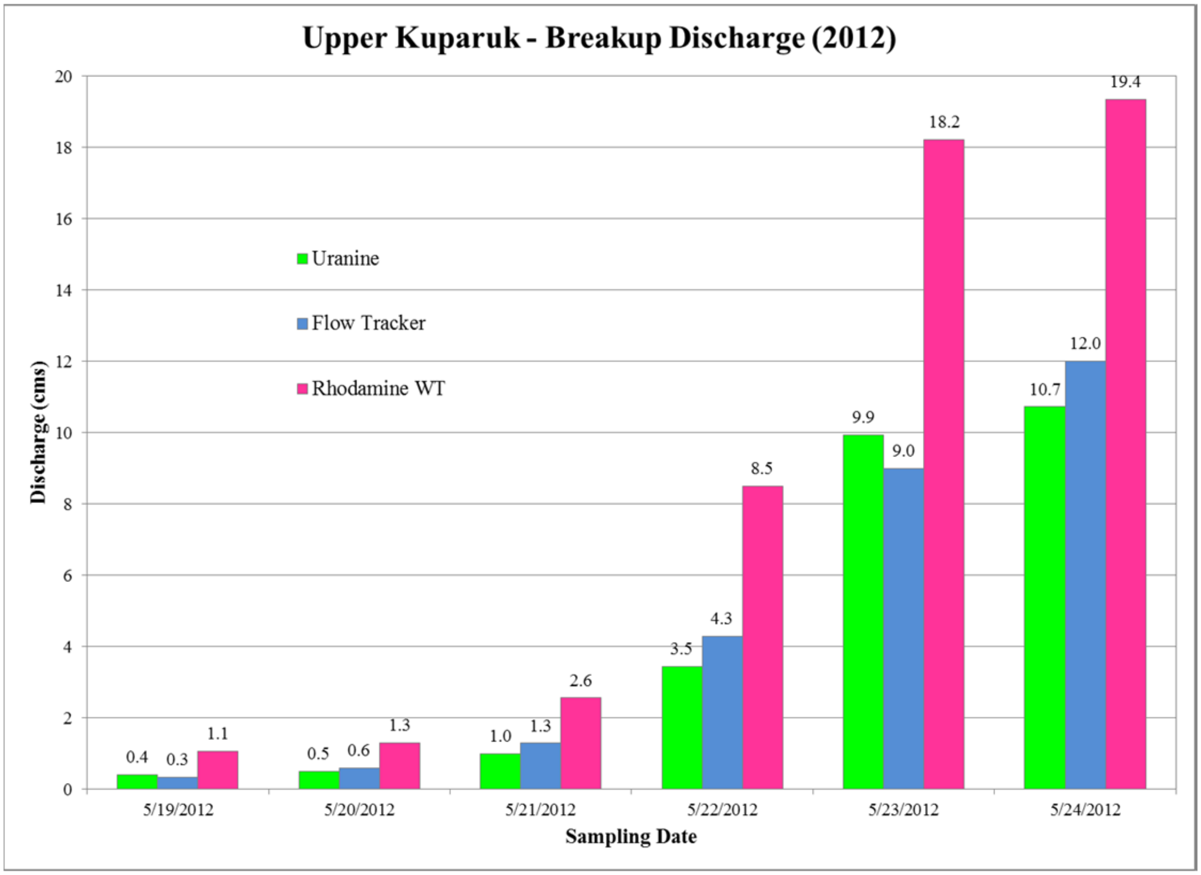


Figure 32. Dye tracer and acoustic Doppler discharge results during 2012 Upper Kuparuk breakup.

Table 27 presents a summary of the 2012 experimental conditions and results. The table also includes the verification test performed on the Itkillik River in July 2012. As indicated in the table, the rhodamine WT consistently overpredicted the acoustic Doppler discharge by a rough factor of two, whereas the uranine results were relatively consistent with the acoustic Doppler. This result was verified on the Upper Itkillik River during July 2012, indicating that the effect is not necessarily limited to breakup. Given that the midsummer flow on the Itkillik was relatively low in total suspended solids, we conclude that additional unknown factors that inhibit rhodamine WT recovery must exist. However, since uranine discharge results matched acoustic Doppler results at low flows, we recommend uranine dye tracer as a potential method for obtaining discharge measurements during breakup when ice may prevent us from entering the stream with a boat. More testing of this method is needed for high flows.

Table 27. Experimental conditions and results of 2012 dye tracer tests.

					Discharge (cm)		
Site	Date	Dye Powder (g)		River Reach (km)	FL24		FlowTracker Handheld-ADV
Upper Kuparuk	**5/19/2012**	Uranine	15.0	0.87	Uranine	0.4	0.33
		Rhodamine WT	15.0		Rhodamine WT	1.1	
Upper Kuparuk	**5/20/2012**	Uranine	80.0	1.46	Uranine	0.5	0.6
		Rhodamine WT	80.0		Rhodamine WT	1.3	
Upper Kuparuk	**5/21/2012**	Uranine	40.0	1.15	Uranine	1.0	1.29
		Rhodamine WT	40.0		Rhodamine WT	2.6	
Upper Kuparuk	**5/22/2012**	Uranine	40.1	1.65	Uranine	3.5	4.3
		Rhodamine WT	40.2		Rhodamine WT	8.5	
Upper Kuparuk	**5/23/2012**	Uranine	80.3	1.69	Uranine	9.9	9
		Rhodamine WT	80.0		Rhodamine WT	18.2	
Upper Kuparuk	**5/24/2012**	Uranine	90.4	1.69	Uranine	10.7	12
		Rhodamine WT	90.3		Rhodamine WT	19.4	
Itkillik	**7/28/2012**	Uranine	2009.5	6.68	Uranine	52.5	39 (StreamPro)
		Rhodamine WT	2009.5		Rhodamine WT	115.1	

6.9.3 Lower Itkillik River 2013 Breakup and Spring Flood

The river at the new Lower Itkillik station nearer to the coastal plain and the confluence with the Colville River has a lower gradient with a braided channel morphology compared to the river near the Upper Itkillik station. However, the new site offered one of the few reaches where the river flowed in a single channel even at high flows. Upon our arrival at the station on May 24, 2013, the river was completely ice covered with no standing water; large snowdrifts at the cut banks (Figure 33) were present.

Figure 33. Lower Itkillik gauge site May 24, 2013. The photo on the left was taken at a low level looking north, showing the river ice and snow conditions. On the right is a high-level photo of the river at the site near the ice road crossing looking south. Arrows indicate the flow direction.

Time lapse photos indicate that overflow (flow of water over ice) reached the site at 6:30 A.M. on May 26 (Figure 34). An aerial photograph of the river at the station on May 27 also shows the presence of the May 26 overflow (Figure 35). The early overflow increased gradually until 11:30 A.M. on May 28, when the breakup front (considerably more water with ice) passed the Lower Itkillik gauging site (Figure 36).

The flow increased steadily, widening the channel and eroding the drifted snow in the stream channel for the next several days. Low clouds and fog prevented flying to the site on June 3 and 4, when the river was peaking. The river crested at around 6:00 A.M. on June 3, 2013 (Figure 37–Figure 39). The stage began receding by midmorning, but the river was over bankfull for most of the day, according to pressure transducer data and webcam images. The stage remained near bankfull until late on June 4, when it began receding in response to colder weather. The stage continued to fall until warmer weather, beginning June 5, initiating a second, lower spring snowmelt peak.

Figure 34. Flow over the ice begins at the Lower Itkillik station on May 26. Arrows indicate flow direction.

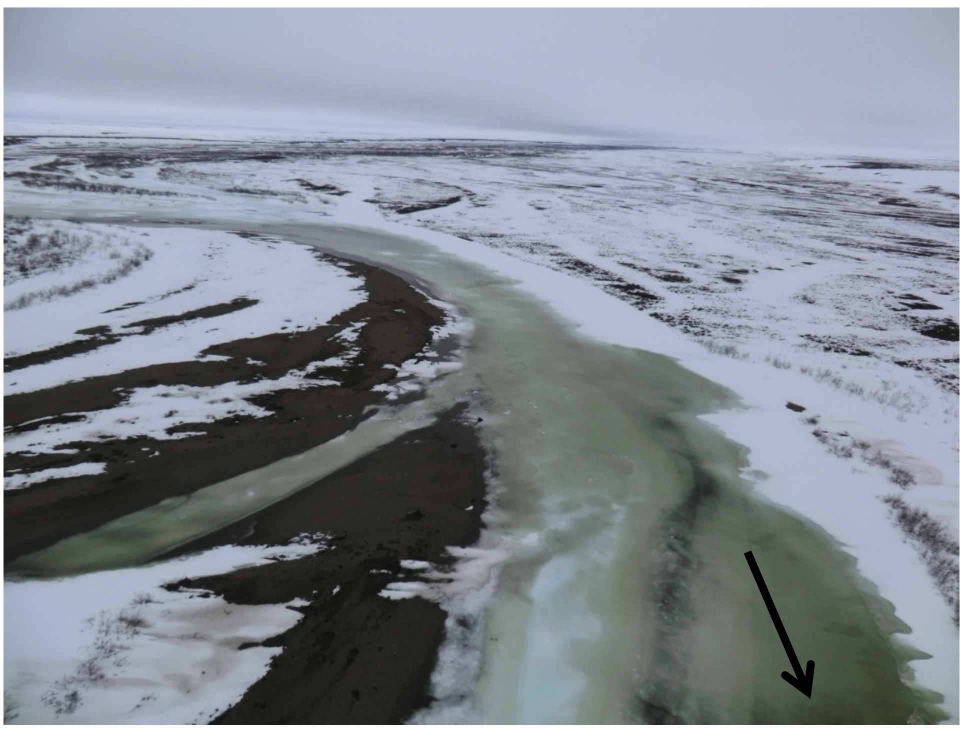


Figure 35. View looking south of overflow on the Lower Itkillik River at the gauging station at 3:47 P.M. on May 27. Arrow indicates flow direction.

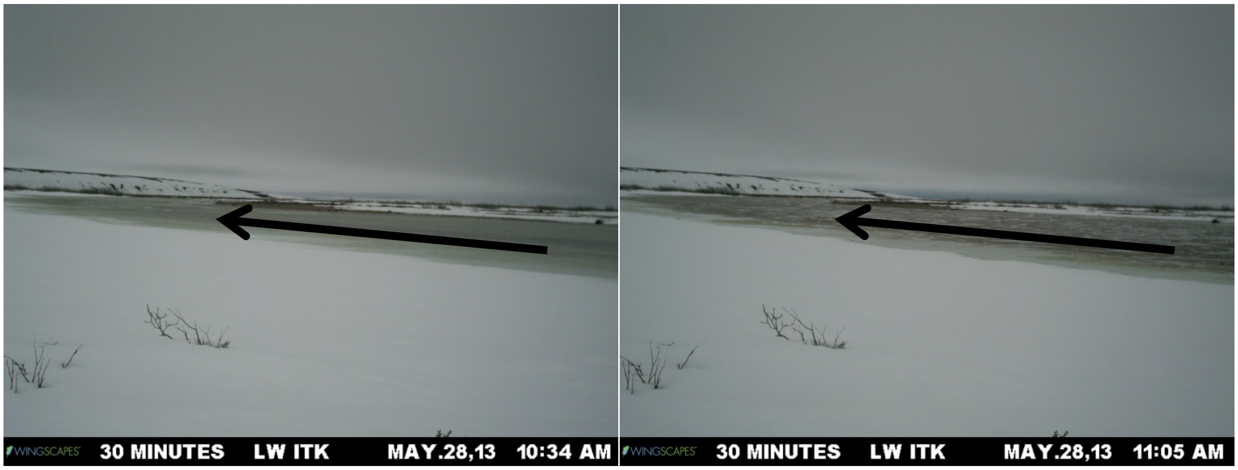


Figure 36. Breakup front reaches the Lower Itkillik gauging site at approximately 11:00 A.M. on May 28, 2013.

Figure 37. Increasing stage and peak flow on May 31 through June 3, showing over bankfull conditions on June 3.

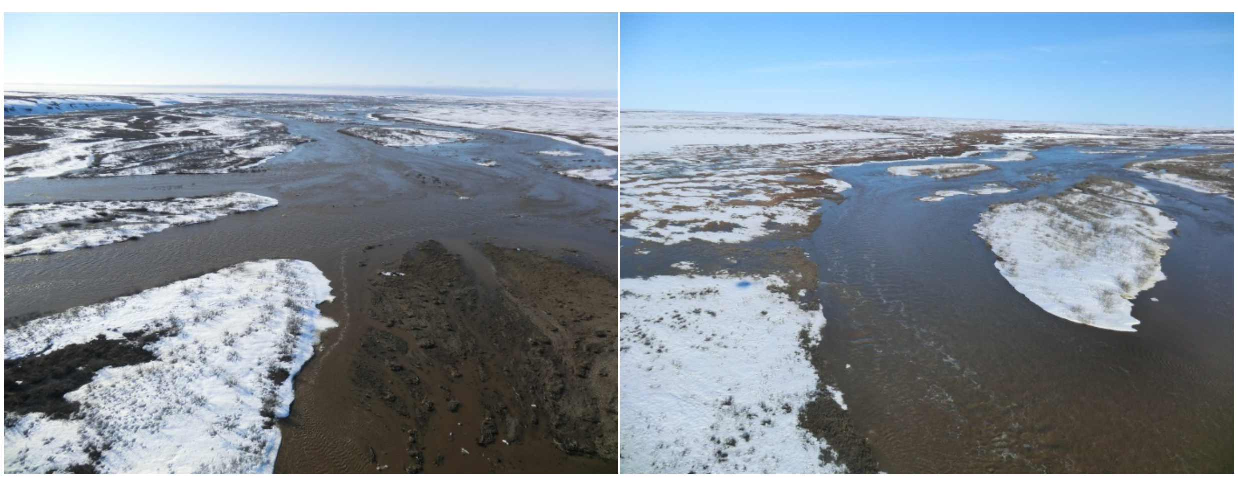


Figure 38. Low-level aerial view of the channel looking north (left) and south (right) on May 31, 2013.

Figure 39. High-level views taken on June 5, 2013, looking north (left) and south (right) of the Lower Itkillik near the proposed road crossing.

Figure 40 shows a hydrograph of the continuous water level elevations for 2013. The datum for the station is arbitrary. As previously discussed, stages were highest during snowmelt runoff, with several smaller summer events occurring in response to rainfall. Peak water levels for the year are shown in Table 28. Table 29 presents all ADCP discharge measurements by UAF at the Lower Itkillik River. All measurements were made near the possible bridge-crossing location. A preliminary rating curve was developed for the Lower Itkillik River (Appendix E) based on individual discharge (using an ADCP) and stage measurements collected by UAF. The rating curve was then applied to continuous stage readings in order to estimate continuous discharge Figure 41). This rating curve is very basic and does not include any shifts to the rating points. When the stage is over bankfull, discharge is not estimated due to high uncertainty in the rating curve. Appendix E contains the expanded rating table and a summary of all discharge measurements.

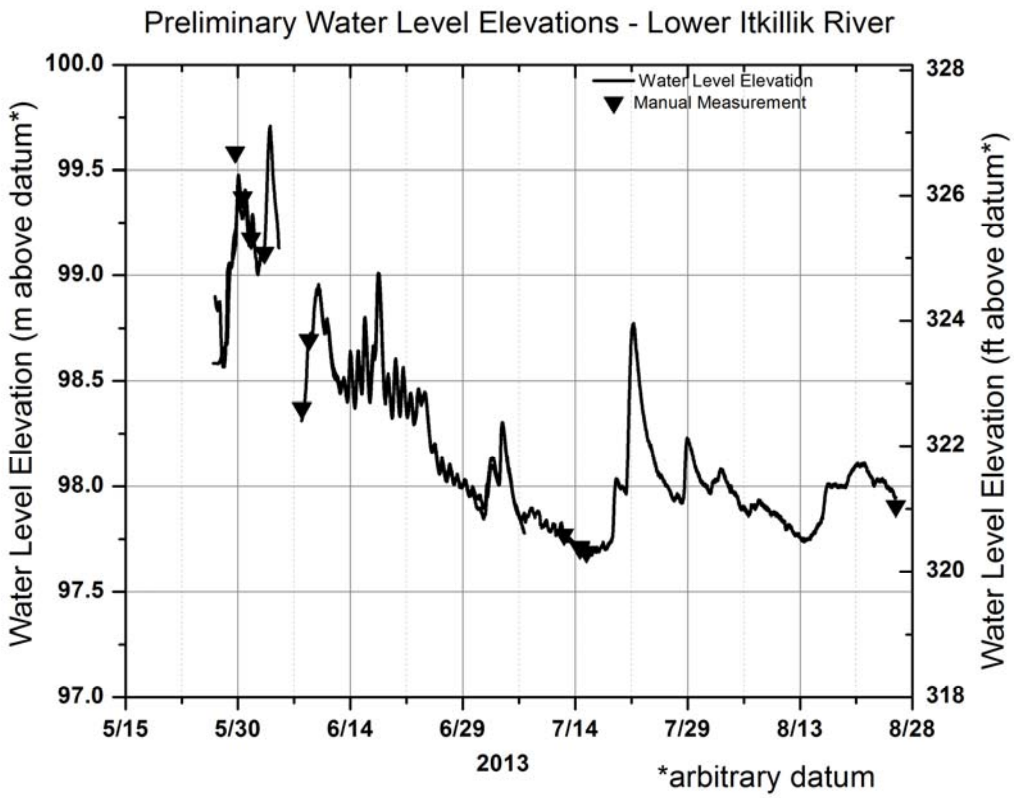


Figure 40. Continuous and manual measurements of water level at Lower Itkillik River station in 2013. The datum is arbitrary.

Table 28. Estimated peak spring breakup and summer water-level events for the Lower Itkillik River 2013. The stage is reported in units above the arbitrary datum.

Date	Peak Water Level Elevation (m)	Peak Water Level Elevation (ft)
Spring: June 3, 2013	99.71	327.10
Summer: June 17, 2013	99.01	324.84

Table 29. Discharge measurements for the Lower Itkillik River, 2012–2013. The stage is reported in units above the datum (GEOID09AK).

Date	No.	Discharge (m^3/s)	Discharge (ft^3/s)	Stage (m)	Stage (ft)	Quality (%)	Mean Velocity (m/s)	Mean Depth (m)	Approx. Width (m)	Location
8/28/2012 11:00	1	28	990	97.79	320.83	5	0.7	0.63	63	Station
5/31/2013 16:45	2	247	8,720	99.18	325.38	10	1.9	0.99	132	Station
6/2/2013 11:45	3	322	11,370	99.12	325.15	8	2.0	1.49	107	Station
6/7/2013 10:20	4	110	3,880	98.37	322.74	8	1.1	1.48	68	Station
6/8/2013 9:45	5	193	6,810	98.70	323.80	5	1.5	1.63	81	Station
7/12/2013 11:30	6	39	1,380	97.77	320.77	5	1.0	0.78	47	Station
8/25/2013 15:00	7	49	1,730	97.91	321.21	8	1.2	0.79	51	Station

Peak flows (Table 30) for 2013 were obtained from the continuous discharge data (Figure 41) and are considered preliminary due to the uncertainty in the rating curve at high stage and the possibility of ice affecting the stage measurements. However, it was observed that by peak flow, most of the ice had left the channel. The maximum flow measured with an ADCP is 322 m^3/s (11,370 ft^3/s) on June 2; however, higher stages (over bankfull) occurred on June 4 that probably resulted in flows greater than 600 m^3/s (21,800 ft^3/s) (according to the preliminary rating curve). The summer peak flow for 2013 was 257 m^3/s (9075 ft^3/s), but summer flows on the Upper Itkillik have been recorded over 268 m^3/s (9460 ft^3/s), so it is likely that even higher summer flows may occur on the Lower Itkillik. The low-flow discharge on the Upper Itkillik River for 2013 is around 35 m^3/s (1235 ft^3/s). The maximum difference in water levels (from lowest to highest stage difference) reached 2 m (~6.5 ft).

Table 30. Estimated peak runoff for the Lower Itkillik River.

Date	Peak Runoff (m^3/s)	Peak Runoff (ft^3/s)
Spring: June 3, 2013	350+	12,360+
Summer: June 17, 2013	257	9,075

* Higher uncertainty due to over bankfull conditions and preliminary rating curve.

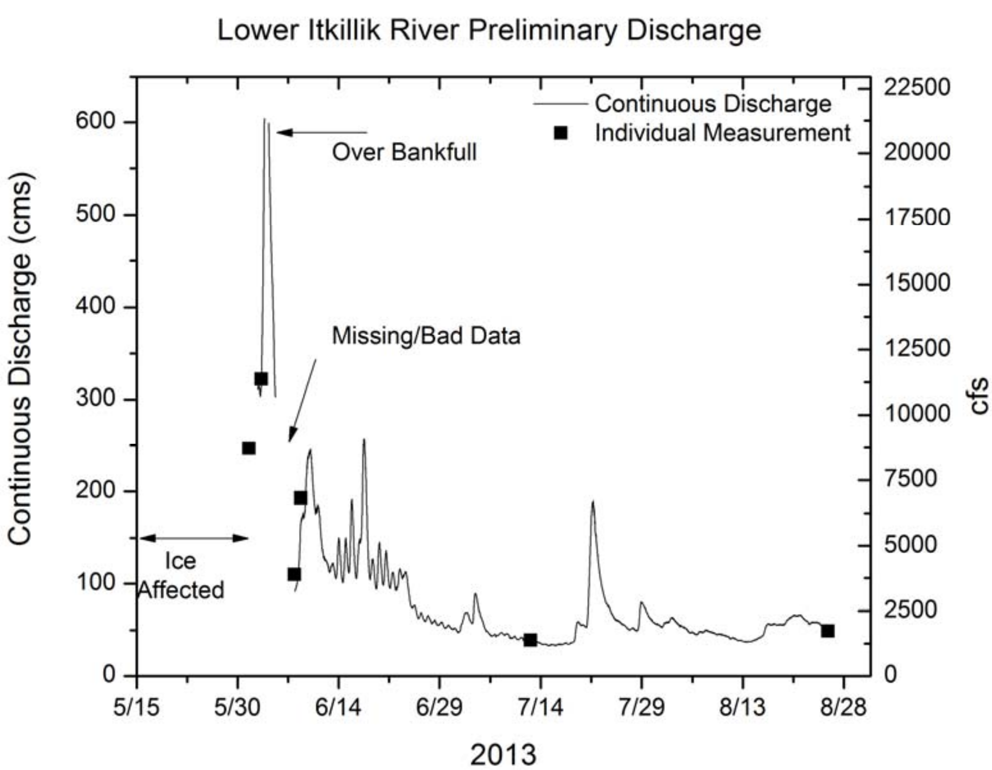


Figure 41. Continuous and manual measurements of discharge at Lower Itkillik River station for 2013. Units of m^3/s is on the left axis and ft^3/s is the right axis.

6.9.4 Anaktuvuk River

The Anaktuvuk River, which is approximately 215 km long and has a drainage area of 7100 km^2, flows from the Endicott Mountains (~2000 m elevation) to the Colville River near Umiat (elevation ~90 m). Included in the Anaktuvuk basin drainage network are the Nanushuk and Tuluga Rivers. In early May 2009, UAF installed an observation station approximately 15 km to the north (downstream) of the ADOT&PF proposed bridge-crossing location. The station records water levels continuously, and discharge measurements are made near the station. Field visits were made in spring and summer 2010, spring and summer 2011, summer 2012 (no spring trip), and spring and summer 2013. The previous data reports (Youcha et al., 2011; Kane et al., 2012) summarize the early results of the project and provide more details on the breakup events of 2009–2011. This section includes updated stage and discharge data through 2013, and summarizes spring breakup in 2013.

Spring breakup began very late on the Anaktuvuk River in 2013; the river channel was fully ice- and snow-covered on May 24. Overflow from early melt and springs in the southern headwaters of the basin reached the gauging site and the crossing early on the morning of May 25. This flow continued to increase gradually through May 27, flowing over the ice and eroding the snow, thus widening the channel. Beginning May 28, the rate of stage rise increased, and large open reaches appeared in the channel by May 29. The main breakup front, marked by a rapid rise in stage with large ice and debris, reached the site midmorning on May 29. The stage continued to rise steadily, with bankfull conditions beginning on June 2 (Figure 42), until cresting late evening June 3, when over bankfull conditions occurred. This event is captured in camera images at the station (Figure 43) and aerial images at the proposed bridge crossing in Figure 44–Figure 47). Snow cover disappeared on the floodplain and the south- and west-facing hillslopes by June 2.

During this last stage of breakup, a new channel formed on the western side of the floodplain, opposite our gauging site. While this channel existed during peak flows in 2011 (spring 2012 was not observed), water flowed through it at only the highest discharges. The channel was observed to be only a few meters wide and relatively shallow during gauging in 2011. This new channel redirected water away from where we have gauged discharge in the past, and the change in the flow pattern became obvious when the site was visited in July 2013. The gauging site where flow was measured and stage recorded was a backwater, receiving a small portion of the flow. This change in channel morphology affected the stage discharge relationship at low flows, and a shift was applied to the rating curve at low stage. The high flow relationship did not seem to be similarly affected. After the crest, cold weather beginning June 3 caused a freeze-back, and the river discharge began falling rapidly. The stage rebounded as the weather warmed on June 5, resulting in a second lower peak on June 10. The recession resumed on June 10 and continued reaching base flow levels by late June, with small peaks in response to summer rain events throughout the summer.

Figure 42. Anaktuvuk River at the gauging site on June 2, 2013. River is bankfull.

Figure 43. Sequential view at 2-day interval of the Anaktuvuk River at the possible crossing at midday from May 24 through June 5, 2013. Peak flow occurred June 3, late in the evening. Flow is from right to left.

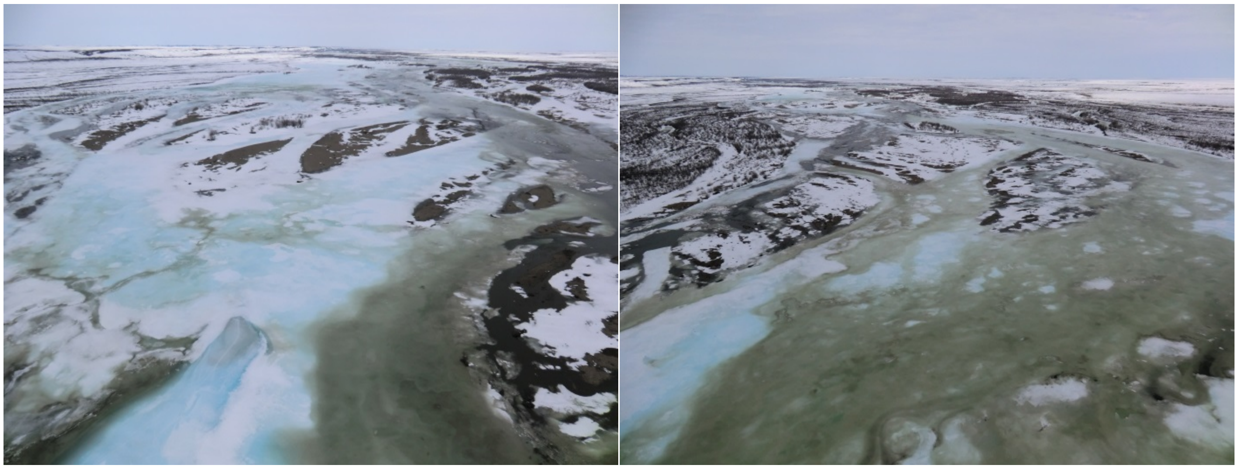


Figure 44. Anaktuvuk River at the proposed road crossing May 26, 2013. View looking north (left) and south (right).

Figure 45. Anaktuvuk River at the proposed road crossing May 29, 2013. View looking north at low altitude (left) and south at high altitude (right).

Figure 46. Aerial view of the Anaktuvuk River at the proposed road crossing taken June 2, 2013, looking north (left) and south (right). Peak flow occurred late at night on June 3.

Figure 47. Left: Anaktuvuk River at the proposed road crossing looking south on June 7 showing lower flow after the cold weather and freeze-back. Right: Anaktuvuk River looking north on June 9 after a second rise in stage in response to warmer weather.

Figure 48 shows the water level elevations on the Anaktuvuk River from 2009–2013. The datum for the station is GEOID09AK, and establishment of the temporary benchmarks was made in 2009 and 2010 with a survey grade GPS, as described in Kane et al. (2012). Peak water levels are shown in Table 31, with the highest recorded stage occurring in 2013. Table 32 shows all discharge measurements made on the Anaktuvuk River during the study period. From this data, a rating curve was developed. As previously mentioned, shifts were applied to the rating curve in 2011 and again in 2013 for low flow conditions due to changing channel geometry. The rating curve (see Appendix E) was applied to the continuous water levels, and the resulting continuous discharge is shown in Figure 49. Peak flows were obtained from the continuous discharge data (Table 33) and have a degree of uncertainty due to the uncertainty in the rating curve at high stage and the possibility of ice affecting the stage measurements. However, it was observed that by the time of peak flow, most of the ice had left the channel. The highest flows occurred during spring breakup. The maximum flow measured with an ADCP was 1100 m^3/s (38,850 ft^3/s); however, higher stages occurred in both 2011 and 2013 that likely resulted in flows greater than 1460 m^3/s (51,560 ft^3/s). Summer flows have been recorded up to 600 m^3/s (21,200 ft^3/s) in response to summer rain events. The low-flow discharge on the Anaktuvuk River for each year is around 35 m^3/s (1200 ft^3/s).

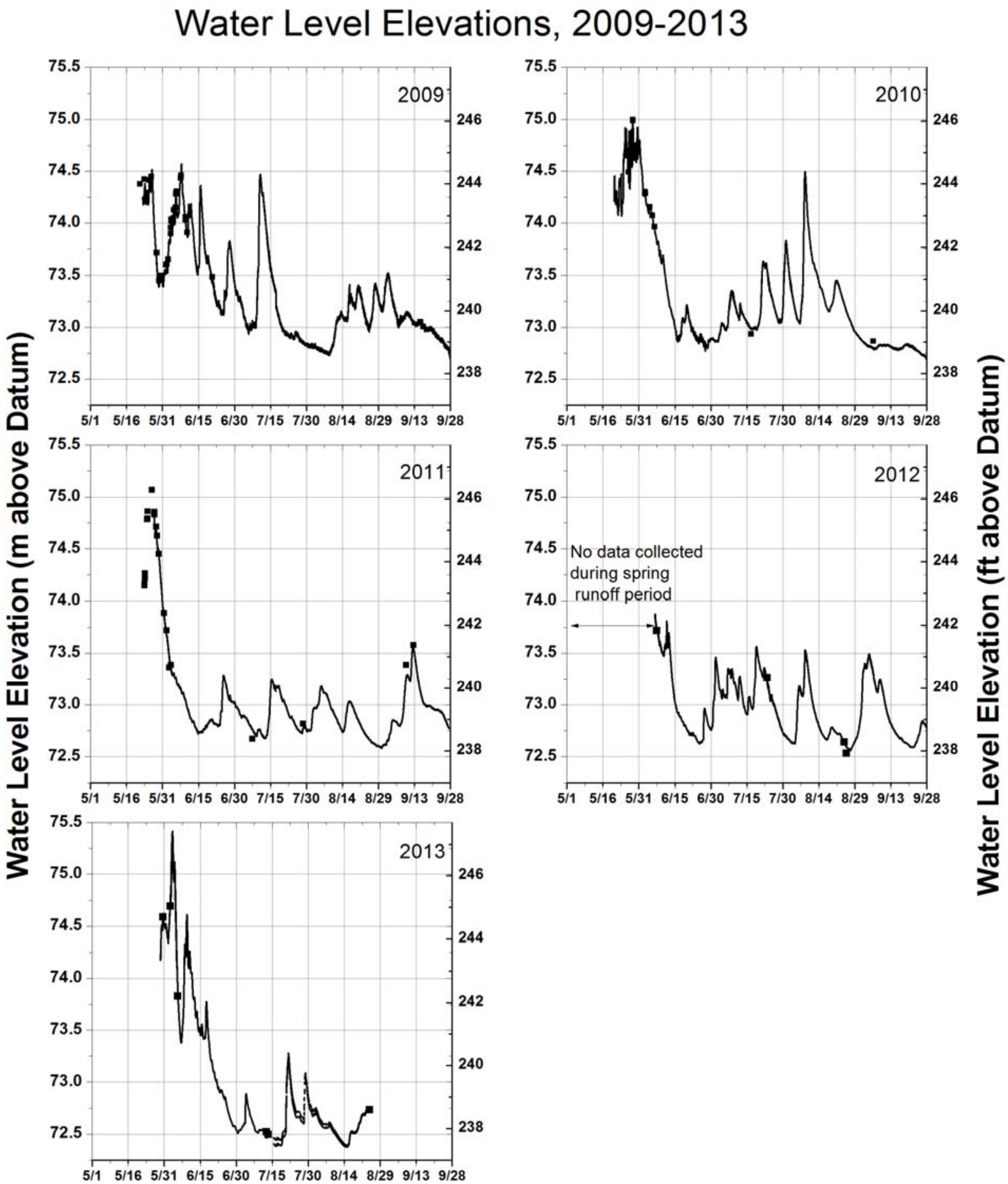


Figure 48. Continuous and manual measurements of water level at the Anaktuvuk River station from 2009–2013. The datum is GEOID09AK.

Table 31. Peak spring breakup and summer water-level events for the Anaktuvuk River 2009–2013. The stage is reported in units above the datum (GEOID09AK).

Date	Peak Water Level Elevation (m)	Peak Water Level Elevation (ft)
Spring: May 26, 2009	74.44	244.22
Summer: June 7, 2009	74.55	244.58
Spring: May 28, 2010*	75.02	246.13
Summer: August 8, 2010	74.49	244.39
Spring: May 25, 2011	75.20	246.72
Summer: September 12, 2011	73.58	241.40
Spring 2012 not measured	n/a	n/a
Summer: June 11, 2012	73.80	242.13
Spring: June 3, 2013	75.46	247.57
Summer: June 17, 2013	73.96	242.65

Table 32. Discharge measurements for the Anaktuvuk River, 2009–2011. The stage is reported in units above the datum (GEOID09AK).

Date	No.	Discharge (m^3/s)	Discharge (ft^3/s)	Stage (m)	Stage (ft)	Quality (%)	Mean Velocity (m/s)	Mean Depth (m)	Approx. Width (m)	Location
5/25/2009 16:30	1	532	18,787	74.46	244.2	10	1.5	1.40	275	Station
5/28/2009 13:00	2	206	7,275	73.71	241.8	10	1.0	1.24	160	Station
5/30/2009 12:00	3	162	5,721	73.50	241.1	10	1.0	1.09	145	Station
6/1/2009 14:00	4	184	6,498	73.63	241.5	10	1.0	1.14	145	Station
6/3/2009 13:00	5	326	11,513	74.04	242.9	8	1.4	1.41	160	Station
6/4/2009 12:45	6	374	13,207	74.05	242.9	8	1.3	1.47	190	Station
6/5/2009 16:45	7	504	17,798	74.30	243.7	8	1.6	1.54	200	Station
6/7/2009 15:00	8	574	20,270	74.43	244.1	8	1.4	1.52	265	Station
6/9/2009 13:45	9	356	12,572	74.32	243.8	10	1.6	1.37	165	Station
9/16/2009 11:00	10	66	2,331	73.01	239.5	10	0.9	0.65	95	¼ mile d.s.*
6/2/2010 13:40	11	512	18,081	74.28	243.7	10	1.4	2.04	180	Station
6/4/2010 14:00	12	388	13,702	74.15	243.3	8	1.4	1.66	165	Station
6/5/2010 13:30	13	339	11,971	74.06	243.0	8	1.4	1.54	160	Station
6/6/2010 12:00	14	290	10,241	73.96	242.6	8	1.2	1.47	160	Station
7/16/2010 12:00	15	54	1,907	72.95	239.3	5	0.7	1.12	65	¼ mile d.s. station
9/3/2010 17:00	16	45	1,554	72.88	239.1	8	1.2	0.69	50	¼ mile d.s. station
5/25/2011 12:00	17	580	20,480	75.14	246.5	20	n/a	n/a	n/a	Station
5/27/2011 21:00	18	1,100	38,841	74.73	245.2	10	1.8	1.93	315	Station
5/28/2011 18:54	19	830	29,307	74.62	244.8	20	1.4	2.19	265	Station
5/29/2011 13:00	20	729	25,741	74.45	244.3	10	1.6	1.45	321	Station
6/2/2011 14:00	21	191	6,744	73.55	241.3	5	1.0	1.11	160	Station
7/7/2011 14:00	22	48	1,695	72.77	238.7	5	0.5	1.01	95	Station
9/12/2011 12:45	23	212	7,486	73.58	241.4	5	1.1	1.27	150	1 mile d.s. station
6/7/2012 14:00	24	280	9,890	73.67	241.4	5	1.4	1.52	128	Station

Date	No.	Discharge (m^3/s)	Discharge (ft^3/s)	Stage (m)	Stage (ft)	Quality (%)	Mean Velocity (m/s)	Mean Depth (m)	Approx. Width (m)	Location
7/27/2012 10:40	25	89	3,140	72.91	239.2	5	0.9	1.02	96	Station
8/25/2012 14:45	26	46	1,620	72.59	238.2	5	0.6	1.25	65	1 mile d.s. station
6/5/2013 16:00	27	454	16,030	73.83	242.2	8	1.1	1.37	322	Station
7/13/2013 14:15	28	60	2,120	72.90	239.2	5	1.0	0.91	66	1 mile d.s. station
8/24/2013 15:30	29	118	4,170	72.87	239.1	5	1.5	1.13	68	1 mile d.s. station

*d.s. = downstream

Table 33. Estimated peak discharge events for the Anaktuvuk River.

Date	Peak Runoff (m^3/s)	Peak Runoff (ft^3/s)
Spring: May 26, 2009	767	27,090
Summer: June 7, 2009	797	28,145
Spring: May 31, 2010[1]	1,091	38,530
Summer: August 8, 2010	636	22,460
Spring: May 26, 2011[1]	1,476	52,125
Summer: September 12, 2011	175	6,180
Spring 2012 not measured	n/a	n/a
Summer: June 11, 2012	275	9710
Spring: June 3, 2013[2]	1,460+	51,560+
Summer: June 17, 2013	324	11,440

[1] High uncertainty; channel may have been slightly ice-affected and flow was over bankfull.
[2] Flow was over bankfull.

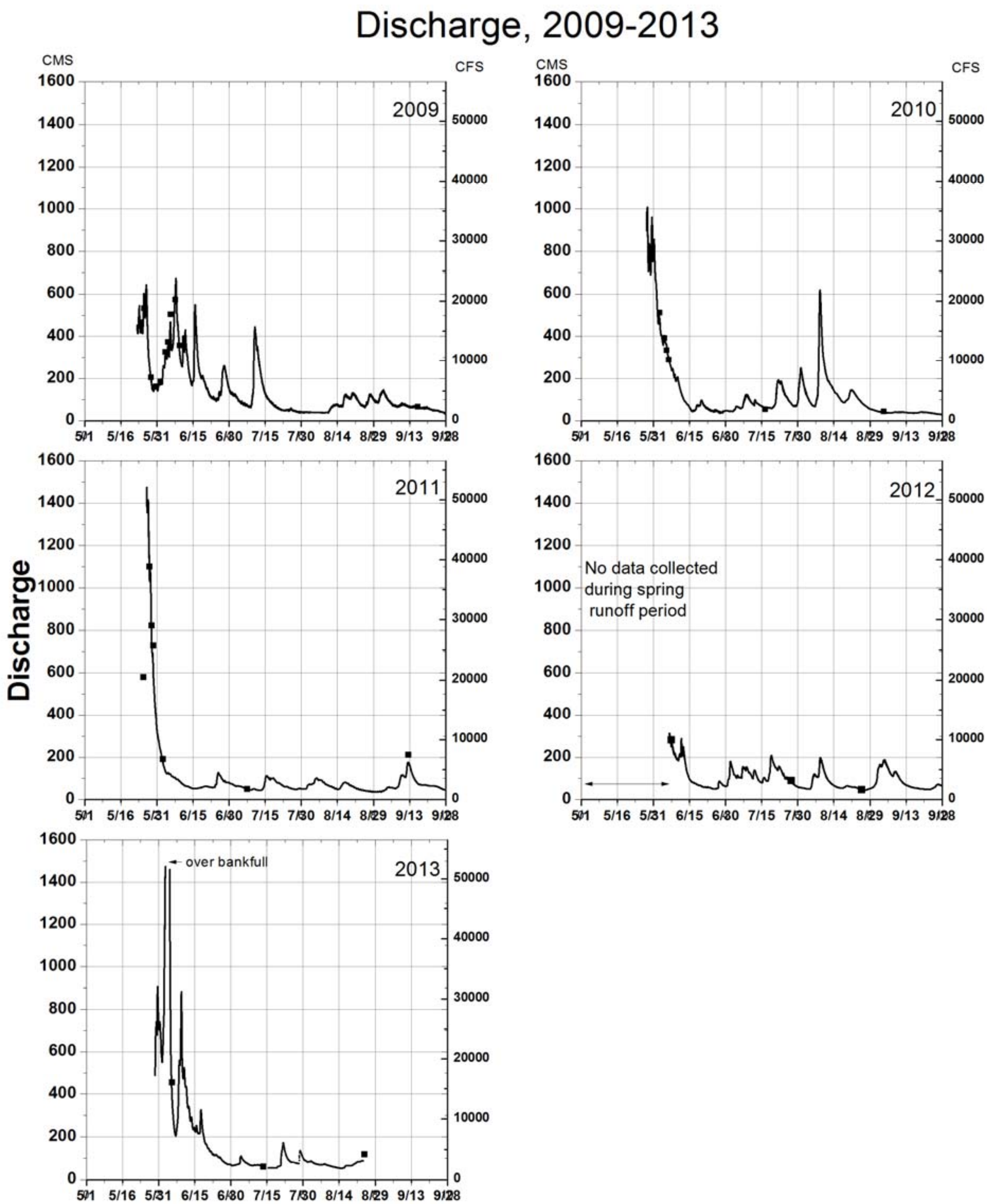


Figure 49. Continuous and manual measurements of discharge at the Anaktuvuk River station from 2009–2013. Units of m^3/s is on the left axis and ft^3/s is the right axis.

6.9.5 Chandler River

The Chandler River, located in the far west of the study area, emanates from the high-elevation Chandler Lake in the Brooks Range and flows north to the Colville River near Umiat (elevation ~90 m). The Chandler River is approximately 225 km long with a drainage area of 5800 km^2. The Chandler basin also includes the Siksikpuk and the Ayiyak drainages. In early May 2009, UAF installed an observation station approximately 15 km to the south (upstream) of the ADOT&PF proposed bridge-crossing location. Located on a bluff above the river, the station recorded water levels in 2009. In 2010, the station was expanded, becoming a full meteorological station. In spring 2011, because of difficulties accessing the river from the bluff and sensor damage due to thawing and sloughing of the bank, a new water-level observation station was established within the floodplain approximately 2.4 km downstream from the original station. Discharge measurements are typically made downstream from the bluff station about 1.3 km. The previous data reports (Youcha et al., 2011; Kane et al., 2012) summarize the early results of the project and provide more details on the breakup events of 2009–2011. This section includes updated stage and discharge data through 2013, and summarizes spring breakup in 2013.

Snowmelt ablation and the initiation of runoff at the North Slope occurred later in 2013 as compared with the long-term records at other rivers gauged in that region, and the Chandler River was no different. The Chandler River was still ice covered on May 24, with some early overflow present along the shoreline and near gravel bars at the gauging station and at the proposed road crossing. Substantial flow over the ice began on May 25 and increased steadily until early on May 27, when channel ice began breaking up. Later, on May 27, an ice jam formed downstream of the gauging station and water instrumentation sites (Figure 50), resulting in very high stages. This ice jam was also observed in 2011. The ice jam persisted in the channel until midday May 29, when it began to break apart as the stage continued to rise. From pictures, it was estimated that the larger pieces of ice were at least 4 to 5 m in length and width and nearly 2 m thick. The channel was clear and flowing free again by 3:00 P.M. AST on May 29. Bankfull conditions occurred beginning on June 2 (Figure 51). The peak flow occurred late evening of June 3, with over bankfull river conditions. The peak flow was not directly observed, as fog and freezing precipitation prevented flying to the river. Because of the cold weather and freeze-back that occurred from June 4 until early June 6, the river stage began to fall after the peak. Warmer weather beginning after midday on June 6 reinitiated snowmelt, and river stage again began to rise. A secondary lower snowmelt peak occurred on June 11. The stage receded after the secondary peak until it rose occasionally in response to summer rain events. A significant change in channel morphology occurred during the 2013 breakup. Summer stages at sloughs near the Chandler River station were noticeably higher during baseflow conditions. It is possible that the ice jam caused a gravel bar to form downstream, putting the station in a backwater at lower flow rates. Higher flow rates did not indicate a similar shift.

The snow cover disappeared by the afternoon of June 2 in riparian lowland areas and on the south- and west-facing slopes. Figure 52 to Figure 55 are aerial images taken at the proposed bridge crossing during spring breakup, approximately 8 miles downstream from the gauging site.

Figure 50. Sequential photos of an ice jam formation on the Chandler River at the water instrumentation station. The first 11 images were taken at half-hour intervals beginning at 7:30 P.M. AST on May 27, 2013, and ending at 1:00 A.M. AST on May 28, 2013, when ice tilted the camera (frame number 12 looking at sky). The last 8 frames show the ice jam breaking up after the camera was moved to higher ground and reset beginning at 1:00 P.M., and ending at 4:37 P.M. on May 28, 2013. Camera images show over bankfull river conditions during the ice jam. Flow is from left to right in images.

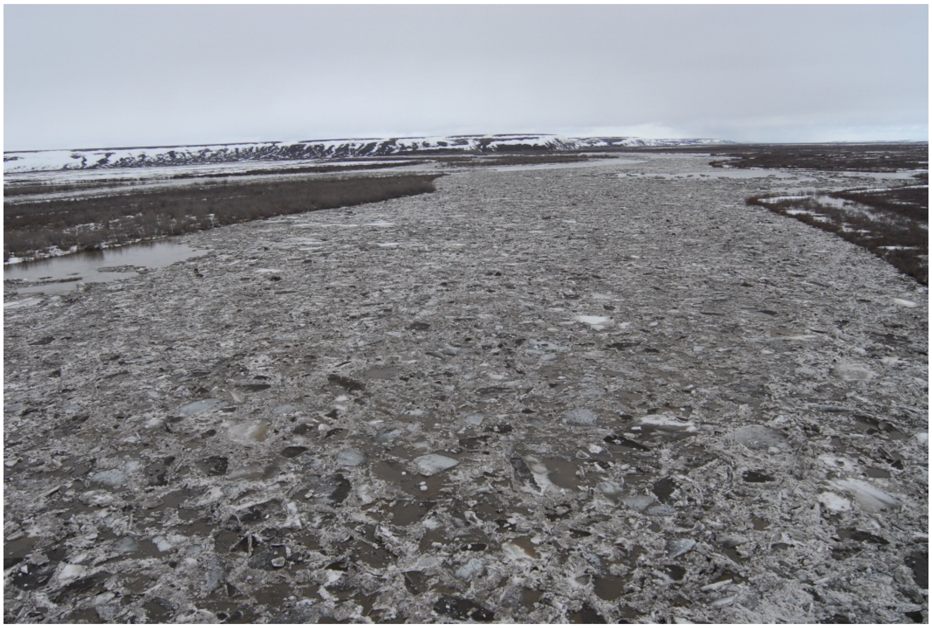


Figure 51. Aerial view (looking downstream) of the ice jam at the Chandler Water Station taken May 28, 2013. Ice pans 4–5 m in size are visible in the photograph.

Figure 52. Chandler River June 2, 2013, looking south from the gauge site at near bankfull stage conditions. Over bankfull conditions were observed here in 2013 as well as in 2011.

Figure 53. Chandler River at the proposed road crossing on May 26, 2013, looking south (left) and north (right).

Figure 54. Chandler River at the proposed road crossing on June 2, 2013, one day before peak flow, looking south (left) and north (right).

Figure 55. Chandler River at the proposed road crossing June 9, 2013, looking south (left) and north (right).

Figure 56 shows the water level elevations from 2009–2013. Water levels were collected at the Bluff station in 2009 and 2010. The datum for the station during this period of record is GEOID09AK, and establishment of the temporary benchmarks was made in 2009 and 2010 with a survey grade GPS, as described in Kane et al. (2012). Unfortunately, due to technical issues, damage to sensors (thawing and sloughing of hill slope), and data-quality problems, the 2010 water level data cannot be used. In 2011, the station was relocated downstream, and an arbitrary datum was established. Water level data were collected there from 2011 through 2013. The rating curve was not applied to the 2009 water level data due to the change in station location.

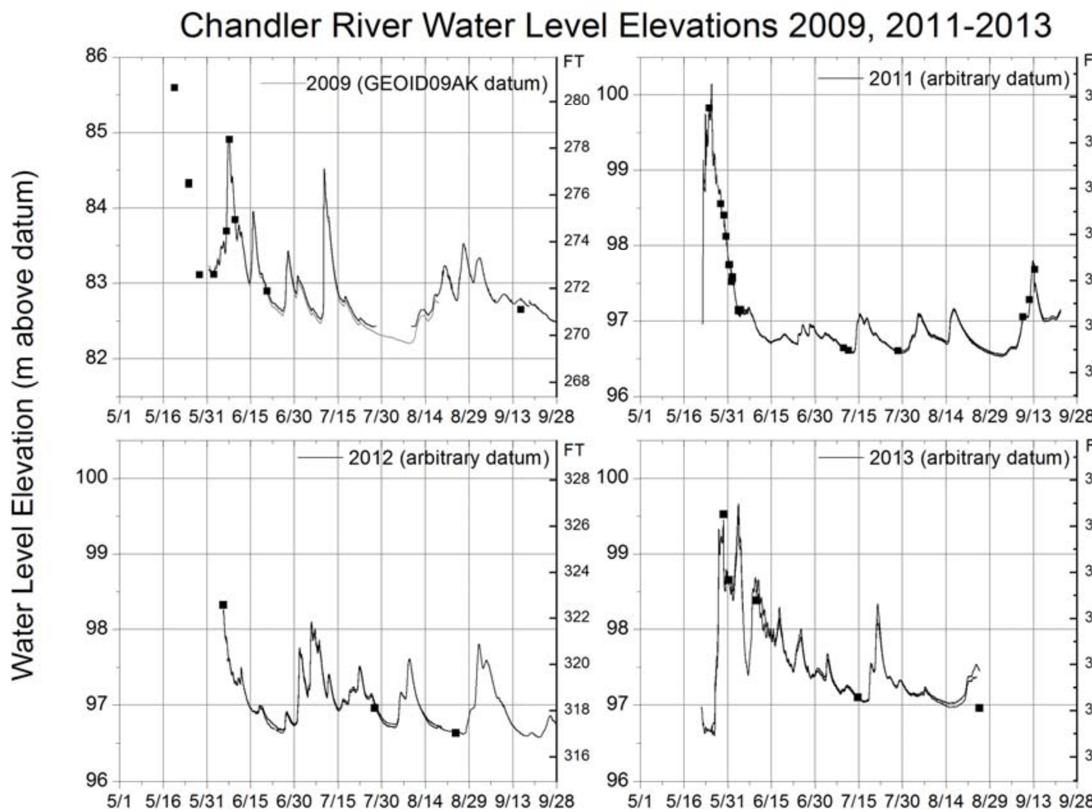


Figure 56. Continuous and manual measurements of water level at the Chandler River for 2009 and 2011–2013. In 2009, the data was collected at the Chandler River Bluff station, and the water level datum was GEOID09AK. Due to technical difficulties (thawing and sloughing of permafrost), damage to sensors, and data-quality problems, water levels for 2010 are not available. In 2011, a new station was established approximately 1 mile downstream from the original bluff station, and the new datum is arbitrary.

Discharge measurements were collected between the Bluff station and the new downstream station. Peak water levels are shown in Table 34, with the highest recorded stage occurring in 2011 during the ice jam. Similar high stages were also observed during the ice jam in 2013.

Table 34. Peak spring breakup and summer water-level events for the Chandler River 2009–2013. The stage is reported in units above the datum. The datum changed from GEOID09AK to an arbitrary datum in 2011

Date	Peak Water Level Elevation (m)	Peak Water Level Elevation (ft)
Spring: May 20, 2009	85.59	280.81
Summer: June 7, 2009	84.93	278.64
Spring: May 31, 2010	n/a	n/a
Summer: August 8, 2010	n/a	n/a
Spring: May 25, 2011	100.14	328.54
Summer: September 12, 2011	97.81	320.90
Spring 2012 not measured	n/a	n/a
Summer: June 5, 2012	98.25	322.34
Spring: June 3, 2013	99.64	326.90
Summer: June 17, 2013	98.27	322.41

Table 35 shows all discharge measurements made on the Chandler River during the study period. From this data, a rating curve was developed. As previously mentioned, a shift was applied to the rating curve in 2013 for low flow conditions due to changing channel morphology. The rating curve (see Appendix E) was applied to the continuous water levels, and the resulting continuous discharge is shown in Figure 57. Peak flows were obtained from the continuous discharge data (Table 36) and have a degree of error due to the uncertainty in the rating curve at high stage and the possibility of ice affecting the stage measurements. However, it was observed that by the peak flow, most of the ice had left the channel. The highest flows occurred during spring breakup. The maximum flow measured with an ADCP is 1030 m^3/s (36,350 ft^3/s) during breakup in 2011; however, higher stages occurred in both 2011 and 2013 that likely resulted in flows greater than 1460 m^3/s (51,560 ft^3/s). Summer flows have been recorded around 500 m^3/s (17,650 ft^3/s) in response to summer rain events. The low-flow discharge on the Chandler River for each year is around 22 m^3/s (775 ft^3/s).

Table 35. Discharge measurements for the Chandler River, 2010–2013. Stage datum is arbitrary.

Date	No.	Discharge (m^3/s)	Discharge (ft^3/s)	Stage (m)	Stage (ft)	Quality (%)	Mean Velocity (m/s)	Mean Depth (m)	Approx. Width (m)	Location
7/16/2010 14:00	1	15	544	n/a	n/a	10	0.2	1.91	50	Bluff Station
9/3/2010 14:00	2	30	1,080	n/a	n/a	5	0.8	0.53	70	500 m d.s.* station
5/26/2011 16:50	3	1,029	36,339	99.08	325.06	10	2.3	2.18	210	500 m d.s. station
5/28/2011 12:25	4	729	25,744	98.55	323.33	10	2.1	1.68	210	500 m d.s. station
5/29/2011 11:45	5	424	14,973	98.40	322.83	5	1.7	1.78	145	500 m d.s. station
5/31/2011 15:00	6	268	9,464	97.74	320.66	5	1.3	1.71	130	500 m d.s. station
6/1/2011 11:10	7	242	8,546	97.52	319.94	5	1.1	1.84	120	500 m d.s. station
6/3/2011 14:15	8	112	3,955	97.14	318.69	8	1.5	1.19	65	500 m d.s. station
7/9/2011 16:30	9	25	883	96.64	317.07	5	1.2	0.52	42	500 m d.s. station
9/11/2011 15:25	10	118	4,167	97.28	319.17	5	1.5	0.80	120	500 m d.s. station
9/13/2011 11:15	11	258	9,111	97.68	320.48	10	1.6	1.11	145	500 m d.s. station
6/6/2012 12:00	12	328	11,581	97.86	320.98	5	1.8	1.26	150	500 m d.s. station
7/27/2012 15:00	13	97	2,683	97.03	318.26	5	0.8	1.26	75	500 m d.s. station
8/24/2012 13:45	14	26	932	96.63	316.93	5	0.8	0.66	49	500 m d.s. station
6/1/2013 18:15	15	577	20,373	98.40	322.75	10	2.0	1.97	145	500 m d.s. station
6/2/2013 17:40	16	872	30,790	98.81	324.09	10	2.3	2.30	165	500 m d.s. station
6/6/2013 16:00	17	187	6,602	97.46	319.67	8	1.0	1.83	107	500 m d.s. station
6/8/2013 15:15	18	532	18,785	98.40	322.75	10	1.7	2.14	144	500 m d.s. station
7/13/2013 12:00	19	38	1,341	97.15	318.65	5	0.6	1.07	63	500 m d.s. station
8/25/2013 10:25	20	77	2,718	n/a	n/a	10	0.9	1.20	70	500 m d.s. station

* d.s. = downstream

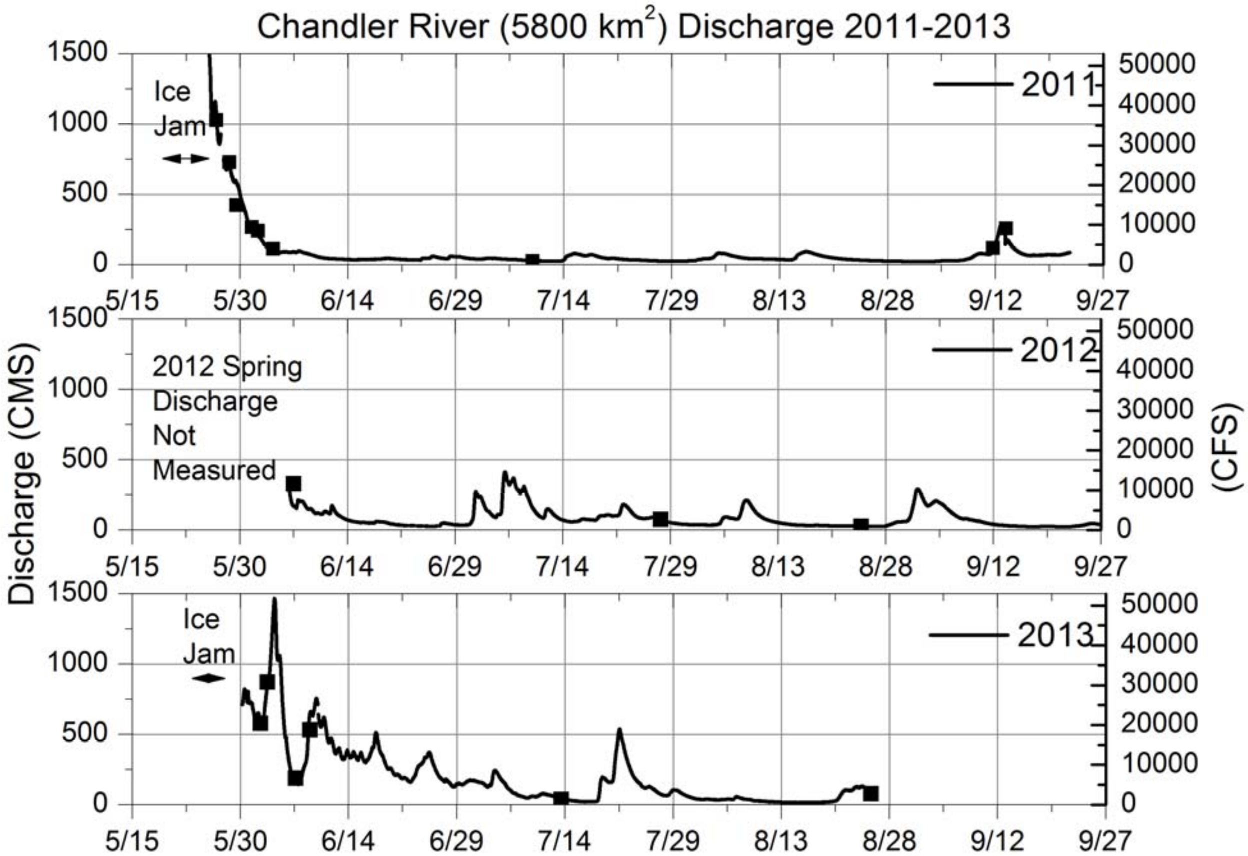


Figure 57.Continuous and manual measurements of discharge at Chandler River station from 2011–2013. Units of m^3/s are on the left axis, and ft^3/s is the right axis. Discharge data are not available during the ice jam in 2011 and 2013.

Table 36. Estimated peak discharge, Chandler River.

Date	Peak Runoff (m^3/s)	Peak Runoff (ft^3/s)
Spring: May 26, 2011*	1,160	40,965
Summer: September 12, 2011	291	10,276
Spring 2012 not measured	N/A	N/A
Summer: July 5, 2012	417	14,726
Spring: June 3, 2013	1,467+	51,806+
Summer: June 17, 2013	513	18,116

6.9.6 Additional Field Observations

Runoff at several other rivers within or near the study region has also measured by UAF and the USGS. This section presents runoff measurements from 2007 through 2013 on the Upper Sagavanirktok (USGS), Upper Kuparuk (UAF, funded by U.S. Fish and Wildlife Service [USF&WS]), Kuparuk at Prudhoe Bay (USGS), Colville River at Umiat (USGS), and

Putuligayuk at Prudhoe Bay (UAF, funded by USF&WS) Rivers. Since 1985, runoff data have been collected on Imnavait Creek (UAF, funded by National Science Foundation). We can use these data to examine relationships between basins with long-term runoff records and basins with short-term runoff records.

The Upper Sagavanirktok River originates in the Brooks Range and flows north into the Arctic Ocean near Deadhorse. The basin area at the USGS gauge site is 4100 km^2 (the entire basin is approximately 14,000 km^2), and runoff is measured in the Sagavanirktok before the confluence with the Ivishak River. Above the gauge site, most of the basin area lies in the mountains; a smaller percentage of the basin area is within the foothills region. Figure 58 presents hydrographs for the Upper Sagavanirktok River from 2007 through 2013, although spring runoff data are uncertain. Runoff during spring may not be measured due to ice conditions; it is typically estimated and often reported as mean daily discharge. For this reason, conducting a flood-frequency analysis for the spring snowmelt period is not possible; it is also not possible to do a spring water balance because the cumulative spring runoff is unavailable. Spring runoff is the largest event of the year in terms of cumulative runoff volume, but summer rainfall also contributes to high runoff events. The timing and magnitude of the highest flow events on the Upper Sagavanirktok correlate well with observations on the Itkillik, Anaktuvuk, and Chandler Rivers due to similar basin characteristics. For example, in 2009, the early summer high runoff event on June 7 was also observed on the Itkillik, Anaktuvuk, and Chandler Rivers. The runoff events on the nearby Itkillik River appear to be the most similar to the Upper Sagavanirktok in terms of peak and timing of not only the summer events, but also the snowmelt recession period. The Itkillik River is smaller than the Upper Sagavanirktok (in terms of basin area above the gauge site), but it is similar in gradient and the percentage of basin area within the mountains and foothills regions. According to Stuefer et al. (2011), the Sagavanirktok basin average SWE was 187% higher in 2011 than in 2010, but this great increase is not clearly visible in the hydrographs when comparing the two years. This increased snowpack in 2011 was reflected in the hydrographs for the Itkillik and Anaktuvuk Rivers (no comparison is available for the Chandler River due to missing data). Stuefer et al. (2014) reported another high snowpack year, with high flows observed on June 3 on the Itkillik, Anaktuvuk, and Chandler Rivers. High flows were not recorded during breakup for the Upper Sagavanirktok, but it is likely that peak occurred on June 3, similar to the Umiat area rivers.

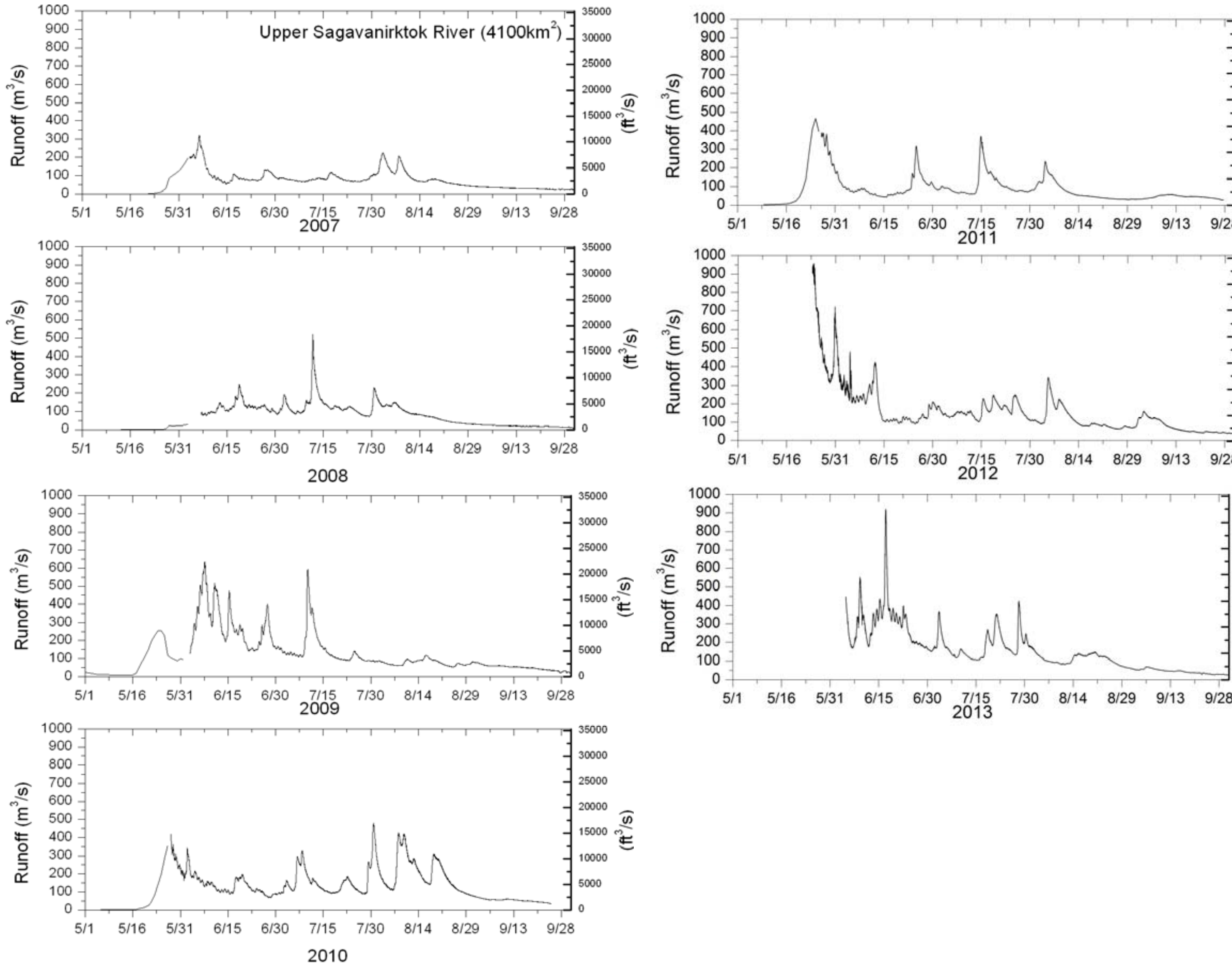


Figure 58. Upper Sagavanirktok River runoff, 2007 to 2013 (USGS, 2014). Data during peak spring runoff are often estimated due to ice or lack of frequent measurements, and runoff data are mean daily values.

The Upper Kuparuk River (142 km^2 above the gauge site) is a small basin that originates in the foothills of the Brooks Range and is the headwaters of the Kuparuk River basin. Runoff in the Upper Kuparuk River is measured by UAF at the Dalton Highway road crossing, just northeast of Toolik Field Station. Runoff is manually measured twice daily during the spring runoff period in order to capture discharge when the channel is ice-affected, and once or twice per summer to verify and improve the station rating curve. Runoff for the Upper Kuparuk from 2007 to 2013 is presented in Figure 59. Annual peak flow may be due to snowmelt runoff or summer runoff. Floods of record will always be rainfall generated (Kane et al., 2008a). The timing of both spring and summer peak flow events on the Upper Kuparuk correlates well not only with other nearby small gauged basins (such as the Atigun and Oksrukuyik Rivers that used to be gauged by the USGS), but also with the nearby Itkillik and Sagavanirktok Rivers. The summer floods of 1999 and 2002 are the largest floods during the 19-year period of record. In 2011, the largest snowmelt runoff event on record occurred, but unfortunately, the peak discharge was not measured. In 2013, another high runoff event occurred during the snowmelt period, which correlates well with the higher snowpack observed by Stuefer et al. (2014). Additionally, the timing of the 2013 peak correlates with the nearby Upper Itkillik River.

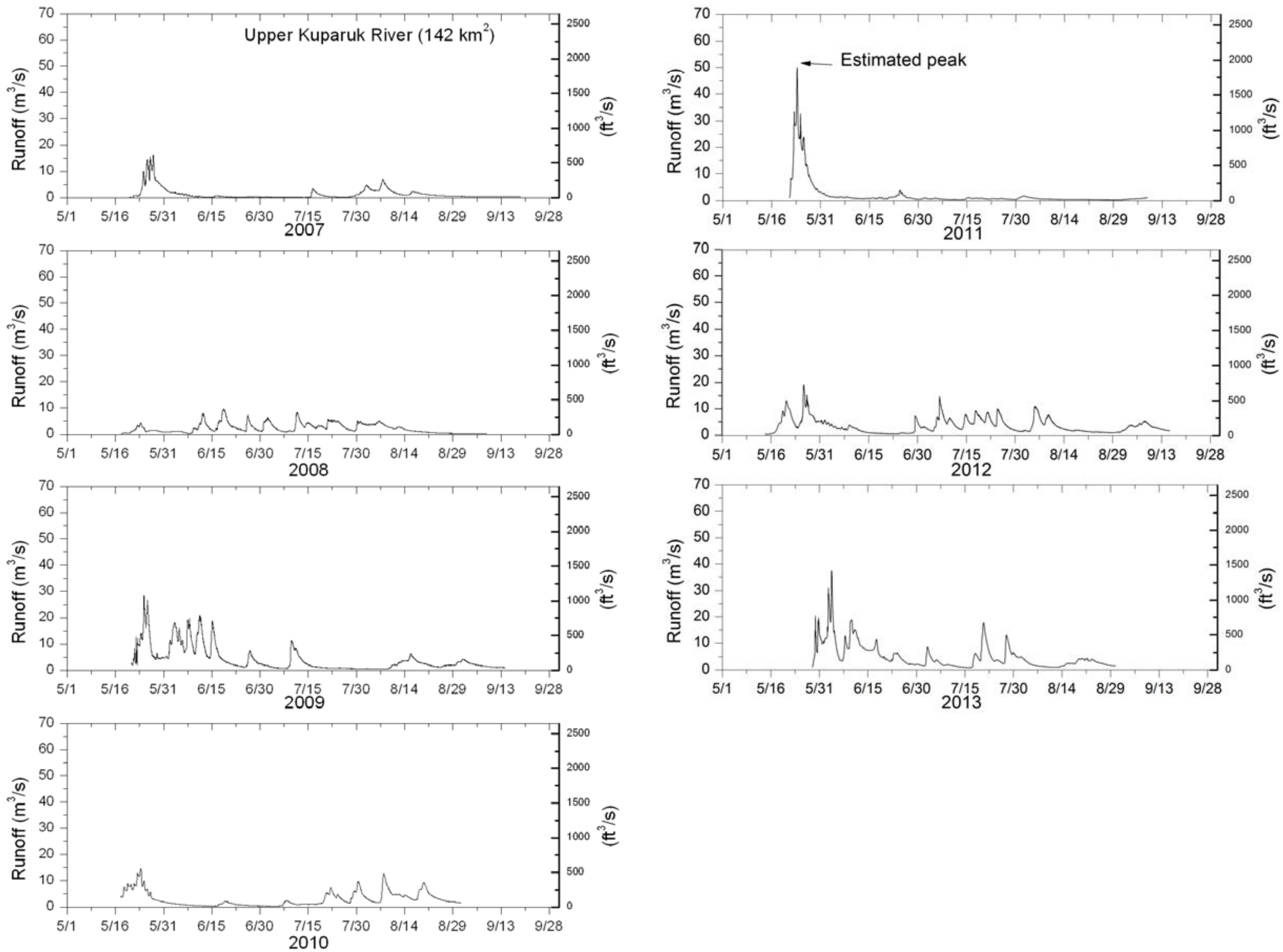


Figure 59. Upper Kuparuk River hydrographs, 2007–2013. The peak flow for spring 2011 is estimated.

The Kuparuk River originates in the foothills of the Brooks Range and flows north through the coastal plain to the Arctic Ocean. It is a medium-gradient basin of relatively large size (8100 km^2). Approximately 62% of the basin area is within the foothills region, and 38% is within the coastal plain. Runoff is measured by the USGS near Prudhoe Bay, and this data (2007 through 2013) are presented in Figure 60. Since runoff observations began in 1971, the largest event (in terms of total volume of runoff and annual peak flow) has always occurred during snowmelt runoff. For the early part of snowmelt runoff, the runoff presented in Figure 60 may be estimated (or reported as mean daily values) if the channel is still ice-affected. The peak snowmelt runoff on the Kuparuk was the highest in 2013 during the seven-year study period (based on 15-minute-interval data) and occurred sometime between June 3 and 5, similar to the Chandler, Anaktuvuk, and Itkillik. Typically, these more southern rivers peak a week or so before the Kuparuk at Deadhorse, but due to a late breakup, they peaked later than usual.

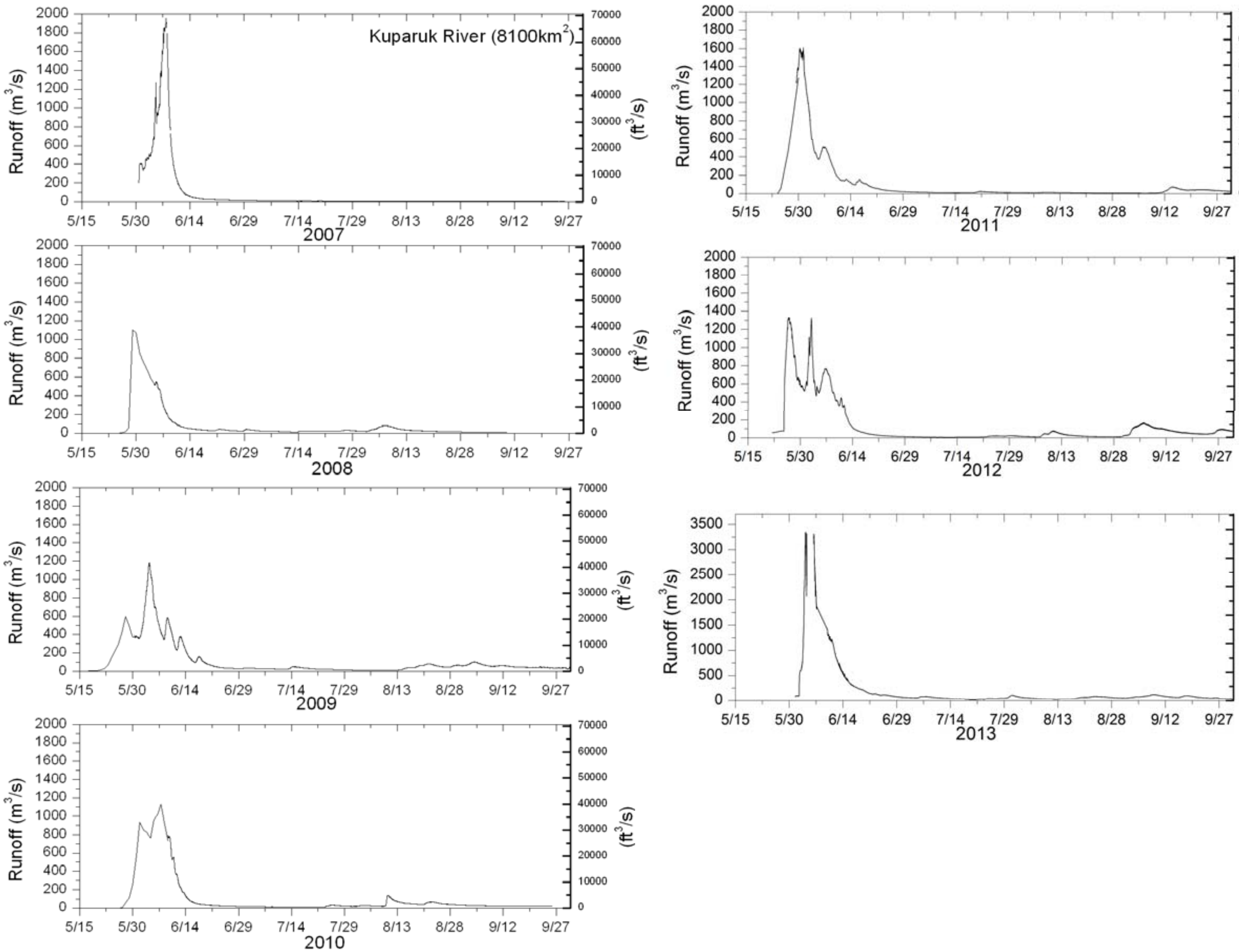


Figure 60. Kuparuk River (at Prudhoe Bay) hydrographs, 2007 to 2013 (USGS, 2014). Note that early data during spring runoff may be estimated due to ice in the channel. Also, note the change in the *y*-axis scale for 2013.

The Putuligayuk River (471 km^2) is a low-gradient basin contained entirely within the coastal plain and constrained by the Kuparuk to the west and the Sagavanirktok to the east. Snowmelt runoff is the only significant runoff event of the year, because what little precipitation that occurs during summer goes into deficit storage in the numerous lakes and wetlands within the basin. Figure 61 presents hydrographs for the Putuligayuk River. The Putuligayuk is measured twice daily by UAF/WERC during snowmelt runoff and once or twice during the summer months during low flow conditions. The years 2007 and 2008 had lower magnitudes and lower total volumes of runoff. In 2010, the highest peak runoff was recorded; however, the total volume of runoff was similar to 2011. As with other basins in the region, the shape of the hydrograph during snowmelt may be very different each year, depending not only on the basin SWE, but also on local meteorology, which can prolong the snowmelt runoff period during cold times.

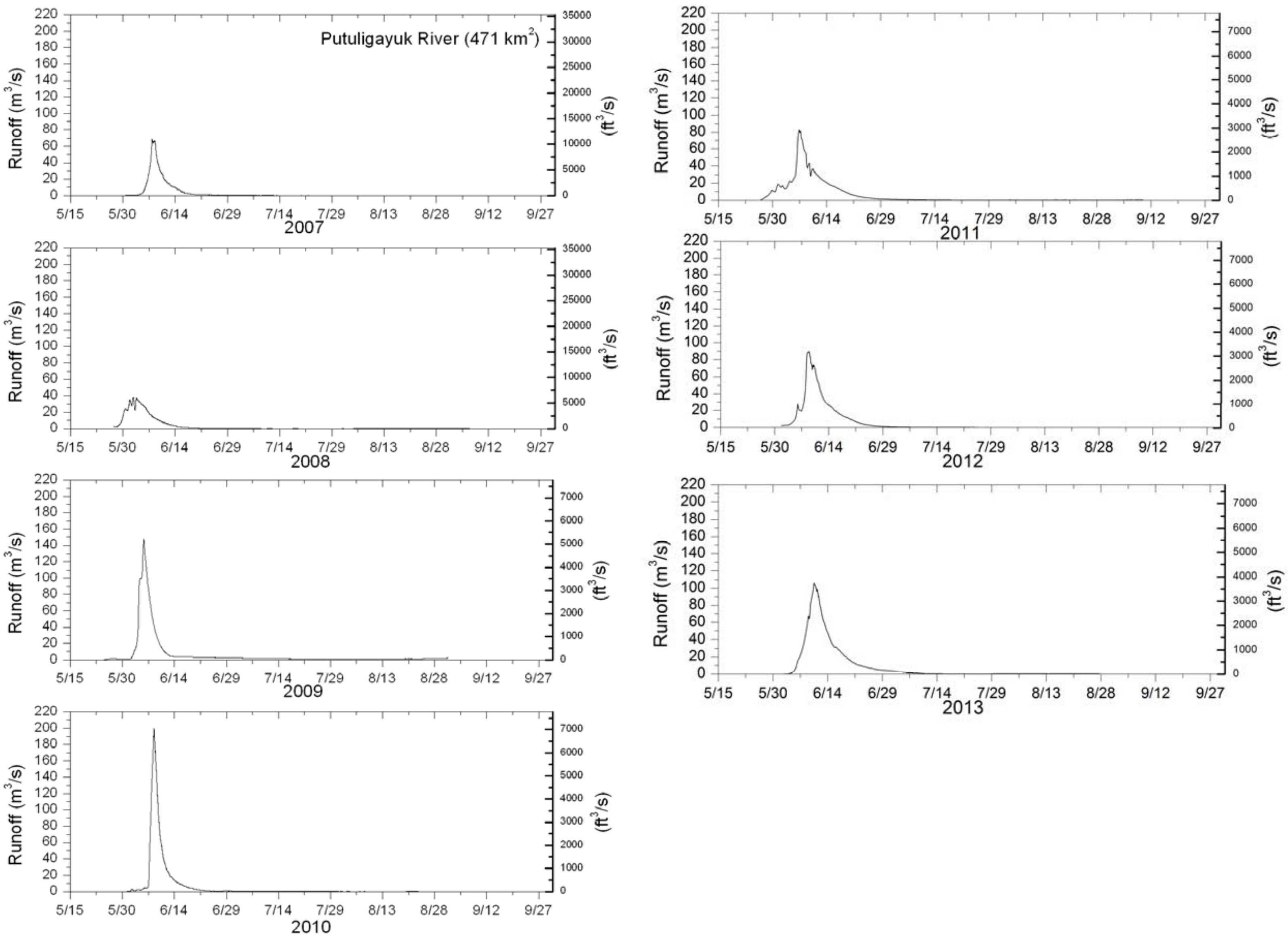


Figure 61. Putuligayuk River hydrographs, 2007–2013.

The Colville River is the largest Arctic basin (35,819 km^2 above the USGS gauge site at Umiat) in Alaska. The river is braided and drains a large area of the west-central Brooks Range, foothills, and coastal plain into the Arctic Ocean. At Umiat, the majority of the contributing watershed area is within the mountains and foothills regions. Near the Umiat area, the Itkillik, Anaktuvuk, Chandler, and Killik Rivers all drain into the Colville River. Figure 62 shows the hydrographs for the Colville River, which is gauged by the USGS. The river peaks in late May or early June, and several smaller events occur during the summer months from rainfall. Of the six years of available data, 2011 and 2013 had high discharges during snowmelt, which correlates well with the observed snowpack and to observations on other nearby rivers.

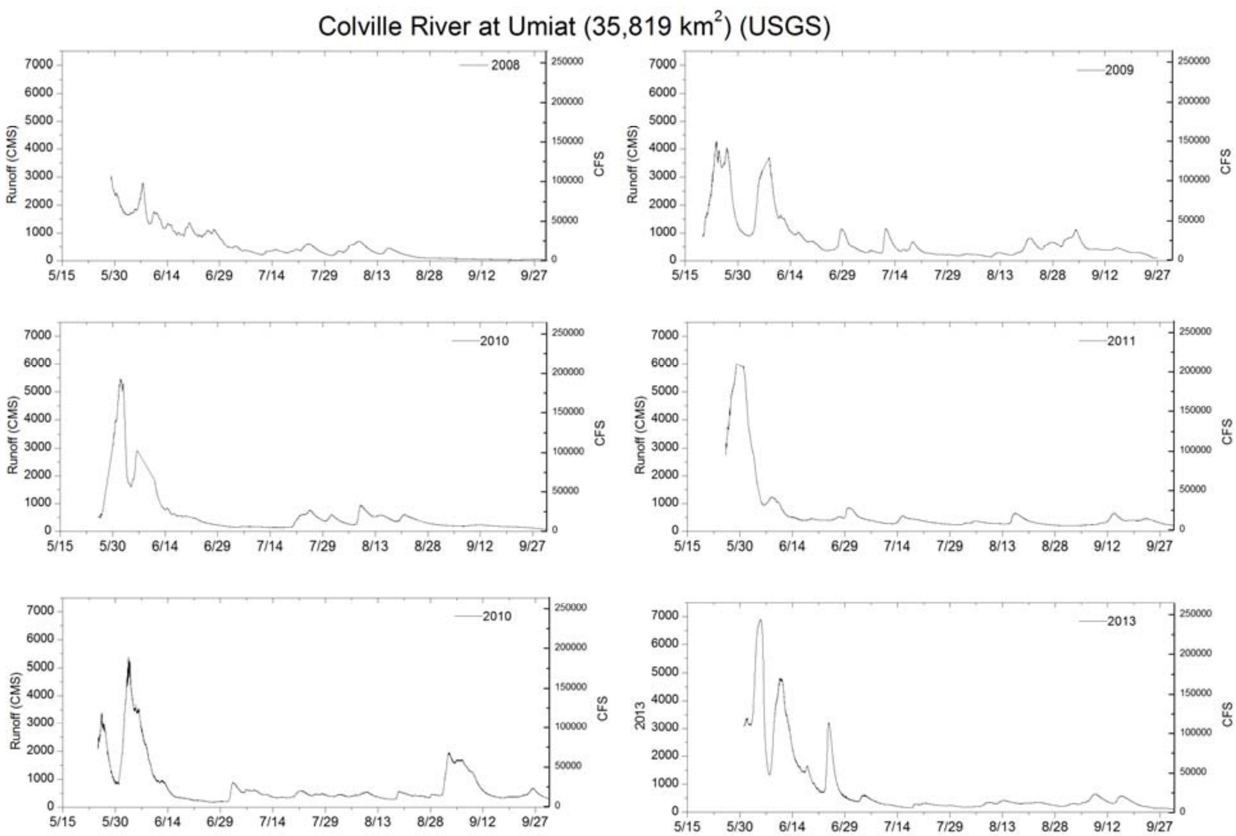


Figure 62. Colville River hydrographs, 2008–2013 (USGS, 2014).

6.10 River Sediment Results

6.10.1 Correlation between Isco and Depth-Integrated Samples

A comparison between SSC calculated from both the Isco sampler and the depth-integrated sampler is shown for the Anaktuvuk River in Figure 63. A linear fit was used, with the Isco usually underpredicting SSC when compared with the depth-integrated sampler. The Isco sampler intakes, while not usually on the bed itself, were in the lower portions of the water column. As most suspended sediments are carried at roughly 60% of the water depth (Garcia 2008), the relatively low location in the water column of the Isco intake led to an underprediction of SSC when compared with a depth integrated sample. On the Chandler River (Figure 63), the Isco sampler usually underpredicted the SSC value as well, but in a few instances, the depth-integrated sampler had a slightly lower SSC value than the concurrent Isco sampler had at times of low flow. Again, the same pattern was seen at both of the Itkillik River stations (Figure 63). With such high R^2 values, it is clear from the relationship between the point Isco samples and the depth-integrated samples that this is an accurate method for evaluating SSC throughout the entire river cross section and throughout time. A higher R^2 value would be expected on the Lower Itkillik River with the collection of more depth-integrated samples. Three depth-integrated samples were collected on the Lower Itkillik River, compared with eight on the Chandler River and six on the Anaktuvuk River.

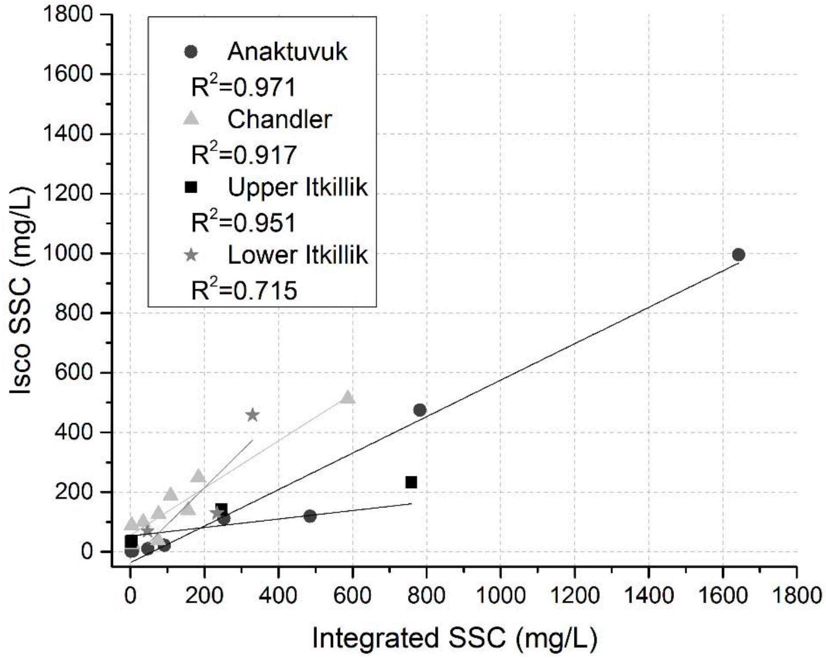


Figure 63. Comparison of SSC for depth-integrated samples vs. SSC of Isco samples.

6.10.2 Suspended Sediment Rating Curves

Suspended sediment rating curves were produced for the Anaktuvuk, Chandler, and Itkillik Rivers, relating SSC and discharge (Figure 64). These rating curves do not reflect periods of time when the channel was ice-affected; they are accurate for flows that occur after spring breakup. The suspended sediment rating curves were developed using depth-integrated samples. Considering the rating curves shown in Figure 64, it is evident that the Chandler River carried a larger suspended sediment load than the Anaktuvuk River for the same discharge, and the Lower Itkillik River even more still. The best fit was linear at the Upper and Lower Itkillik River stations, while a power fit was used on the Chandler and Anaktuvuk Rivers. Note that at both of the Itkillik River stations, a limited number of samples were collected, and discharges were not nearly as large as those on the Chandler and Anaktuvuk Rivers. The exponent of the power function is larger for the Chandler River, which indicates that for the same increase in discharge, the Chandler will show a larger increase in SSC than the Anaktuvuk. On the Itkillik River, these rating curves show that, at the same discharge, the Lower Itkillik station has a higher SSC than the Upper Itkillik station has because of increased access to sediments.

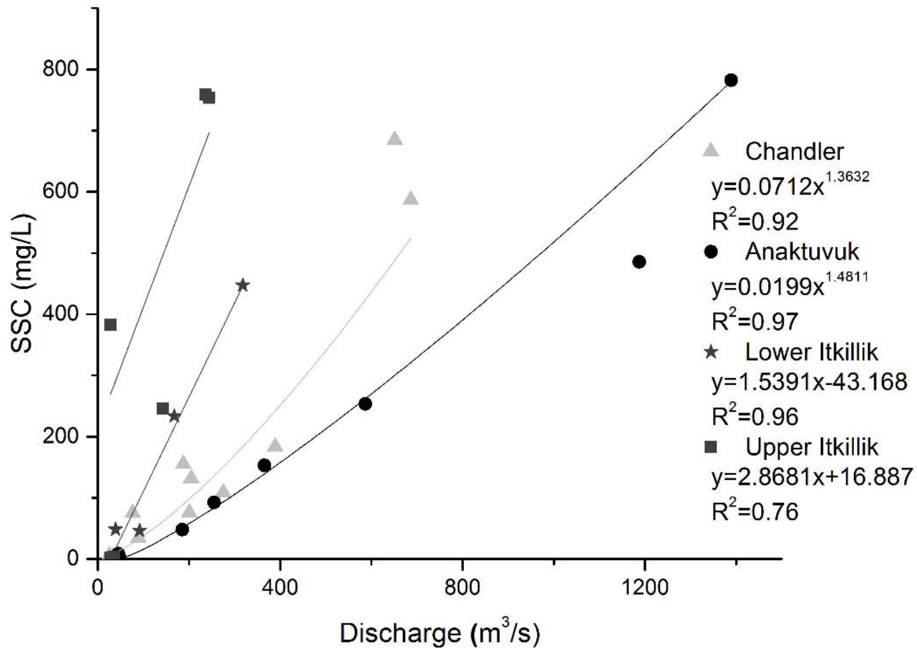


Figure 64. Suspended sediment rating curves for three North Slope Rivers: Itkillik, Anaktuvuk, and Chandler Rivers.

6.10.3 Suspended Sediment Concentrations

The amount of suspended sediment in each river varied dramatically throughout the flow season. By plotting the SSC of the Isco samples and discharge throughout the summer flow season, a picture of suspended sediment transport over time can be generated. Considering the Anaktuvuk River (Figure 65), in 2011 SSC started quite low and then rose dramatically to a high value of 994.8 mg/L on May 25, 2011, at 12:40 P.M. AST. This rise in SSC corresponded to the lifting of some bottom ice and the erosion of snow in the river channel, exposing sediments and allowing for the dramatic rise in sediment transport. As for 2011, the only flow season with a relatively consistent record of SSC, it is clear that for this year, the majority of suspended sediment transport on the Anaktuvuk River occurred during spring melt, as minimal summer storms caused little additional change in the summer volume of SSC.

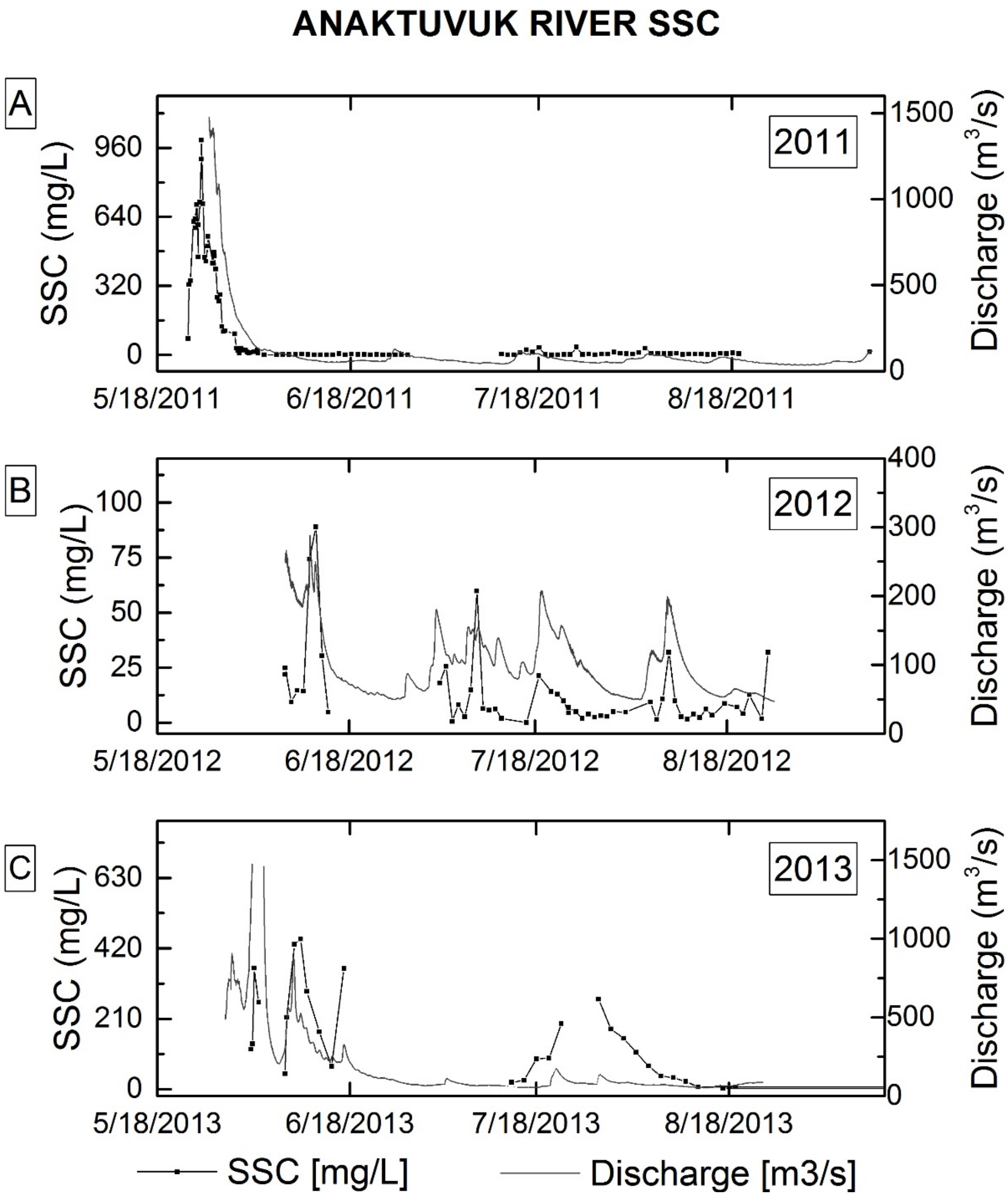


Figure 65. SSC (Isco) and discharge for the Anaktuvuk River for the period 2011–2013. Note the change in *y*-axis scale for the three years.

On the Chandler River, large fluctuations in SSC and discharge also occurred during spring breakup, as well as during the summer (Figure 66). As with the Anaktuvuk River, in 2011 the Chandler River started flowing with essentially no sediments entrained, and then SSC quickly rose and peaked on May 26, 2011, at 3:00 P.M. at 2193 mg/L. The Chandler River experienced larger increases in SSC than the Anaktuvuk River for the same increase in discharge (Figure 64). In 2012 for the Chandler, a rain event in June, following on the heels of breakup, caused an increase in the hydrograph and a rise of SSC to 1203 mg/L on July 7, 2012; the largest SSC recorded in the summer of 2011 was 457 mg/L on August 5, 2011. During breakup in 2013, the largest SSC recorded on the Chandler was 1708 mg/L on May 28, 2013, at 9:00 P.M. There is a gap in SSC measurements, however, from May 30, to June 6, 2013, during which peak discharge occurred on June 3, 2013, at 5:30 P.M. and a flow of 1467 m^3/s. It could be expected that the maximum SSC value occurred during this time (turbidity peaked shortly after the peak in the hydrograph, Figure 74). Using the suspended sediment rating curve for the Chandler River (Figure 64), an SSC of approximately 1477 mg/L would be expected at this discharge of 1467 m^3/s (51,800 ft^3/s).

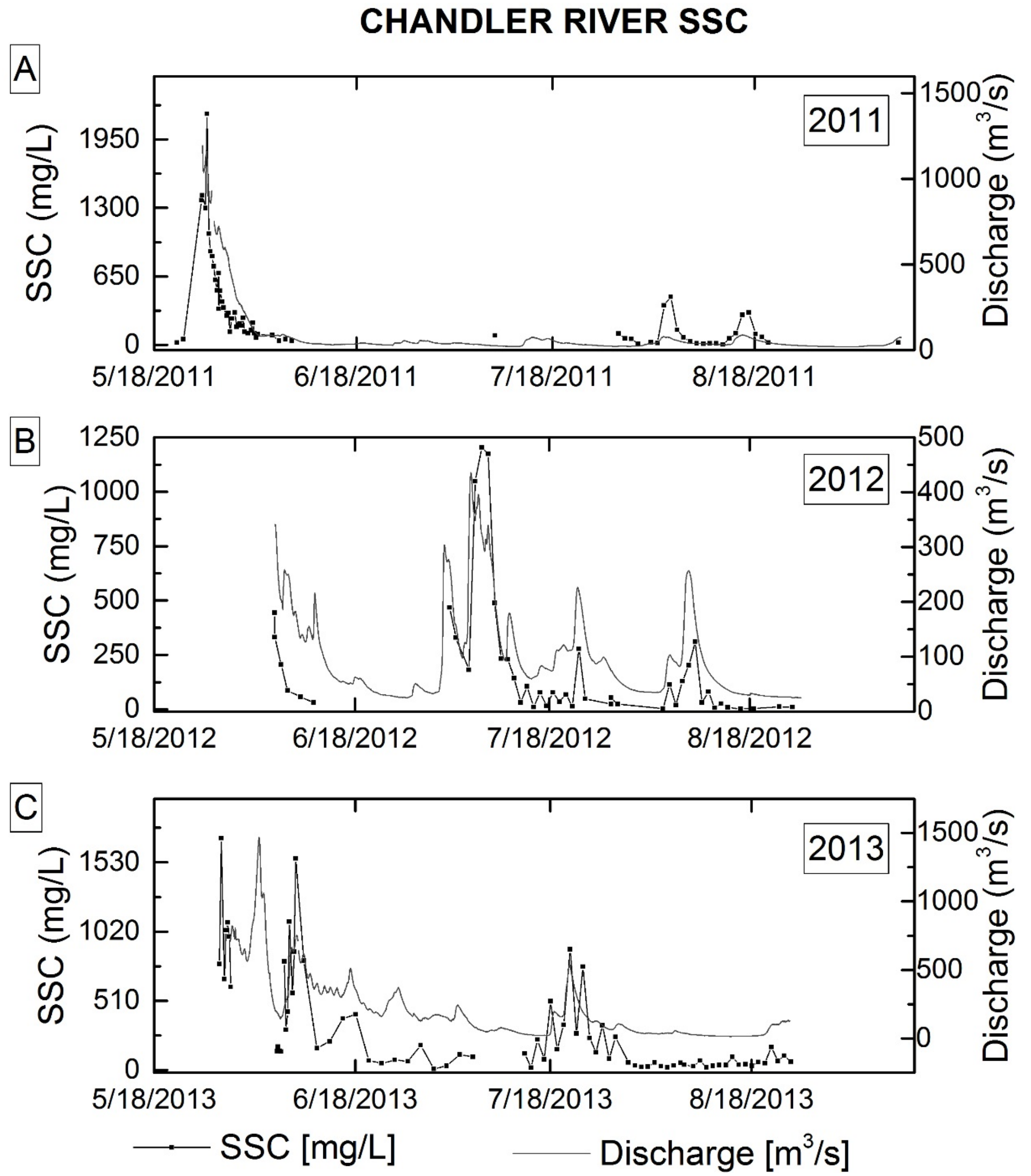


Figure 66. SSC (Isco) and discharge for the Chandler River for the period 2011–2013. Note the change in *y*-axis scale for the three years.

The Upper Itkillik River clearly had a suspended sediment transport regime that responded strongly to increases in discharge, as well as a "flashy" runoff response to summer precipitation events (Figure 67). The narrow shape of the Itkillik watershed and the fact that much of the upper reaches are located in the high-hydraulic-gradient mountains cause the river to respond more intensely to summer precipitation events. The smaller size of the watershed also means that a rain event affects a larger percentage of the watershed area than a similarly sized event over a much larger watershed. The highest value of SSC recorded on any river was on the Itkillik River on June 8, 2012, a combination of the spring freshet and a rain event; 6.9 cm (2.7 in.) of rain fell at the May Creek station on June 3, 2012. The June 8, 2012, SSC value of 3947 mg/L is dramatically higher than any value recorded during breakup or the summer on the Anaktuvuk and Chandler Rivers, indicating that the Itkillik River has abundant sources of sediment that are easily accessed by relatively minor increases in discharge. The increase in SSC from June 4 to June 8, 2012, was an increase of 3772 mg/L, or 2100%. The discharge, on the other hand, increased by 37.5%. The presence of intermediate SSC samples on both the rising and falling limbs of the hydrograph for this rain event confirms that the exceptionally high SSC measured on June 8, 2012, is most likely accurate. This pattern is seen again throughout the summers of 2011 and 2012, as summer rain events cause moderate increases in discharge and large changes in SSC. The Isco samplers on the Upper Itkillik failed during the summer of 2013, but did capture samples during spring breakup. The highest SSC value recorded in 2013 was 759 mg/L on June 3, 2013.

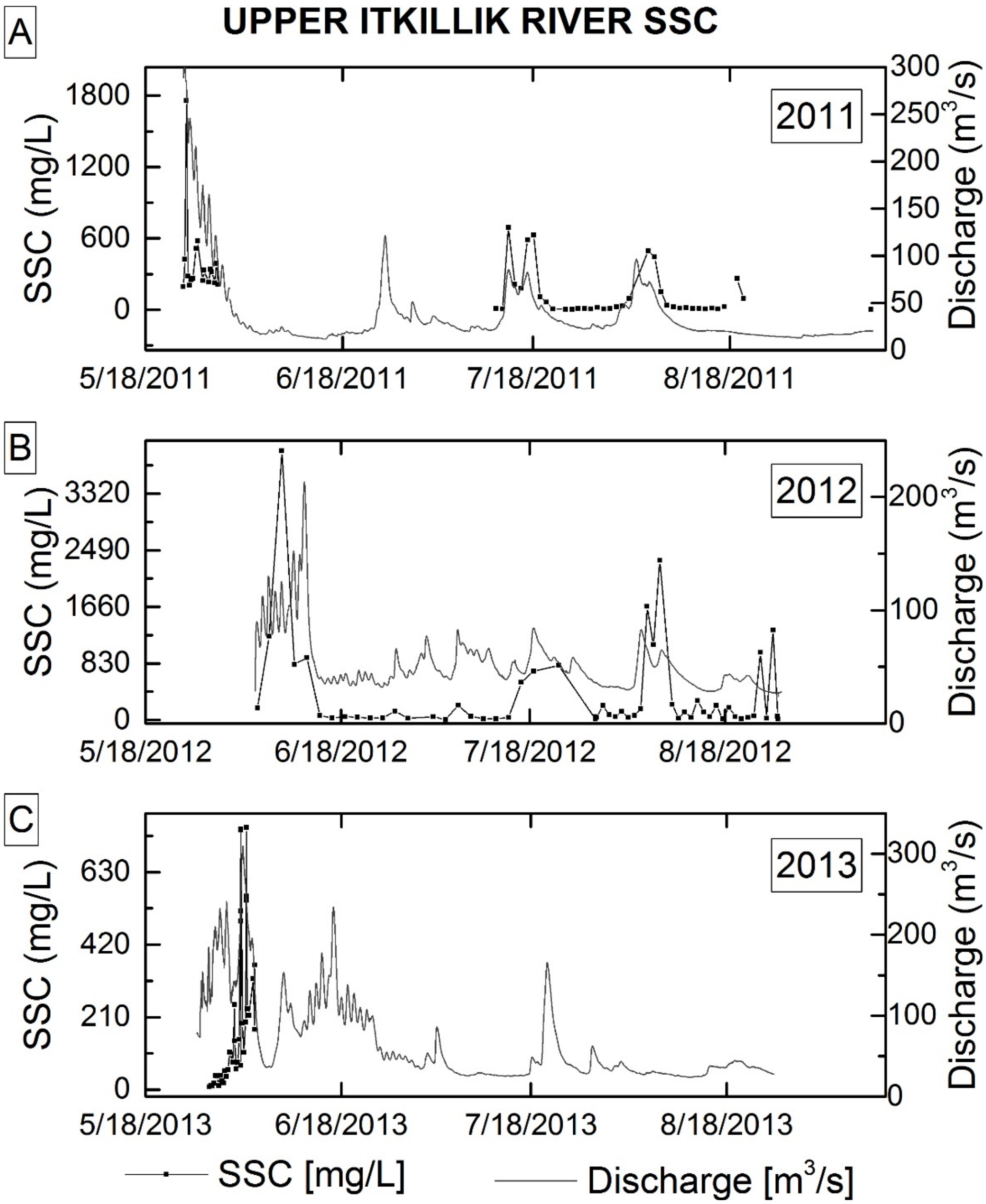


Figure 67. SSC (Isco) and discharge for the Upper Itkillik River for the period 2011–2013. Note the change in *y*-axis scale for the three years.

Suspended sediment samples were taken on the Lower Itkillik River for the first time in the spring of 2013. Due to a limited number of samples and instrument malfunction, it is difficult to draw any conclusions about suspended sediment transport dynamics in the Lower Itkillik River (Figure 68), or how this relates to the suspended sediment regime of the Upper Itkillik River.

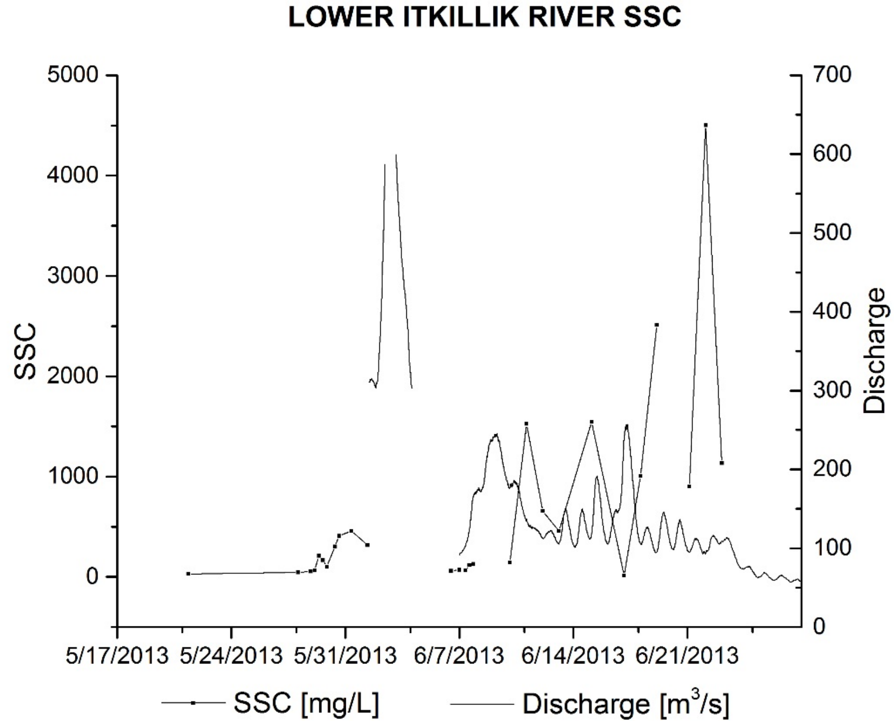


Figure 68. SSC (Isco) and discharge for the Lower Itkillik River for 2013.

6.10.4 Suspended Sediment Discharge

While considering SSC at specific points in time conveys a large amount of information about the sediment transport regime of a river, an insight to this regime is provided by considering the suspended sediment discharge (q_s), which allows for the comparison of sediment loads between rivers of varying discharges and within the same river over time as discharge fluctuates. Suspended sediment discharge curves were developed for the Chandler (Figure 69) and Anaktuvuk (Figure 70) Rivers using the suspended sediment rating curves developed from depth-integrated samples (Figure 64) and the values of discharge at 15-minute intervals during periods of flow when the channels were not ice-affected. Note that no hydrologic measurements were made during spring breakup in 2012 on the Anaktuvuk, Chandler, and Itkillik Rivers. Comparing Figure 69 and Figure 70, it is clear that the Chandler River peaked at a higher q_s in 2011 than the Anaktuvuk River, despite the fact that the Anaktuvuk River peaks at a higher water discharge; the same occurred during spring breakup in 2013.

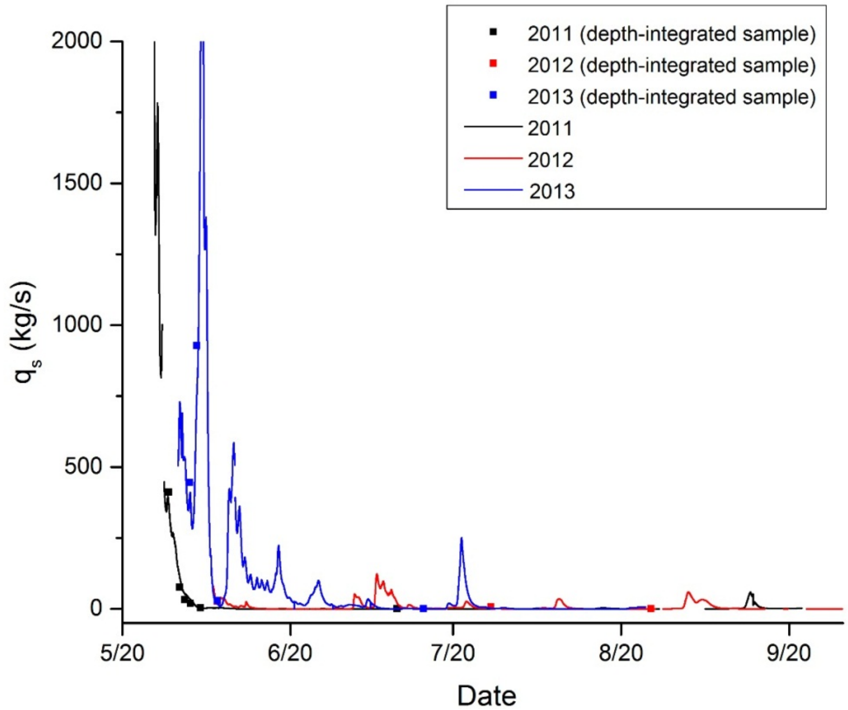


Figure 69. Chandler River estimated suspended sediment discharge for the period 2011–2013 (no observations during 2012 breakup).

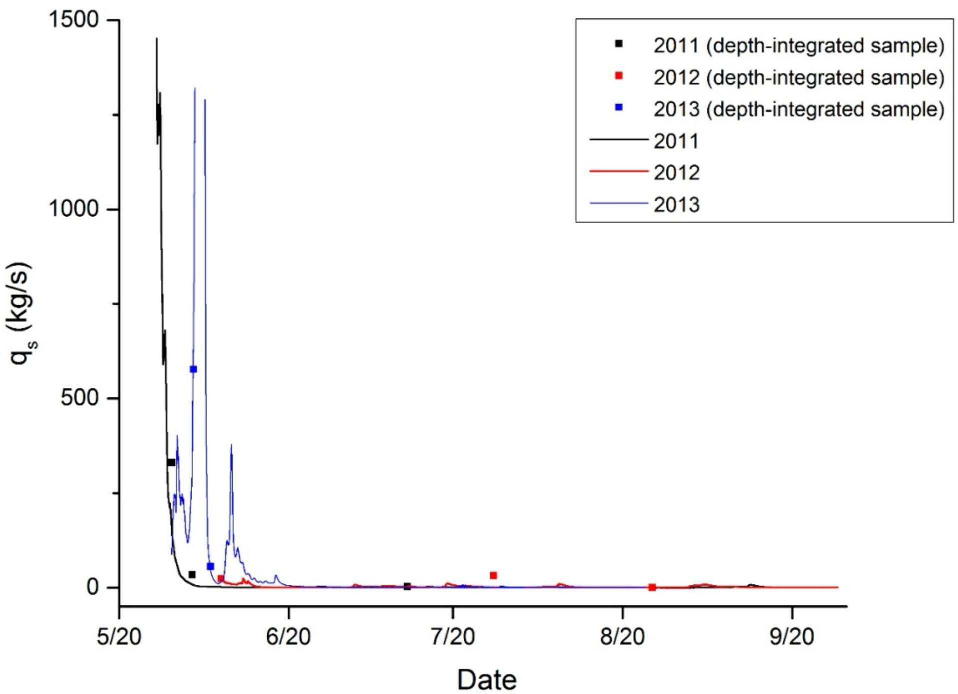


Figure 70. Anaktuvuk River estimated suspended sediment discharge for the period 2011–2013 (no observations during 2012 breakup).

The Upper Itkillik River has a different suspended sediment discharge regime than the Anaktuvuk or Chandler Rivers (Figure 71). A less clearly defined peak in suspended sediment discharge is seen during spring breakup (possibly this is due to bottom ice in the channel, but this has not been quantified), and during spring 2013, large amounts of sediment were transported through the month of June. The Lower Itkillik River (Figure 72) has a regime that is a single large peak during spring breakup, with low values during the warm season.

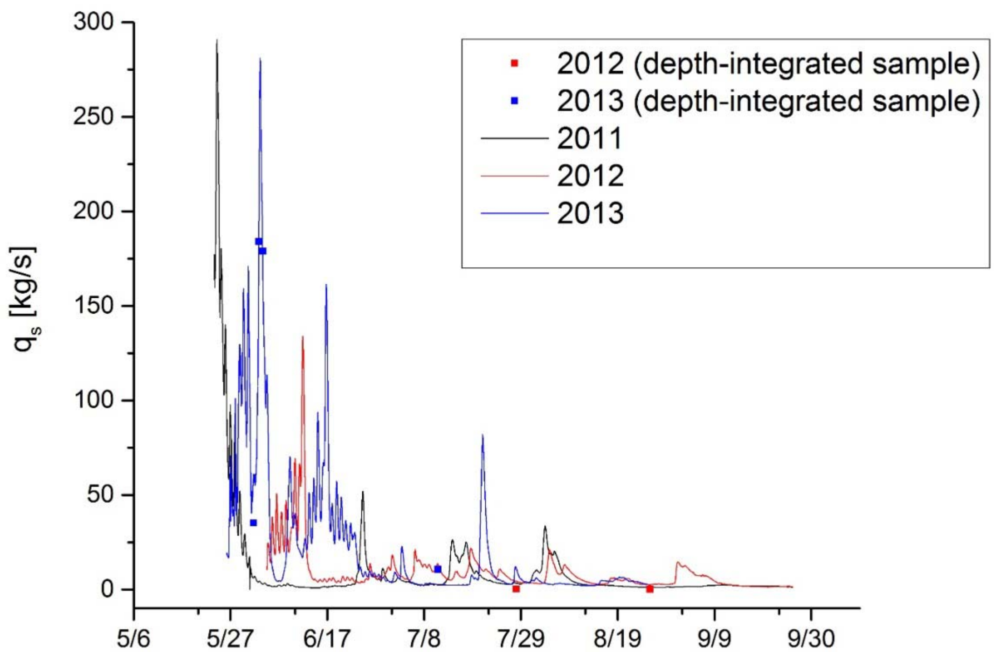


Figure 71. Upper Itkillik River estimated suspended sediment discharge for the period 2011–2013 (no observations during 2012 breakup).

Considering Figure 69 and Figure 70, it is evident that most of the suspended sediment transport of the open-water season occurred during spring breakup for 2011 and 2013 on the Chandler and Anaktuvuk Rivers (no observations in 2012). Looking at suspended sediment yields month by month reveals how big an event the spring melt is on rivers in the Alaska Arctic; although the month in which breakup occurs can change from year to year (for example, breakup peaked in May in 2011, but June in 2013), it is the major event for suspended sediment transport.

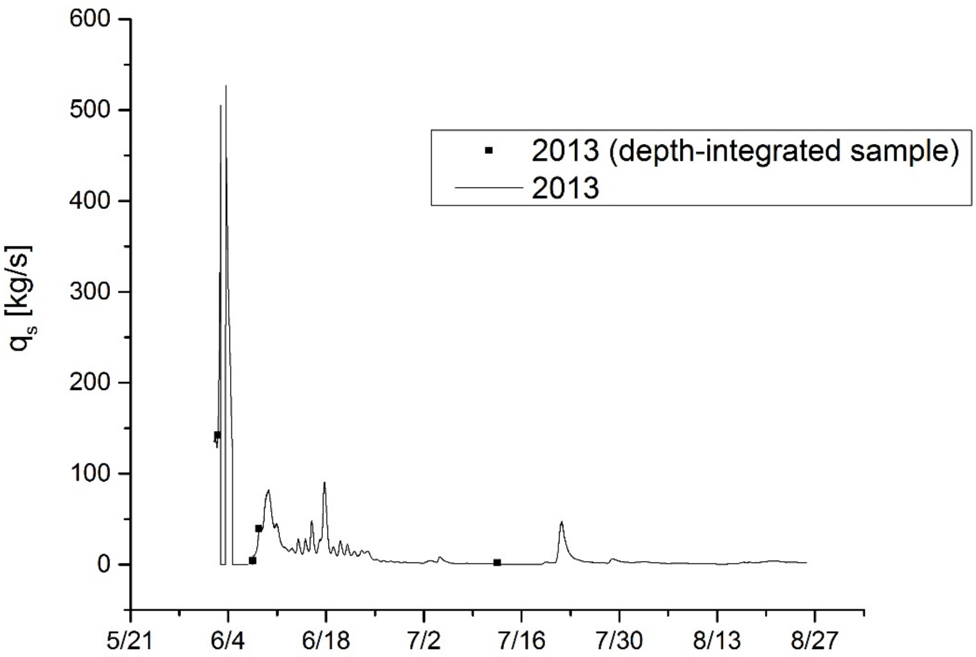


Figure 72. Lower Itkillik estimated suspended sediment discharge for 2013.

On the Anaktuvuk River in 2011, 94% of suspended sediments were moved in the month of May (Table 37), actually within a one-week period at the very end of the month, from May 26 to May 31, 2011. On the Chandler River (Table 38) the spring melt moved 93% of suspended sediments in 2011, during the period of May 25 to May 31, 2011. In 2013 on the Anaktuvuk River, 38% of suspended sediments were moved in May and 71% in June, due to a later breakup. The same pattern occurs on the Chandler River, where 82% of sediments were moved in June of 2013. If discharge is also considered for the entire flow season, on the Anaktuvuk River in 2011 approximately 31% of flow occurred during the month of May; on the Chandler River in 2011 39% of flow occurred in May. This indicates that the large volume of water flow during breakup is not enough alone to cause the considerable flux of suspended sediments.

Along with the magnitude of spring melt, another obvious feature of the suspended sediment yields is the large interannual variability within both rivers. On the Anaktuvuk River in July, q_s in 2012 increased 333% over q_s in 2011, while the Chandler River in July experienced an even larger increase between those two years. This variability is due to changing patterns of precipitation, in which the summer of 2012 was overall a wetter summer than 2011. On the

Upper Itkillik River (Table 39) in 2011, however, 55% of sediments were moved in May, and then roughly equal percentages were transported in June, July, and August (11–16%). In 2013, 22% of suspended sediments were transported during the last week of May, 61% in June, and 12% in July. Due to gaps in the discharge record, it was not possible to do similar calculations for the Lower Itkillik River.

Table 37. Suspended sediment yields for the Anaktuvuk River for 2011–2013, in metric tonnes per month, and monthly percentages. (Note that no observations were made in May 2012 and September 2013.)

	2011		2012		2013	
May	165637	93.6%	N/A	N/A	51323	26.8%
June	5033	2.8%	7649	32.8%	135454	70.8%
July	1810	1.0%	7821	33.6%	2891	1.5%
August	1659	0.9%	3213	13.8%	1569	0.8%
September	2853	1.6%	4614	19.8%	N/A	N/A

Table 38. Suspended sediment yields for the Chandler River in 2011 and 2012, in metric tonnes per month, and monthly percentages (Note that no observations were made in May 2012 and September 2013).

	2011		2012		2013	
May	251069	93.0%	N/A	N/A	84257	12.4%
June	6799	2.5%	13590	17.8%	555739	81.7%
July	1252	0.5%	40060	52.4%	38638	5.7%
August	2037	0.8%	7541	9.9%	1755	0.3%
September	8950	3.3%	15289	20.0%	N/A	N/A

Table 39. Suspended sediment yields for the Upper Itkillik River in 2011 and 2012, in metric tonnes per month, and monthly percentages. (Note that no observations were made in May 2012 and September 2013.)

	2011		2012		2013	
May	60049	55.8%	N/A	N/A	37359	22.1%
June	12315	11.4%	39430	44.8%	103621	61.2%
July	17110	15.9%	24178	27.5%	20398	12.1%
August	14010	13.0%	14367	16.3%	7881	4.7%
September	4105	3.8%	10054	11.4%	N/A	N/A

6.10.5 Turbidity

Turbidimeters were used as a surrogate for continuous, remote estimation of SSC. Installed in July 2011, results varied between rivers and over time. While it is evident that turbidity should relate strongly to SSC, in practice this relationship is more complex. The Anaktuvuk and

Chandler Rivers in particular carry organic material as well as suspended sediments, and in 2011 this organic material caused inaccurate readings on the turbidimeters because wipers were not installed on the instruments originally. The effect is especially obvious on the Anaktuvuk River (Figure 73), where we see turbidity rising rapidly in late August despite a declining discharge. This is a clear indication that the turbidimeter is not reading correctly. The Chandler (Figure 74) and Upper Itkillik (Figure 75) Rivers had fewer issues with fouling than the Anaktuvuk River. For the summers of 2012 and 2013, the turbidimeters were installed with wipers on the optical windows to reduce the problems with organic matter. While the goal was to establish a relationship between turbidity and SSC, poor measurements and large amounts of noise in the turbidity readings made this impractical.

Turbidity measurements on the Anaktuvuk River (Figure 73) were the least accurate of the three rivers. Fouling caused very poor readings in 2011, and in 2012 and 2013, very large fluctuations in readings make it difficult to see well-defined patterns in the turbidity measurements. While increases in turbidity in response to increases in the hydrograph are seen in both 2012 and 2013, the exact response to increases in discharge is difficult to determine due to the large amount of background noise.

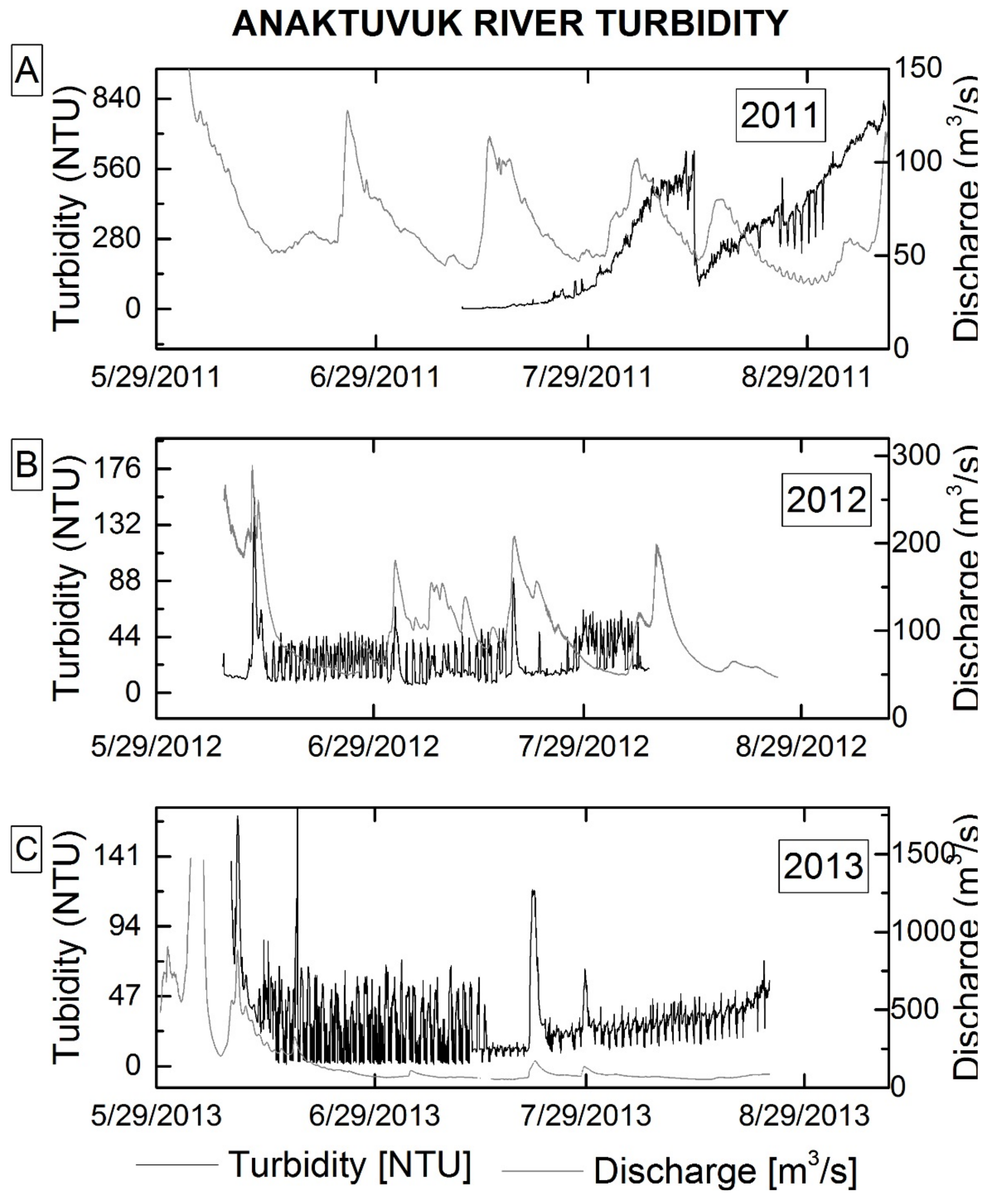


Figure 73. Anaktuvuk River turbidity and discharge for the period 2011-2013. Note the change in *y*-axis scale for the three years.

Turbidity measurements on the Chandler River (Figure 74) were better than the turbidity measurements made on the Anaktuvuk River. Responses in turbidity are difficult to distinguish in 2011 prior to the installation of wipers, but in 2012, the Chandler River turbidimeters functioned satisfactorily for the duration of the open-water flow season. In July 2012, distinct increases in turbidity that correspond to increases in discharge are seen on July 1, 2012, July 5, 2012, July 11, 2012, and July 23, 2012. For the event that occurred on July 5, 2012, there is an increase in discharge from 48 m^3/s to 134 m^3/s, and on July 7, 2012; the corresponding increase in turbidity is from 40 NTU to 1833 NTU. In 2013, large peaks in turbidity occurred during spring breakup, with a maximum of 2572 NTU recorded on June 6, 2013, at 8:00 A.M.; while a value of 507 NTU was recorded on June 2, 2013, at 2:00 A.M., which is nearer to the peak in discharge. It is observed that tubidity peaks after the discharge peaks. Discharge peaked on June 3, 2013, at 7:30 P.M. Turbidity remained extremely low throughout the summer of 2013, and did not increase even with summer peaks in the hydrograph and SSC values, indicating a possible malfunction in the instrument.

On the Upper Itkillik River, turbidity measurements for 2011 through 2013 are satisfactory (Figure 75). Turbidity unmistakably rises when discharge does, and very little “noise” is seen, as with the Anaktuvuk and Chandler Rivers. This difference is most likely because the Itkillik River carries less organic matter at this location, so the turbidimeter experiences less fouling.

A turbidimeter was installed at the Lower Itkillik River station in 2013, the last year of the study, but malfunctioned during spring breakup. Part of the summer data was lost due to datalogger malfunction, and as a result, no turbidity data are presented for the Lower Itkillik River station.

Previous studies have compared SSC to turbidity, with the relationship typically being linear (Foster et al., 1992; Grayson et al., 1995; Lewis, 1996; Lewis, 2003; Lewis et al., 2005), with high R^2 values of 0.875 (Grayson et al., 1995) and 0.93 (Lewis et al., 2005) reported as examples. The relatively limited number of depth-integrated SSC samples at these remote sites makes it difficult to compare SSC and turbidity on the Upper Itkillik River, which had the most reliable measurements of any of the sites. On the Anaktuvuk and Chandler Rivers, the high amount of fouling that occurred in 2011, and to some extent in 2012 and 2013, also clouded the comparison between SSC and turbidity. Future work should include more measurements and the correlation of SSC and turbidity.

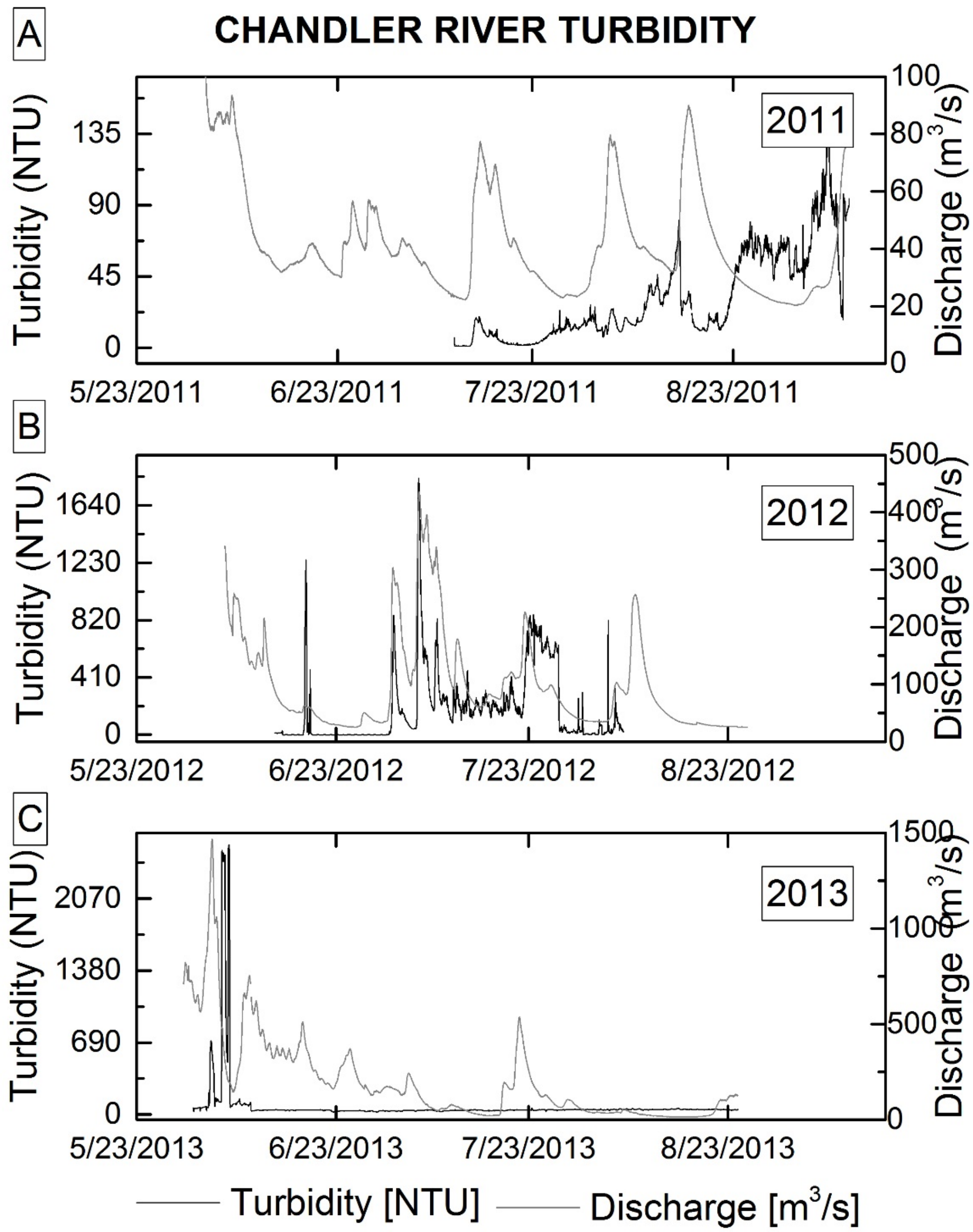


Figure 74. Chandler River turbidity and discharge for the period 2011–2013. Note the change in *y*-axis scale for the three years.

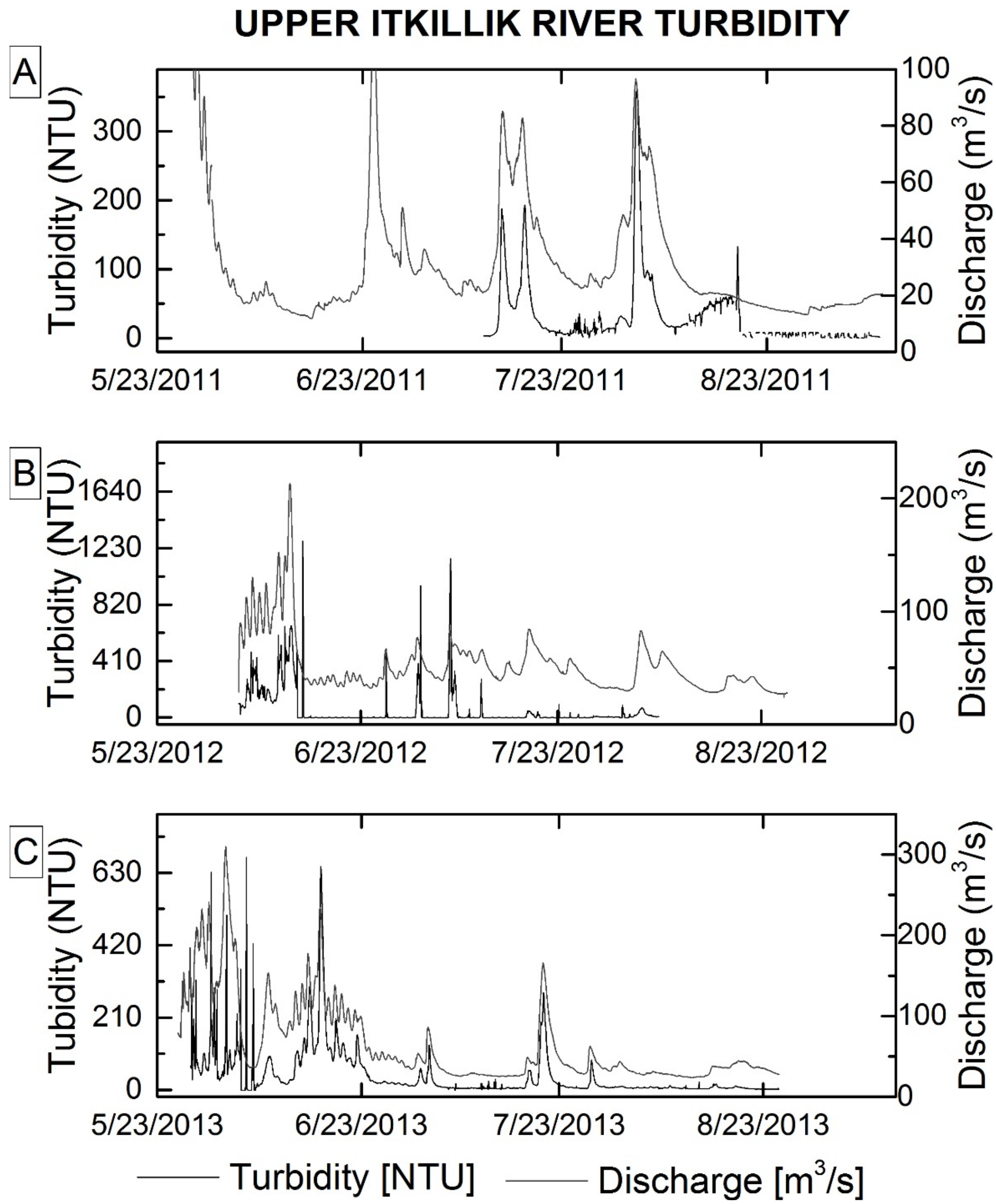


Figure 75. Upper Itkillik River turbidity and discharge for the period 2011–2013. Note the change in *y*-axis scale for the three years.

6.10.6 Bed Sediment Distribution

Calculation of the bed sediment distribution in a river, and subsequent determination of the D_{50}, allows for the use of multiple equations to determine hydraulic parameters. Examples include calculation of the bankfull discharge, dimensionless bed shear stress, and Reynold's number (Parker et al., 2007). The ability to estimate these parameters increases our understanding of a river and its sediment transport regime. Bed sediment distributions were calculated for the Chandler, Upper Itkillik, and Anaktuvuk Rivers (Table 40 and Table 41).

Table 40. Bed sediment distribution by weight for the Chandler and Itkillik Rivers

	% Finer by Weight		
Diameter [mm]	**Chandler [Coarse]**	**Chandler [Fine]**	**Upper Itkillik**
7	0	0	0
9.5	4.5	0	0
13.5	10.0	3.9	2.0
19	18.7	11.8	8.2
27	33.1	49.9	16.8
38.4	55.1	76.2	29.9
54.5	72.2	93.0	44.2
77	90.1	97.7	56.5
109	98.5	100	72.1
154	100	100	88.6
218	100	100	96.3

Table 41. Bed sediment distribution for the Anaktuvuk River.

	% Finer by Weight
Diameter [mm]	**Anaktuvuk**
15.2	0
33.0	38.8
63.5	79.3
101.6	95.5
127.0	99.3

Looking at Figure 76, the Itkillik is the coarsest of all the rivers, with a D_{50} (65 mm) equivalent to very large gravel, almost small cobbles. On the Anaktuvuk, the D_{50} (35.8 mm) is also very large gravel, while on the Chandler, it ranges between coarse gravel and very coarse gravel (27.1 to 41.5 mm). Two grids were measured on the Chandler; this was done due to the large variation in bed sediments that existed on the gravel bar chosen for study. These measurements highlight the large spatial variation that occurs in sediment transport, even within relatively small regions, emphasizing the need for large data sets and increased sampling.

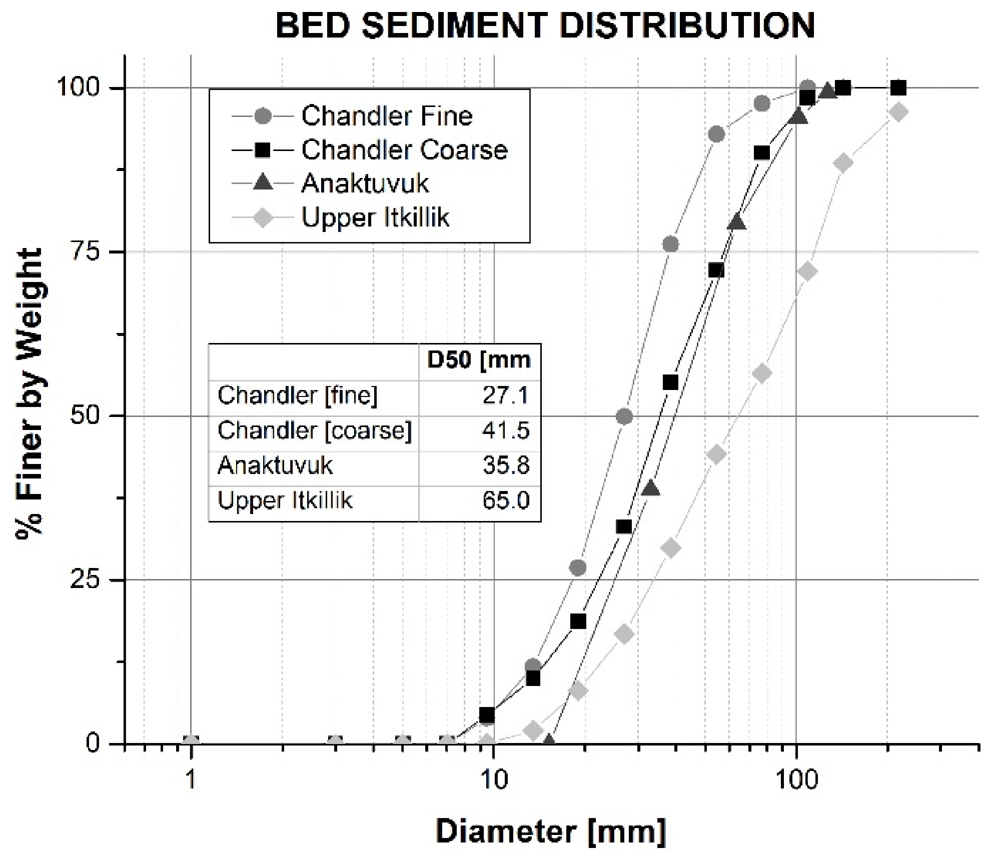


Figure 76. Bed sediment distribution for the Chandler, Anaktuvuk, and Upper Itkillik Rivers.

6.10.7 Suspended Sediment Grain-Size Distribution

The D_{50} of the suspended sediment grain-size distribution is presented for the four river gauging sites in Table 42. On the Anaktuvuk River, two samples were analyzed for spring flows; despite an increase in SSC, the D_{50} of the suspended sediments decreased. We see a similar trend on the Chandler River; between June 1, 2013, and June 2, 2013, SSC increased over 300 mg/L, but the D_{50} decreased by almost 24%. The Lower Itkillik River shows a steady decrease in D_{50} throughout the first half of the flow season. The decrease in D_{50} on these rivers as the flow season progresses indicates a changing sediment source for the suspended solids within the flow column. At higher flows, the river is likely accessing coarser sediments along the banks (or the floodplain if rivers are over bankfull). The Upper Itkillik River is the only site that showed an increase in D_{50} over the flow season. The sample from July 11, 2013, may be misleading, due to the extremely low SSC calculated for this sample. Sample suspended sediment grain-size distribution plots are shown for the Chandler and Lower Itkillik Rivers (Figure 77, Figure 78).

Table 42. Grain sizes for the Anaktuvuk, Chandler, and Itkillik Rivers.

River	Date	SSC [mg/L]	Volume Based D50 [µm]
Anaktuvuk	6/2/2013 14:45	362	52.80
	6/5/2013 17:30	458	27.63
Chandler	6/1/2013 11:05	682	23.50
	6/2/2013 18:20	1000	17.94
	6/6/2013 13:00	181	14.46
	7/14/2013 17:30	17	30.78
Lower Itkillik	5/31/2013 13:15	179	50.03
	6/2/2013 12:05	389	38.20
	6/8/2013 9:30	172	32.49
	7/12/2013 13:00	48	24.80
Upper Itkillik	6/1/2013 14:15	162	19.99
	6/3/2013 13:00	602	27.63

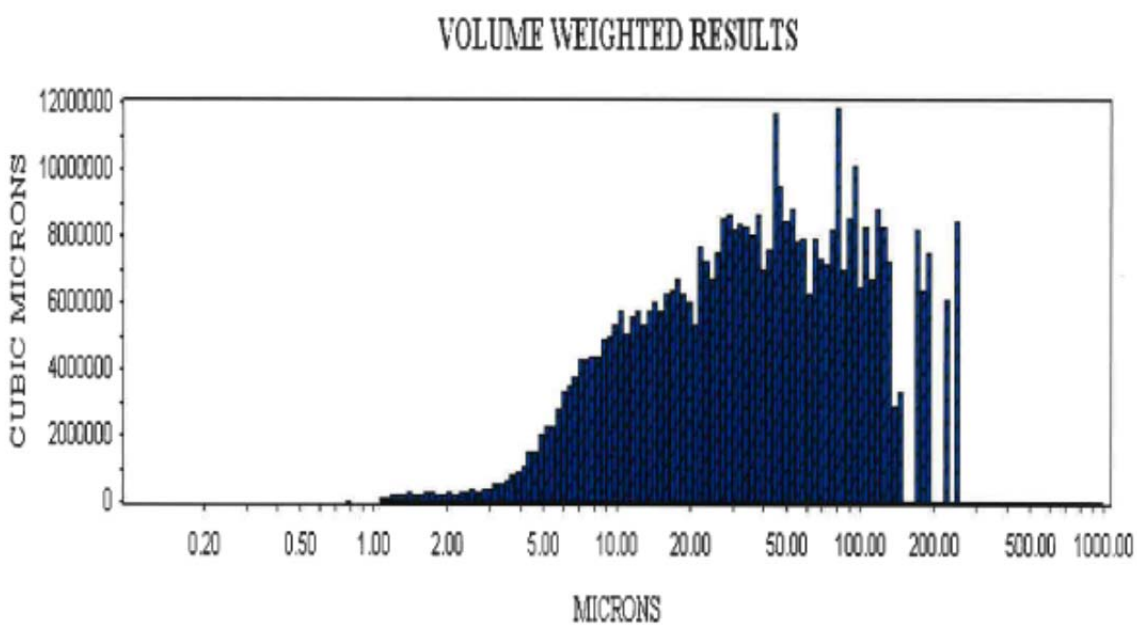


Figure 77. Suspended sediment grain-size distribution (volume weighted) for the Lower Itkillik River on June 2, 2013.

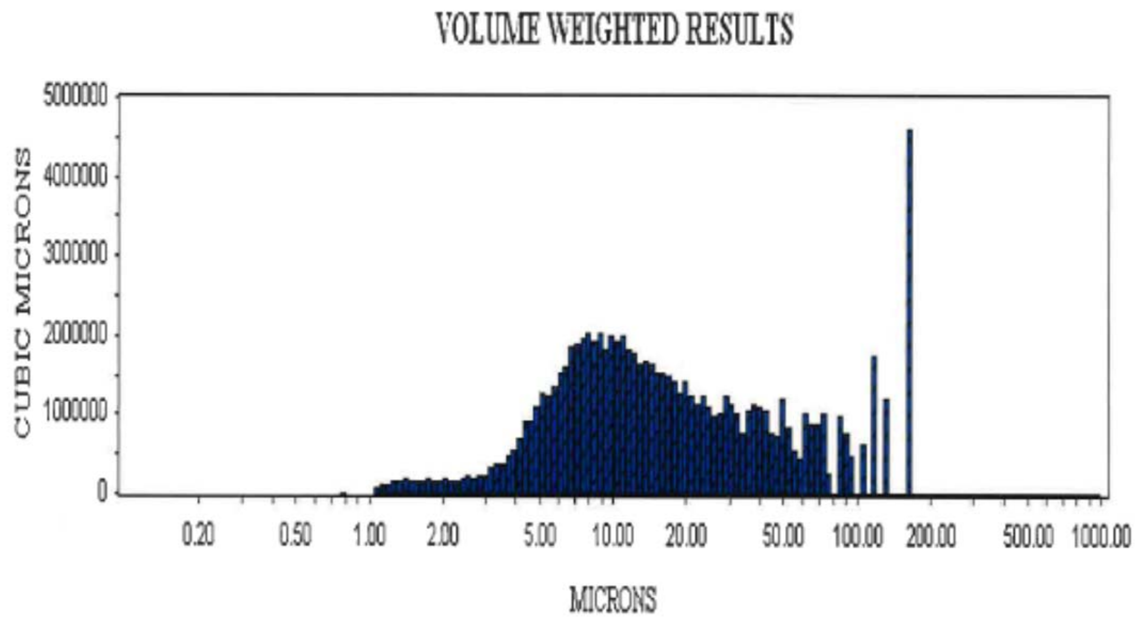


Figure 78. Suspended sediment grain-size distribution (volume weighted) for the Chandler River on June 6, 2013.

7 HYDROLOGIC ANALYSIS

7.1 Precipitation Frequency Analysis

Another way to evaluate the importance of precipitation during the period of record for stations in and adjacent to the Umiat study area is to compare the magnitude of individual precipitation events observed against precipitation frequency estimates (Perica et al., 2012) for recurrence intervals of 2, 5, 10, 25, 50, and 100 years. In Table 43 is shown the precipitation frequency estimates for durations of 60 min and 24 hours for the above-mentioned recurrence intervals at 26 sites. The 2 highest hourly and daily observed precipitation events are compared against the precipitation frequency estimates to determine the approximate recurrence interval for each storm. The first station in Table 43 is Betty Pingo on the coastal plain near the Arctic Ocean. This station had 19 years of data and the 2 highest hourly events during that time were 0.36 and 0.31 in. (9.2 and 7.8 mm), with return periods between 10 and 25 years each year. In comparison, the 2 largest daily (24 hr) events had return periods between 2 to 5 years.

In general, the longer the period of observation the more likely a precipitation event with a high recurrence interval (or lower probability of occurrence) will be observed. We had 10 stations with 14 to 29 years of observations. Most of these stations experienced at least one hourly and one daily storm with a return period of 10 to 25 years or more; three hourly and two daily station events had return periods of 25 to 50 years, and one hourly event had return periods of 50 to 100 years. Most of the short-duration stations (< 7 years) had storms with return periods typically in the 5-year range as expected. Two exceptions were the Anaktuvuk River (DUS2, 5-year duration) and White Lake (DUM6, 3-year duration) that had a 25- to 50-year hourly event.

Table 43. Comparison of the two largest observed precipitation events for period of record against precipitation frequency estimates for 1-hour and 24-hour durations. Stations arranged by elevation, lowest to highest.

Station Name (Code)	Duration	Precipitation Frequency Estimates - recurrence interval (years)												Number of years of observed summer precipitation	Maximum Observed Rainfall - inches (mm): average recurrence interval
		2		5		10		25		50		100			
		in	mm	in	mm	in	mm	in	mm	in	mm	in	mm		
Betty Pingo (BP)	60-min	0.19	4.78	0.25	6.38	0.30	7.70	0.37	9.50	0.43	10.90	0.48	12.29	19	0.36 (9.24): 10-25 yr, 0.31 (7.8): 10-25 yr
	24-hr	0.59	14.99	0.77	19.63	0.91	23.01	1.08	27.43	1.20	30.48	1.33	33.78		0.73 (18.6): 2-5 yr, 0.70 (17.9): 2-5 yr
Franklin Bluffs (FB)	60-min	0.20	5.05	0.27	6.83	0.33	8.31	0.41	10.34	0.47	11.91	0.53	13.49	27	0.37 (9.4): 10-25 yr, 0.28 (7.1): 5-10 yr
	24-hr	0.63	15.90	0.85	21.49	1.02	25.91	1.27	32.26	1.46	37.08	1.67	42.42		1.22 (30.9): 10-25 yr, 0.83 (21.0): 2-5 yr
Anaktuvuk River (DUS2)	60-min	0.28	6.99	0.37	9.50	0.46	11.58	0.57	14.43	0.66	16.64	0.74	18.85	5	0.63 (16): 25-50 yr, 0.50 (12.6): 10-25 yr
	24-hr	0.82	20.88	1.13	28.70	1.38	35.05	1.77	44.96	2.09	53.09	2.44	61.98		1.08 (27.4): 2-5 yr, 1.02 (26): 2-5 yr
North White Hills (DFM3)	60-min	0.22	5.51	0.30	7.49	0.36	9.14	0.45	11.40	0.52	13.16	0.59	14.91	7	0.32 (8.1): 5-10 yr, 0.21 (5.3): 2 yr
	24-hr	0.68	17.32	0.93	23.62	1.13	28.70	1.42	36.07	1.65	41.91	1.90	48.26		0.79 (20.1): 2-5 yr, 0.72 (18.3) 2-5 yr
Chandler River Bluff (DUS3)	60-min	0.29	7.29	0.39	9.96	0.48	12.14	0.60	15.16	0.69	17.50	0.78	19.84	3	0.42 (10.6): 5-10 yr, 0.32 (8.1): 2-5 yr
	24-hr	0.86	21.92	1.21	30.73	1.51	38.35	1.99	50.55	2.39	60.71	2.83	71.88		0.88 (22.4): 2-5yr, 0.74 (18.8): 1-2 yr
Northwest Kuparuk (DFM4)	60-min	0.21	5.28	0.28	7.16	0.34	8.69	0.43	10.82	0.49	12.47	0.56	14.10	7	0.18 (4.6): 1-2 yr, 0.14 (3.6): < 1yr
	24-hr	0.64	16.26	0.85	21.67	1.02	25.91	1.27	32.26	1.46	37.08	1.66	42.16		0.58 (14.7): 1-2 yr, 0.55 (14.0): 1-2 yr
Sagwon (SH)	60-min	0.22	5.56	0.30	7.65	0.37	9.37	0.46	11.76	0.54	13.59	0.61	15.42	26	0.48 (12.3): 25-50 yr, 0.44 (11.2): 10-25 yr
	24-hr	0.79	20.04	1.14	28.96	1.44	36.58	1.85	46.99	2.17	55.12	2.52	64.01		1.74 (44.1): 10-25 yr, 1.22 (31.1): 10-25 yr
South White Hills (DFM1)	60-min	0.29	7.34	0.40	10.13	0.49	12.47	0.62	15.65	0.71	18.11	0.81	20.57	7	0.85 (21.6): >100 yr, 0.5 (12.7): 10-25 yr
	24-hr	0.87	22.10	1.21	30.73	1.50	38.10	1.94	49.28	2.32	58.93	2.75	69.85		1.12 (28.4): 2-5 yr, 0.86 (21.8): 1-2 yr
White Hills (DFM2)	60-min	0.28	7.06	0.38	9.60	0.46	11.71	0.58	14.61	0.66	16.81	0.75	19.05	3	0.32 (8.1): 2-5 yr, 0.28 (7.1): 2 yr
	24-hr	0.83	21.03	1.11	28.19	1.34	34.04	1.67	42.42	1.94	49.28	2.23	56.64		0.92 (23.4): 2-5 yr, 0.89 (22.6) 2-5 yr
Siksikpuk (DUM8)	60-min	0.38	9.68	0.53	13.36	0.65	16.41	0.81	20.62	0.94	23.88	1.07	27.18	3	0.3 (7.6) 1-2 yr, 0.22 (5.3): < 1 yr
	24-hr	1.10	27.94	1.52	38.61	1.91	48.51	2.51	63.75	3.05	77.47	3.66	92.96		0.84 (21.3): 1-2 yr, 0.62 (15.7): < 1 yr
Tuluga (DUM4)	60-min	0.37	9.30	0.51	12.85	0.62	15.82	0.78	19.91	0.91	23.06	1.03	26.16	5	0.6 (15.3): 5-10 yr, 0.42 (10.7): 2-5 yr
	24-hr	1.05	26.67	1.47	37.34	1.84	46.74	2.42	61.47	2.94	74.68	3.54	89.92		1.31 (33.3): 2-5 yr, 1.26 (31.9): 2-5 yr
Nanushuk (DUM3)	60-min	0.35	8.86	0.49	12.40	0.60	15.34	0.76	19.38	0.89	22.48	1.01	25.65	5	0.4 (10.2): 2-5 yr, 0.32 (8.1): 1-2 yr
	24-hr	1.00	25.40	1.40	35.56	1.76	44.70	2.34	59.44	2.86	72.64	3.46	87.88		1.22 (31): 2-5 yr, 0.95 (24.2): 1-2 yr
Hatbox Mesa (DUM7)	60-min	0.39	9.91	0.54	13.67	0.66	16.79	0.83	21.08	0.96	24.41	1.09	27.69	3	0.4 (10.1): 2-5 yr, 0.36 (9.1): 1-2 yr
	24-hr	1.14	28.96	1.59	40.39	2.00	50.80	2.64	67.06	3.21	81.53	3.85	97.79		1.06 (26.8): 1-2 yr, 0.9 (22.9) 1-2 yr
Rooftop Ridge (DUR8)	60-min	0.35	8.99	0.49	12.47	0.61	15.37	0.76	19.35	0.88	22.40	1.00	25.40	2	0.92 (23.4): 50-100 yr, 0.41 (10.4): 2-5 yr
	24-hr	1.02	25.91	1.42	36.07	1.77	44.96	2.33	59.18	2.83	71.88	3.39	86.11		1.09 (27.7): 2-5 yr, 0.98 (24.9): 1-2 yr
Upper Kuparuk (UK)	60-min	0.40	10.26	0.57	14.43	0.70	17.88	0.89	22.63	1.03	26.16	1.18	29.97	20	0.76 (19.3): 10-25 yr, 0.62 (15.8): 5-10 yr
	24-hr	1.17	29.72	1.64	41.66	2.08	52.83	2.78	70.61	3.42	86.87	4.18	106.17		2.30 (58.5): 10-25 yr, 2.27 (57.8): 10-25 yr
North Headwater (NH)	60-min	0.42	10.77	0.60	15.14	0.74	18.75	0.94	23.75	1.09	27.69	1.24	31.50	14	1.06 (26.9): 25-50 yr, 0.44 (11.3): 2-5 yr
	24-hr	1.21	30.73	1.71	43.43	2.16	54.86	2.89	73.41	3.55	90.17	4.34	110.24		2.11 (53.6): 5-10 yr, 1.99 (50.6): 5-10 yr
Green Cabin Lake (GCL)	60-min	0.39	9.78	0.54	13.72	0.67	17.02	0.85	21.54	0.99	25.02	1.12	28.45	18	0.93 (23.6): 25-50 yr, 0.57 (14.5): 5-10 yr
	24-hr	1.10	27.94	1.56	39.62	1.98	50.29	2.66	67.56	3.29	83.57	4.03	102.36		3.04 (77.1): 25-50 yr, 1.57 (40.0): 5-10 yr
East Headwater (EH)	60-min	0.44	11.20	0.62	15.75	0.77	19.51	0.97	24.69	1.13	28.70	1.29	32.77	15	0.91 (23.1): 10-25 yr, 0.87 (22.2): 10-25 yr
	24-hr	1.19	30.23	1.69	42.93	2.14	54.36	2.88	73.15	3.56	90.42	4.37	111.00		2.42 (61.6): 10-25 yr, 2.19 (55.6): 10-25 yr
Imnavait Basin (IB)	60-min	0.42	10.59	0.59	14.88	0.73	18.44	0.92	23.34	1.07	27.18	1.22	30.99	29	1.18 (30.3): 50-100 yr, 0.87 (22.0): 10-25 yr
	24-hr	1.25	31.75	1.76	44.70	2.24	56.90	3.02	76.71	3.73	94.74	4.57	116.08		2.55 (64.8): 10-25 yr, 2.49 (63.3): 10-25 yr
Upper Headwater (UH)	60-min	0.41	10.49	0.58	14.73	0.72	18.26	0.91	23.11	1.06	26.92	1.20	30.48	14	0.90 (22.9): 10-25 yr, 0.52 (13.1): 2-5 yr
	24-hr	1.16	29.46	1.64	41.66	2.07	52.58	2.78	70.61	3.44	87.38	4.21	106.93		2.89 (73.5): 25-50 yr, 2.05 (52): 5-10 yr
West Headwater (WH)	60-min	0.43	10.95	0.61	15.37	0.75	19.05	0.95	24.10	1.10	27.94	1.26	32.00	14	0.55 (13.9): 2-5 yr, 0.44 (11.3): 2-5 yr

Station Name (Code)	Duration	Precipitation Frequency Estimates - recurrence interval (years)												Number of years of observed summer precipitation	Maximum Observed Rainfall - inches (mm): average recurrence interval
		2		5		10		25		50		100			
		in	mm	in	mm	in	mm	in	mm	in	mm	in	mm		
	24-hr	1.20	30.48	1.70	43.18	2.15	54.61	2.89	73.41	3.56	90.42	4.35	110.49		2.66 (67.7): 10-25 yr, 1.48 (37.5): 2-5 yr
White Lake (DUM6)	60-min	0.45	11.51	0.62	15.85	0.77	19.48	0.96	24.46	1.11	28.19	1.27	32.26	3	1.11 (28.3): 50 yr, 0.54 (13.8): 2-5 yr
	24-hr	1.31	33.27	1.81	45.97	2.25	57.15	2.96	75.18	3.58	90.93	4.30	109.22		1.22 (31.1): 1-2 yr, 1.09 (27.8): 1-2 yr
Itikmalakpak (DUM1)	60-min	0.44	11.13	0.61	15.47	0.75	19.05	0.95	24.00	1.10	27.94	1.25	31.75	5	0.5 (12.7): 2-5 yr, 0.24 (6.2): < 1 yr
	24-hr	1.21	30.73	1.67	42.42	2.08	52.83	2.74	69.60	3.33	84.58	4.03	102.36		1.11 (28.1): 1-2 yr, 0.98 (24.9): 1-2 yr
Encampment Creek (DUM5)	60-min	0.46	11.76	0.64	16.26	0.79	19.99	0.99	25.12	1.14	28.96	1.30	33.02	3	0.65 (16.4): 5-10 yr, 0.41 (10.4): 1-2 yr
	24-hr	1.31	33.27	1.81	45.97	2.25	57.15	2.96	75.18	3.60	91.44	4.33	109.98		1.49 (37.9): 2-5 yr, 1.03 (26.1): 1-2 yr
Upper May Creek (DUM2)	60-min	0.45	11.38	0.63	15.90	0.77	19.66	0.98	24.82	1.13	28.70	1.29	32.77	5	0.74 (18): 5-10 yr, 0.42 (10.8): 1-2 yr
	24-hr	1.22	30.99	1.70	43.18	2.13	54.10	2.81	71.37	3.44	87.38	4.17	105.92		1.75 (44.3): 5-10 yr, 1.59 (40.4): 2-5 yr
Accomplishment Creek (DBM1)	60-min	0.47	11.81	0.65	16.48	0.80	20.35	1.01	25.65	1.17	29.72	1.33	33.78	6	0.37 (9.4): 1-2 yr, 0.37 (9.4): 1-2 yr
	24-hr	1.34	34.04	1.86	47.24	2.33	59.18	3.08	78.23	3.77	95.76	4.57	116.08		1.25 (31.8): 1-2 yr, 0.76 (19.3): < 1 yr

7.2 Manning's Roughness Coefficient (*n*) Calculations Revisited

Estimates of Manning's roughness coefficient *n*, dimensionless roughness coefficient (C_f), and bed shear stress (τ_b) for the Anaktuvuk River study reach were presented in Toniolo et al. (2010) and our preliminary hydrology report in 2011 (Youcha et al., 2011). These estimates have been updated based on additional data collection in 2012 and 2013 and quality reviews of the parameters collected during all the ADCP measurements. The study reach was previously defined in 2009–2011 as an approximately 300 m section of river in front of the Anaktuvuk River station, where discharge measurements are most often made. Water surface slope measurements concurrent with the discharge measurement were made just upstream of the station on the right bank (location 1 in Figure 79) to characterize the river hydraulics. We used the channel area, width, and velocity, from the ADCP measurement, along with surveyed water slopes to back-calculate Manning's roughness coefficient, *n*, for the study reach with the following equation:

$$n = \frac{1}{U} H^{\frac{2}{3}} S^{\frac{1}{2}} \qquad (1)$$

where *U* (m/s) is the cross-sectional average velocity U; *H* (m) is the average depth (area/width), and *S (m/m)* is the water slope at the measurement reach. Discharge (Q, m^3/s) may be determined by shuffling terms in Equation 1 and multiplying both sides of the equation by the cross-sectional area (A, m^2), where the hydraulic radius can be replaced by the depth for a wide channel:

$$Q = UA = \frac{1}{n} H^{\frac{2}{3}} S^{\frac{1}{2}} \mathrm{A} \qquad (2)$$

We also calculated the dimensionless roughness coefficient, C_f, from the following relationship:

$$C_f = \frac{g}{U^2} HS \qquad (3)$$

where *g* (m/s^2) is gravity. Bed shear stress, τ_b (N/m^2), was calculated from the following relationship:

$$\tau_b = g\rho HS \qquad (4)$$

where ρ (kg/ m^3) denotes density of water. Using the above relationships, we attempted to give an approximation of the average hydraulic characteristics along the study reach at the Anaktuvuk River. These parameters were updated and expanded to include recent data and are presented in Table 44. The location of each measurement is indicated on the table and shown in the photographs in Figure 79. It was not possible to measure slope consistently at the same location

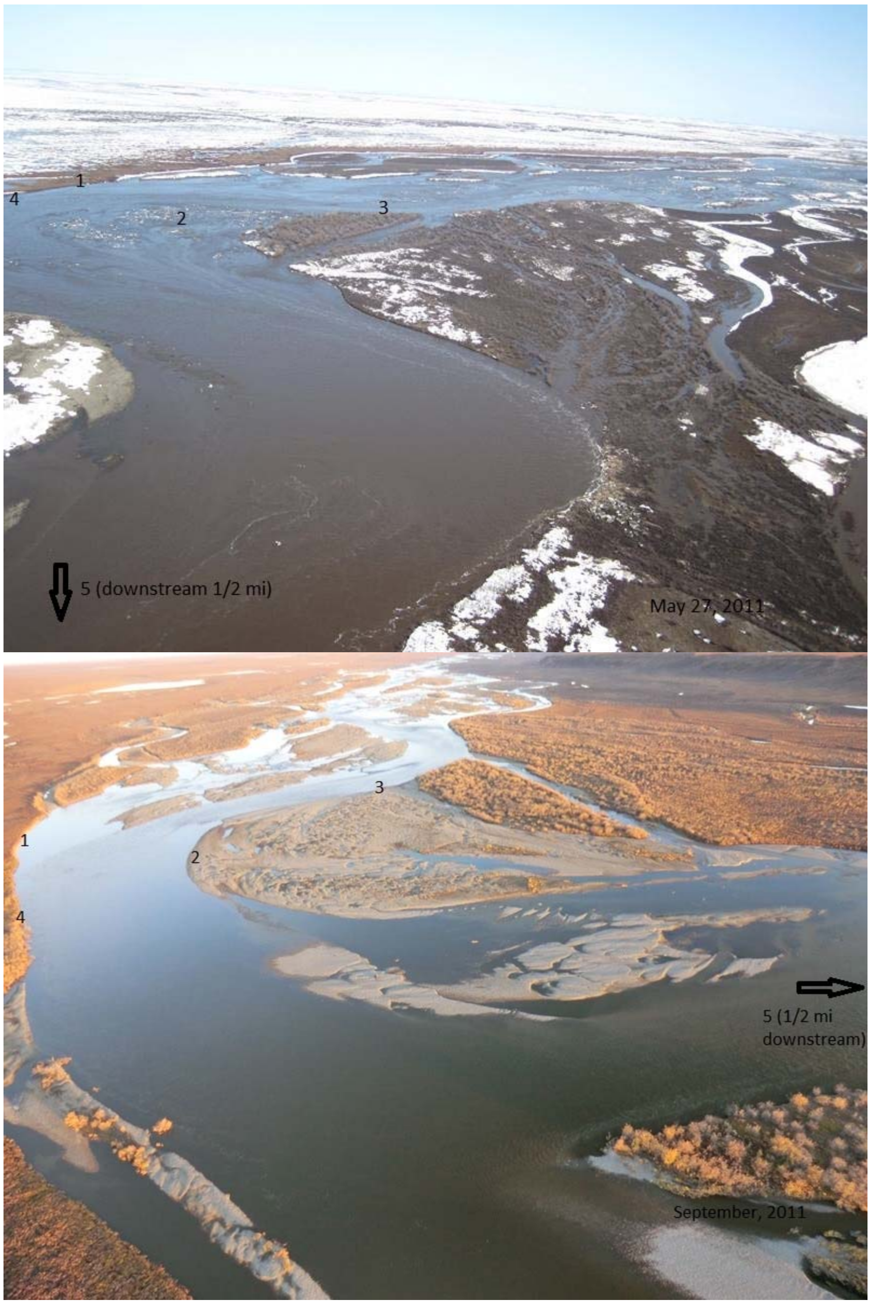


Figure 79. Locations of the various river slope measurements are indicated with a number and explained in Table 44. The top photo is during high-stage conditions (1000+ m^3/s); the bottom photo is taken during medium-low-stage conditions (220 m^3/s).

Table 44. Measurements of slope and calculation of hydraulic parameters for Anaktuvuk River near the station. Measurement locations are indicated on the map in Figure 79.

Date	Q (m^3/s)	S	B (m)	A (m^2)	U (m/s)	H (m)	n	C_f ($x10^{-2}$)	τ_b (N/m^2)	Slope Measurement Location
5/30/2009	162	0.000454	147	159	1.02	1.09	0.022	0.47	4.85	1) Right bank, between station and slough
6/1/2009	184	0.000710	146	166	1.06	1.14	0.026	0.71	7.94	1) Right bank, between station and slough
6/3/2009	326	0.000846	161	227	1.43	1.41	0.026	0.57	11.70	1) Right bank, between station and slough
6/4/2009	374	0.000795	190	279	1.34	1.47	0.028	0.64	11.46	1) Right bank, between station and slough
6/5/2009	504	0.000801	203	312	1.61	1.54	0.024	0.47	12.10	1) Right bank, between station and slough
6/7/2009	574	0.001000	264	399	1.44	1.52	0.030	0.72	14.91	1) Right bank, between station and slough
6/9/2009	356	0.000849	164	224	1.59	1.37	0.022	0.45	11.41	1) Right bank, between station and slough
6/4/2010	388	0.000538	163	271	1.43	1.66	0.023	0.43	8.77	1) Right bank, between station and slough
6/5/2010	339	0.000501	158	245	1.38	1.55	0.021	0.40	7.62	1) Right bank, between station and slough
6/6/2010	290	0.000269	161	235	1.23	1.46	0.017	0.25	3.85	1) Right bank, between station and slough
5/27/2011	1100	0.000832	316	574	1.84	1.82	0.023	0.44	14.83	1) Right bank, between station and slough
5/29/2011	729	0.000658	320	445	1.64	1.39	0.019	0.33	8.97	1) Right bank, between station and slough
9/12/2011	212	0.000428	150	189	1.50	1.27	0.016	0.24	5.33	5) 1 mile downstream of station, straight parabolic reach
6/7/2012	278	0.001228	128	196	1.43	1.52	0.032	0.90	18.31	4 Right bank next to station and downstream station in flowing water
7/27/2012	89	0.000433	96	97	0.91	1.02	0.023	0.52	4.34	2) Left bank opposite station on inside bend / gravel bar, slightly slower and flatter than upstream
8/25/2012	46	0.000064	65	81	0.55	1.25	0.017	0.26	0.79	5) 1 mile downstream of station, straight parabolic reach
6/5/2013	455	0.001030	322	445	1.08	1.37	0.037	1.19	13.84	1) Right bank, between station and slough
7/13/2013	60	0.000308	66	60	1.00	0.91	0.017	0.28	2.75	1) Right bank, between station and slough
8/24/2013	114	0.000867	68	77	1.48	1.13	0.022	0.44	9.61	5) 1 mile downstream of station, straight parabolic reach

Our updated calculations of Manning's roughness coefficient range from 0.016 and 0.037 depending on the river conditions and where the slope measurement was made. The average calculation of Manning's roughness coefficient (*n*) for the Anaktuvuk River near the station is 0.023. Figure 80 shows the range of *n* with discharge, indicating an increasing trend with increasing discharge. The only measurement that had over bankfull conditions was taken on May 27, 2011, when discharge was measured at 1100 m^3/s (38,800 ft^3/s).

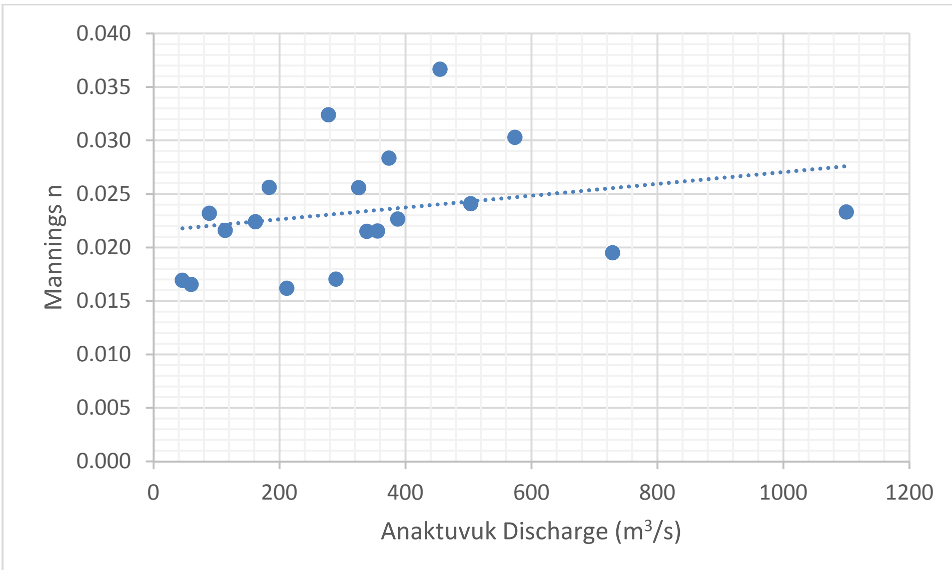


Figure 80. Manning's roughness coefficient (*n*) plotted with discharge for the Anaktuvuk River.

Slope is an important parameter in the calculation of the roughness coefficient. The slope has been measured at various locations near the Anaktuvuk station (photographs in Figure 79) to illustrate the difficulty in obtaining a meaningful measurement of slope and calculation of Manning's *n*. The first photograph shows the river at high stage; the second photograph shows the river at medium-low stage. Initially, measures of slope were made at location 1 in the photographs. Recently, at lower stages this location is not always representative of the river slope, because the main channel may not flow at location 1. The slopes may vary greatly, depending on where measurements are taken and on the river conditions; it was not always possible to find a consistent place to measure slope. We found that it was no longer possible to measure discharge and slope in the same location every time due to differences in the channel geometry at different stages, and changes in the measurement reach itself over time. The initially established location for measuring slope on the Anaktuvuk River (upstream of the station, location 1 in Figure 79) is only possible during the highest flows, because during lower flows, the reach is affected by an eddy/backwater area near a slough off the main channel and there is no flow past the slope measurement location. When the slope is measured at this location during medium to low flows, the slope would be essentially zero (flat) and unrepresentative of the slope of the flowing river reach where the discharge measurement is made. It is challenging to find a location on the river to measure slope at all stages. Additionally, due to frequent bends and multiple river channels, there are very few other locations where a good measurement of slope can be made. Lastly, the slope is measured by taking the stage difference upstream and downstream, and dividing by the length between the two stage readings. This distance between the upstream and downstream stage is often variable (ranging from 75 to 200 m apart), depending on field conditions (wind, sunlight, etc.) or river conditions (bends, access, etc.) and who is conducting the survey.

Additional errors in the calculation of the hydraulic parameters in Table 44 may be from the river width, area, and depth from the ADCP measurement, because the measurement transect is not made exactly perpendicular to the flow direction, particularly during high flows. Therefore, the river characteristics of width and area are calculated for each ADCP ensemble perpendicular to mean flow direction (rather than along the actual path the boat takes, which may not be perpendicular to the flow direction).

Since collecting the additional slope and ADCP measurements, we conclude that the measurements of river slope during lower stages at the original measurement reach on the Anaktuvuk River may not always be useful for calculating Manning's roughness coefficient. Data we collected are presented in this section to demonstrate the difficulties associated with obtaining usable input data for the estimation of hydraulic parameters.

In 2013, slope measurements were also collected on the Lower Itkillik River at the station for comparison with Anaktuvuk River data (Table 45). All measurements were taken immediately upstream of the station. The range of Manning's *n* was slightly higher than what was calculated for the Anaktuvuk River, ranging from 0.023 to 0.044, with the average of 0.033.

Table 45. Measurements of slope and calculation of hydraulic parameters for the Lower Itkillik River at the station.

Date	Q (m^3/s)	S	B (m)	A (m^2)	U (m/s)	H (m)	n	C_f ($x10^{-2}$)	τ_b (N/m^2)	Slope Measurement Location
8/28/2012	28	0.001013	63	40	0.70	0.63	0.034	1.29	6.30	Station
5/31/2013	245	0.002277	132	128	1.93	0.99	0.025	0.59	22.07	Station
6/2/2013	322	0.001274	106	159	2.04	1.49	0.023	0.45	18.62	Station
6/7/2013	110	0.001454	68	98	1.12	1.48	0.044	1.68	21.10	Station
6/8/2013	193	0.001974	80	129	1.50	1.63	0.041	1.40	31.57	Station
7/12/2013	39	0.001542	46	36	1.05	0.80	0.032	1.10	12.06	Station
8/25/2013	49	0.00195	51	40	1.23	0.79	0.031	1.00	15.04	Station

The USGS publication "Roughness Characteristics of Natural Channels" (Barnes, 1967) was reviewed to find a river with similar riverbed and channel characteristics to compare with the Anaktuvuk River. The river that has similar characteristics is the Columbia River at Vernita, Washington, which is mostly vegetation-free and has a streambed that consists of cobbles and gravel. The Manning's *n* for this river is reported as 0.024, similar to what we calculated at the Anaktuvuk River.

7.3 Hydrological Modeling

To aid in the understanding of Arctic hydrology, we undertook a modeling exercise. The Swedish Meteorological and Hydrological Institute (SMHI) developed the HBV model, which we selected as a tool to understand the hydrologic cycle and the runoff response to precipitation events for arctic rivers because of its relative simplicity (minimum amount of measured field data required) and robustness. Additionally, the model is a semi-distributed model, which is particularly important when simulating flow in large basins with non-uniform spatial processes. We applied the runoff model for the Anaktuvuk, Upper Kuparuk, Upper Sagavanirktok, Putuligayuk, Shaviovik, and Kadleroshilik Rivers. The purpose of the modeling effort was to develop an understanding of the processes controlling runoff in arctic rivers. We intended to develop HBV parameter sets that can adequately describe the runoff of gauged basins, and test these parameter sets on ungauged (or minimally gauged) basins to predict runoff in response to extreme events. Detailed results of the modeling effort were presented in Kane et al. (2012).

The HBV model requirements include input data (hourly or daily precipitation, air temperature, and discharge, and daily or monthly evapotranspiration) and model parameters for the snow, soil moisture accounting, response, and transformation routines (Figure 81). Water enters the model simulation as either snow or rain, the form determined by the model by setting a threshold temperature to separate the states. Water infiltrates the soil in the moisture routine, where overland flow is initiated if the soil moisture exceeds the maximum soil moisture. The water is then routed through two separate but connected reservoirs: the upper and the lower. Runoff may only occur from the upper reservoir, but water may percolate to the lower zone, which in traditional interpretations of the model represents contributions to groundwater levels. In the simulations, only the upper reservoir is used to simulate a continuous permafrost condition, where no deeper groundwater exists.

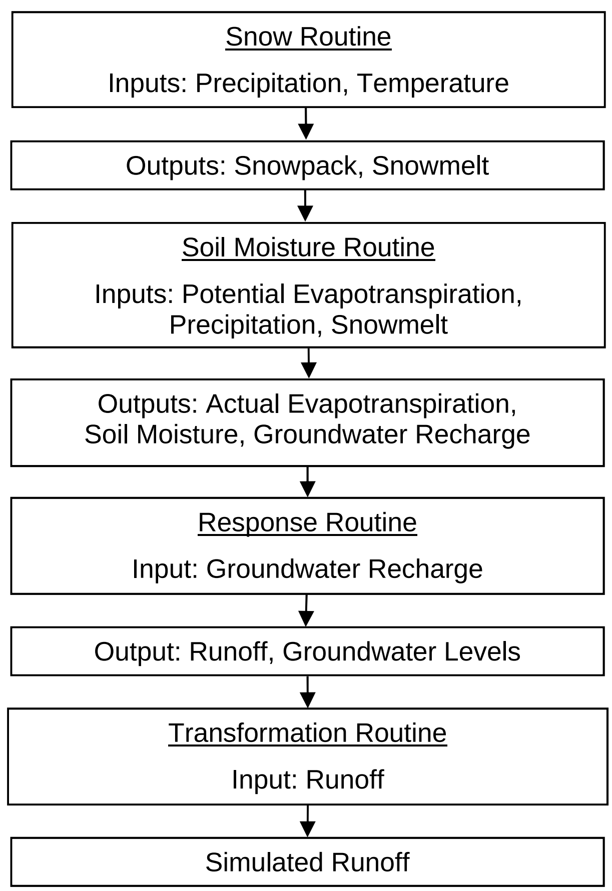


Figure 81. HBV routines and input data.

Our approach was to define a set of parameters that apply to basins with similar characteristics. For example, one parameter set was developed for upland (high gradient) basins such as the Upper Kuparuk, Anaktuvuk, and Upper Sagavanirktok that lie in the foothills and mountains region of the Brooks Range. Annual peak flow in these basins may be snowmelt or rainfall, depending on basin size; however, record peak discharge may be rainfall-generated. Another parameter set was developed for the low-gradient coastal plain basins (such as the Putuligayuk and Kadleroshilik), where snowmelt is the main factor governing the runoff response and summer runoff is minimal. The model may be improved for each year; however, for this simulation, the goal was to find a unique set of parameters that adequately simulate flow in any given year. The idea is that this set of parameters could be used in similar ungauged basins.

In the high-gradient basins, the model always overpredicted the volume of runoff during the spring runoff event, but it did a relatively good job at predicting the snowmelt peak and timing, which is partly controlled by the degree-day snowmelt factor and threshold temperature. We found that the model was sensitive to the average end-of-winter SWE for the basin, which impacts the peak and total volume of flow during the snowmelt runoff period. Improving the accuracy and precision of end-of-winter SWE is a priority for accurate snowmelt runoff modeling, but it is not easy to quantify the spatial distribution of this heterogeneous snowpack, particularly over large basins or basins within the mountains region.

These results were promising, but we found that the model could be improved with better input data (i.e., more spatially distributed data). When we added the SWE data from other snow survey sites in the Upper Kuparuk basin, the snowmelt simulation improved. The Upper Kuparuk station, which has the highest SWE and snow depth in the basin, is not a good proxy for basin-wide average ablation.

The model performed poorly for the two coastal plain rivers for a few of the years simulated. The main problem with poorly simulated years is the timing of snowmelt, which is mostly controlled by the threshold temperature for the snowmelt parameter and the observed hourly air temperature. Additionally, the model is sensitive to the input of end-of-winter SWE. The poor results of model timing may be due to significant year-to-year variability of the physical processes that affect snowmelt runoff in coastal plain basins and inadequate input of SWE data.

The conditions of the previous fall also greatly impact the spring runoff ratio and could be incorporated into the simulation. The snowpack recharges the thousands of tundra lakes, ponds, and wetlands, and this process may not be adequately described in the HBV model. Lastly, the limited distribution of SWE measurements within the basin may result in a poor estimate of basin average SWE for the model.

We anticipate that the unique parameter set will have limitations (i.e., perform reasonably in some years and poorly in other years) due to our inability to track soil conditions during the year and the limited distribution of snow measurements. The use of runoff models in ungauged basins for predicting runoff in engineering applications should exercise an adequate safety factor for precipitation. Additionally, the model should always be validated in other basins of similar size and condition that are limited by lack of data.

A flow frequency analysis was conducted to examine the frequency of peak and low flow events on arctic streams (Kane et al., 2008a; Kane et al., 2012), and the results were updated in this report for several of the rivers. All analyses were completed according to the Interagency Advisory Committee on Water Data, Hydrology Subcommittee, Bulletin 17B (Log Pearson III distribution) using HEC software. The results of the flood frequency analysis for Imnavait Creek (through 2013), Upper Kuparuk River (through 2013), and Putuligayuk River (through 2013) are summarized in this section (Figure 82 through Figure 85). The results of additional analyses of the Upper Sagavanirktok, the Atigun River, and the Oksrukuyik River (also known as “Ox Creek”) for this report were presented in Kane et al. (2012). The frequency analyses by Kane et al. (2008a) were separated into spring (snowmelt) and summer (rain) peak flow, and a third analysis was completed for low flow. Table 46and Table 47 summarize the number of events and period of record for the updated analysis. Flood frequency analyses for the Upper Sagavanirktok River near Pump Station 3 (USGS 15908000), Atigun River near Pump Station 4 (15904800), and Sagavanirktok River Tributary (Oksrukuyik [Ox] River 15906000) presented in the Kane et al. (2012) report were completed using summer data based on USGS records. The annual peak on the smaller rivers may occur during either spring or summer runoff, but snowmelt peak-flow analyses are not conducted on these streams due to uncertainty about the snowmelt peak.

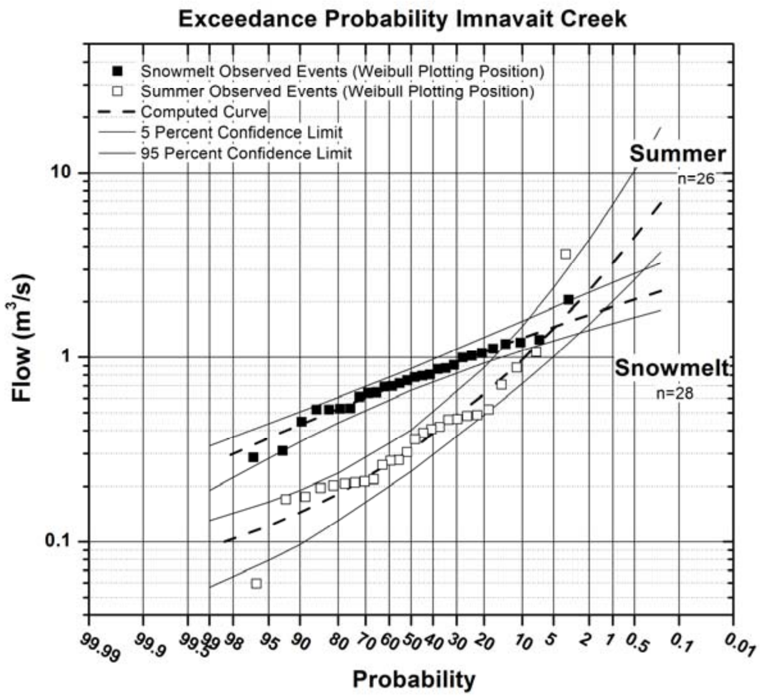


Figure 82. Flood frequency for Imnavait Creek (2.2 km^2).

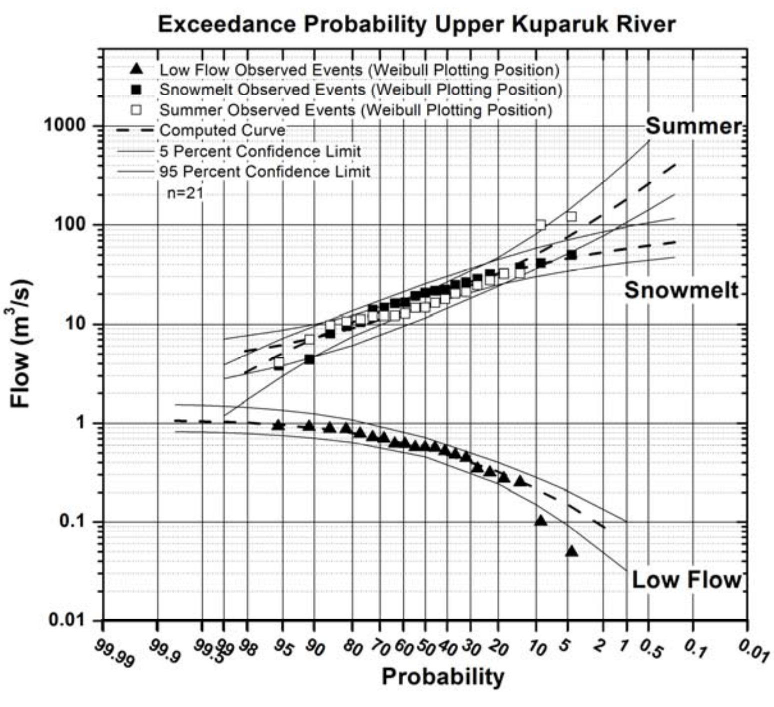


Figure 83. Flood frequency for Upper Kuparuk River (142 km^2).

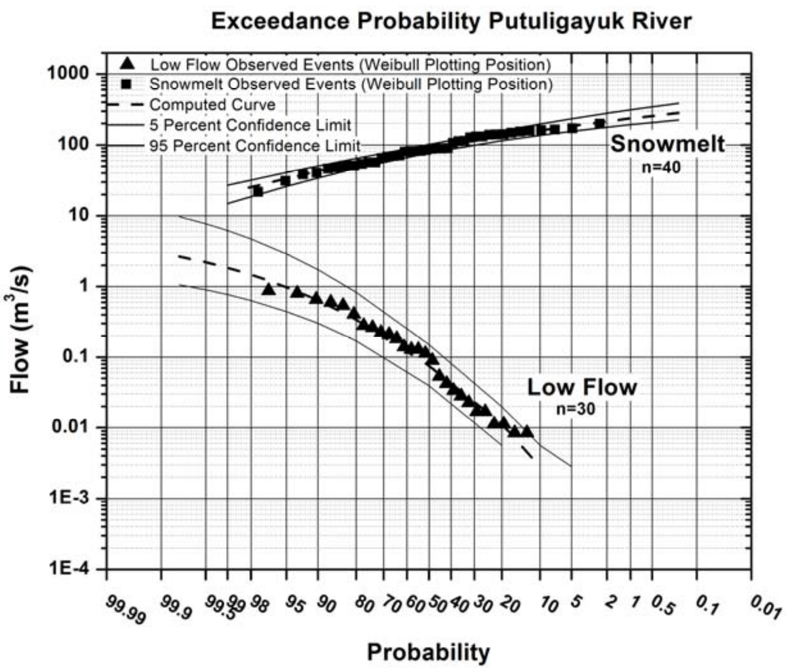


Figure 84. Flood frequency for Putuligayuk River (471 km^2).

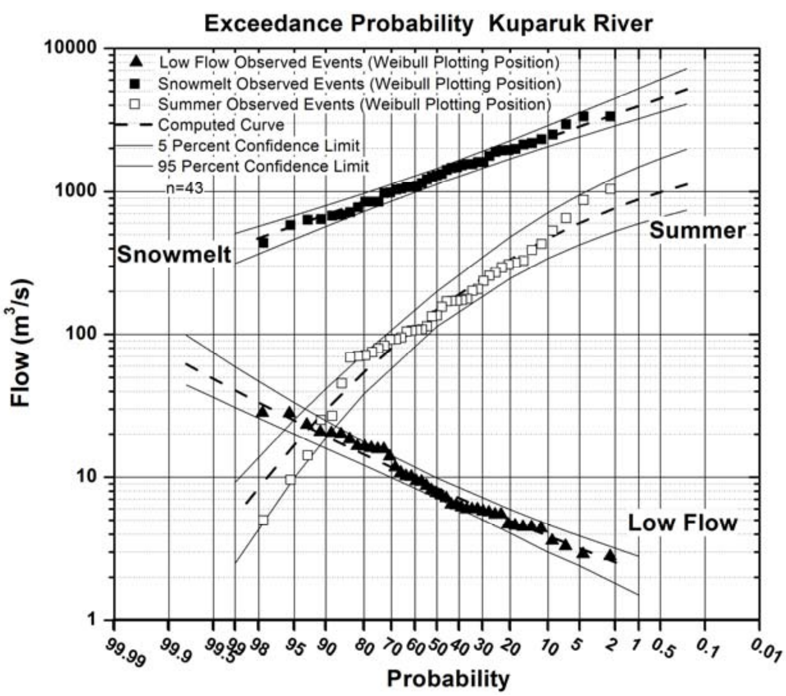


Figure 85. Flood frequency for Kuparuk River at Deadhorse (8140 km^2).

Table 46. Number of events in analysis.

Basin	Number of Events Snow	Number of Events Summer	Number of Events Low Flow
Imnavait Creek	28	26	n/a
Upper Kuparuk River	21	21	21
Kuparuk River	43	43	43
Putuligayuk River	40	n/a	30

Table 47. Period of record in analysis.

Basin	Period of Record Snow	Period of Record Summer	Period of Record Low Flow
Imnavait Creek	1985–2007, 2008-09, 2012-13	1986–2007, 2008-09, 2012-13	n/a
Upper Kuparuk River	1993–2013	1993–2013	1993–2013
Kuparuk River Deadhorse	1971–2013	1971–2013	1971–2013
Putuligayuk River	1970–1980, 1982–1995, 1999–2013	n/a	1970–1979, 1982–1986, 1999–2013

The calculated station coefficient of skewness for each river is presented in Table 48. The generalized skew reported in the USGS tables by Curran et al. (2003) for Region 7 (based on only 7 stations with at least 25 systematic annual peaks) is -0.52, but the range we calculated is -1.517 to +0.934 and differs depending on the use of a spring or summer peak. Therefore, a regional skewness coefficient was not applied to the analysis; the station skewness was calculated for each site.

Table 48. Coefficient of skewness.

Basin	Coefficient of Skewness Snow	Coefficient of Skewness Rain	Coefficient of Skewness Low Flow
Imnavait Creek	-0.196	0.827	n/a
Upper Kuparuk River	-0.810	0.934	-1.517
Kuparuk River	-0.004	-0.796	0.205
Putuligayuk River	-0.487	n/a	-0.950

There are challenges when comparing the results of flood frequency of rivers that have long-term data with the runoff response of rivers we observed in this study with only short-term data in 2009–2013. We hoped to use a river with long-term data that has similar characteristics to the Itkillik, Anaktuvuk, and Chandler, conduct a flood frequency analysis for it, and use the results to understand the frequency of floods in these three rarely gauged rivers. The Upper

Sagavanirktok River is the only long-term gauged station in which the basin characteristics (such as basin area, latitude, and gradient) are similar to the three, relatively large, rivers (Itkillik, Anaktuvuk, and Chandler) in the study area. However, after reviewing the available data for the Upper Sagavanirktok gauge site, we found that the spring peak runoff data were uncertain, as discussed earlier in Section 6.9.4, "Additional Observations," and not suitable for flood frequency analysis. We were still able to examine summer peak data using the Upper Sagavanirktok and estimate a return period for summer floods. The Kuparuk River at Deadhorse has peak snowmelt runoff data, but the basin characteristics are not very similar (the Kuparuk basin lacks extensive mountain area in the headwaters) to the Itkillik, Anaktuvuk, and Chandler Rivers. Additionally, a large percentage of the Kuparuk River basin area is within the low-gradient coastal plain region, which is colder than the southern foothills and mountains regions during the month of May. Colder May temperatures may result in a longer, prolonged runoff period for the Kuparuk River, which decreases the magnitude of the peak spring discharge. The Upper Sagavanirktok, Itkillik, Anaktuvuk, and Chandler basins experience warmer air temperatures due to their southern location and tend to peak earlier and more quickly than the Kuparuk.

In both 2011 and 2013, the spring flows of rivers draining the foothills and mountains probably were greater than a 5-year event based on the available data. Many of the rivers in the analysis show spring runoff 2013 as a low probability flood event with high return periods: Imnavait Creek (29-year return period), Upper Kuparuk (7 years), and Kuparuk at Deadhorse (22 years) (see Table 49–Table 51). Although the 2013 event on the Kuparuk could be a rare event, the uncertainty in the analysis is higher due to the use of mean daily discharge at times as input data (instead of instantaneous peak). However, the increased snowpack observed by Stuefer et al. (2014) supports the high streamflow. The Upper Kuparuk event in 2011 was estimated to be a 20-plus year event. An exception is the Putuligayuk, the coastal plain river, which did not have very high flows in 2011 and 2013 but had the highest flow on record in 2010 (Table 52). However, in terms of the total volume of water, the 2010 cumulative flow is similar to 2011 on the Putuligayuk. Most of the summer floods observed during the study period on the Itkillik, Anaktuvuk, and Chandler Rivers are probably less than 5-year events if we use the Upper Sagavanirktok summer analysis in Kane et al. (2012) for comparison.

Table 49. Imnavait Creek peak discharge, 2002 and 2007–2009 and 2012–2013.

Year	Spring Peak Runoff (m^3/s)	Summer Peak Runoff (m^3/s)	Spring Return Period (yr)	Summer Return Period (yr)
2002	1.25 on 5/22	3.64 on 8/15	14	27
2007	0.78 on 5/25	0.42 on 8/6	2.1	2.7
2008	0.29 on 5/27	0.88 on 6/25	1.0	9
2009	0.87 on 5/25	0.31 on 6/15	1.2	2.9
2012	0.61 on 5/29	0.46 on 7/15	1.1	3.4
2013	2.04 on 5/29	0.52 on 7/20	29	5.4

Table 50. Upper Kuparuk River peak discharge, 2002 and 2007–2013.

Year	Spring Peak Runoff (m^3/s)	Summer Peak Runoff (m^3/s)	Spring Return Period (yr)	Summer Return Period (yr)
2002	22 on 5/24	120 on 8/16	2.4	22
2007	16 on 5/27	7 on 8/7	1.6	1.1
2008	4 on 5/23	10 on 6/18	1.0	1.2
2009	28 on 5/24	21 on 6/11	3.7	3.1
2010	14 on 5/23	13 on 8/7	1.4	1.7
2011	50 (estimated) on 5/23	4 on 6/24	22	1.0
2012	19 on 5/29	15 on 7/7	1.8	2.0
2013	37 on 6/3	18 on 7/20	7.3	2.4

Table 51. Kuparuk River peak discharge, 2007–2013.

Year	Spring Peak Runoff (m^3/s)	Summer Peak Runoff (m^3/s)	Spring Return Period (yr)	Summer Return Period (yr)
2007	1951 on 6/7	n/a	5.0	
2008	850 on 5/31 (daily mean peak)	79 on 8/7	1.4	1.3
2009	1073 on 6/3	106 on 9/3	1.6	1.6
2010	1262 on 6/7	135 on 8/10	1.9	2.0
2011	1608 on 5/31	72 on 9/14	3.2	1.3
2012	1328 on 5/26	173 on 9/5	2.1	2.4
2013	3341 on 6/3	108 on 7/31	22+	1.8

Table 52. Putuligayuk River peak discharge, 2007–2013.

Year	Spring Peak Runoff (m^3/s)	Spring Return Period (yr)
2007	69 on 6/7	1.5
2008	38 on 6/2	1.1
2009	148 on 6/5	5.8
2010	199 on 6/8	41
2011	83 on 6/6	1.9
2012	90 on 6/8	2.4
2013	106 on 6/10	2.6

8 CONCLUSIONS

This report is the culmination of a seven-year study (2006 through 2013) funded by the Alaska Department of Transportation and Public Facilities on the meteorology and hydrology of the central Alaskan Arctic, north of the continental divide in the Brooks Range. The study concentrated on the Itkillik, Anaktuvuk, and Chandler River basins, but also took advantage of the abundant data collected in the adjacent Kuparuk River basin for other studies. Basically, our approach was to install meteorological stations that were spatially distributed around the basin and hydrological stations to monitor stage, discharge, and suspended sediment transport, and for general observations. All three watersheds of interest in this study emanate from the Brooks Range, travel north through the foothills, and discharge into the Colville River (which eventually empties into the Arctic Ocean) on the southern edge of the coastal plain near Umiat.

From earlier investigations of drainages to the east of this study area, it was clear that the hydrologic response of the three physiographic areas (mountains, foothills, and coastal plain) varies considerably.

- There is a very strong pattern of warm season rainfall over the area. More rainfall occurs at higher elevations, where the foothills get approximately twice as much rainfall as the coastal plain, and the mountains get three times as much as the coastal plain.

- Spring runoff is a significant hydrologic event in all three physiographic regions. The runoff response from each region varies because of different hydrologic processes. The mountains and foothills shed snowmelt because of steep hydraulic gradients, while the coastal plain discharges water because of limited storage.

- Continuous permafrost limits the subsurface storage of the active layer. On the coastal plain, surface storage in the form of extensive lakes, ponds, and wetlands also impacts the runoff response.

- In the foothills and mountains, summer runoff events are common; as mentioned above, more warm season precipitation is received in these areas.

- On the coastal plain, there is only one significant runoff event: snowmelt. Usually before any noteworthy runoff occurs, the snowpack on the tundra has completely melted.

In this low-gradient drainage system, snow damming at lake outlets and drainage channels plays an important role in the timing of the runoff event. When these snow dams are breached by snowmelt, streamflow rapidly increases to the annual peak.

● During the warm season, streams on the coastal plain go into recession after the snowmelt peak. This trend continues throughout the summer; only occasionally have we observed small increases in flow. Because of low amounts of precipitation, evapotranspiration is generally greater than precipitation in June, July, and August, and surface storage deficit accrues. If any warm season precipitation events ensue, this water goes into surface storage.

● July and August are the wettest months, while June and September can also be wet. March, April, and May are dry months, along with June occasionally.

In 2012, we published an intermediate report (Kane et al., 2012), in which we made some preliminary conclusions. Since then we have collected two more years of data. Below we re-examine these conclusions in light of the new data:

● Quantifying the regional snowpack at winter's end is still challenging due to the heterogeneous snowpack in this windy, treeless environment and the difficulty of accessing sites in the mountains on steep side-slopes. While there is considerable local variation, an analysis of all our data shows that very little variation in density, snow depth, and SWE occurs when averaged over the region.

● In the 2012 report, we commented on the temporal variability of warm season precipitation. Sizeable variation (factor of five or more) is seen in all the long-term stations (20 years) in the Kuparuk watershed; meteorological stations of shorter duration (4 to 5 years or less) are apt to show a fairly consistent pattern of cumulative precipitation each year, which is misleading.

● With only four or five years of discharge data, it is difficult to do flood frequency analysis on the rivers studied in the Umiat area. We carried out extreme flow frequency analysis for the Upper Kuparuk and Kuparuk Rivers, Putuligayuk River, and Imnavait Creek with approximately 20 to 40 years of data. The flood estimates are quite similar to those in the 2012 report. Also in the 2012 report were flood estimates for rivers in the area that are no longer gauged.

- The floods of record for large watersheds (Sagavanirktok, Colville, Kuparuk) will be snowmelt-generated. Floods of record for smaller watersheds (Upper Kuparuk, Upper Itkillik, and Atigun) have a high probability of being rainfall-generated. For large watersheds, low-pressure systems are limited in size and only produce runoff from a fraction of the watershed. For small watersheds, rainfall covers the entire area and thus produces high runoff volumes. Also, rainfall intensities exceed snowmelt rates. Rainfall floods on small streams have positive coefficients of skewness, and large rivers have negative ones.

- In summer, air temperatures are the warmest in the foothills, less warm on the coastal plain, and on average, coolest in the mountains. During the cold season, the coastal plain is the coldest, followed by the foothills. The mountains are warmest. This pattern has not changed.

- The warmest annual average soil temperatures occur in the south, and the coolest soil temperatures in the north. Soil moisture data show poorly drained/wettest soils in the north with well-drained soils in the mountains and foothills. This was expected.

During the last two years, we have continued all of our original observations from the commencement of this study. We made more of an effort to document conditions at each site during breakup, such as ice conditions, water level changes, channel changes, etc. We also increased our efforts to quantify suspended sediment transport in the three rivers, re-examine Manning's *n* for the Anaktuvuk and Lower Itkillik Rivers for a range of flow conditions, and examine the frequency of storms that we measured. The following are some conclusions of that effort:

- During peak flows, side channels and sloughs were observed to be full of water on both the Anaktuvuk and Chandler Rivers. On the Upper Itkillik near the station and proposed crossing, the flow was confined to the main channel during our field observations.

● Over bankfull conditions were observed most years on both the Anaktuvuk and the Chandler Rivers. In 2013, over bankfull conditions occurred on the Lower Itkillik River (the only year of observation).

● During the study period, stages varied up to 3 m on the Anaktuvuk and Chandler Rivers, and up to 2 m on the Upper Itkillik River.

● Ice jams were observed on all three rivers during breakup. The ice jams formed very quickly; within minutes, stages increased at least 1 m. The most notable ice jam occurred on the Chandler River; one ice jam was observed repeatedly in the vicinity of our monitoring station (lasting several days with over bankfull conditions) and another was observed upstream of the proposed crossing, approximately one mile.

● Ice pans at least 30 ft (8 to 9 m) in length were observed on the Chandler and Anaktuvuk Rivers. Ice thicknesses are around 4 to 5 ft (~1½ m). Smaller ice chunks (10 or more ft (a few meters) were observed on the Upper Itkillik River.

● Initial flows during breakup consisted of very clear water with low suspended sediment loads, but after a few days, the bottom ice and snow eroded off the streambed and the suspended sediment load (turbidity) increased substantially. The Chandler River had the highest suspended sediment discharge, although the Anaktuvuk River had a higher discharge.

● We made some rough calculations of Manning's *n* for the Anaktuvuk River at our stream gauging site. For a range of flow conditions, our estimates ranged from 0.016 to 0.037. These values are lower than the values reported earlier in Youcha et al. (2011). On large rivers like the Anaktuvuk, at high stages it is difficult to measure the slope accurately.

● Using the precipitation frequency atlas for Alaska (Perica et al.,2012), we made frequency estimates for observed storms on the North Slope in our study area. As expected, for short records of warm season rainfall, the storms were mainly low return periods. We had 10 stations with 14 to 29 years of observations; most of these stations had one hourly and one daily storm with a return period of 10 to 25 years. We captured three hourly and two daily storms, with return periods between 25 and 50 years, and one hourly storm between 50 and 100 years.

9 REFERENCES

Barnes, H.H., Jr. (1967). Roughness Characteristics of Natural Channels, U.S. Geological Survey Water-Supply Paper 1849.

Berezovskaya, S.L., Derry, J.E., Kane, D.L., Gieck, R.E., Lilly, M.R., and White, D.M. (2007). Snow Survey Data for the Kuparuk Foothills Hydrology Study: Spring 2007. July 2007, University of Alaska Fairbanks, Water and Environmental Research Center, Report INE/WERC 07.17, Fairbanks, Alaska, 21 pp.

Berezovskaya, S.L., Derry, J.E., Kane, D.L., Gieck, R.E., Lilly, M.R., and White, D.M. (2008). Snow Survey Data for the Kuparuk Foothills Hydrology Study: Spring 2008. June 2008, University of Alaska Fairbanks, Water and Environmental Research Center, Report INE/WERC 08.14, Fairbanks, Alaska, 40 pp. [Amended Figures 3 & 4 Aug. 26, 2008]

Berezovskaya, S., Derry, J., Kane, D., Gieck, R., and Lilly, M. (2010a). Snow Survey Data for the Central North Slope Watersheds: Spring 2009. University of Alaska Fairbanks, Water and Environmental Research Center, Report INE/WERC 09.01, Fairbanks, Alaska, 21 pp.

Berezovskaya, S., Hilton, K., Derry, J., Youcha, E., Kane, D., Gieck, R., Homan, J., and Lilly, M. (2010b). Snow Survey Data for the Central North Slope Watersheds: Spring 2010. University of Alaska Fairbanks, Water and Environmental Research Center, Report INE/WERC 10.01, Fairbanks, Alaska, 50 pp.

Best, H., McNamara, J.P., and Liberty, L. (2005). Association of ice and river channel morphology determined using ground-penetrating radar in the Kuparuk River, Alaska. *Arctic, Antarctic, and Alpine Research* 37(2): 157–162.

Curran, J.H., Meyer, D.F.,and Tasker, G.D. 2003. Estimating the magnitude and frequency of peak streamflows for ungaged sites on streams in Alaska and conterminous basins in Canada. Water-Resources Investigation Report 03-4188, U.S. Geological Survey.

Forbes, A.C., and Lamoureux, S.F. (2005). Climatic controls on streamflow and suspended sediment transport in three large middle arctic catchments, Boothia Peninsula, Nunavut, Canada. *Arctic, Antarctic, and Alpine Research* 37(3): 304–315.

Foster, I., Millington, R. and Grew, R. (1992). The impact of particle size controls on stream turbidity measurement; some implications for suspended sediment yield estimation. *Erosion and Sediment Transport Monitoring Programmes in River Basins* 210: 51–62.

Garcia, M.H., Ed. (2008). *Sedimentation Engineering: Processes, Measurements, Modeling, and Practice*. American Society of Civil Engineers.

Goodison, B.E., Louie, P.Y.T., and Yang, D. (1998). *WMO Solid Precipitation Measurement Intercomparison.* World Meteorological Organization, Instrument and Observing Methods Report No. 67, WMO/TD Report No. 872, 212 pp.

Grayson, R.B., Finlayson, B.L., Gippel, C.J., and Hart, B.T. (1995). The potential of field turbidity measurements for the computation of total phosphorous and suspended solid loads. *Journal of Environmental Management* 47: 257–67.

Hinzman, L.D., Kane, D.L., Gieck, R.E., and Everett, K.R. (1991). Hydrologic and thermal properties of the active layer in the Alaskan Arctic. *Cold Regions Science and Technology*, 19: 95–110.

Hinzman, L.D., Goering, D.J., and Kane, D.L. (1998). A distributed thermal model for calculating soil temperature profiles and depth of thaw in permafrost regions. *Journal of Geophysical Research* 103(D22): 28,975–28,991.

Kane, D.L., L.D. Hinzman, C.S. Benson and K.R. Everett. 1989. Hydrology of Imnavait Creek, an arctic watershed. *Holarctic Ecology*, 12:262-269.

Kane, D.L., J.P. McNamara, D. Yang, P.Q. Olsson and R.E. Gieck. (2003). An Extreme Rainfall/Runoff Event in Arctic Alaska. *Journal of Hydrometeorology*, 4(6):1220-1228.

Kane, D.L., Gieck, R.E., Kitover, D.C., Hinzman, L.D., McNamara, J.P., and Yang, D. (2004). Hydrologic Cycle on the North Slope of Alaska. Int. Association of Hydrological Sciences Publication 290, pp. 224–236.

Kane, D.L., Berezovskaya, S., Irving, K., Busey, R., Chambers, M., Blackburn, A.J., and Lilly, M.R. (2006). Snow Survey Data for the Kuparuk Foothills Hydrology Study: Spring 2006. July 2006, University of Alaska Fairbanks, Water and Environmental Research Center, Report INE/WERC 06-06, Fairbanks, Alaska, 12 pp.

Kane, D.L., Gieck, R.E., and Hinzman, L.D. (2008a). Water Balance for a Low-Gradient Watershed in Northern Alaska. In: Proceedings of Ninth International Conference on Permafrost, D.L. Kane and K.M. Hinkel (Eds.), University of Alaska, Institute of Northern Engineering, pp. 883–888.

Kane, D.L., Hinzman, L.D., Gieck, R.E., McNamara, J.P., Youcha, E., and Oatley, J.A. (2008b). Contrasting Extreme Runoff Events in Areas of Continuous Permafrost, Arctic Alaska. *Hydrology Research* 38(4): 287–298.

Kane, D., White, D., Lilly, M., Toniolo, H., Berezovskya, S., Schnabel, W., Youcha, E., Derry, J., Gieck, R., Paetzold, R., Trochim, E., Remillard, M., Busey, R., and Holland, K. (2009). Meteorological and Hydrological Data and Analysis Report for Bullen Point and Foothills Projects: 2006–2008. University of Alaska Fairbanks, Water and Environmental Research Center, Report INE/WERC 08.18, Fairbanks, Alaska, 180 pp.

Kane, D.L., Youcha, E.K., Stuefer, S., Toniolo, H., Schnabel, W., Gieck, R., Myerchin-Tape, G., Homan, J., Lamb, E., and Tape, K.(2012). Meteorological and Hydrological Data and Analysis Report for Foothills/Umiat Corridor and Bullen Projects: 2006–2011. University of Alaska Fairbanks, Water and Environmental Research Center, Report INE/WERC 12.01, Fairbanks, Alaska, 260 pp + Appendices.

Kane, D.L., Yoshikawa, K., and McNamara, J.P. (2013). Regional groundwater flow in an area mapped as continuous permafrost, NE Alaska (USA). *Hydrogeology Journal* 21: 41–52.

Lewis, J. (1996). Turbidity-controlled suspended sediment sampling for runoff-event load estimation. *Water Resources Research* 32(7): 2299–2310.

Lewis, J. (2003). Turbidity-controlled sampling for suspended sediment load estimation. *IAHS Publication*: 13–20.

Lewis, T., Braun, C., Hardy, D.R., Francus, P., and Bradley, R.S. (2005). An extreme sediment transfer event in a Canadian High Arctic stream. *Arctic, Antarctic, and Alpine Research* 37(4): 477–482.

McNamara, J., Oatley, J., Kane, D., and Hinzman, L. (2008). Case study of a large summer flood on the North Slope of Alaska: bedload transport. *Hydrology Research* 39(4).

Oatley, J.A. (2002). Ice, bedload transport, and channel morphology on the Upper Kuparuk River. University of Alaska Fairbanks, MS thesis, 92 pp.

Parker, G., Wilcock, P.R., Paola, C., Dietrich, W.E., Pitlick, J. (2007). Physical basis for a quasi-universal relations describing bankfull hydraulic geometry of single-thread gravel bed rivers. *Journal of Geophysical Research* 112: F04005.

Perica, S., Kane, D., Dietz, S., Maitaria, K., Martin, D., Pavlovic, S., Roy, I., Stuefer, S., Tidwell, A., Trypaluk, C., Unruh, D., Yekta, M., Betts, E., Bonnin, G., Heim, S., Hiner, L., Lilly, E., Narayanan, J., Yan, F., and Zhao, T. (2012). NOAA Atlas 14, Volume 7, Version 2.0, Precipitation-Frequency Atlas of the United States, Alaska. NOAA, National Weather Service, Silver Spring, MD.

Stein, J., and Kane, D.L. (1983). Monitoring the unfrozen water content of soil and snow using time domain reflectometry. *Water Resources Research* 19(6): 1573–1584.

Stuefer, S.L., Youcha, E.K, Homan, J.W., Kane, D.L., and Gieck, R.E. (2011). Snow Survey Data for the Central North Slope Watersheds: Spring 2011. University of Alaska Fairbanks, Water and Environmental Research Center, Report INE/WERC 11.02, Fairbanks, Alaska, 47 pp.

Stuefer, S.L., Homan, J.W., Youcha, E.K, Kane, D.L., and Gieck, R.E. (2012). Snow Survey Data for the Central North Slope Watersheds: Spring 2012. University of Alaska Fairbanks, Water and Environmental Research Center, Report INE/WERC 12.22, Fairbanks, Alaska, 38 pp.

Stuefer, S.L., Homan, J.W., Kane, D.L., Gieck, R.E., and Youcha, E.K. (2014). Snow Survey Results for the Central Alaskan Arctic, Arctic Circle to Arctic Ocean. University of Alaska Fairbanks, Water and Environmental Research Center, Report INE/WERC 14.01, Fairbanks, Alaska, 96 pp.

Toniolo, H., Derry, J., Irving, K., and Schnabel, W. (2010). Hydraulic and sedimentological characterization of a reach on the Anaktuvuk River, Alaska. *Journal of Hydraulic Engineering* 136(11): 935–939.

USGS (U.S. Geological Survey). (2014). Water-resources data for the United States, retrieved from http://waterdata.usgs.gov/nwis/ January, 2014.

Wagner, C.R., and Mueller, D.S. (2011). Comparison of bottom-track to global positioning system referenced discharges measured using an acoustic Doppler current profiler. *Journal of Hydrology* 401: 250–258.

Woo, M-K., Kane, D.L., Carey, S.K., and Yang, D. (2008). Progress in permafrost hydrology in the new millennium. *Permafrost and Periglacial Processes* 19: 237–254.

Yang, D., Goodison, B.E., Metcalfe, J.R., Golubev, V.S., Bates, R., Pangburn, T., and Hanson, C.L. (1998). Accuracy of NWS 8″ standard nonrecording precipitation gauge: Results and application of WMO intercomparison. *J. Atmospheric and Oceanic Technology* 15: 54–68.

Yang, D., Goodison, B.E., Metcalfe, J.R., Louie, P., Leavesley, G., Emerson, D., Hanson, C.L., Golubev, V.S., Elomaa, E., Gunther, T., Pangburn, T., Kang, E., and Milkovic, J. (1999). Quantification of precipitation measurement continuity induced by wind shields on national gauges. *Water Resources Research* 35(2): 491–508.

Yang, D., Kane, D.L., Hinzman, L.D., Goodison, B.E., Metcalfe, J.R., Louie, P.Y.T., Leavesley, G., Emerson, D.G., and Hanson, C.L. (2000). An evaluation of the Wyoming gauge system for snowfall measurement. *Water Resources Research* 36(9): 2665–2677.

Yoshikawa, K., Hinzman, L.D., and Kane, D.L. (2007). Spring and aufeis (icings) hydrology in the Brooks Range, Alaska. *Journal of Geophysical Research* 112: G04S43, doi: 10.1029/2006JG000294.

Youcha, E.K, Toniolo, H.A., and Kane, D.L. (2011). Spring and summer runoff observations 2009–2010, Umiat Corridor hydrology project. University of Alaska Fairbanks, Water and Environmental Research Center, Report INE/WERC 11.01, Fairbanks, Alaska, 54 pp + Appendix.

10 APPENDICES

Appendix A – Air Temperature and Relative Humidity

Appendix B – Wind Speed and Direction: Wind Roses

Appendix C – Cumulative Warm Season Precipitation for All Years at Each Station and Cumulative Warm Season Precipitation by Year for All Stations, 2007 to 2013

Appendix D – Soil Temperature and Moisture Content

Appendix E – Rating Curves and Discharge Measurement Summaries

Appendix A – Air Temperature and Relative Humidity

This section contains a table of mean monthly air temperatures at each station in the Kuparuk Foothills and Umiat Corridor projects.

Also included are time series plots of air temperature and relative humidity for each station. For various stations in years prior to 2009, temperatures colder than 40°F were not detectable with the sensor configurations, and actual values are not shown.

Pages A-1 to A-3: Mean monthly air temperatures for the Kuparuk, Itkillik, Anaktuvuk, and Chandler River basins.

Page A-4: Air temperature and relative humidity graphs for the period of record for Accomplishment Creek (DBM1), South White Hills (DFM1), White Hills (DFM2), and North White Hills (DRM3).

Page A-5: Air temperature and relative humidity graphs for the period of record for Northwest Kuparuk (DFM4), Itikmalakpak (DUM1), Upper May Creek (DUM2), and Nanushuk (DUM3).

Page A-6: Air temperature and relative humidity graphs for the period of record for Tuluga (DUM4), Encampment (DUM5), White Lake (DUM6), and Hatbox Mesa (DUM7).

Page A-7: Air temperature and relative humidity graphs for the period of record for Siksikpuk (DUM8), Anaktuvuk (DUS2), Chandler (DUS3), and Green Cabin Lake (GCL).

Page A-8: Air temperature and relative humidity graphs for the period of record for Imnavait Basin (IB), Sagwon Hill (SH), and Upper Kuparuk (UK).

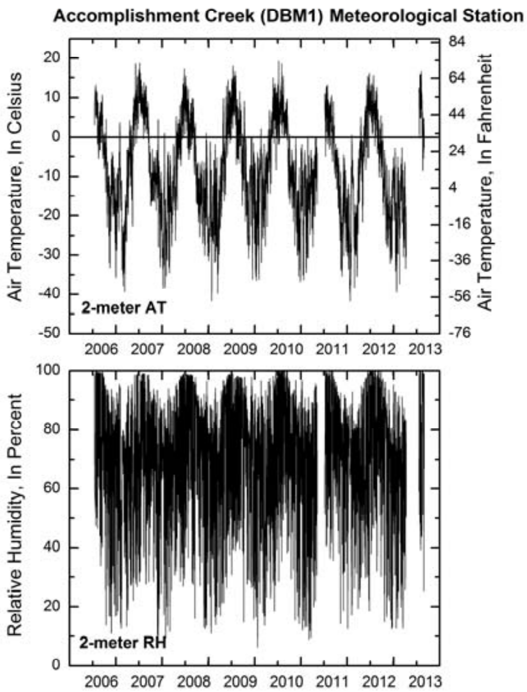
Mean Monthly Air Temperature

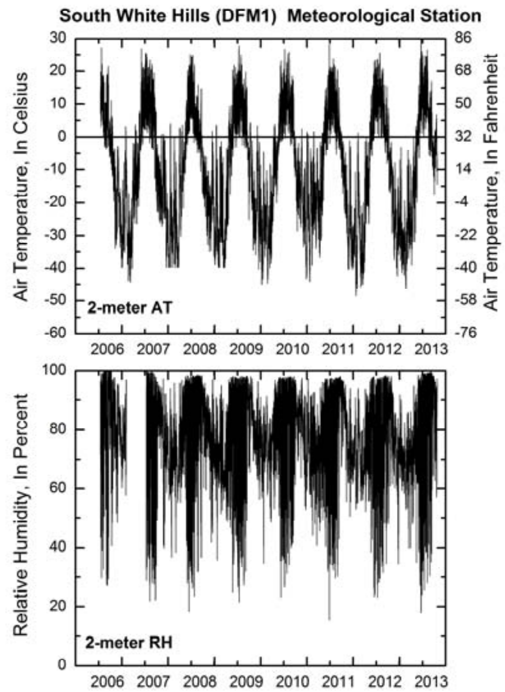
Month	Statistic	DBM1 Accomplish-ment Creek 7/06 to 8/13 Air Temp °C	°F	DFM1 So. White Hills 7/06 to 10/13 Air Temp °C	°F	DFM2 White Hills 7/06 to 9/13 Air Temp °C	°F	DFM3 No. White Hills 7/06 to 10/13 Air Temp °C	°F	DFM4 NW Kuparuk 7/06 to 7/13 Air Temp °C	°F	SH Sagwon Hill 01/06 to 09/11 Air Temp °C	°F	UK Upper Kuparuk 01/06 to 09/11 Air Temp °C	°F
Oct	Mean	-9.8	14.3	-8.4	16.9	-7.7	18.2	-7.9	17.8	-7.2	19.1	-8.7	16.3	-9.9	14.1
	Max	0.9	33.7	3.3	38.0	3.7	38.7	3.8	38.8	2.3	36.2	1.9	35.4	3.1	37.6
	Min	-20.7	-5.2	-22.7	-8.9	-17.7	0.1	-24.1	-11.4	-20.9	-5.6	-19.3	-2.8	-25.0	-13.0
Nov	Mean	-16.4	2.5	-19.6	-3.3	-16.3	2.6	-19.7	-3.4	-17.8	-0.1	-17.6	0.3	-18.9	-2.0
	Max	-5.0	23.1	-4.2	24.4	-4.3	24.2	-4.7	23.5	-4.6	23.7	-4.7	23.5	-2.1	28.2
	Min	-28.7	-19.7	-33.9	-29.1	-27.4	-17.3	-35.9	-32.6	-30.8	-23.5	-28.4	-19.1	-34.2	-29.6
Dec	Mean	-16.8	1.8	-22.9	-9.3	-19.8	-3.7	-24.3	-11.7	-23.2	-9.8	-19.4	-2.9	-21.3	-6.3
	Max	-2.3	28.0	-2.7	27.2	-1.1	30.1	-4.7	23.5	-5.7	21.7	0.3	32.6	0.3	32.6
	Min	-32.7	-26.9	-40.0	-40.0	-35.4	-31.8	-41.0	-41.8	-37.6	-35.6	-34.6	-30.2	-38.2	-36.8
Jan	Mean	-20.0	-4.0	-26.4	-15.5	-23.7	-10.6	-28.9	-20.0	-28.0	-18.4	-24.2	-11.5	-24.5	-12.2
	Max	-2.7	27.2	-0.6	31.0	1.8	35.3	-6.2	20.8	-7.0	19.4	-0.4	31.3	-2.5	27.5
	Min	-38.6	-37.5	-42.8	-45.0	-37.9	-36.2	-44.3	-47.8	-40.7	-41.2	-37.9	-36.2	-39.4	-39.0
Feb	Mean	-17.3	0.9	-24.7	-12.5	-23.4	-10.1	-27.4	-17.4	-26.3	-15.4	-21.3	-6.3	-20.6	-5.1
	Max	-0.6	30.9	-3.0	26.6	-2.8	26.9	-7.2	19.1	-8.6	16.4	0.4	32.8	0.4	32.7
	Min	-36.0	-32.7	-42.4	-44.4	-38.1	-36.6	-43.7	-46.6	-40.3	-40.5	-38.0	-36.3	-39.3	-38.7
Mar	Mean	-17.7	0.1	-26.5	-15.7	-23.2	-9.7	-29.3	-20.7	-27.5	-17.6	-24.4	-11.9	-23.8	-10.8
	Max	-3.7	25.4	-6.4	20.4	-2.5	27.5	-10.8	12.6	-9.6	14.7	-4.9	23.2	-4.4	24.1
	Min	-32.7	-26.9	-39.5	-39.2	-36.4	-33.6	-41.7	-43.1	-38.3	-37.0	-36.1	-33.0	-37.0	-34.5
Apr	Mean	-10.3	13.5	-15.5	4.0	-13.4	7.9	-15.9	3.5	-15.3	4.4	-14.0	6.9	-13.1	8.3
	Max	3.3	37.9	2.1	35.8	4.2	39.6	2.2	35.9	-0.3	31.5	3.2	37.8	5.3	41.6
	Min	-24.6	-12.2	-33.5	-28.3	-26.8	-16.3	-35.3	-31.5	-29.5	-21.1	-26.7	-16.0	-31.0	-23.8
May	Mean	-2.2	28.1	-3.9	24.9	-4.1	24.7	-4.9	23.3	-5.6	22.0	-3.6	25.6	-2.1	28.3
	Max	9.0	48.3	12.9	55.3	13.6	56.5	10.1	50.1	6.7	44.1	12.7	54.9	14.9	58.7
	Min	-18.4	-1.1	-22.9	-9.3	-17.9	-0.2	-22.8	-9.1	-19.4	-2.9	-17.3	0.9	-22.8	-9.0
Jun	Mean	6.9	44.4	9.4	49.0	8.1	46.5	7.7	45.8	5.7	42.2	8.5	47.4	9.6	49.3
	Max	16.0	60.8	25.9	78.6	23.0	73.4	24.5	76.2	22.4	72.4	24.1	75.4	22.7	72.8
	Min	-4.2	24.4	-3.6	25.5	-14.7	5.6	-2.8	26.9	-3.7	25.4	-4.6	23.7	-4.2	24.4
Jul	Mean	7.8	46.1	12.3	54.2	11.5	52.7	11.5	52.8	10.3	50.5	11.3	52.4	11.1	52.0
	Max	16.2	61.1	25.6	78.1	23.8	74.8	24.4	75.9	24.8	76.6	24.9	76.9	22.5	72.5
	Min	-0.2	31.6	0.6	33.0	-9.4	15.0	1.3	34.3	0.2	32.4	0.0	31.9	-0.6	31.0
Aug	Mean	4.4	40.0	8.0	46.4	6.2	43.2	7.0	44.5	6.8	44.3	7.0	44.7	6.8	44.2
	Max	13.7	56.6	21.9	71.5	19.0	66.2	20.6	69.1	20.9	69.5	20.7	69.3	19.2	66.6
	Min	-4.2	24.5	-3.8	25.2	-3.3	26.0	-4.5	23.9	-3.0	26.6	-3.0	26.5	-5.8	21.5
Sep	Mean	-1.0	30.1	1.4	34.6	2.0	35.5	2.0	35.6	1.8	35.3	1.8	35.2	0.1	32.2
	Max	9.3	48.8	17.5	63.4	14.5	58.0	17.9	64.2	16.1	61.0	16.3	61.4	15.0	59.0
	Min	-12.2	10.1	-12.3	9.9	-8.01	17.59	-10.7	12.7	-9.3	15.3	-10.5	13.2	-16.3	2.6

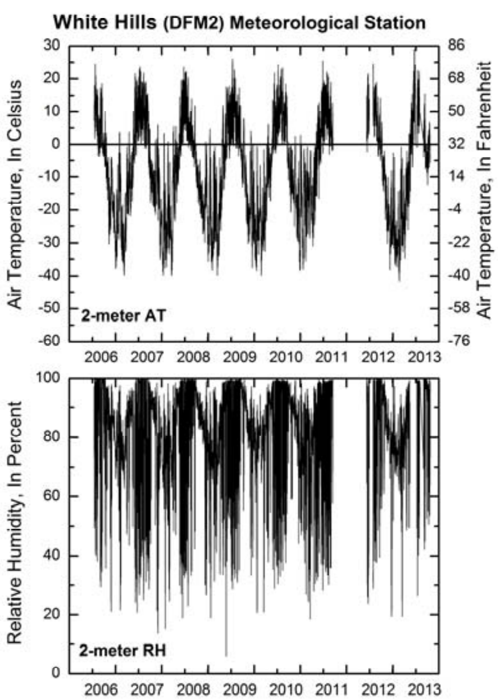
		IB Imnavait Basin		GL Green Cabin Lake		DUM1 Itikmalakpak		DUM2 Upper May Creek		DUM3 Nanushuk		DUM4 Tuluga		DUM5 Encampment	
		01/06 to 09/11		01/06 to 09/11		6/09 to 8/13		6/09 to 8/13		6/09 to 8/13		6/09 to 8/13		9/10 to 8/13	
Month	Statistic	Air Temp		Air Temp		Air Temp		Air Temp		Air Temp		Air Temp		Air Temp	
		°C	°F	°C	°F	°C	°F	°C	°F	°C	°F	°C	°F	°C	°F
Oct	Mean	-8.1	17.4	-9.1	15.7	-7.8	18.0	-8.3	17.1	-8.0	17.7	-7.9	17.8	-9.0	15.8
	Max	2.9	37.3	3.0	37.5	4.6	40.3	4.7	40.5	4.0	39.3	3.5	38.4	1.1	34.0
	Min	-18.2	-0.7	-21.6	-6.9	-19.2	-2.5	-19.4	-3.0	-19.2	-2.6	-19.8	-3.6	-18.5	-1.3
Nov	Mean	-16.0	3.1	-17.7	0.2	-18.4	-1.1	-17.6	0.3	-19.2	-2.6	-18.5	-1.3	-17.7	0.1
	Max	-2.6	27.3	-1.9	28.5	-2.9	26.7	-4.4	24.0	-3.5	25.6	-3.4	25.9	-4.0	24.8
	Min	-28.6	-19.4	-32.2	-25.9	-31.1	-24.0	-30.1	-22.2	-31.1	-23.9	-30.8	-23.5	-29.3	-20.8
Dec	Mean	-17.7	0.1	-18.4	-1.1	-20.4	-4.7	-17.1	1.2	-22.0	-7.7	-20.3	-4.5	-19.9	-3.8
	Max	0.6	33.1	2.1	35.8	-1.9	28.6	-1.2	29.8	-3.8	25.2	0.2	32.4	-4.6	23.8
	Min	-34.5	-30.1	-35.9	-32.6	-36.3	-33.3	-33.2	-27.7	-37.2	-34.9	-37.8	-36.1	-35.1	-31.2
Jan	Mean	-21.3	-6.3	-24.0	-11.1	-19.9	-3.8	-19.0	-2.3	-23.9	-11.0	-23.1	-9.6	-19.2	-2.6
	Max	-1.5	29.3	-0.6	30.9	-3.0	26.7	-3.2	26.3	-3.0	26.6	-1.5	29.4	-4.4	24.0
	Min	-37.5	-35.4	-38.8	-37.9	-37.8	-36.1	-36.4	-33.5	-38.7	-37.6	-37.8	-36.0	-37.2	-34.9
Feb	Mean	-17.8	0.0	-19.3	-2.8	-17.1	1.2	-15.7	3.8	-22.2	-7.9	-19.2	-2.6	-17.0	1.4
	Max	0.2	32.4	0.7	33.2	0.3	32.5	1.2	34.2	-3.4	25.9	1.2	34.1	-2.4	27.7
	Min	-35.9	-32.7	-37.7	-35.9	-37.2	-35.0	-35.4	-31.7	-38.3	-36.9	-38.0	-36.4	-36.2	-33.2
Mar	Mean	-19.8	-3.7	-21.9	-7.4	-16.1	3.1	-15.0	4.9	-21.5	-6.7	-22.1	-7.8	-16.6	2.0
	Max	-4.1	24.7	-4.6	23.7	-1.3	29.6	-0.4	31.3	-6.5	20.3	-5.7	21.7	-4.6	23.7
	Min	-34.9	-30.9	-36.5	-33.6	-30.5	-23.0	-29.8	-21.7	-33.6	-28.5	-34.8	-30.6	-30.1	-22.3
Apr	Mean	-10.9	12.5	-11.8	10.8	-9.3	15.3	-9.3	15.3	-13.8	7.1	-11.9	10.6	-11.0	12.2
	Max	5.3	41.6	5.3	41.5	6.9	44.3	5.3	41.6	4.0	39.1	5.1	41.2	1.8	35.2
	Min	-26.7	-16.0	-28.9	-20.0	-28.7	-19.6	-26.7	-16.1	-32.0	-25.5	-28.0	-18.3	-28.9	-20.0
May	Mean	-1.4	29.5	-1.2	29.9	-0.2	31.6	-0.8	30.5	-3.0	26.6	-2.7	27.2	-2.2	28.0
	Max	14.1	57.4	14.7	58.5	15.0	58.9	12.8	55.1	14.6	58.4	15.4	59.8	13.8	56.8
	Min	-19.3	-2.7	-21.0	-5.9	-20.5	-4.9	-19.2	-2.5	-20.9	-5.6	-19.8	-3.7	-20.6	-5.0
Jun	Mean	8.8	47.8	9.3	48.7	7.9	46.2	7.0	44.6	9.5	49.1	9.1	48.4	7.6	45.8
	Max	20.6	69.0	21.1	70.1	18.5	65.3	16.8	62.2	23.3	74.0	23.5	74.3	19.5	67.1
	Min	-4.7	23.5	-4.2	24.4	-3.8	25.1	-4.7	23.6	-3.6	25.5	-3.8	25.2	-5.8	21.6
Jul	Mean	10.5	50.8	10.8	51.4	9.9	49.9	8.4	47.1	12.3	54.1	12.2	54.0	8.5	47.4
	Max	20.5	68.9	21.1	69.9	18.8	65.8	17.5	63.5	24.1	75.4	24.0	75.1	16.4	61.5
	Min	0.6	33.1	0.6	33.1	2.0	35.6	0.0	31.9	1.8	35.2	1.4	34.5	-0.1	31.9
Aug	Mean	6.5	43.7	7.9	46.2	6.4	43.5	5.3	41.5	8.7	47.6	8.6	47.5	5.6	42.1
	Max	17.4	63.3	17.4	63.3	17.3	63.2	16.0	60.8	21.9	71.4	22.3	72.2	15.0	59.0
	Min	-3.4	25.9	-4.0	24.8	-3.4	25.9	-4.0	24.9	-1.9	28.6	-1.4	29.5	-4.3	24.3
Sep	Mean	0.4	32.7	0.3	32.5	-0.4	31.3	-1.2	29.9	1.3	34.3	1.6	34.9	-0.8	30.5
	Max	13.4	56.1	13.8	56.9	12.3	54.1	10.0	50.1	15.7	60.3	15.7	60.3	9.7	49.5
	Min	-11.4	11.4	-14.1	6.6	-12.0	10.3	-13.2	8.3	-11.0	12.2	-11.0	12.2	-11.3	11.6

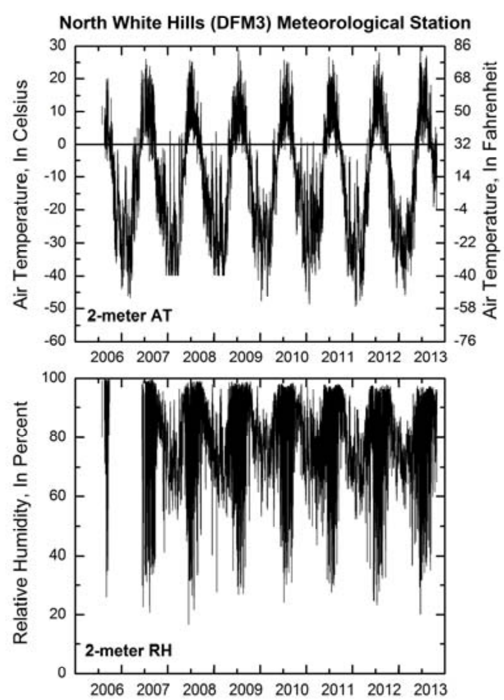
		DUM6 White Lake		DUM7 Hatbox Mesa		DUM8 Siksikpuk		DUS2 Anaktuvuk Met		DUS3 Chandler Met	
		9/10 to 8/13		9/10 to 9/13		9/10 to 8/13		6/09 to 8/13		6/09 to 8/13	
Month	Statistic	Air Temp		Air Temp		Air Temp		Air Temp		Air Temp	
		°C	°F	°C	°F	°C	°F	°C	°F	°C	°F
Oct	Mean	-9.3	15.3	-8.4	16.8	-9.3	15.3	-7.0	19.3	-7.7	18.2
	Max	0.4	32.8	2.1	35.8	1.5	34.8	4.2	39.5	3.8	38.9
	Min	-17.8	0.0	-18.0	-0.3	-21.6	-6.9	-22.4	-8.4	-21.6	-6.9
Nov	Mean	-18.2	-0.7	-18.4	-1.2	-19.8	-3.6	-19.5	-3.0	-18.8	-1.8
	Max	-4.8	23.4	-4.8	23.4	-3.6	25.6	-3.2	26.2	-1.9	28.5
	Min	-30.1	-22.2	-31.6	-24.8	-34.0	-29.1	-35.7	-32.2	-35.7	-32.2
Dec	Mean	-21.0	-5.7	-23.9	-11.1	-26.0	-14.8	-24.5	-12.1	-26.8	-16.2
	Max	-6.4	20.5	-6.1	21.1	-7.0	19.5	-4.1	24.7	-6.1	21.1
	Min	-36.2	-33.2	-37.5	-35.4	-39.1	-38.4	-41.6	-42.9	-41.4	-42.5
Jan	Mean	-20.0	-4.0	-23.1	-9.6	-25.9	-14.7	-29.1	-20.3	-25.7	-14.3
	Max	-4.4	24.2	-4.1	24.7	-3.6	25.4	-8.7	16.3	-10.0	13.9
	Min	-37.5	-35.5	-38.5	-37.3	-41.4	-42.6	-48.4	**-55.1**	-41.7	-43.1
Feb	Mean	-18.2	-0.8	-21.8	-7.2	-24.0	-11.2	-27.2	-16.9	-28.4	-19.1
	Max	-2.5	27.5	-2.8	27.0	-4.6	23.8	-11.1	12.0	-9.7	14.6
	Min	-37.7	-35.9	-40.2	-40.4	-41.4	-42.4	-44.9	-48.8	-41.0	-41.8
Mar	Mean	-17.6	0.3	-20.1	-4.3	-23.1	-9.6	-27.5	-17.6	-24.4	-11.9
	Max	-5.3	22.5	-4.3	24.3	-7.0	19.5	-13.1	8.4	-10.7	12.7
	Min	-30.6	-23.0	-33.6	-28.4	-35.5	-32.0	-42.4	-44.3	-38.7	-37.7
Apr	Mean	-11.6	11.2	-13.9	7.0	-16.4	2.5	-17.2	1.1	-19.1	-2.3
	Max	2.9	37.3	5.3	41.6	1.6	34.9	-1.3	29.6	1.2	34.2
	Min	-30.8	-23.5	-33.0	-27.4	-34.4	-29.9	-36.5	-33.7	-37.8	-36.1
May	Mean	-2.7	27.2	-2.8	26.9	-3.0	26.5	-4.6	23.7	0.2	32.4
	Max	13.7	56.6	14.2	57.5	15.0	59.0	8.2	46.8	13.4	56.1
	Min	-20.7	-5.2	-22.2	-8.0	-24.2	-11.6	-26.2	-15.1	-12.7	9.2
Jun	Mean	8.0	46.3	8.8	47.9	10.4	50.7	7.9	46.2	10.4	50.6
	Max	20.3	68.5	23.9	74.9	26.2	79.1	23.5	74.4	29.7	85.5
	Min	-6.1	21.0	-5.4	22.3	-3.8	25.2	-2.3	27.8	-3.1	26.5
Jul	Mean	9.1	48.4	11.0	51.7	12.3	54.2	13.0	55.5	13.4	56.1
	Max	17.5	63.5	22.0	71.6	23.3	73.9	24.7	76.4	26.2	79.2
	Min	-0.3	31.5	0.9	33.6	1.3	34.3	2.3	36.2	2.1	35.8
Aug	Mean	6.0	42.8	7.6	45.7	8.7	47.7	9.5	49.1	10.6	51.0
	Max	15.8	60.4	19.8	67.7	21.9	71.3	23.8	74.9	25.1	77.2
	Min	-4.1	24.6	-2.6	27.3	-2.6	27.4	-2.1	28.2	-2.1	28.2
Sep	Mean	-0.8	30.5	0.8	33.5	1.2	34.1	2.6	36.6	2.8	37.0
	Max	10.3	50.5	12.7	54.9	15.0	58.9	18.1	64.6	18.8	65.8
	Min	-11.1	12.0	-10.0	13.9	-11.5	11.3	-8.2	17.3	-6.6	20.2

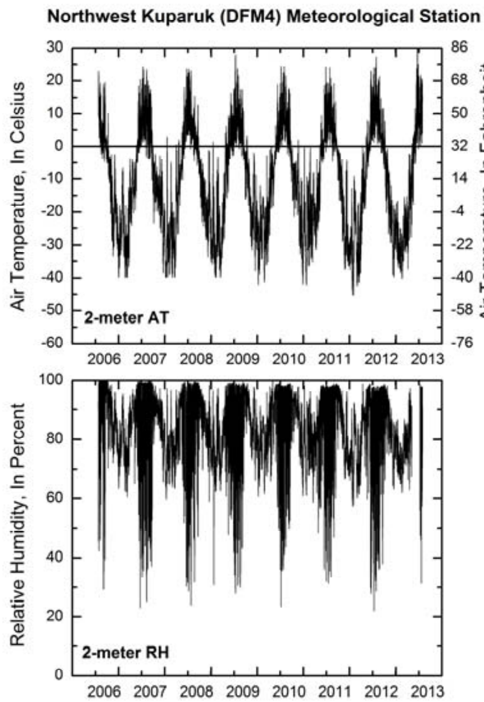
Air Temperature and Relative Humidity for Period of Record

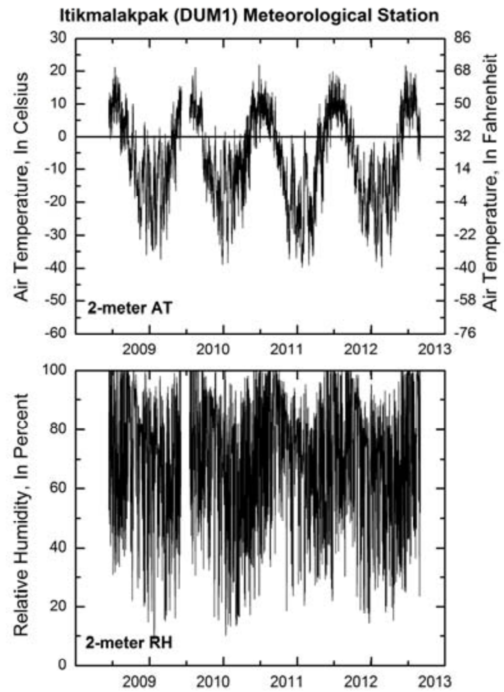


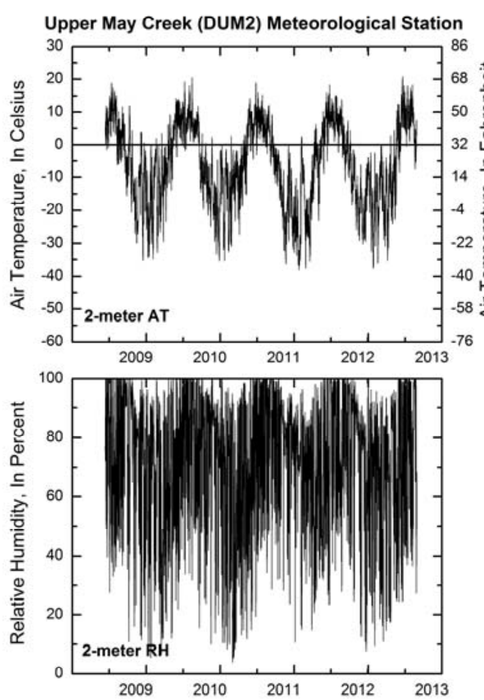


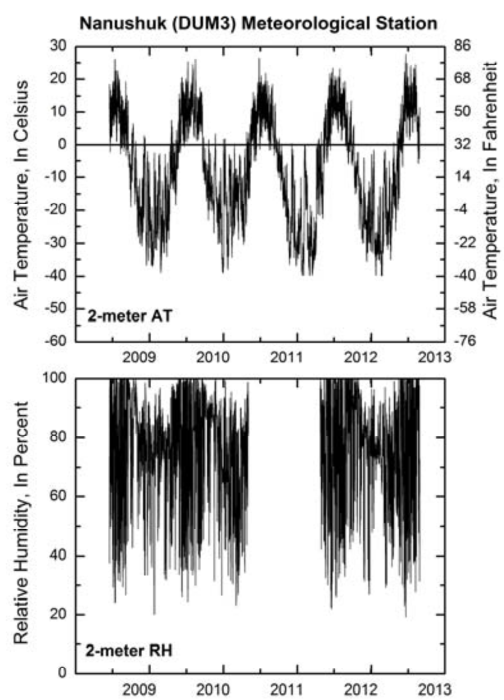


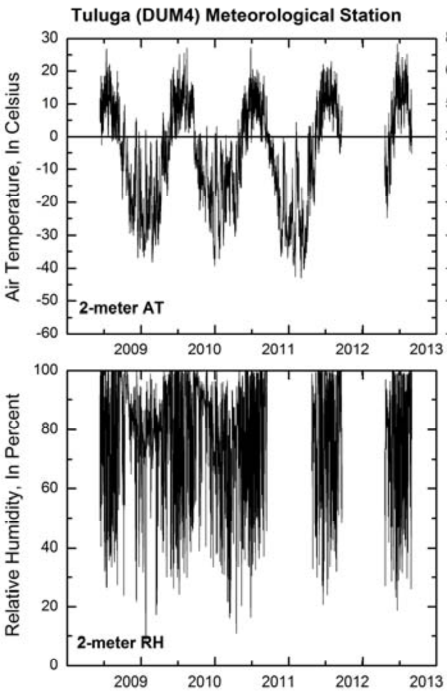


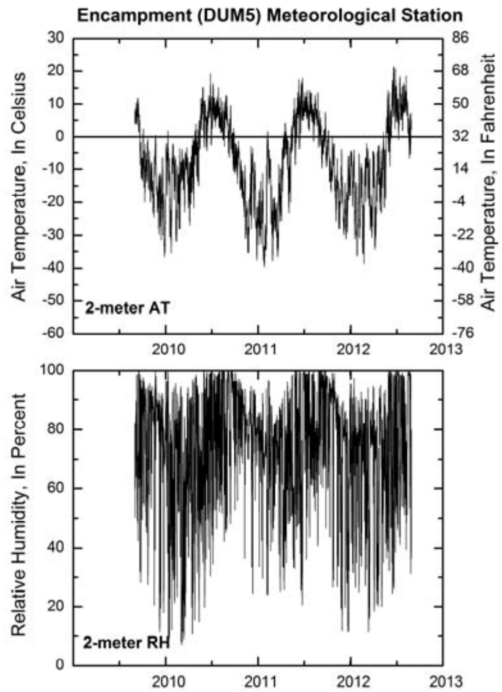

Northwest Kuparuk (DFM4) Meteorological Station
Air Temperature, In Celsius
Air Temperature, In Fahrenheit
2-meter AT
Relative Humidity, In Percent
2-meter RH
2006 2007 2008 2009 2010 2011 2012 2013

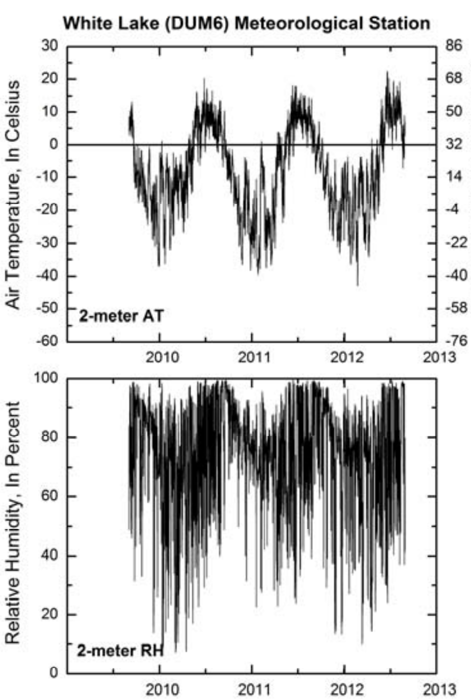

Itikmalakpak (DUM1) Meteorological Station
Air Temperature, In Celsius
Air Temperature, In Fahrenheit
2-meter AT
Relative Humidity, In Percent
2-meter RH
2009 2010 2011 2012 2013

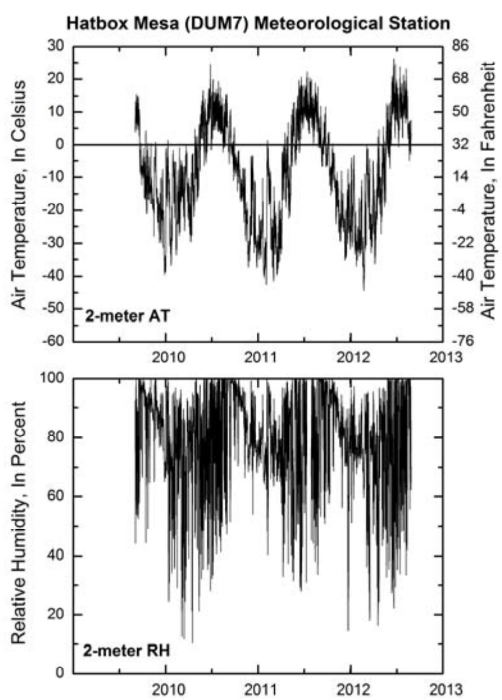

Upper May Creek (DUM2) Meteorological Station
Air Temperature, In Celsius
Air Temperature, In Fahrenheit
2-meter AT
Relative Humidity, In Percent
2-meter RH
2009 2010 2011 2012 2013


Nanushuk (DUM3) Meteorological Station
Air Temperature, In Celsius
Air Temperature, In Fahrenheit
2-meter AT
Relative Humidity, In Percent
2-meter RH
2009 2010 2011 2012 2013

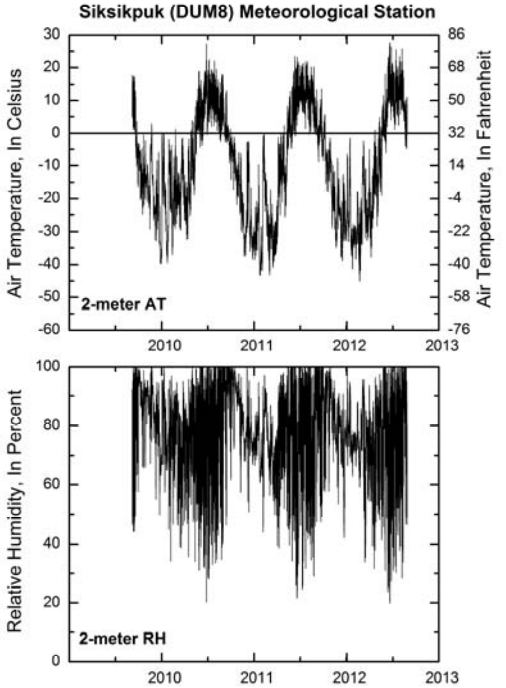

Tuluga (DUM4) Meteorological Station
Air Temperature, In Celsius
Air Temperature, In Fahrenheit
2-meter AT
Relative Humidity, In Percent
2-meter RH


Encampment (DUM5) Meteorological Station
Air Temperature, In Celsius
Air Temperature, In Fahrenheit
2-meter AT
Relative Humidity, In Percent
2-meter RH

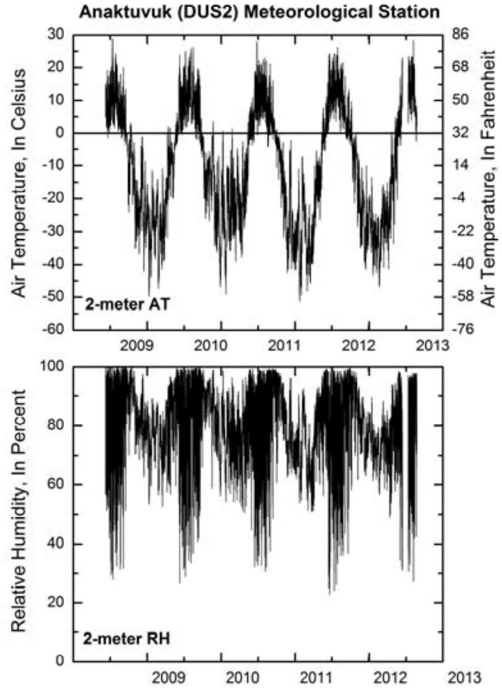

White Lake (DUM6) Meteorological Station
Air Temperature, In Celsius
Air Temperature, In Fahrenheit
2-meter AT
Relative Humidity, In Percent
2-meter RH


Hatbox Mesa (DUM7) Meteorological Station
Air Temperature, In Celsius
Air Temperature, In Fahrenheit
2-meter AT
Relative Humidity, In Percent
2-meter RH

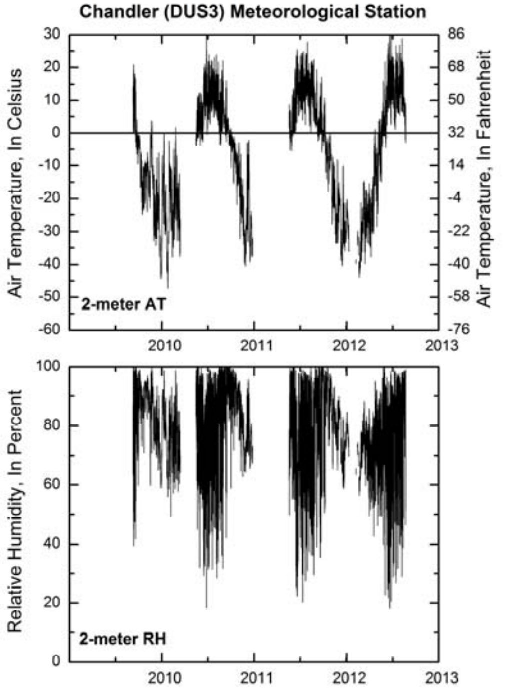
Siksikpuk (DUM8) Meteorological Station



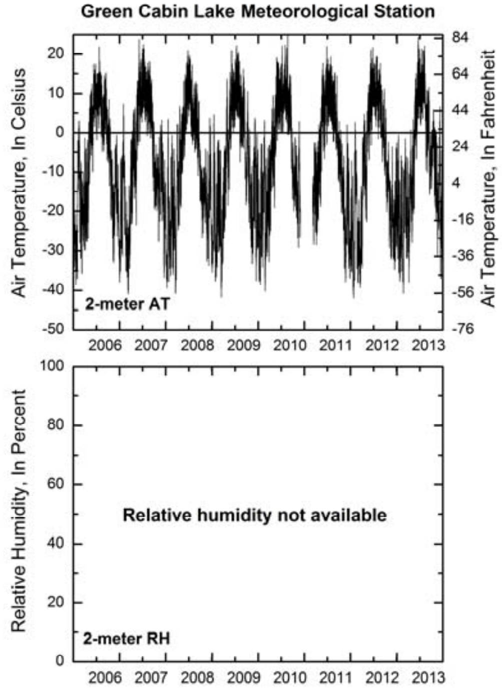
Anaktuvuk (DUS2) Meteorological Station



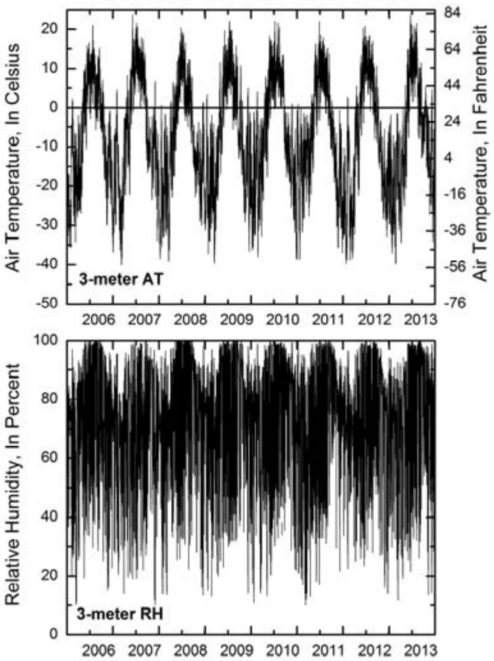
Chandler (DUS3) Meteorological Station



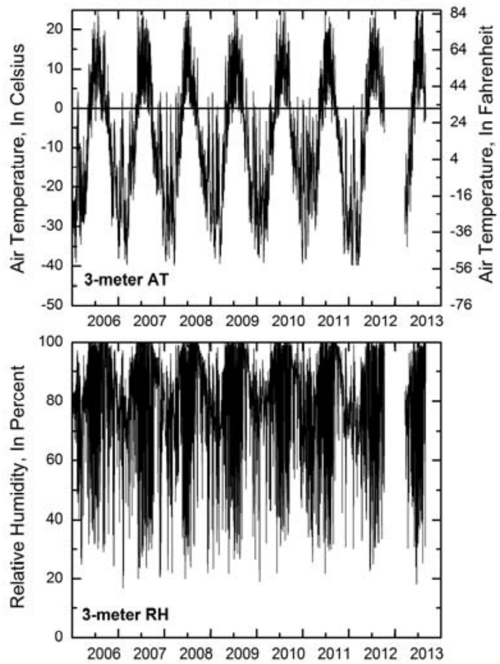
Green Cabin Lake Meteorological Station



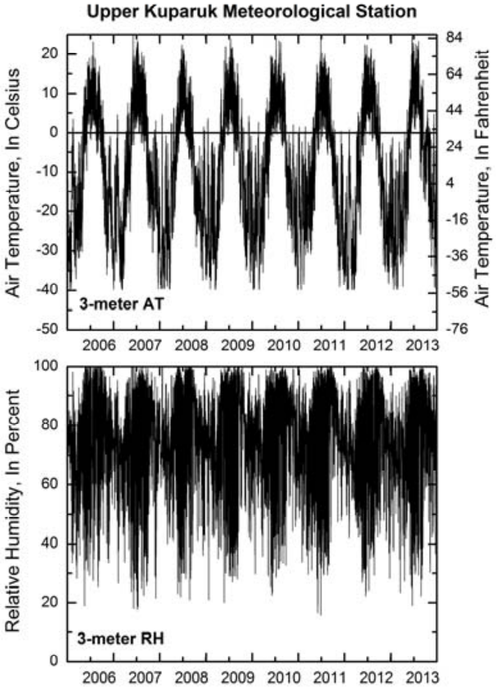
Imnavait Basin Meteorological Station



Sagwon Hill Meteorological Station



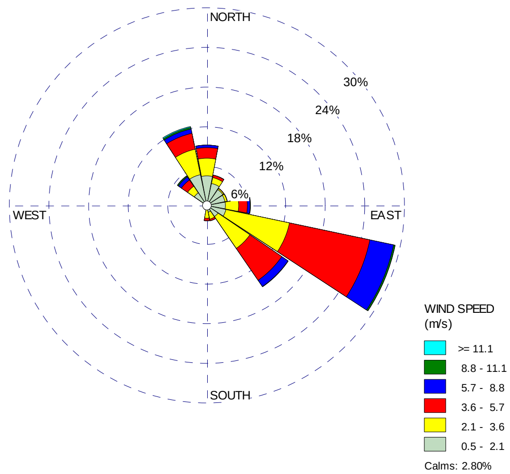
Upper Kuparuk Meteorological Station



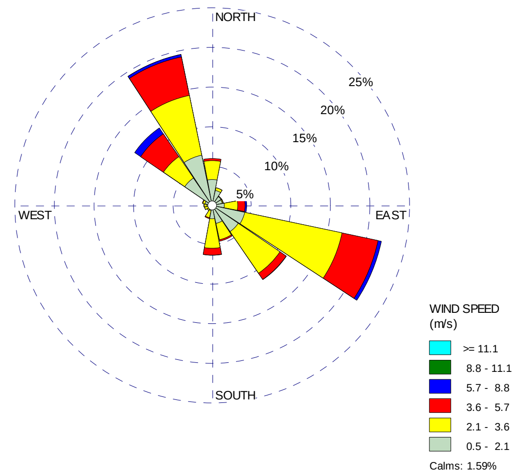
Appendix B – Wind Speed and Direction: Wind Roses

This section contains a wind rose analysis for each station in the Kuparuk Foothills and Umiat Corridor projects. The analysis was conducted annually (January 1 through December 31) and separated also into summer (May 15 through September 15) and winter (September 16 through May 14).

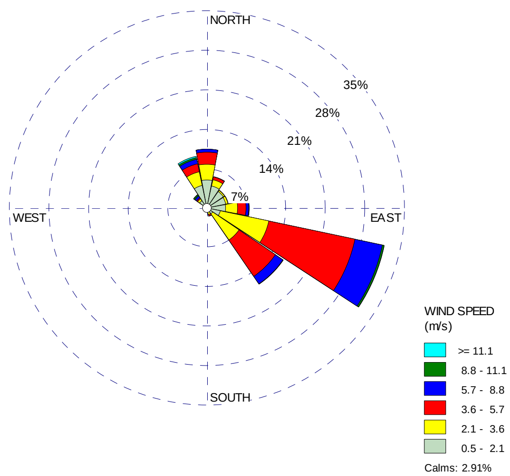
a) DBM1 Accomplishment Creek annual



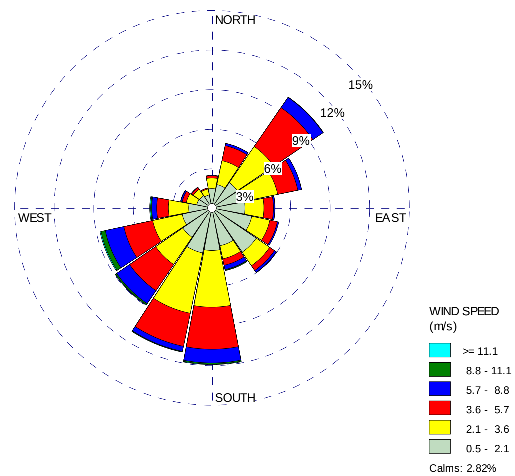
b) DBM1 Accomplishment Creek summer



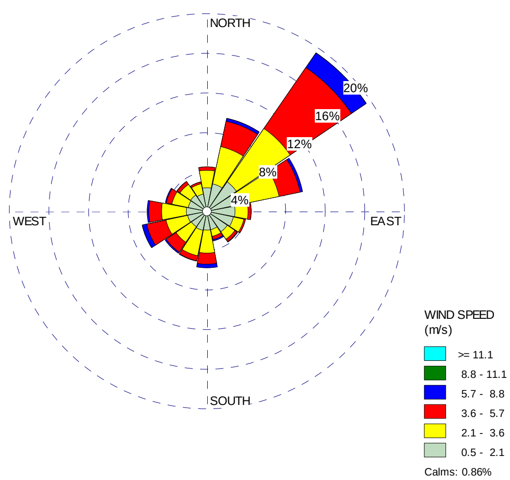
c) DBM1 Accomplishment Creek winter



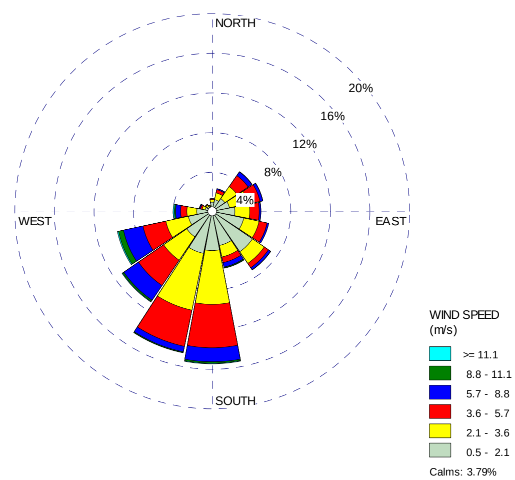
d) DFM1 S. White Hills annual



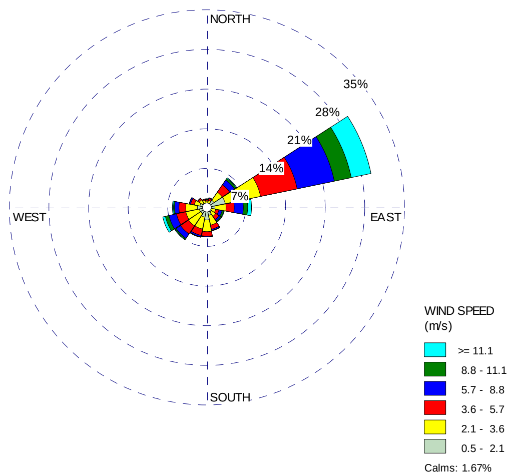
e) DFM1 S. White Hills summer



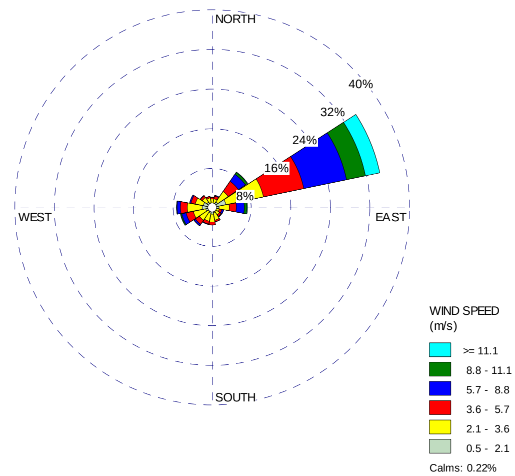
f) DFM1 S. White Hills winter



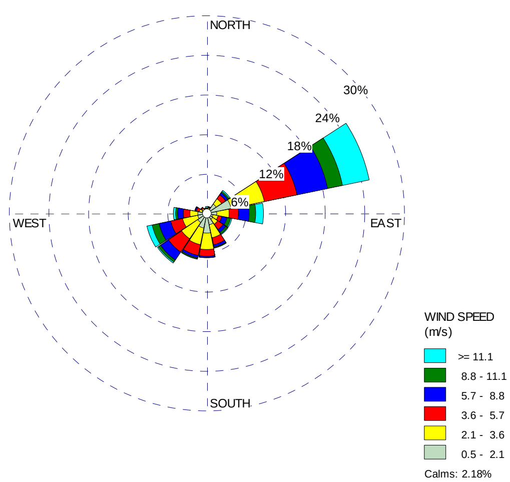
a) DFM2 White Hills annual



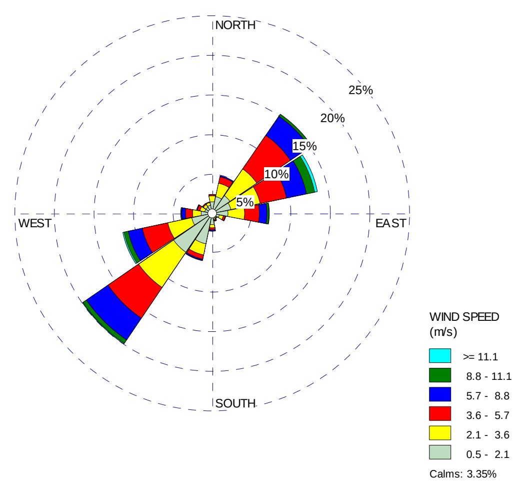
b) DFM2 White Hills summer



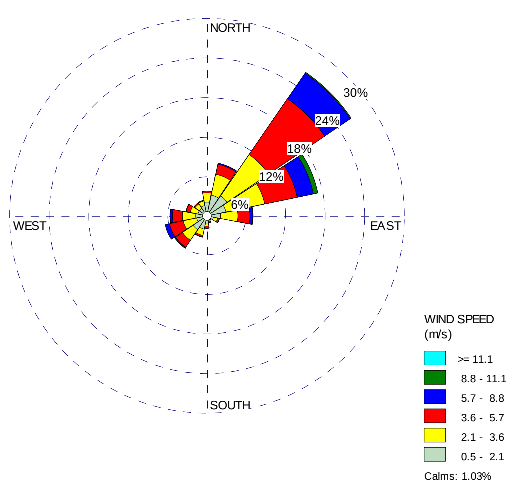
c) DFM2 White Hills winter



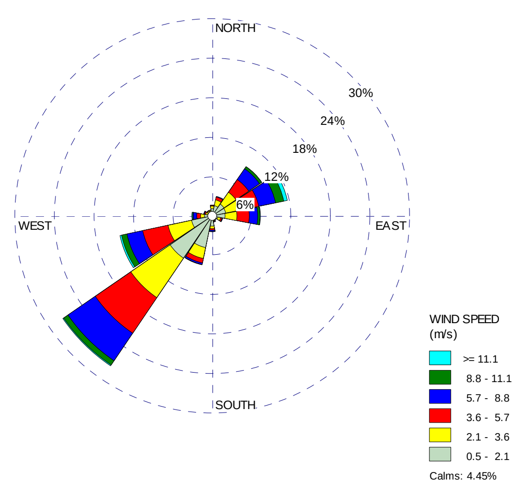
d) DFM3 N. White Hills annual



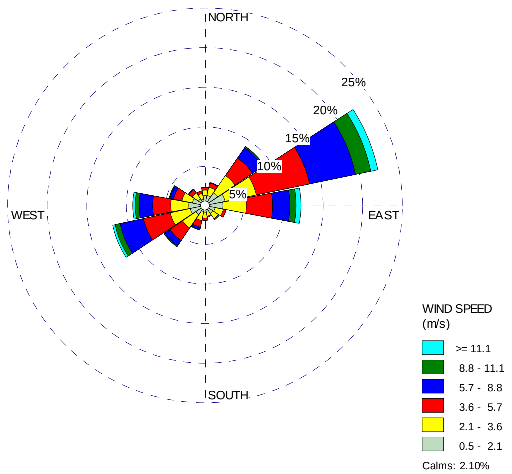
e) DFM3 N. White Hills summer



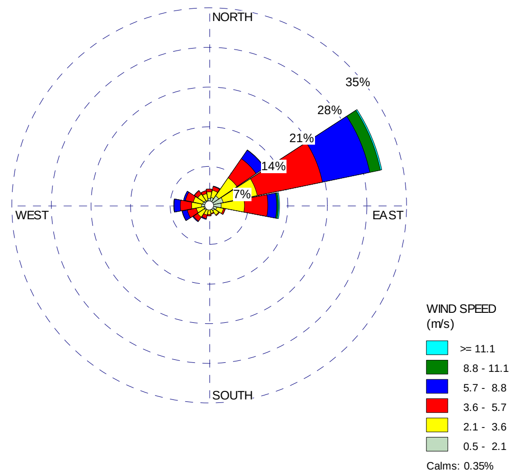
f) DFM3 N. White Hills winter



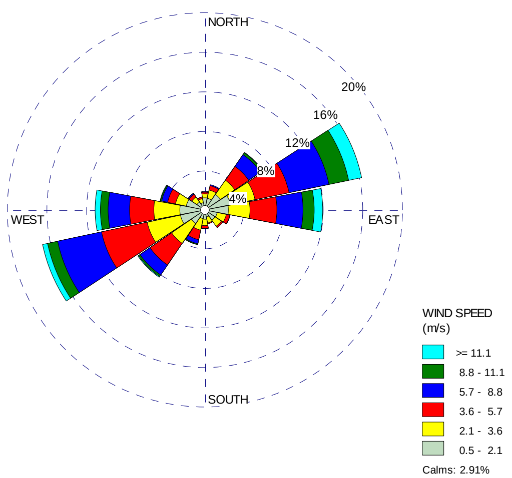
a) DFM4 Northwest Kuparuk annual



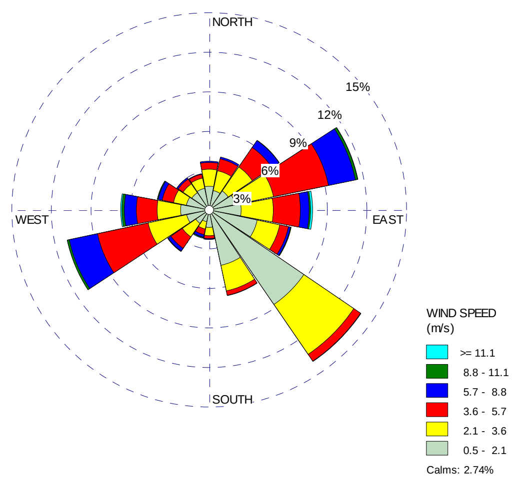
b) DFM4 Northwest Kuparuk summer



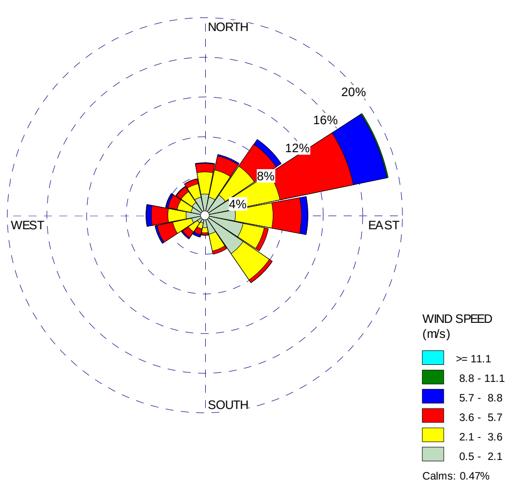
c) DFM4 Northwest Kuparuk winter



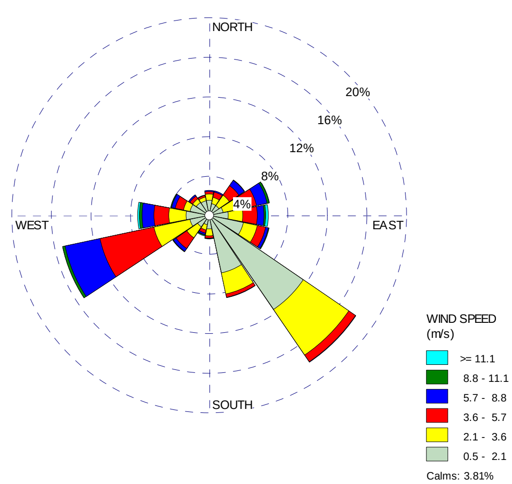
d) DUS2 Anaktuvuk River annual



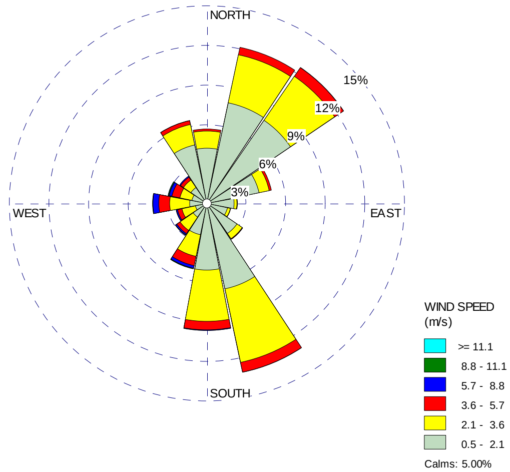
e) DUS2 Anaktuvuk River summer



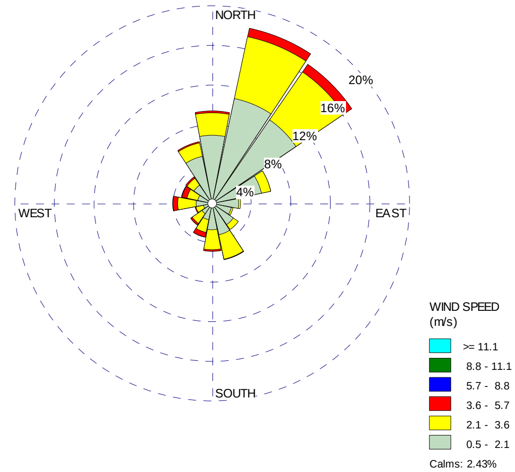
f) DUS2 Anaktuvuk River winter



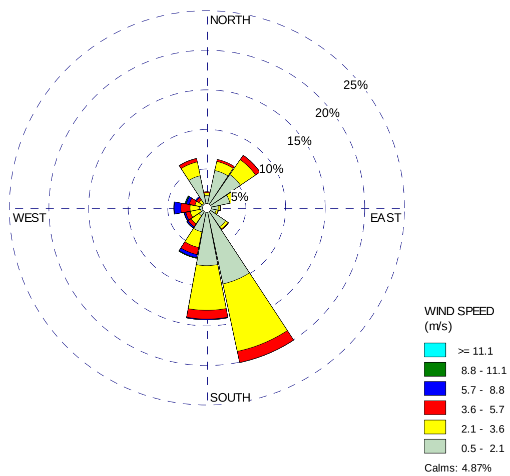
a) DUS3 Chandler River Bluff annual



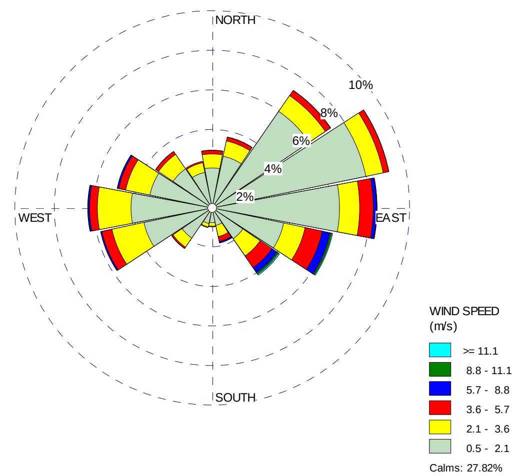
b) DUS3 Chandler River Bluff summer



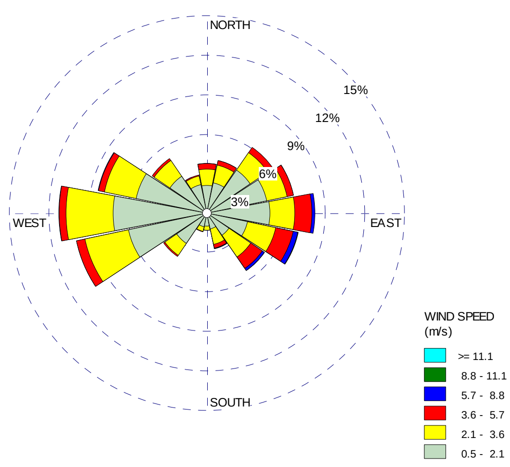
c) DUS3 Chandler River Bluff winter



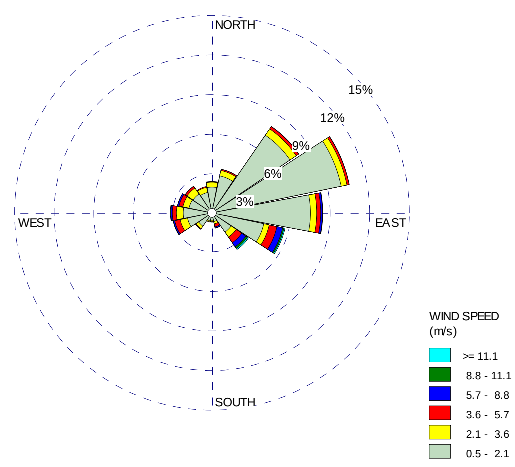
d) DUM1 Itikmalakpak annual



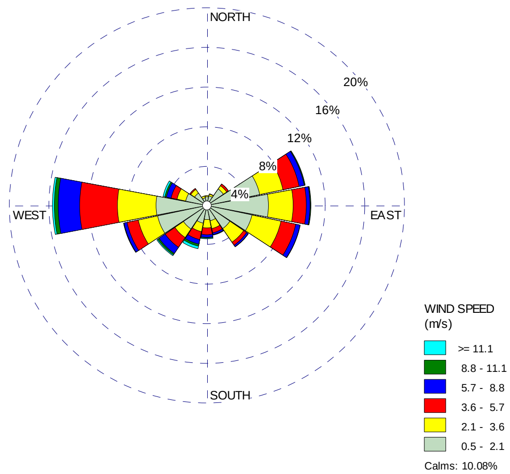
e) DUM1 Itikmalakpak summer



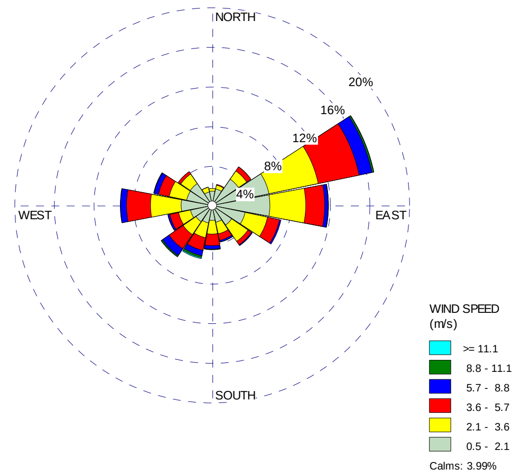
f) DUM1 Itikmalakpak winter



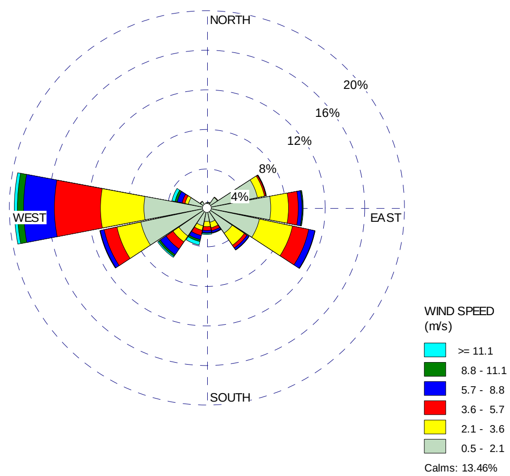
a) DUM2 Upper May Cr. annual



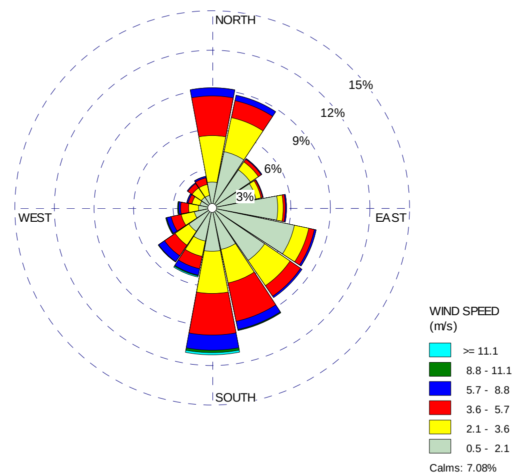
b) DUM2 Upper May Cr. summer



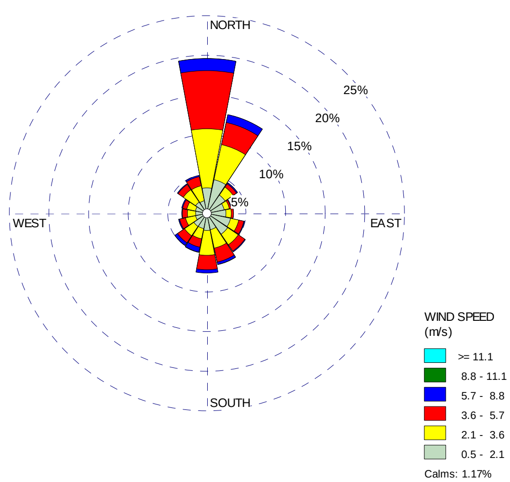
c) DUM2 Upper May Cr. winter



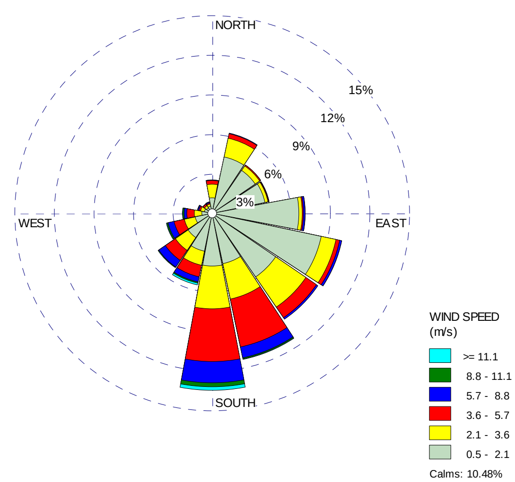
d) DUM3 Nanushuk annual



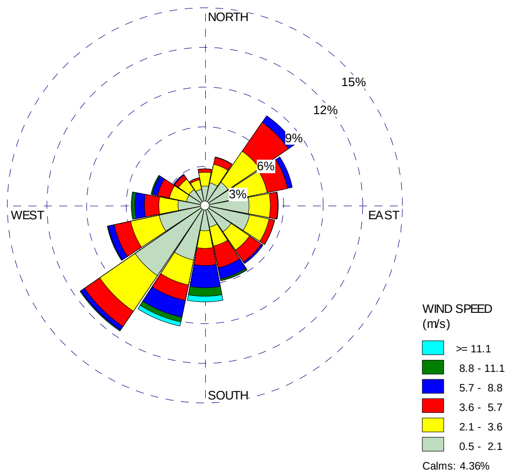
e) DUM3 Nanushuk summer



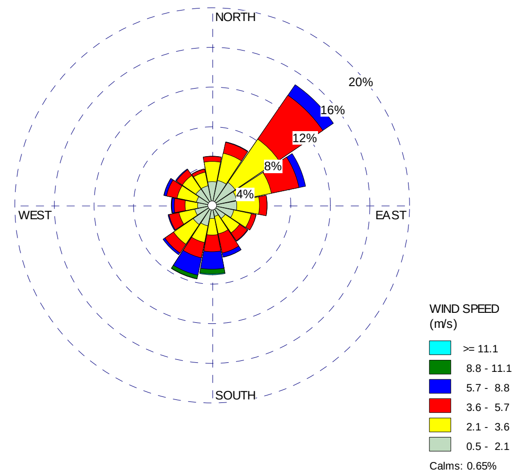
f) DUM3 Nanushuk winter



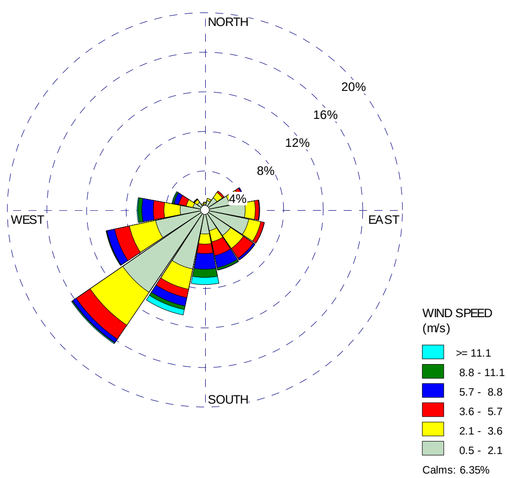
a) DUM4 Tuluga annual



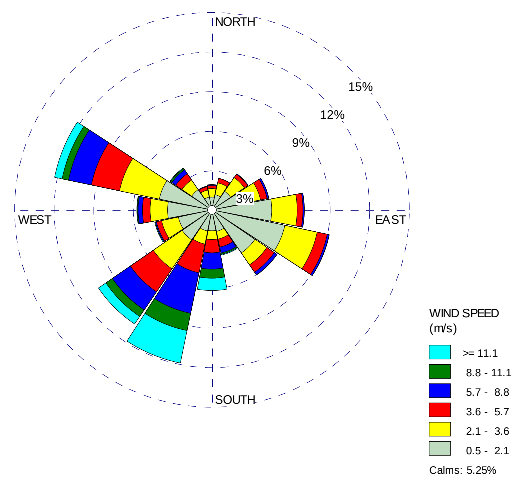
b) DUM4 Tuluga summer



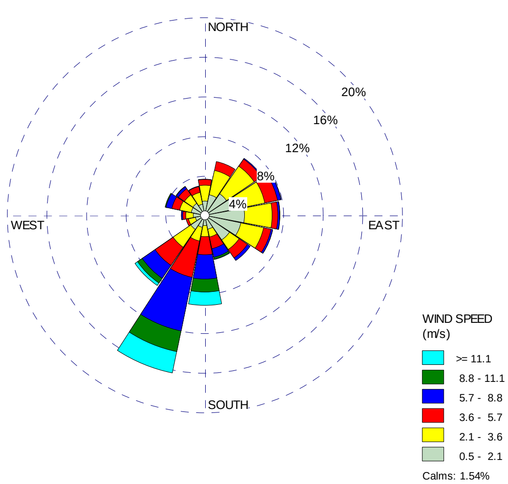
c) DUM4 Tuluga winter



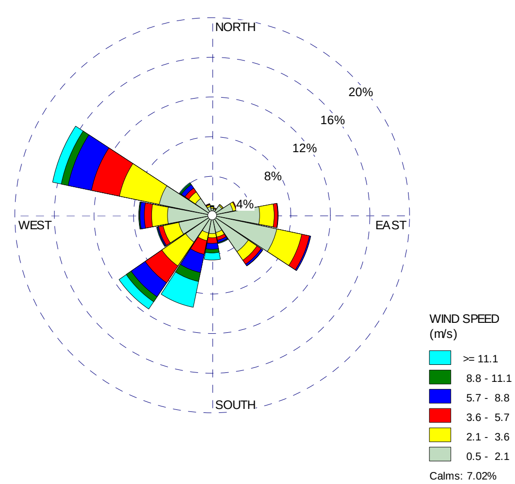
d) DUM5 Encampment annual



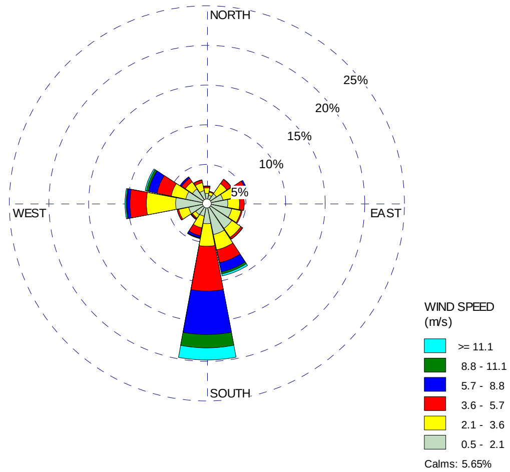
e) DUM5 Encampment summer



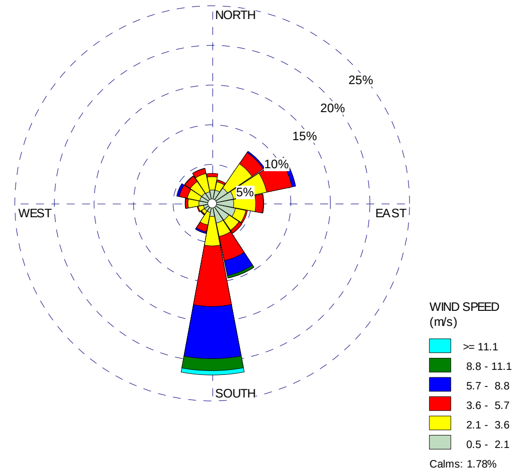
f) DUM5 Encampment winter



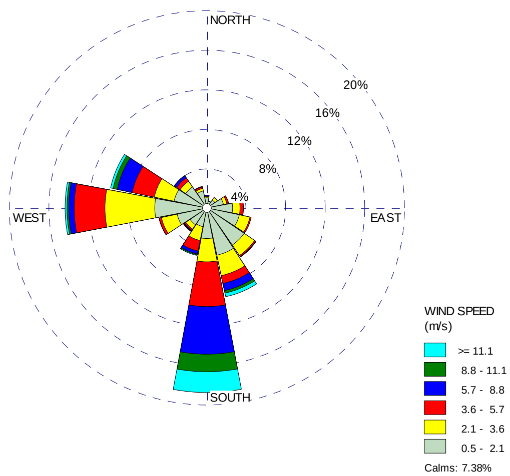
a) DUM6 White Lake annual



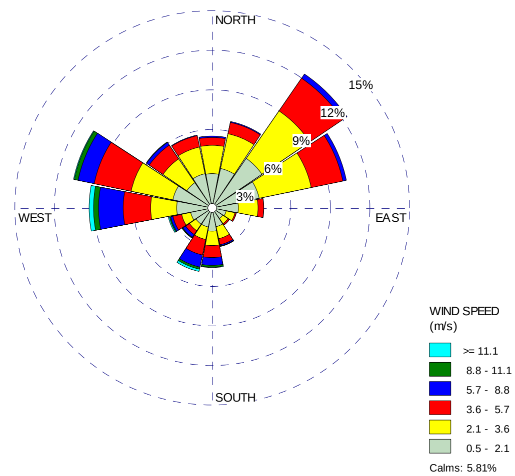
b) DUM6 White Lake summer



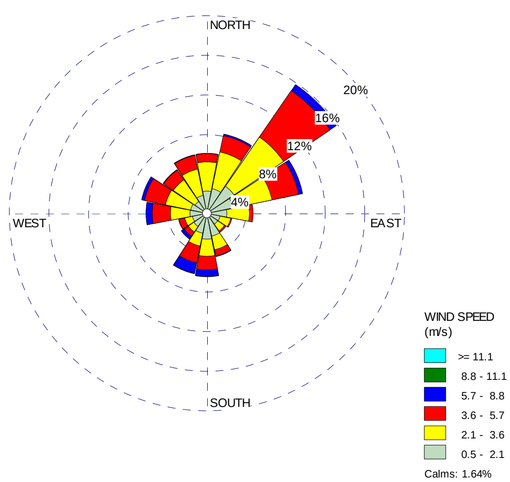
c) DUM6 White Lake winter



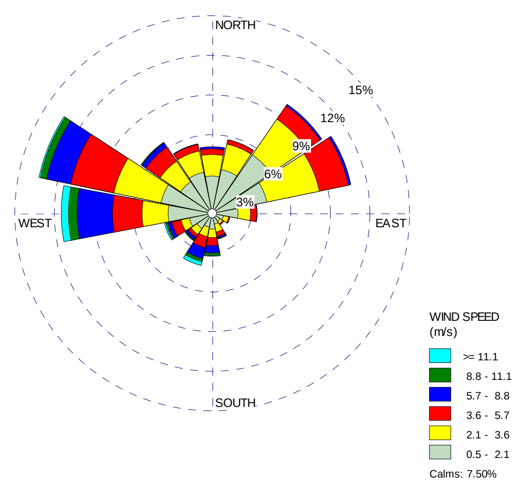
d) DUM7 Hatbox Mesa annual



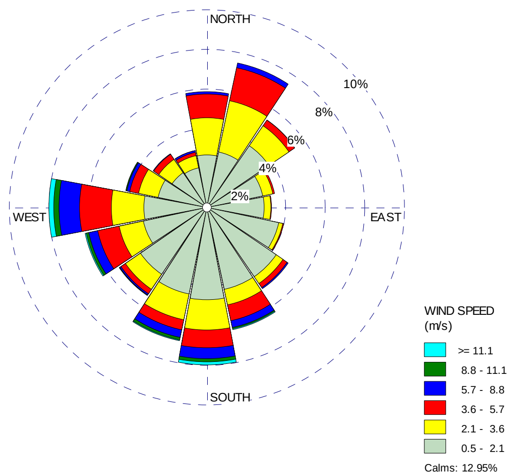
e) DUM7 Hatbox Mesa summer



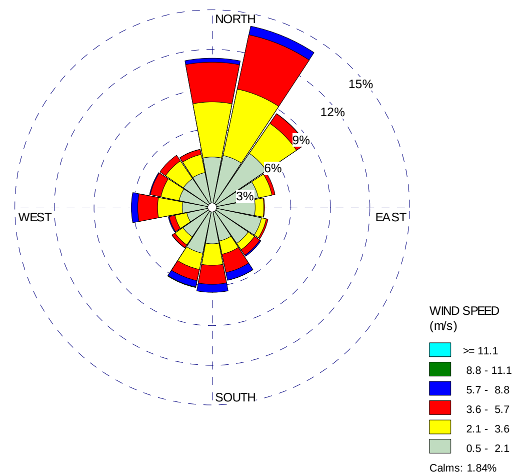
f) DUM7 Hatbox Mesa winter



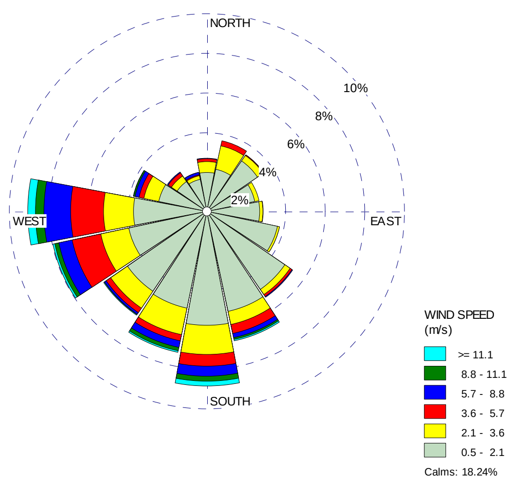
a) DUM8 Siksikpuk annual



b) DUM8 Siksikpuk summer



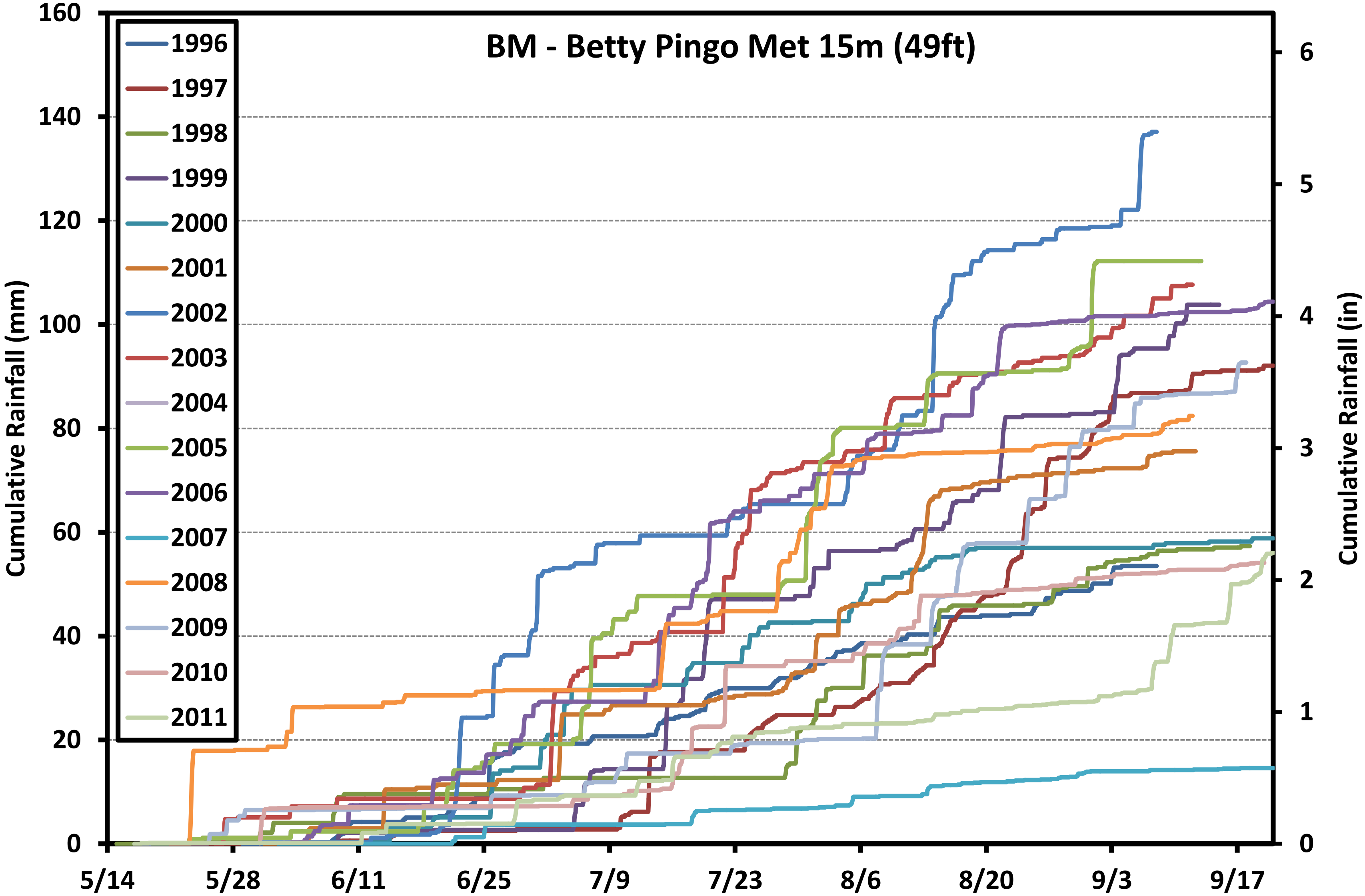
c) DUM8 Siksikpuk winter



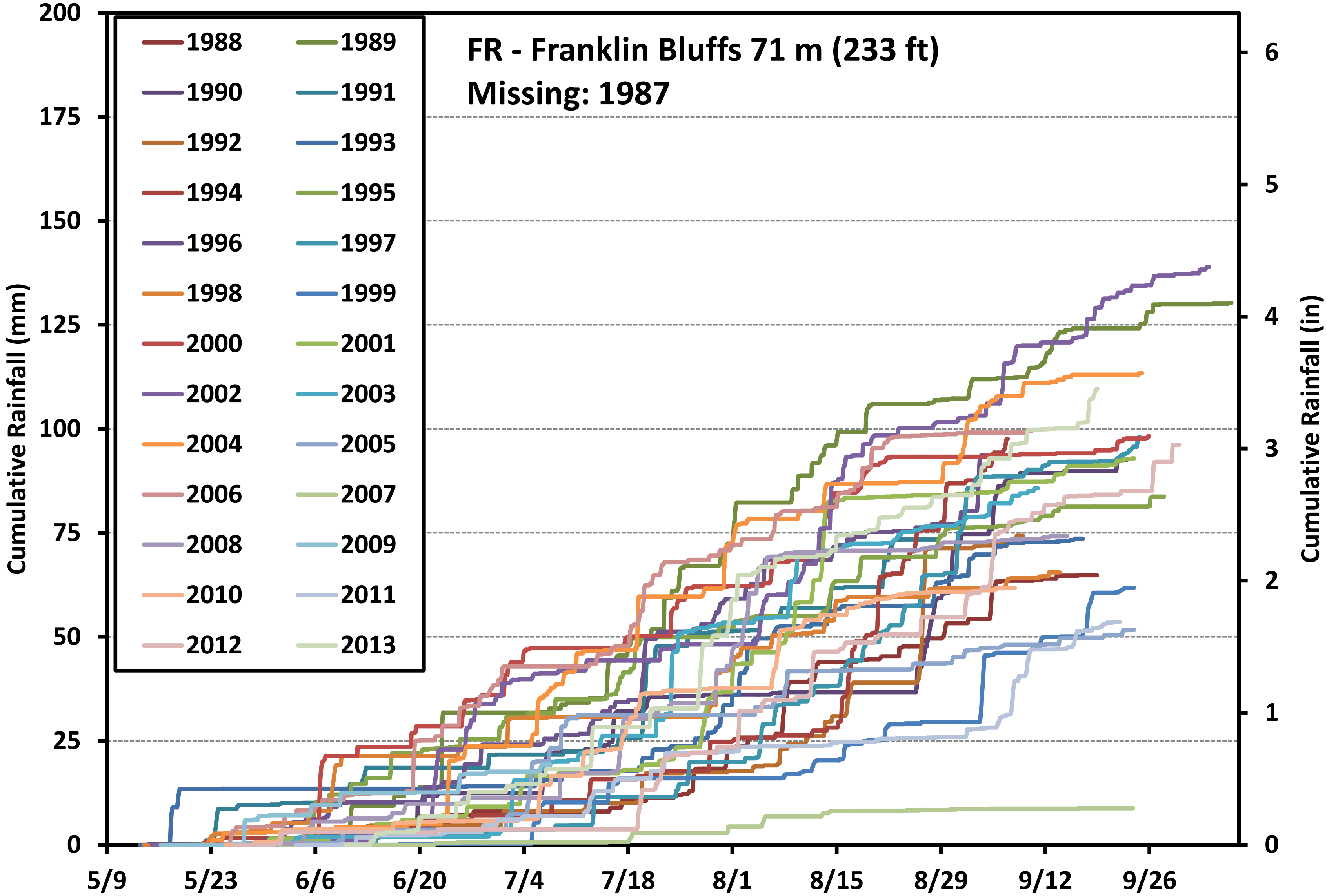
Appendix C – Cumulative Warm Season Precipitation for All Years at Each Station and Cumulative Warm Season Precipitation by Year for All Stations, 2007 to 2013

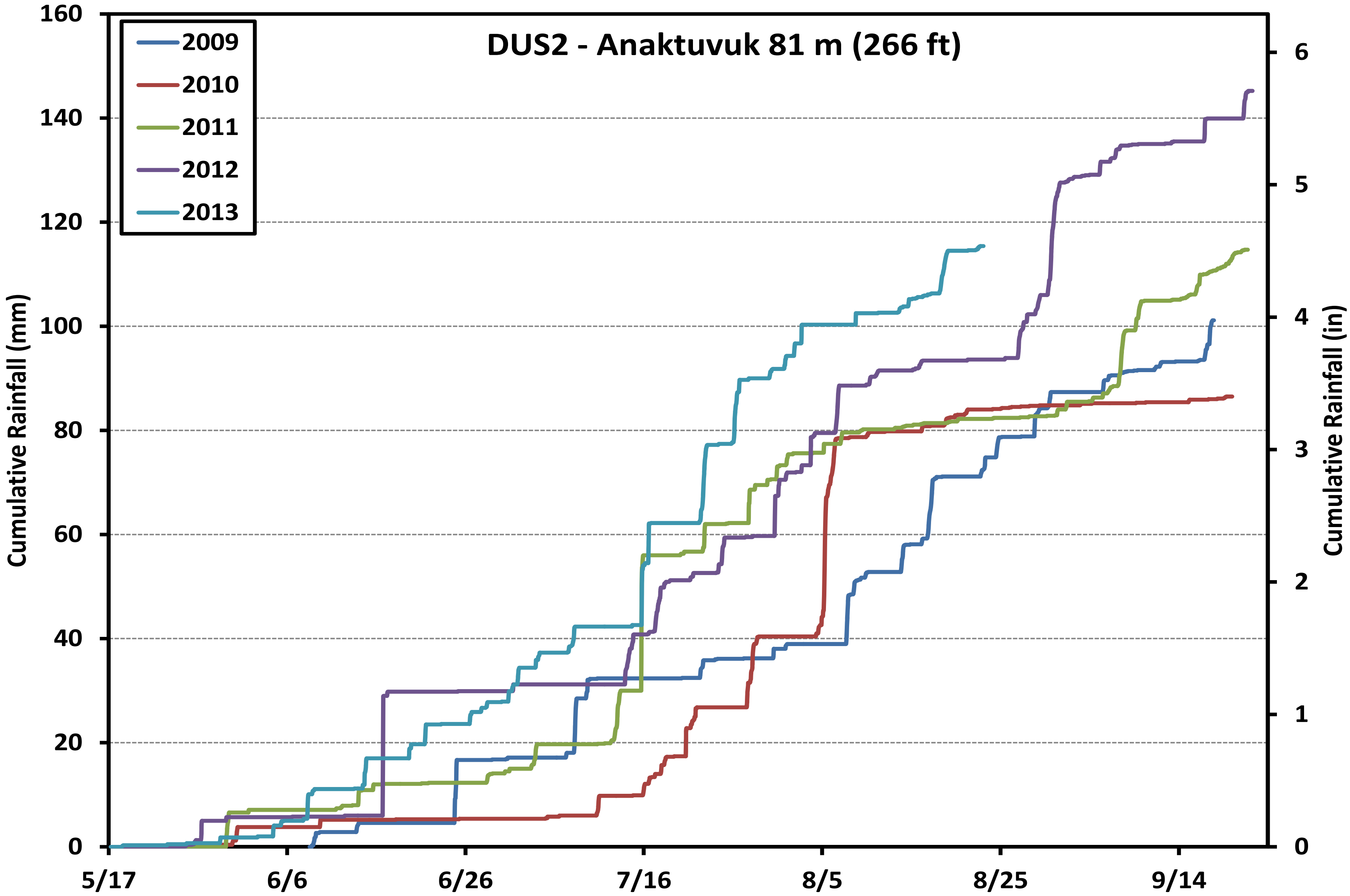
Appendix C reports the cumulative annual warm season precipitation (pages C-1 to C-26) for sites in/near the Umiat study area. The reason for including neighboring meteorological sites is that these stations have existed for a much longer time and give a truer indication of potential precipitation amounts. These graphs show that there is considerable year-to-year variation (sometimes by as much as five times) in the warm season precipitation at these sites. This set of graphs is arranged from lowest elevation to highest. The second set of graphs (pages C-27 to C-33) in this Appendix is a comparison of cumulative warm season precipitation each year (2007 to 2013) of the study.

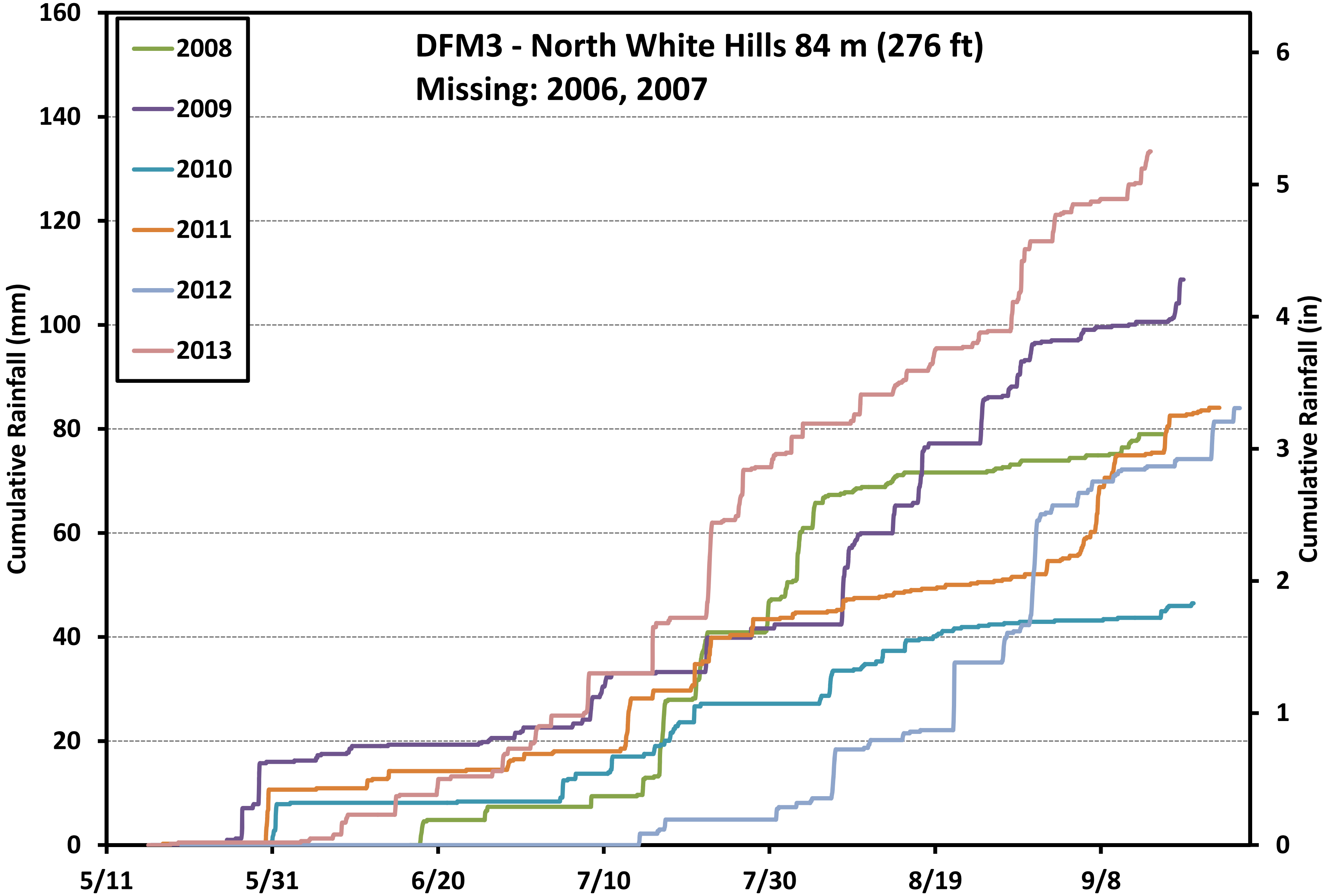
Note: Dashed lines identify years with significant periods of missing data; also, installations were generally made in midsummer so the dataset is not complete for that year. In the second set of figures, station names in red indicate no data were collected that year. As indicated earlier, during this study, stations were added and removed (generally because of funding availability on a wide range of studies in the area).

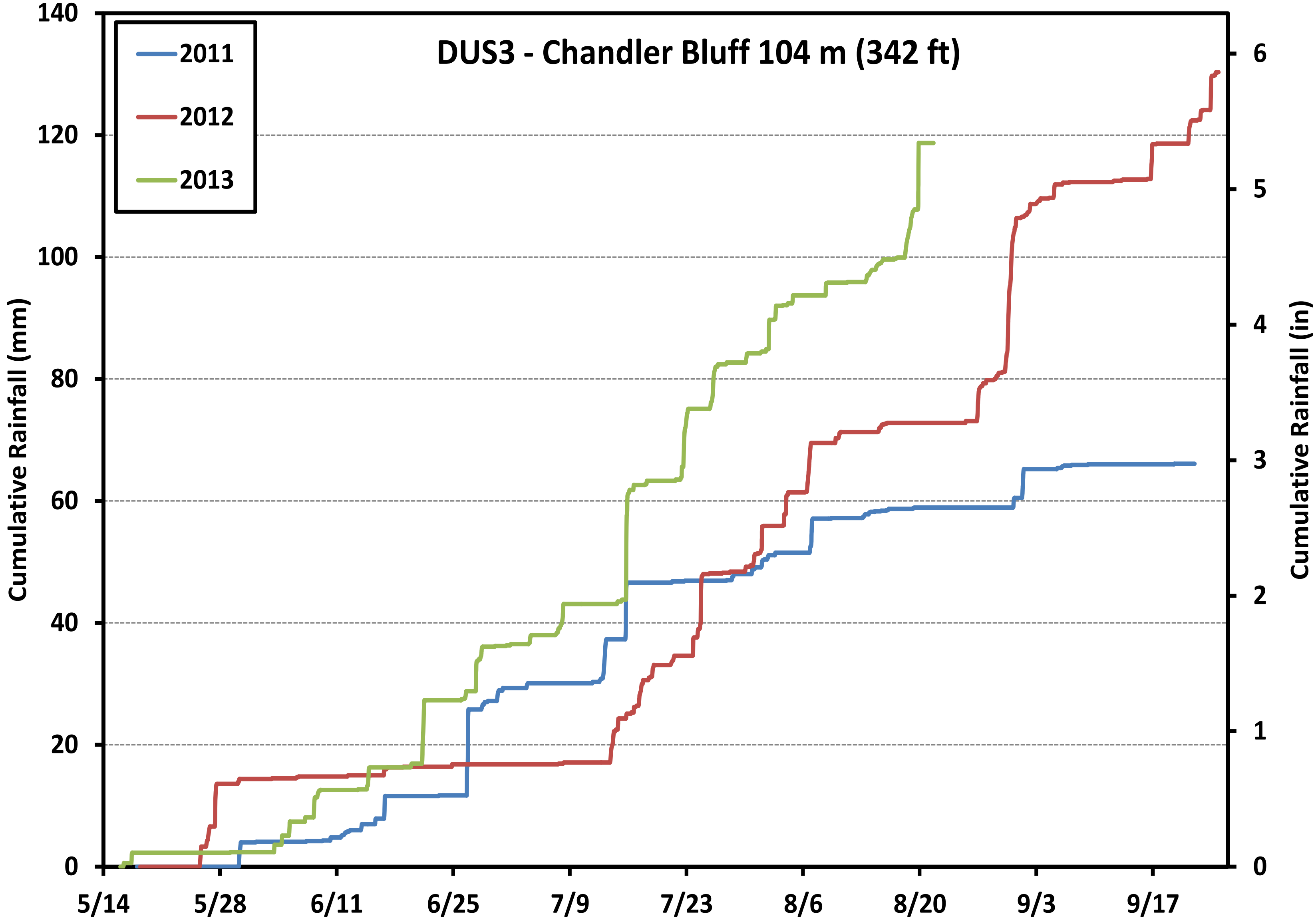


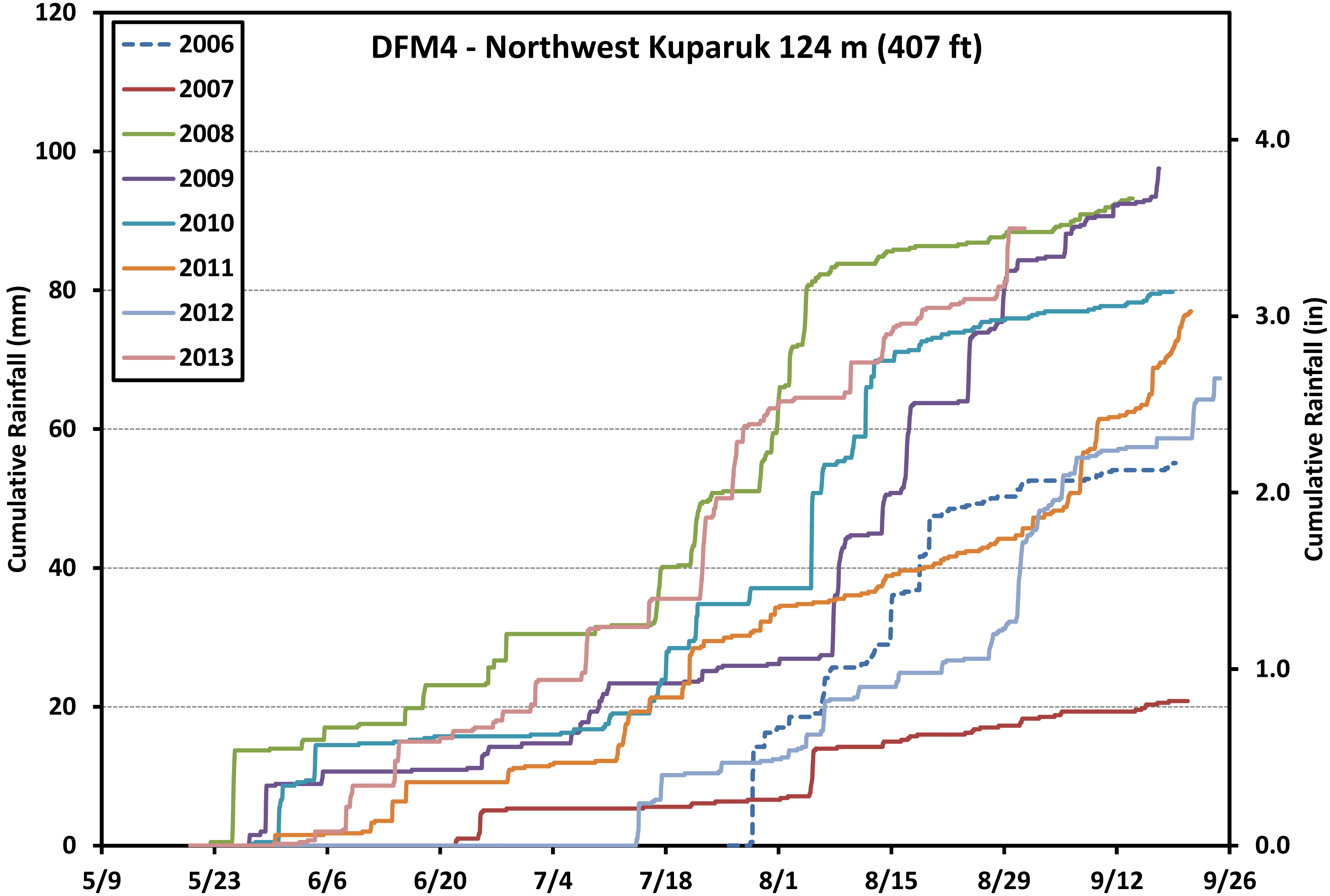
BM - Betty Pingo Met 15m (49ft)
1996
1997
1998
1999
2000
2001
2002
2003
2004
2005
2006
2007
2008
2009
2010
2011
Cumulative Rainfall (mm)
Cumulative Rainfall (in)
0
20
40
60
80
100
120
140
160
0
1
2
3
4
5
6
5/14
5/28
6/11
6/25
7/9
7/23
8/6
8/20
9/3
9/17


FR - Franklin Bluffs 71 m (233 ft)
Missing: 1987
1988
1989
1990
1991
1992
1993
1994
1995
1996
1997
1998
1999
2000
2001
2002
2003
2004
2005
2006
2007
2008
2009
2010
2011
2012
2013
Cumulative Rainfall (mm)
Cumulative Rainfall (in)
0
25
50
75
100
125
150
175
200
0
1
2
3
4
5
6
5/9
5/23
6/6
6/20
7/4
7/18
8/1
8/15
8/29
9/12
9/26

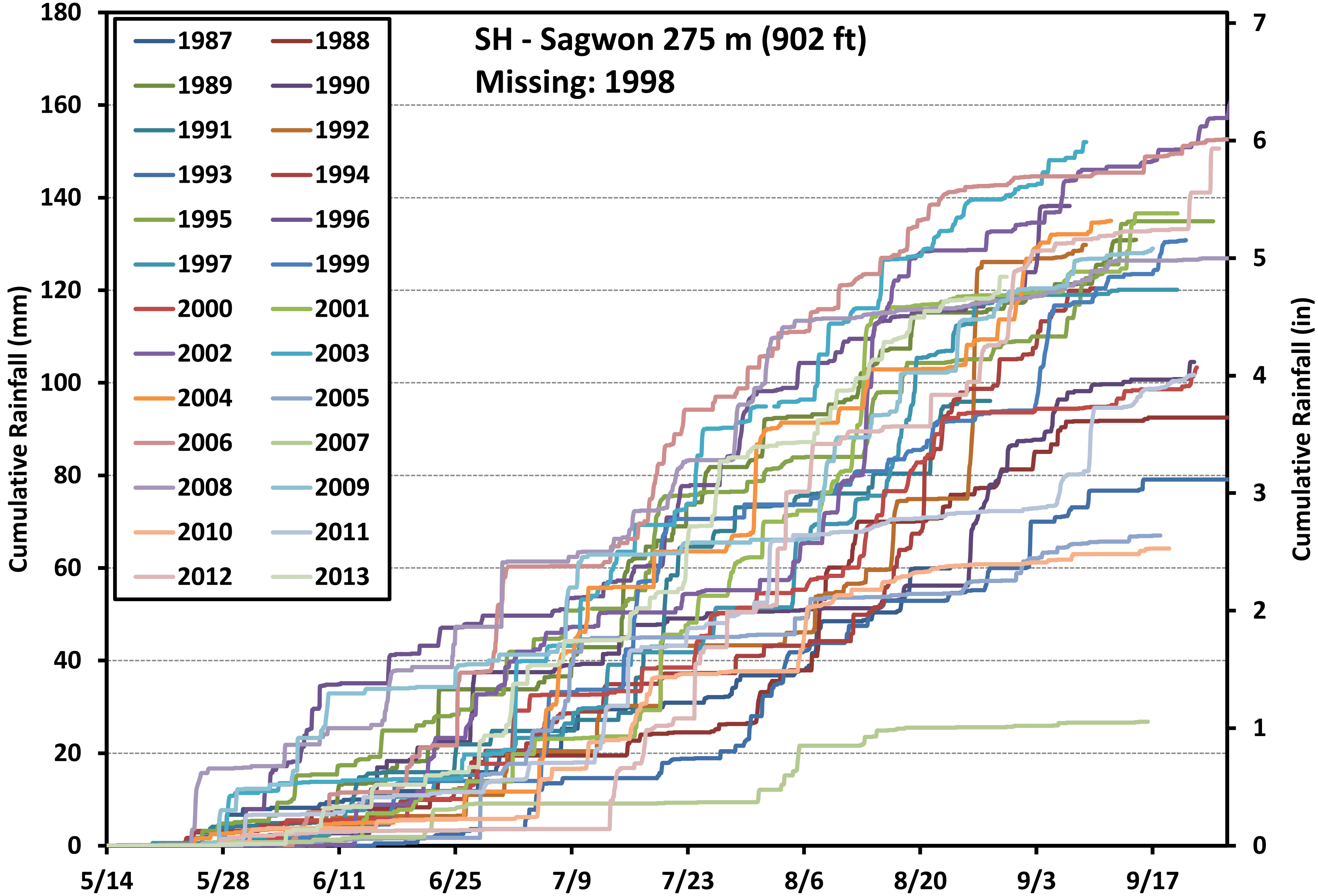

DUS2 - Anaktuvuk 81 m (266 ft)
2009
2010
2011
2012
2013
Cumulative Rainfall (mm)
Cumulative Rainfall (in)
0
20
40
60
80
100
120
140
160
0
1
2
3
4
5
6
5/17
6/6
6/26
7/16
8/5
8/25
9/14

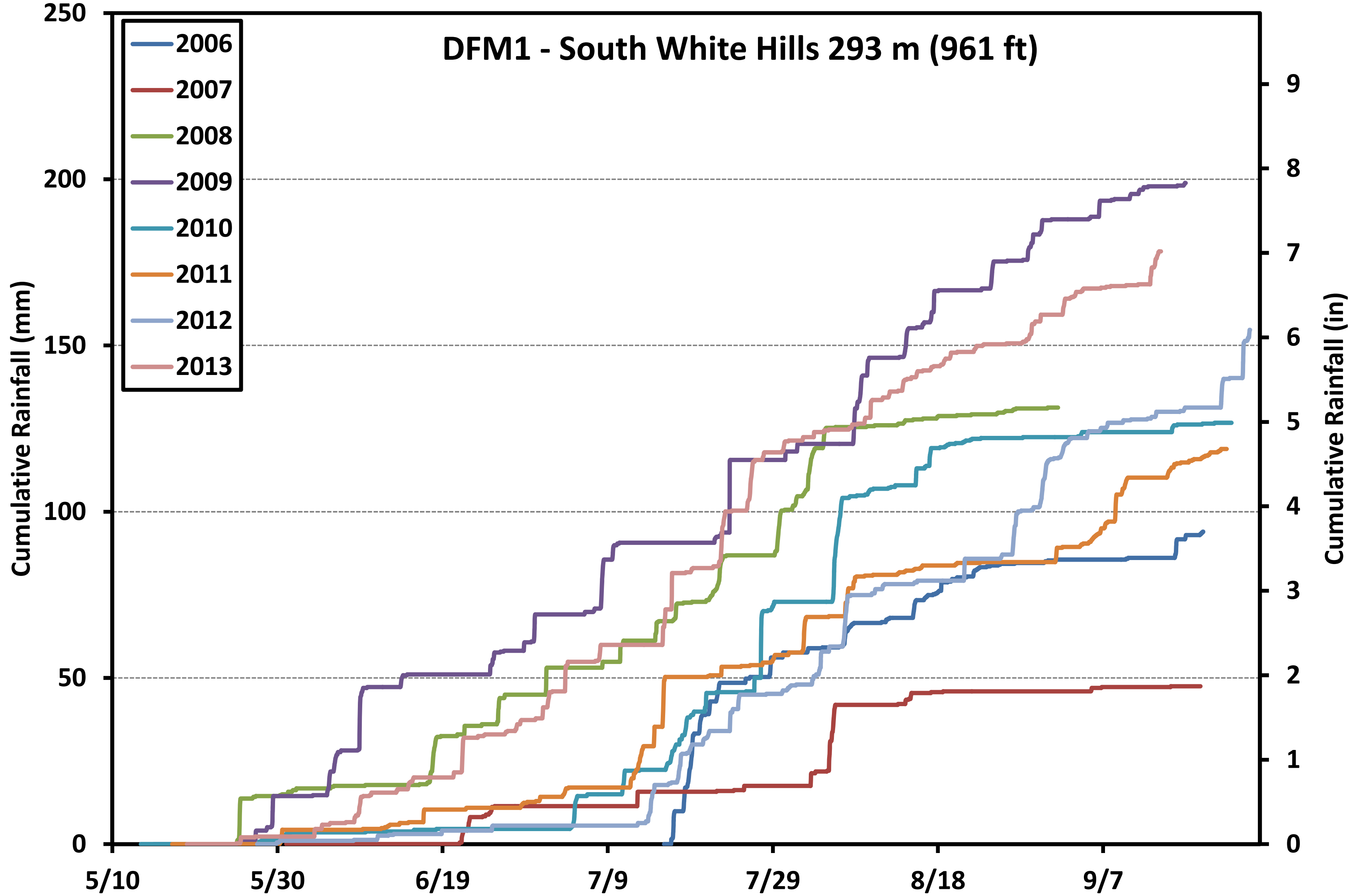

DFM3 - North White Hills 84 m (276 ft)
Missing: 2006, 2007
2008
2009
2010
2011
2012
2013
Cumulative Rainfall (mm)
Cumulative Rainfall (in)
0
20
40
60
80
100
120
140
160
0
1
2
3
4
5
6
5/11
5/31
6/20
7/10
7/30
8/19
9/8


DUS3 - Chandler Bluff 104 m (342 ft)
2011
2012
2013
Cumulative Rainfall (mm)
Cumulative Rainfall (in)
140
120
100
80
60
40
20
0
6
5
4
3
2
1
0
5/14
5/28
6/11
6/25
7/9
7/23
8/6
8/20
9/3
9/17

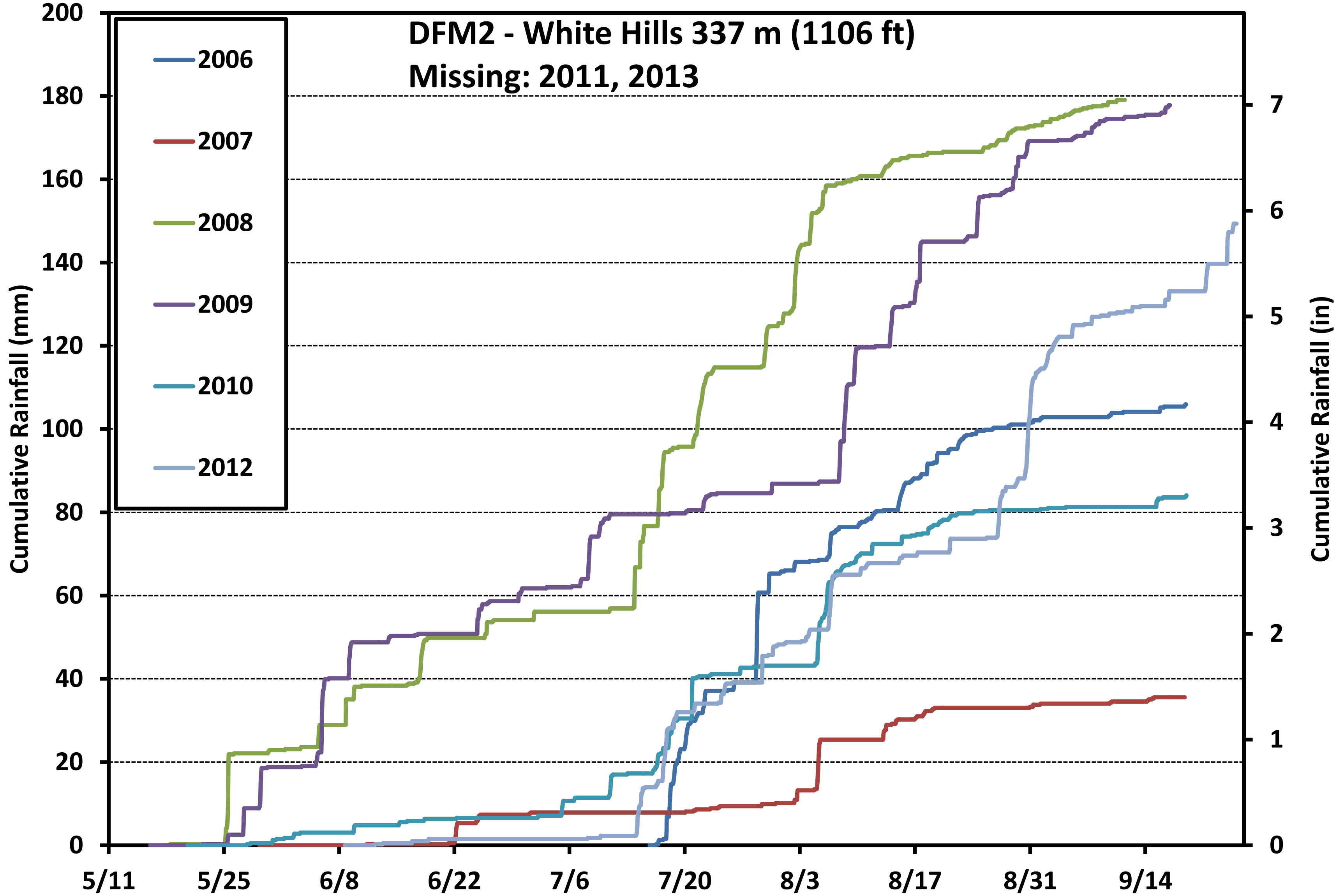


DFM4 - Northwest Kuparuk 124 m (407 ft)
2006
2007
2008
2009
2010
2011
2012
2013
Cumulative Rainfall (mm)
Cumulative Rainfall (in)
120
100
80
60
40
20
0
4.0
3.0
2.0
1.0
0.0
5/9
5/23
6/6
6/20
7/4
7/18
8/1
8/15
8/29
9/12
9/26

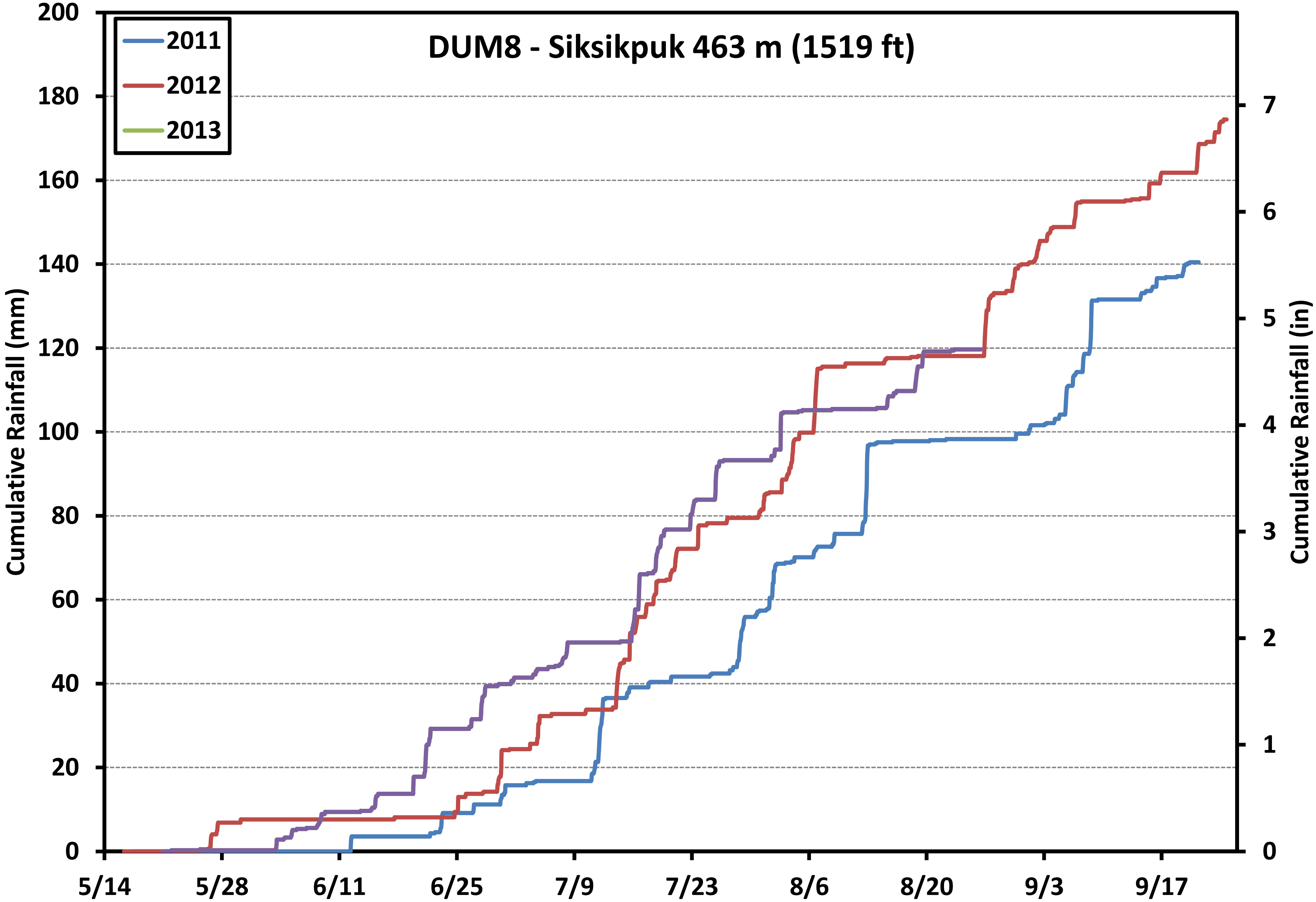

SH - Sagwon 275 m (902 ft)
Missing: 1998
1987
1988
1989
1990
1991
1992
1993
1994
1995
1996
1997
1999
2000
2001
2002
2003
2004
2005
2006
2007
2008
2009
2010
2011
2012
2013
Cumulative Rainfall (mm)
Cumulative Rainfall (in)
0
20
40
60
80
100
120
140
160
180
0
1
2
3
4
5
6
7
5/14
5/28
6/11
6/25
7/9
7/23
8/6
8/20
9/3
9/17



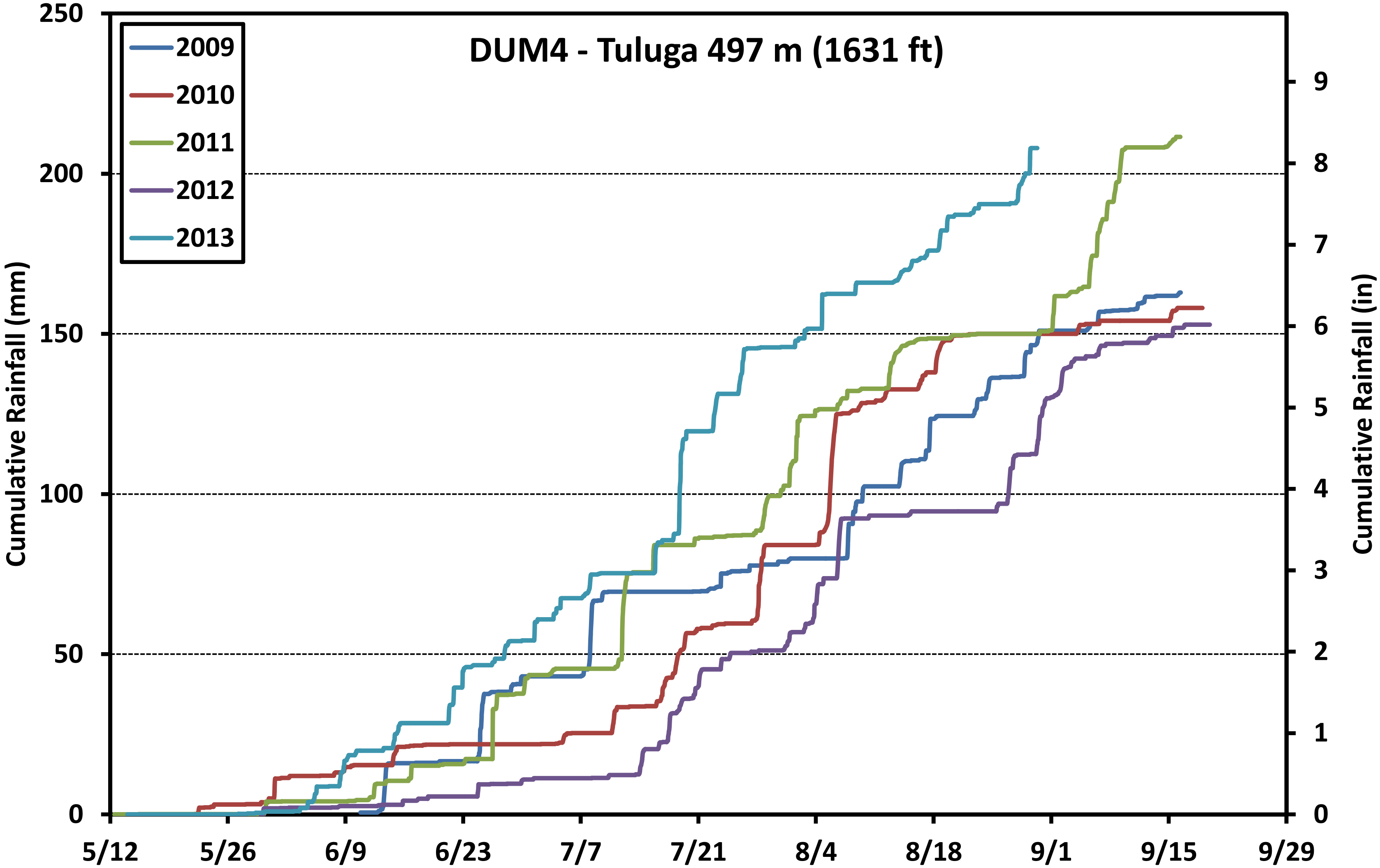
DFM1 - South White Hills 293 m (961 ft)
2006
2007
2008
2009
2010
2011
2012
2013
Cumulative Rainfall (mm)
Cumulative Rainfall (in)
250
200
150
100
50
0
9
8
7
6
5
4
3
2
1
0
5/10
5/30
6/19
7/9
7/29
8/18
9/7



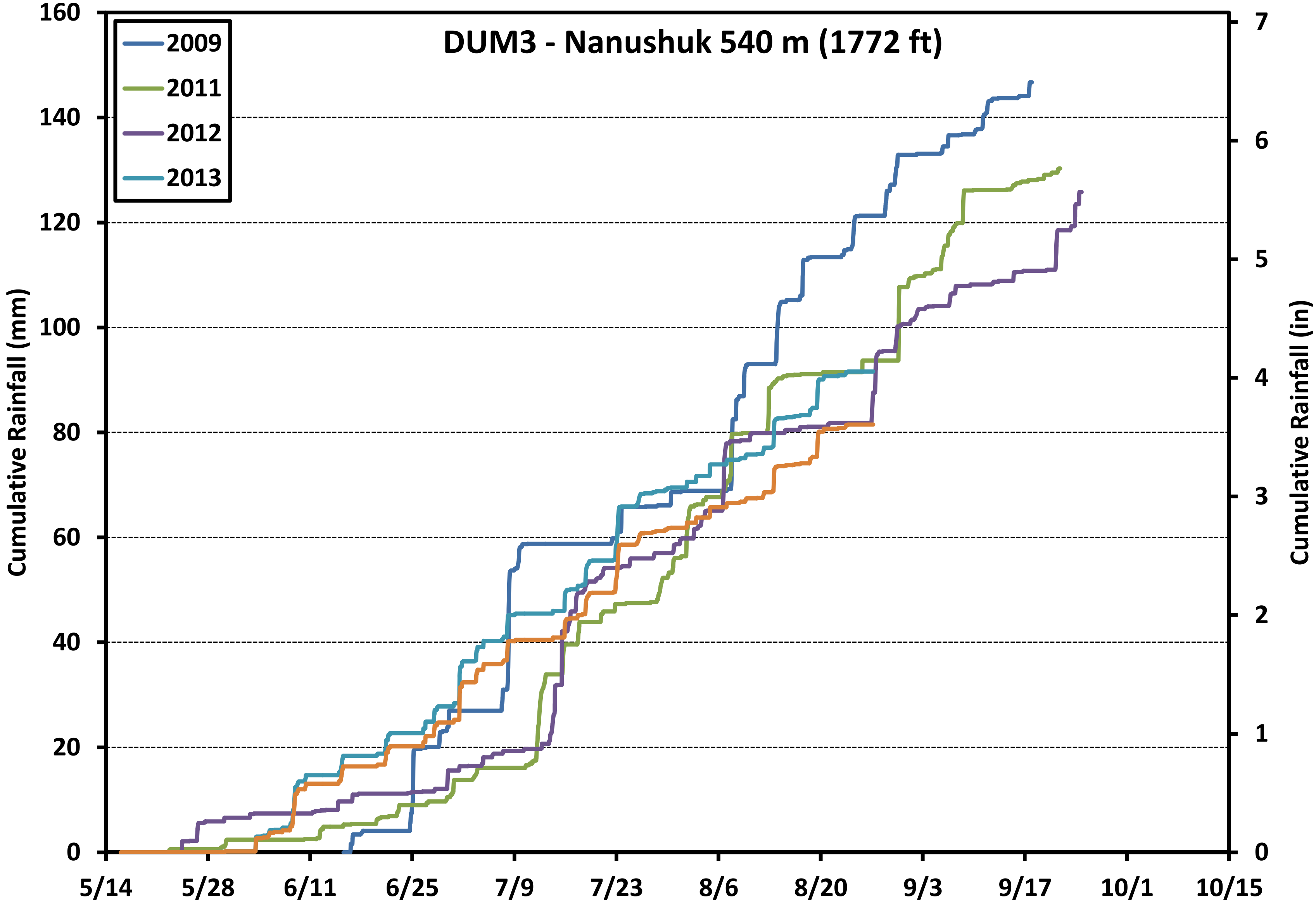
DFM2 - White Hills 337 m (1106 ft)
Missing: 2011, 2013
2006
2007
2008
2009
2010
2012
Cumulative Rainfall (mm)
Cumulative Rainfall (in)
0
20
40
60
80
100
120
140
160
180
200
1
2
3
4
5
6
7
5/11
5/25
6/8
6/22
7/6
7/20
8/3
8/17
8/31
9/14



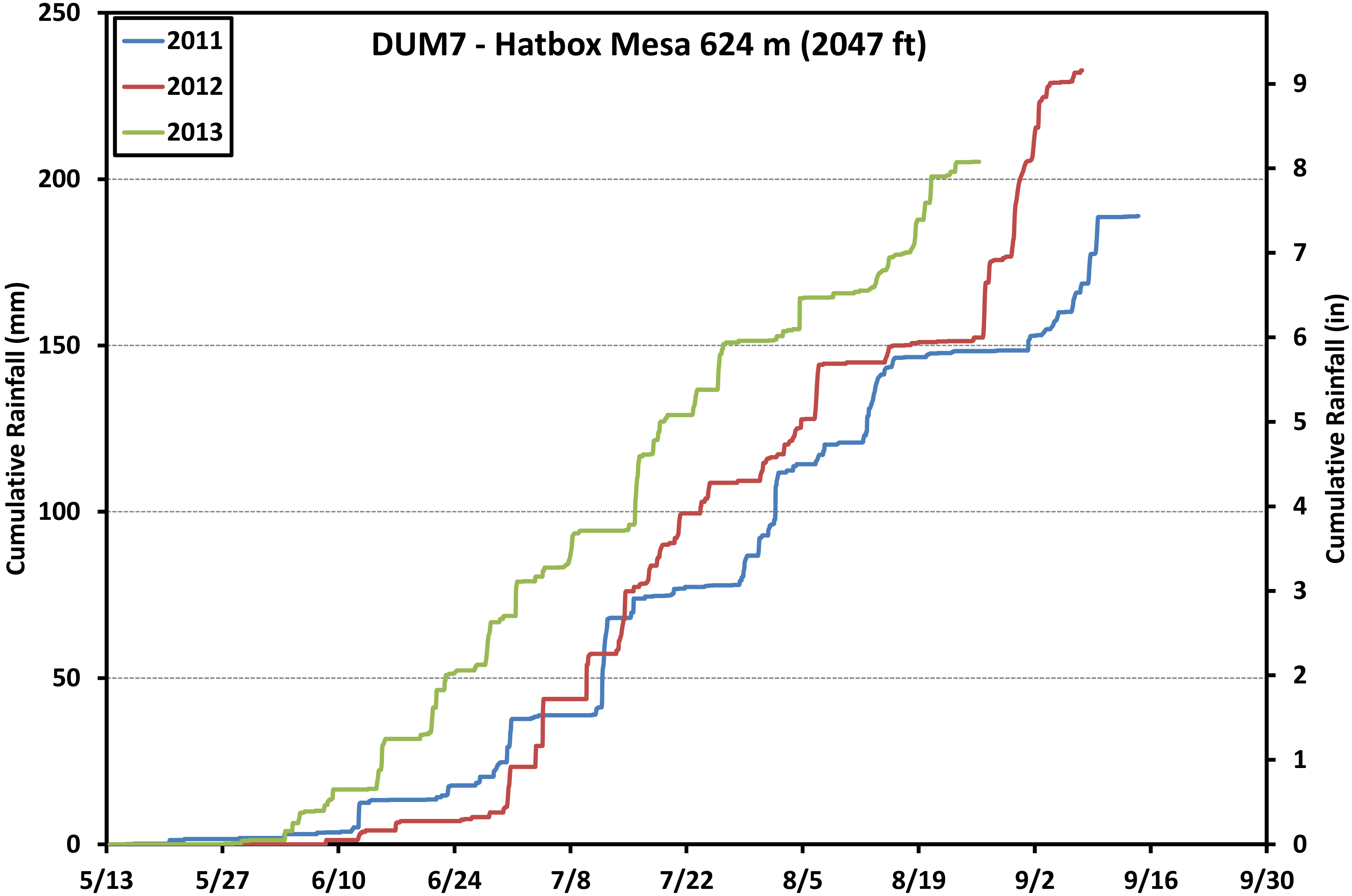
DUM8 - Siksikpuk 463 m (1519 ft)
2011
2012
2013
Cumulative Rainfall (mm)
Cumulative Rainfall (in)
200
180
160
140
120
100
80
60
40
20
0
7
6
5
4
3
2
1
0
5/14
5/28
6/11
6/25
7/9
7/23
8/6
8/20
9/3
9/17

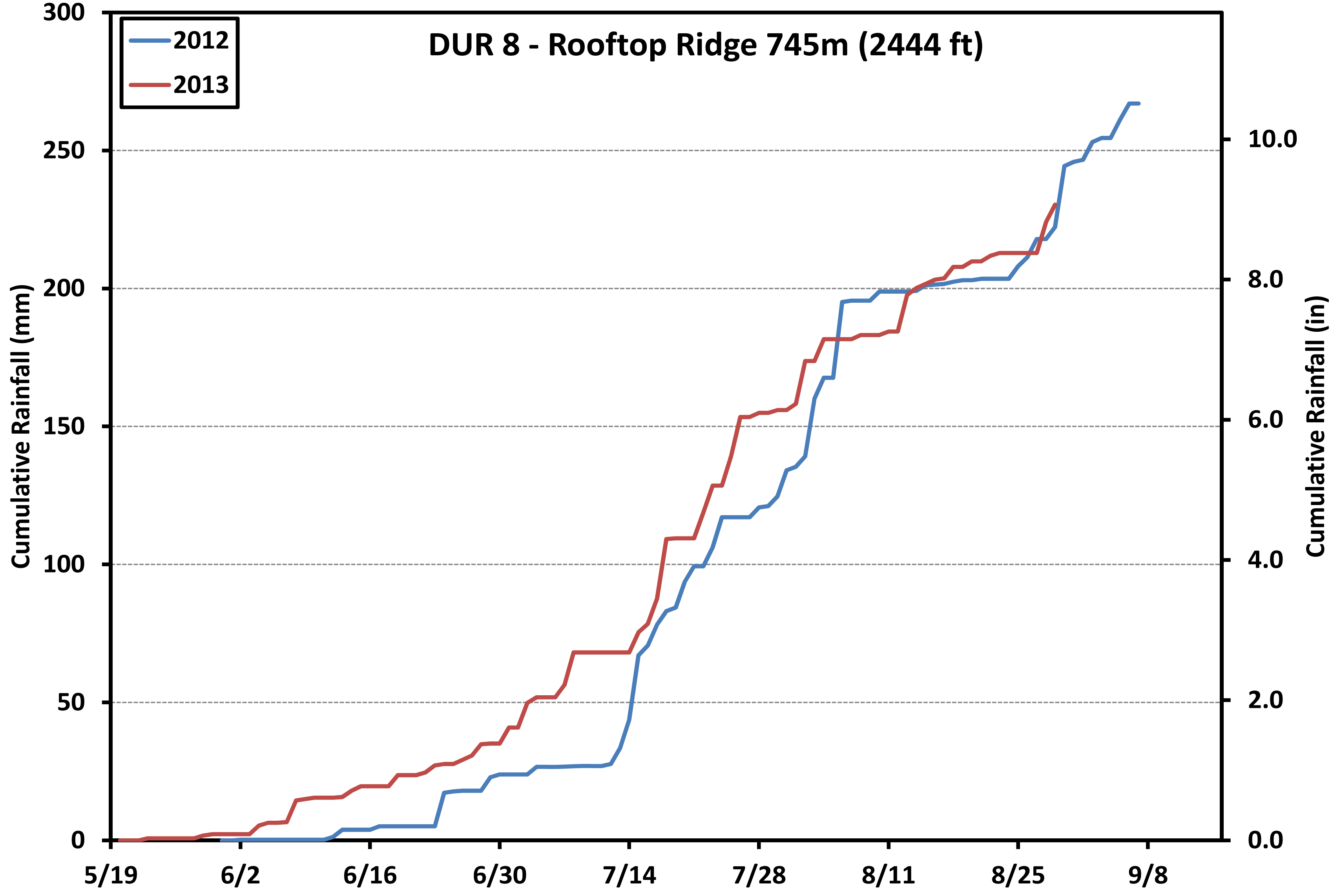


DUM4 - Tuluga 497 m (1631 ft)
2009
2010
2011
2012
2013
Cumulative Rainfall (mm)
Cumulative Rainfall (in)
250
200
150
100
50
0
9
8
7
6
5
4
3
2
1
0
5/12
5/26
6/9
6/23
7/7
7/21
8/4
8/18
9/1
9/15
9/29

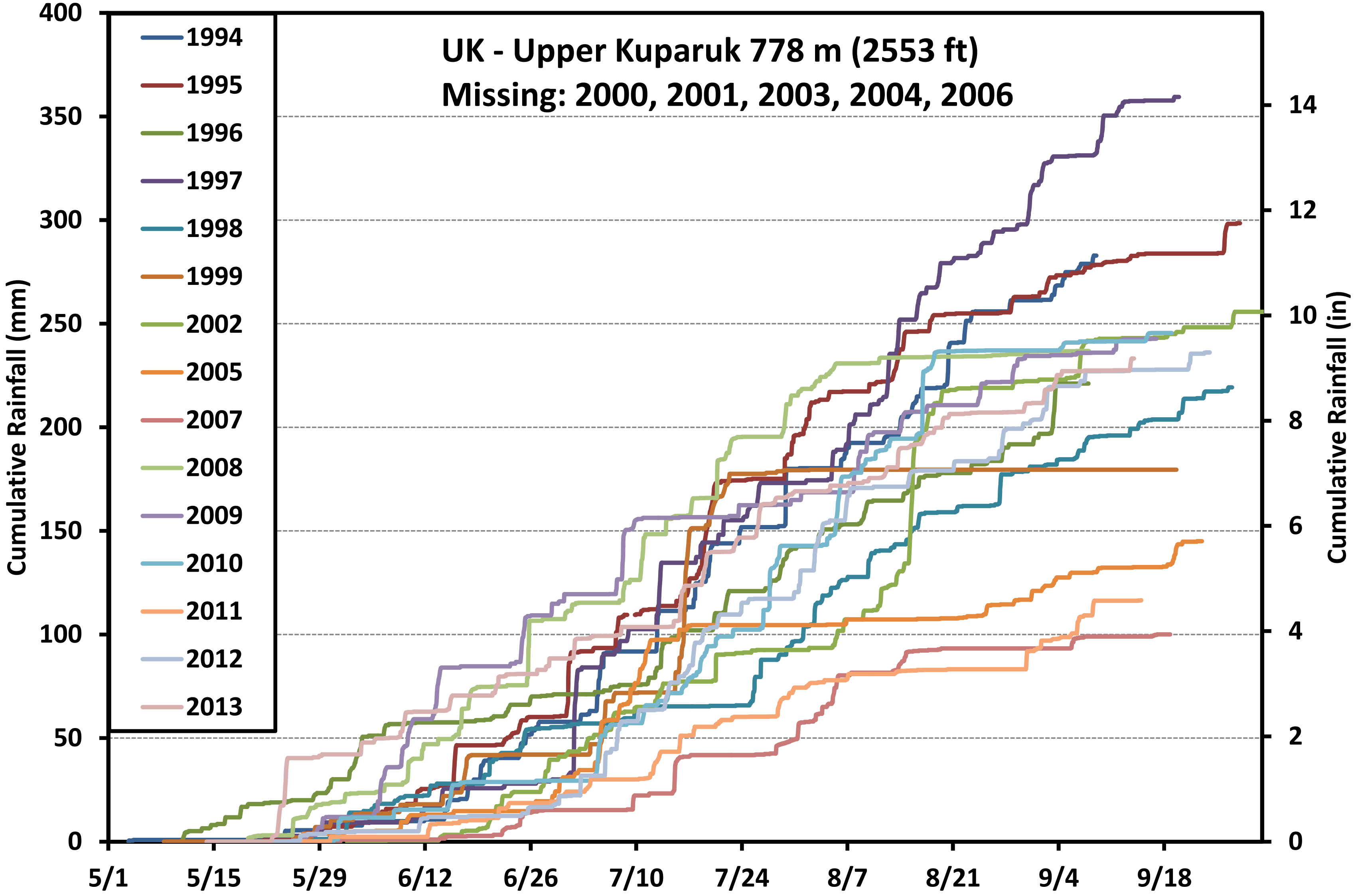


DUM3 - Nanushuk 540 m (1772 ft)
2009
2011
2012
2013
Cumulative Rainfall (mm)
Cumulative Rainfall (in)
160
140
120
100
80
60
40
20
0
7
6
5
4
3
2
1
0
5/14
5/28
6/11
6/25
7/9
7/23
8/6
8/20
9/3
9/17
10/1
10/15

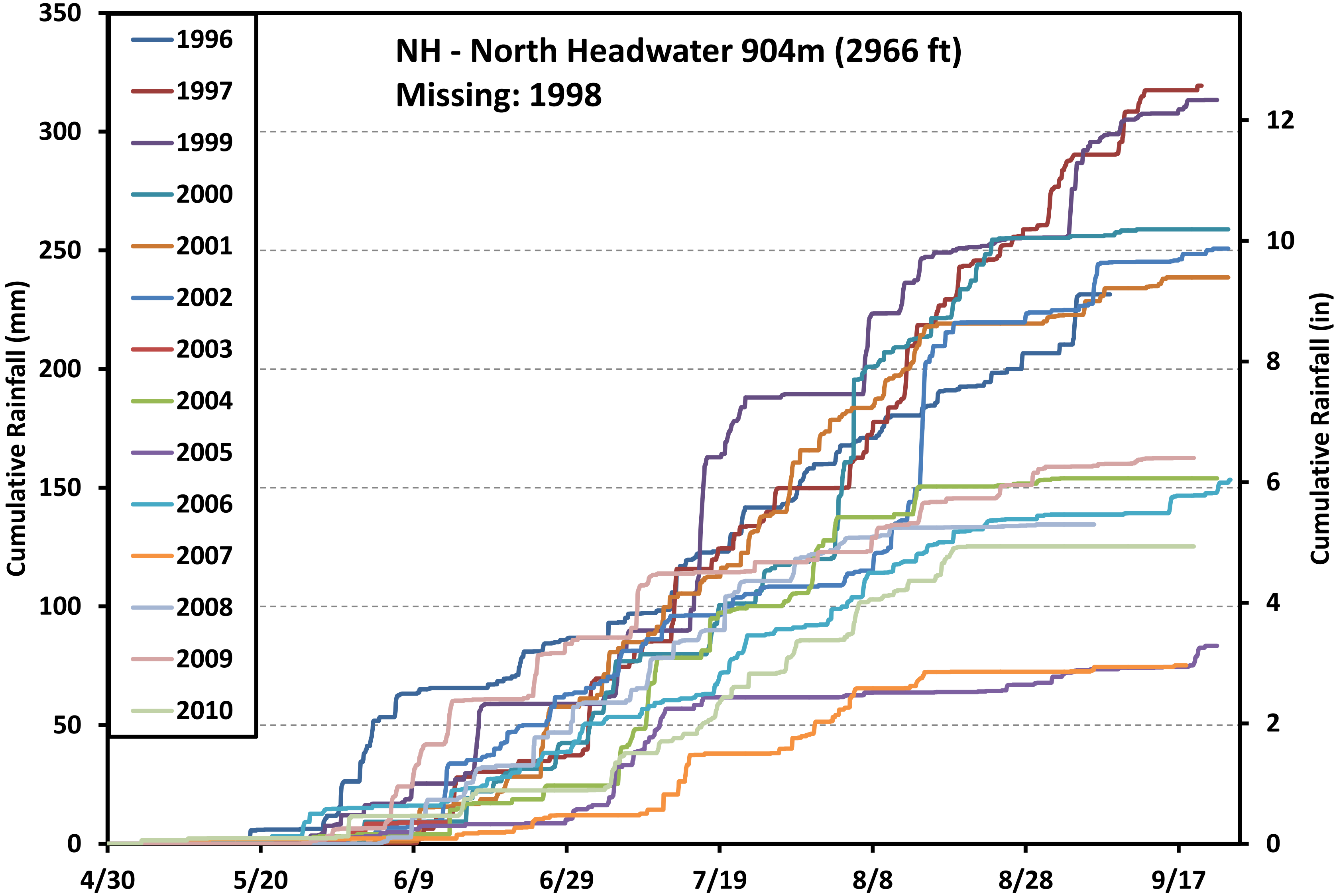

DUM7 - Hatbox Mesa 624 m (2047 ft)
2011
2012
2013
Cumulative Rainfall (mm)
Cumulative Rainfall (in)
250
200
150
100
50
0
9
8
7
6
5
4
3
2
1
0
5/13
5/27
6/10
6/24
7/8
7/22
8/5
8/19
9/2
9/16
9/30



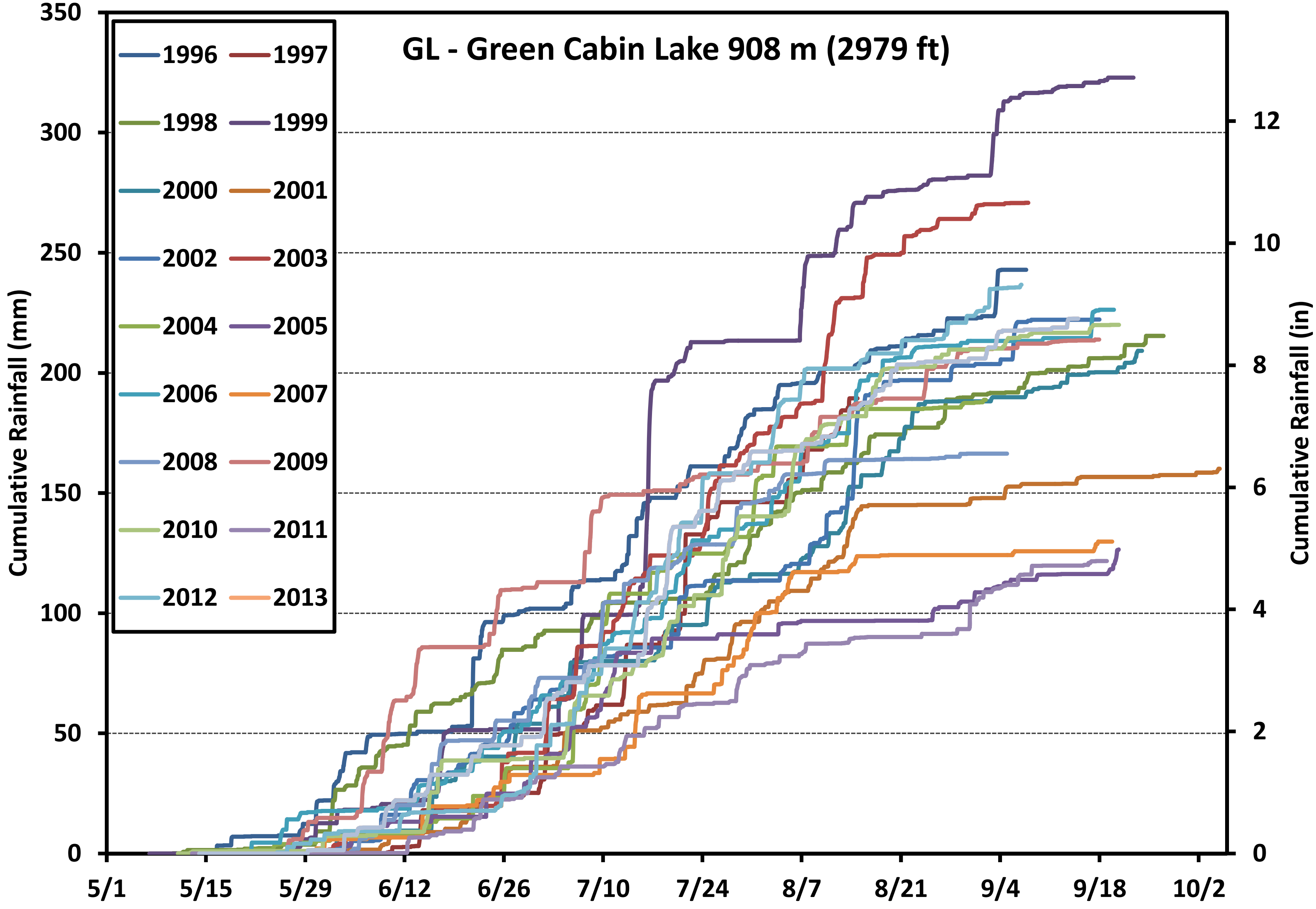
DUR 8 - Rooftop Ridge 745m (2444 ft)
2012
2013
Cumulative Rainfall (mm)
Cumulative Rainfall (in)
300
250
200
150
100
50
0
10.0
8.0
6.0
4.0
2.0
0.0
5/19
6/2
6/16
6/30
7/14
7/28
8/11
8/25
9/8

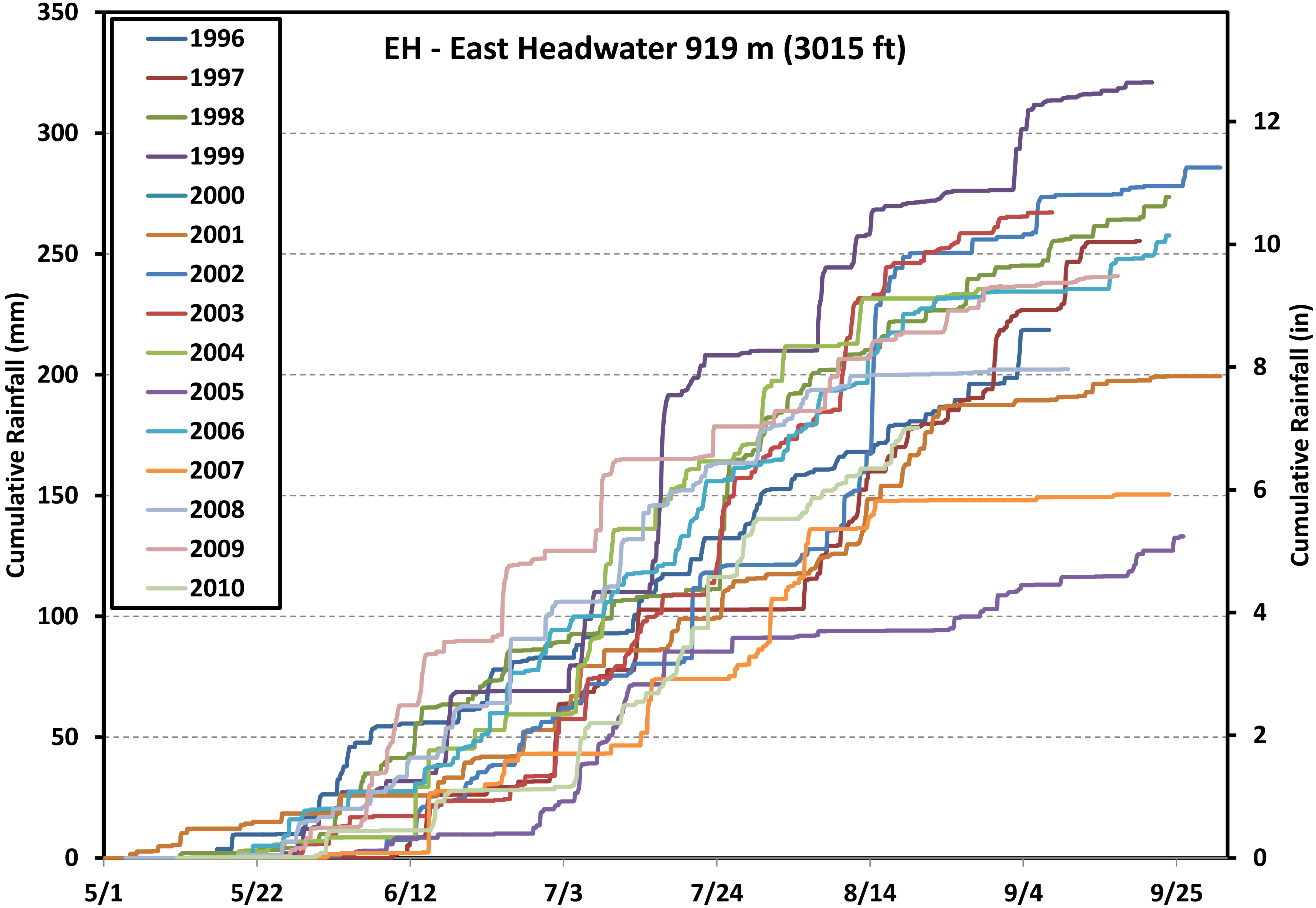


UK - Upper Kuparuk 778 m (2553 ft)
Missing: 2000, 2001, 2003, 2004, 2006
1994
1995
1996
1997
1998
1999
2002
2005
2007
2008
2009
2010
2011
2012
2013
Cumulative Rainfall (mm)
Cumulative Rainfall (in)
0
50
100
150
200
250
300
350
400
0
2
4
6
8
10
12
14
5/1
5/15
5/29
6/12
6/26
7/10
7/24
8/7
8/21
9/4
9/18

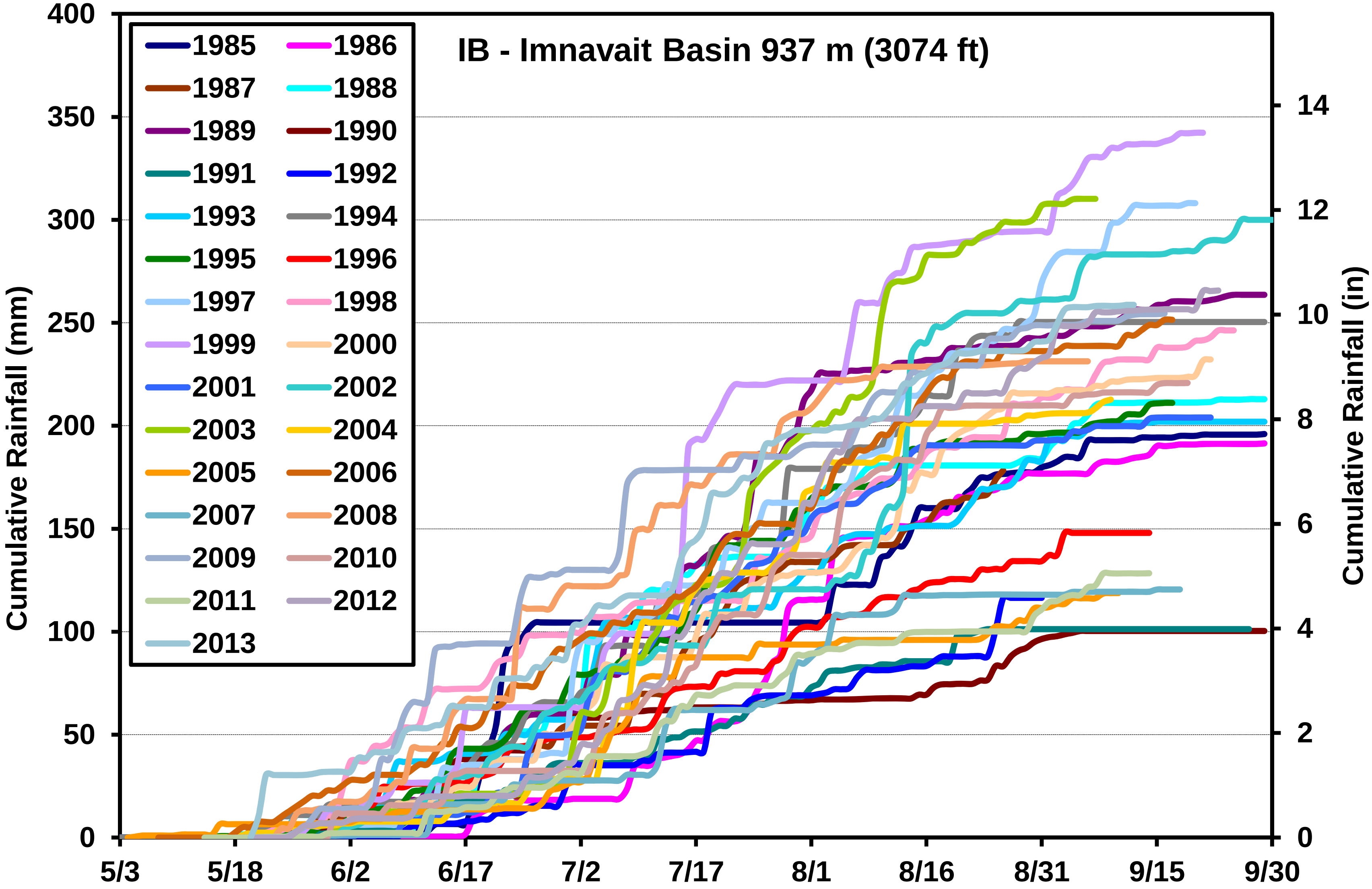


NH - North Headwater 904m (2966 ft)
Missing: 1998
1996
1997
1999
2000
2001
2002
2003
2004
2005
2006
2007
2008
2009
2010
Cumulative Rainfall (mm)
Cumulative Rainfall (in)
0
50
100
150
200
250
300
350
0
2
4
6
8
10
12
4/30
5/20
6/9
6/29
7/19
8/8
8/28
9/17

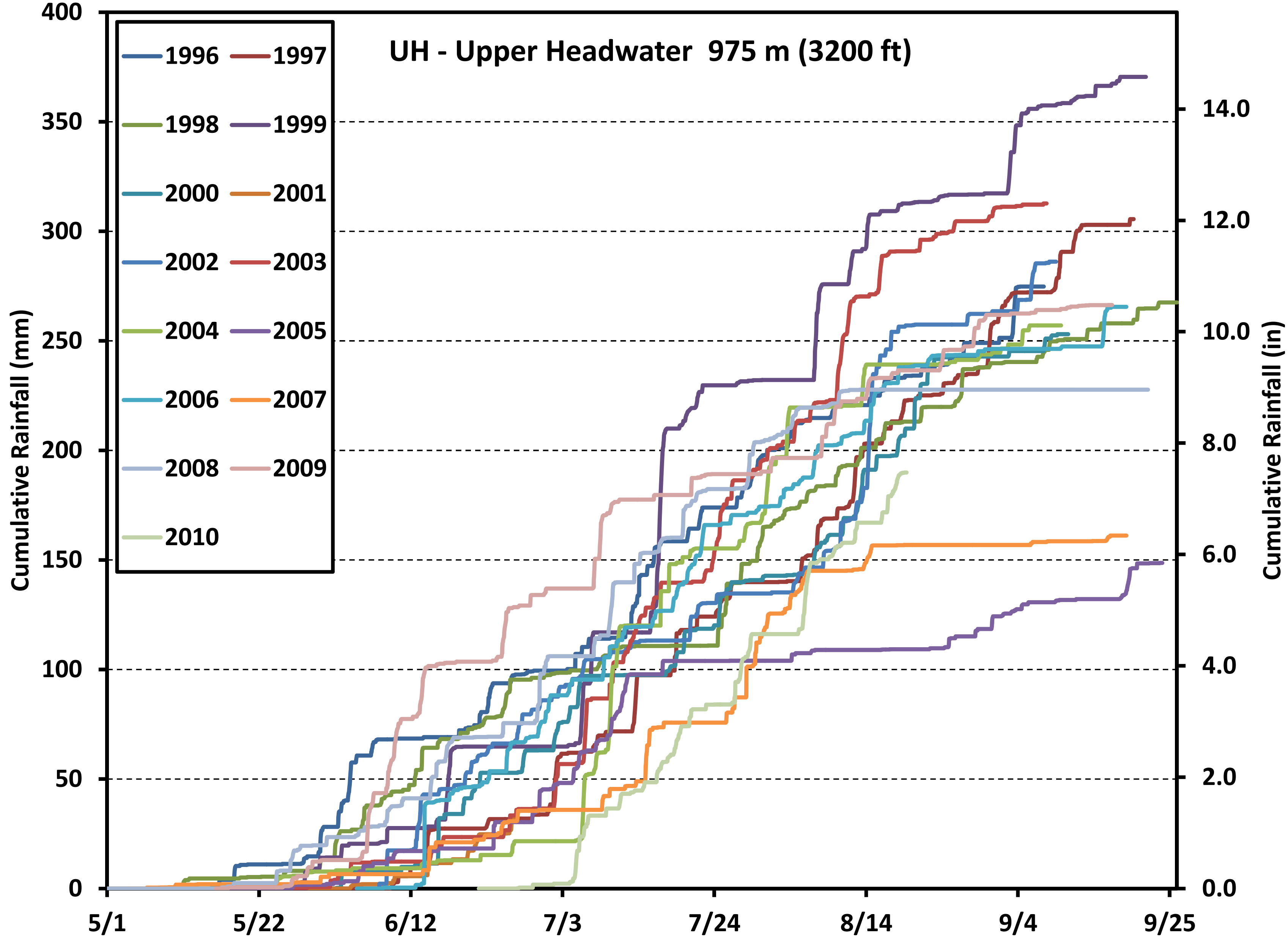

GL - Green Cabin Lake 908 m (2979 ft)
1996
1997
1998
1999
2000
2001
2002
2003
2004
2005
2006
2007
2008
2009
2010
2011
2012
2013
Cumulative Rainfall (mm)
Cumulative Rainfall (in)
0
50
100
150
200
250
300
350
0
2
4
6
8
10
12
5/1
5/15
5/29
6/12
6/26
7/10
7/24
8/7
8/21
9/4
9/18
10/2



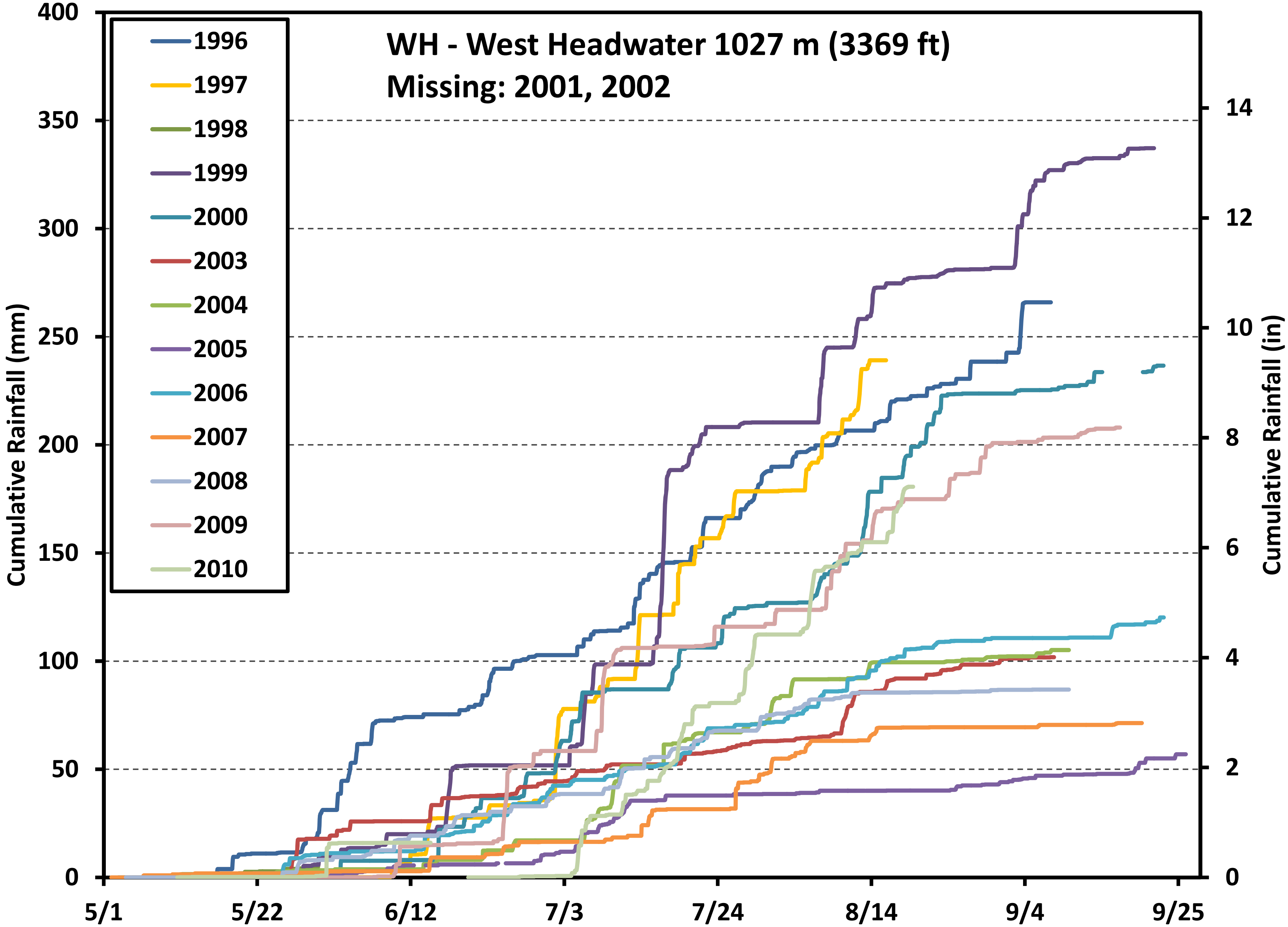
EH - East Headwater 919 m (3015 ft)
1996
1997
1998
1999
2000
2001
2002
2003
2004
2005
2006
2007
2008
2009
2010
Cumulative Rainfall (mm)
Cumulative Rainfall (in)
350
300
250
200
150
100
50
0
12
10
8
6
4
2
0
5/1
5/22
6/12
7/3
7/24
8/14
9/4
9/25



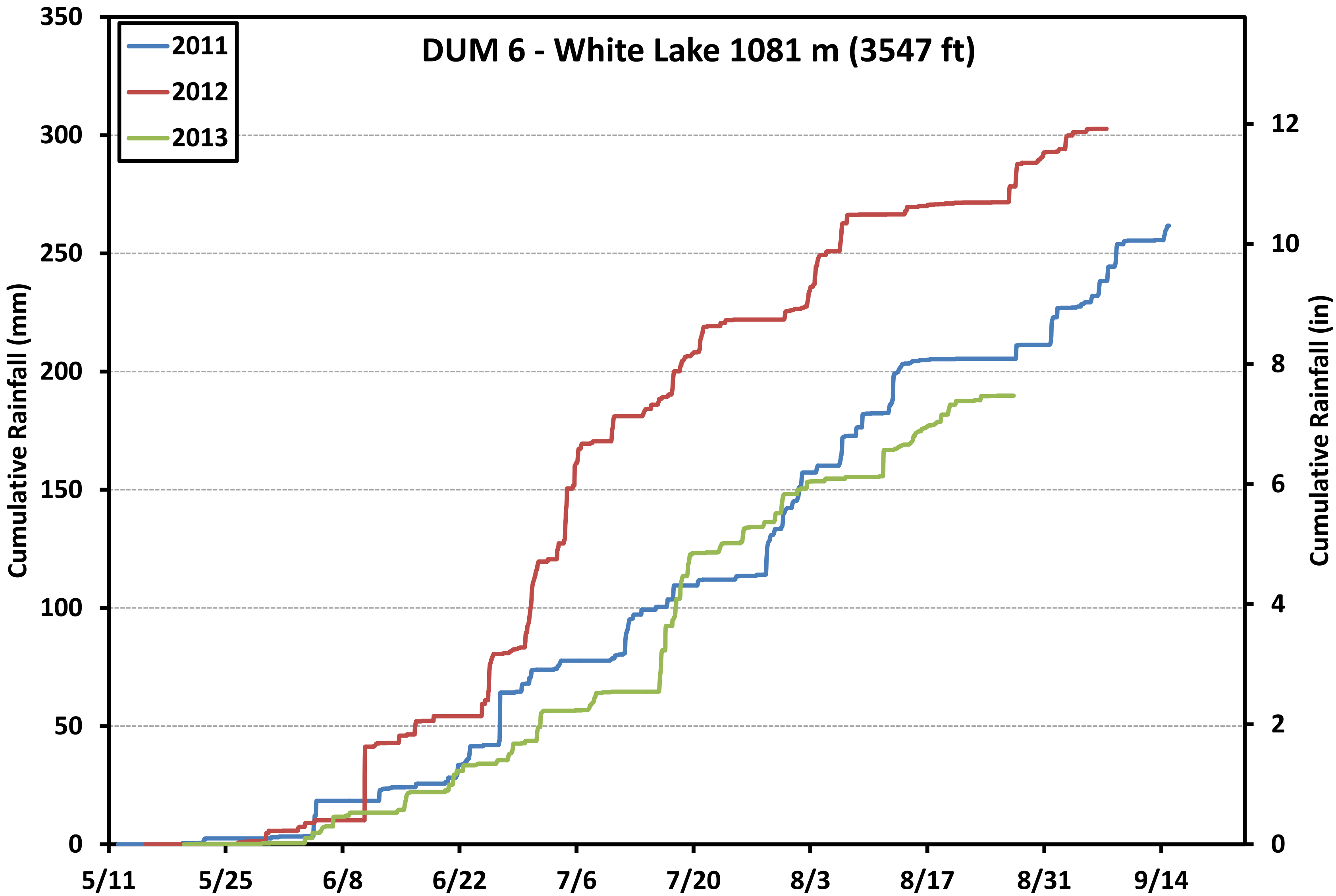
IB - Imnavait Basin 937 m (3074 ft)
1985
1986
1987
1988
1989
1990
1991
1992
1993
1994
1995
1996
1997
1998
1999
2000
2001
2002
2003
2004
2005
2006
2007
2008
2009
2010
2011
2012
2013
Cumulative Rainfall (mm)
Cumulative Rainfall (in)
0
50
100
150
200
250
300
350
400
0
2
4
6
8
10
12
14
5/3
5/18
6/2
6/17
7/2
7/17
8/1
8/16
8/31
9/15
9/30

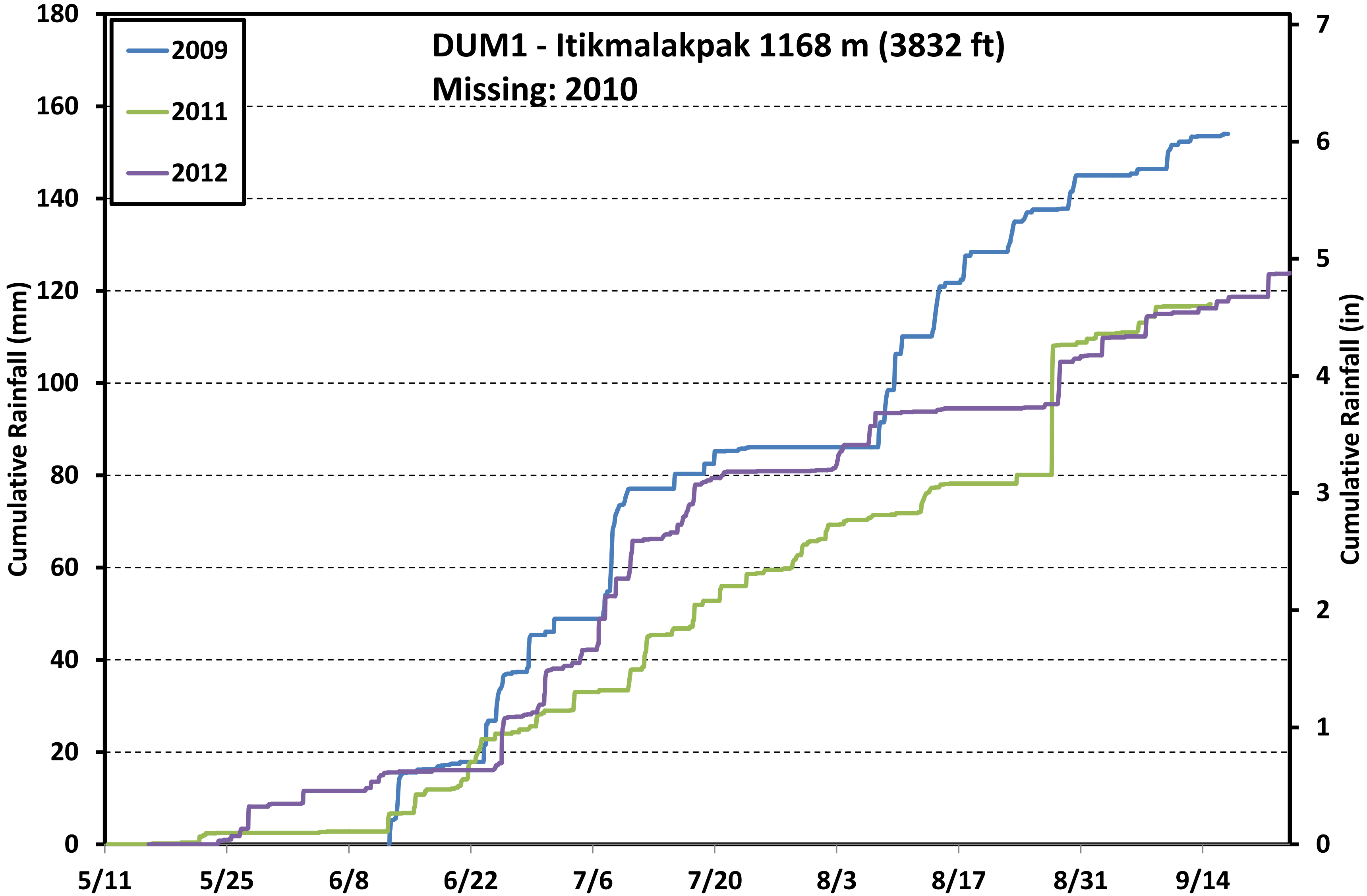


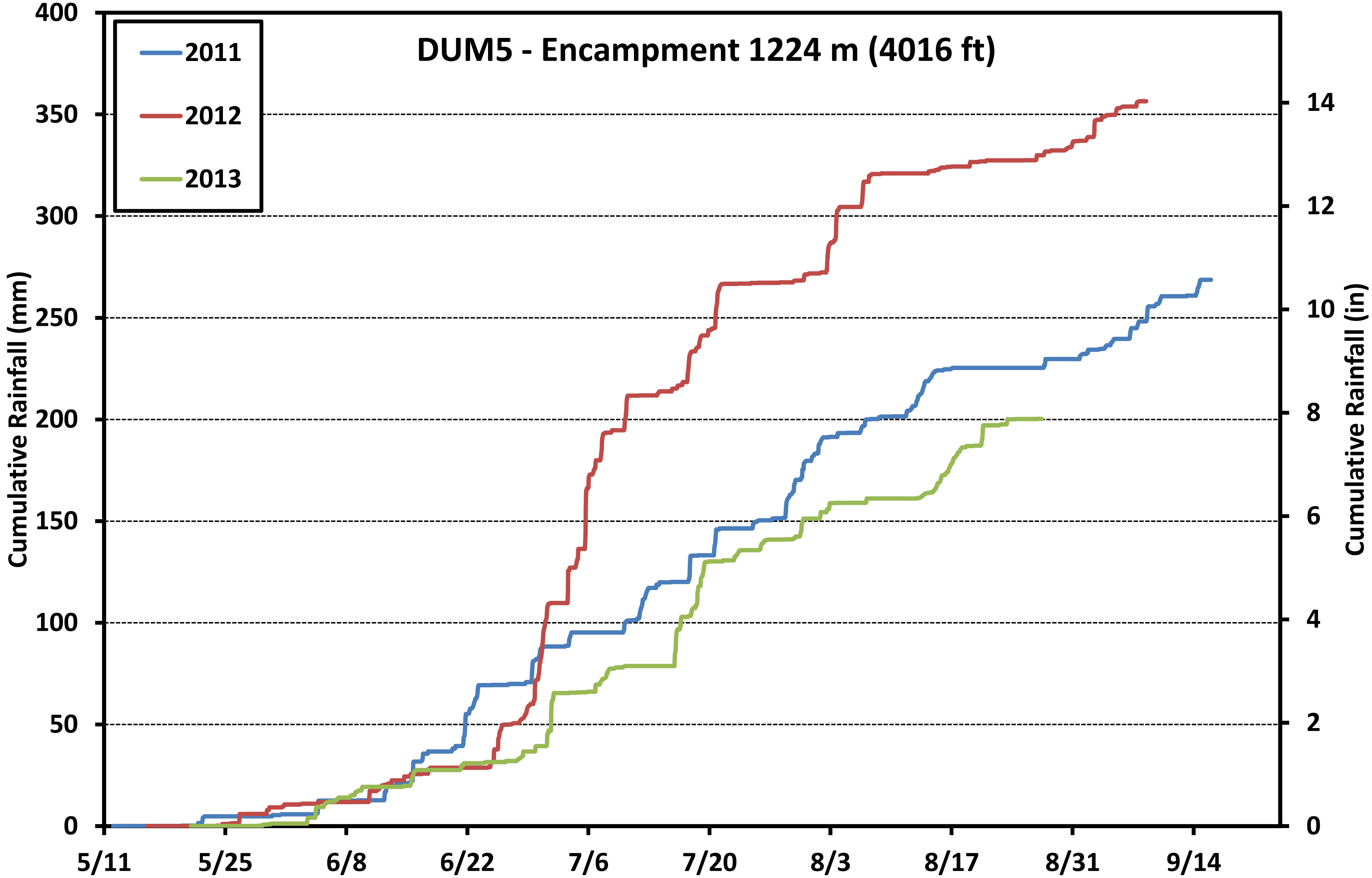
UH - Upper Headwater 975 m (3200 ft)
1996
1997
1998
1999
2000
2001
2002
2003
2004
2005
2006
2007
2008
2009
2010
Cumulative Rainfall (mm)
Cumulative Rainfall (in)
400
350
300
250
200
150
100
50
0
14.0
12.0
10.0
8.0
6.0
4.0
2.0
0.0
5/1
5/22
6/12
7/3
7/24
8/14
9/4
9/25



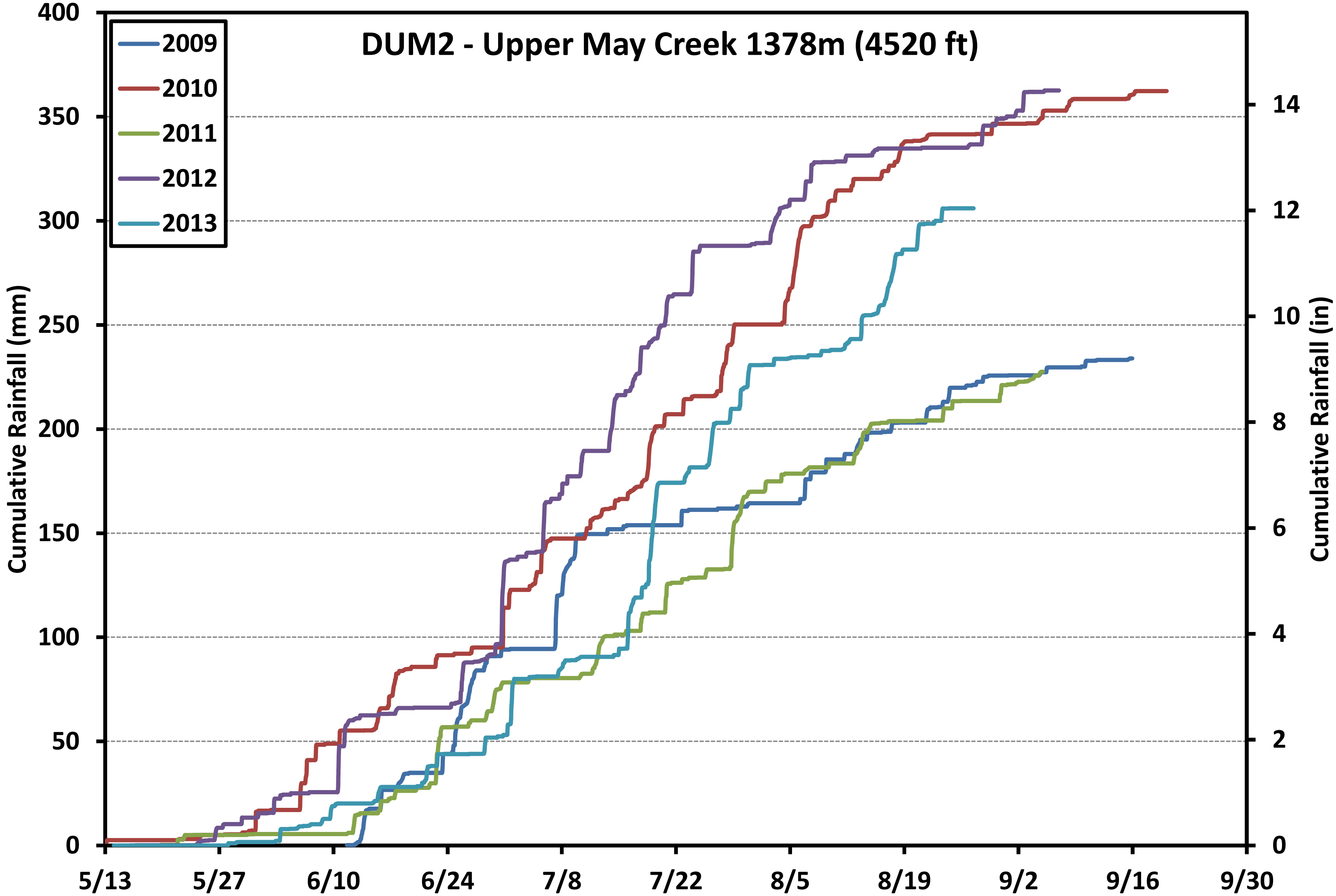
WH - West Headwater 1027 m (3369 ft)
Missing: 2001, 2002
1996
1997
1998
1999
2000
2003
2004
2005
2006
2007
2008
2009
2010
Cumulative Rainfall (mm)
Cumulative Rainfall (in)
0
50
100
150
200
250
300
350
400
0
2
4
6
8
10
12
14
5/1
5/22
6/12
7/3
7/24
8/14
9/4
9/25


DUM 6 - White Lake 1081 m (3547 ft)
2011
2012
2013
Cumulative Rainfall (mm)
Cumulative Rainfall (in)
350
300
250
200
150
100
50
0
12
10
8
6
4
2
0
5/11
5/25
6/8
6/22
7/6
7/20
8/3
8/17
8/31
9/14

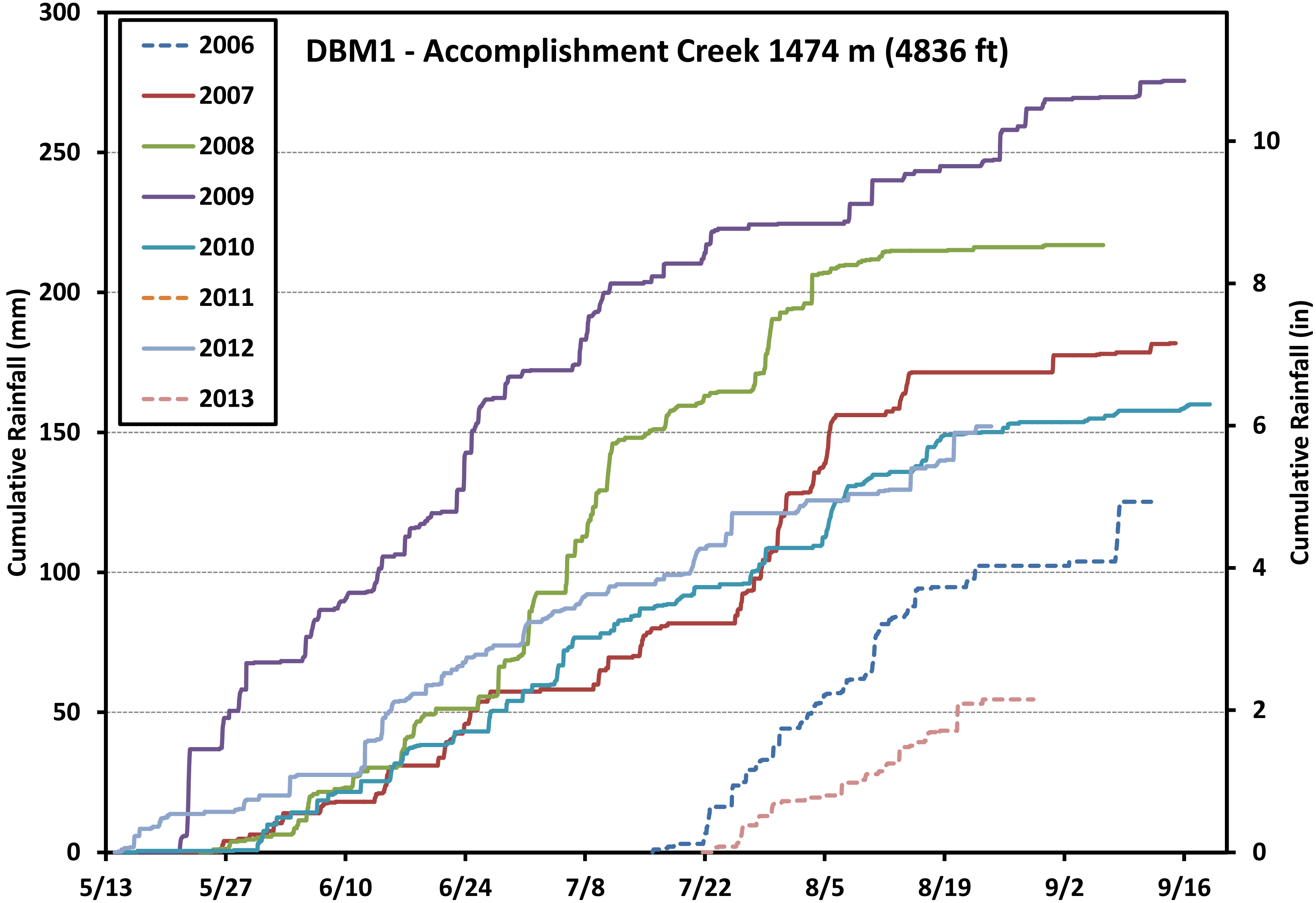

DUM1 - Itikmalakpak 1168 m (3832 ft)
Missing: 2010
2009
2011
2012
Cumulative Rainfall (mm)
Cumulative Rainfall (in)
180
160
140
120
100
80
60
40
20
0
7
6
5
4
3
2
1
0
5/11
5/25
6/8
6/22
7/6
7/20
8/3
8/17
8/31
9/14



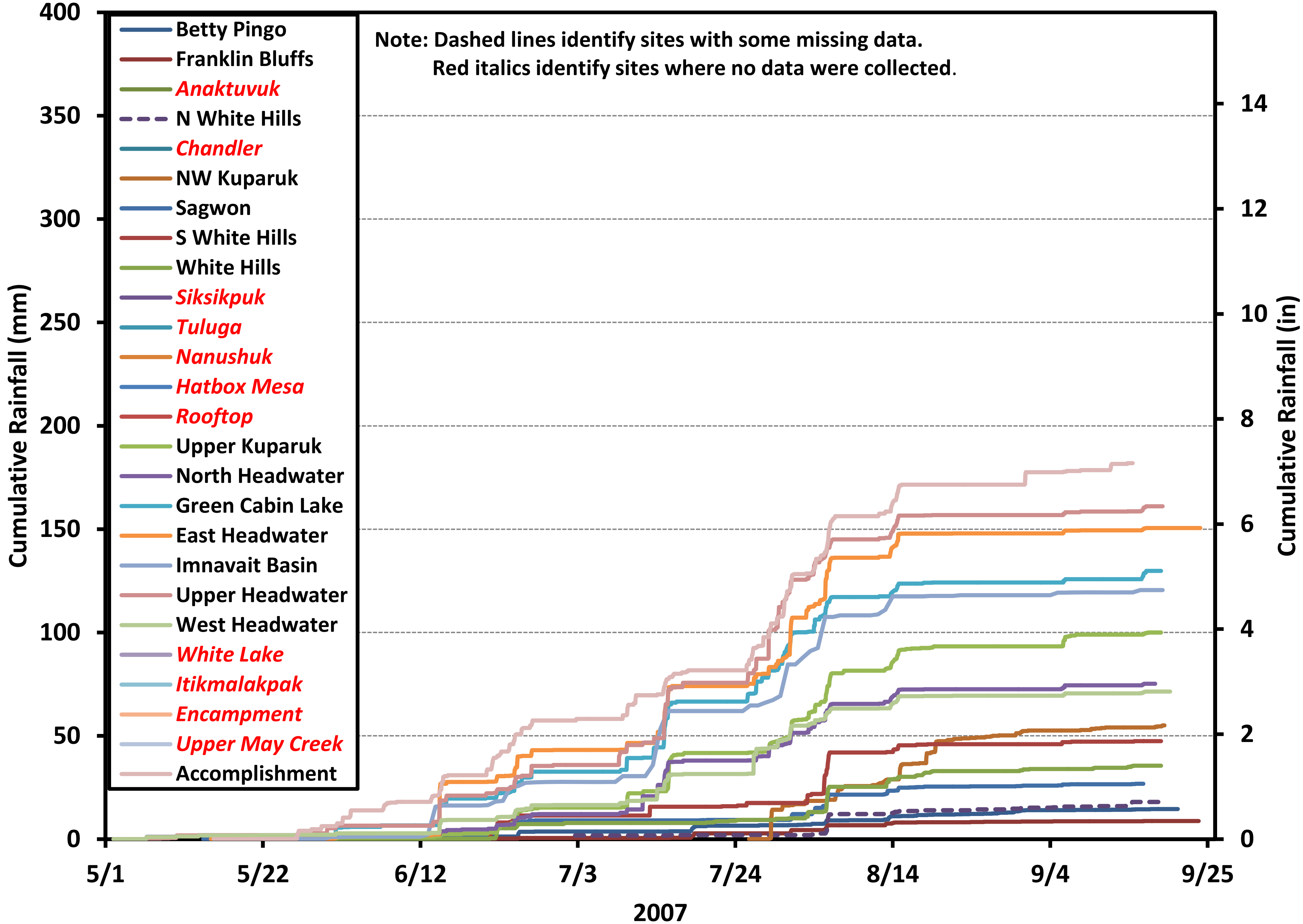
DUM5 - Encampment 1224 m (4016 ft)
2011
2012
2013
Cumulative Rainfall (mm)
Cumulative Rainfall (in)
400
350
300
250
200
150
100
50
0
14
12
10
8
6
4
2
0
5/11
5/25
6/8
6/22
7/6
7/20
8/3
8/17
8/31
9/14



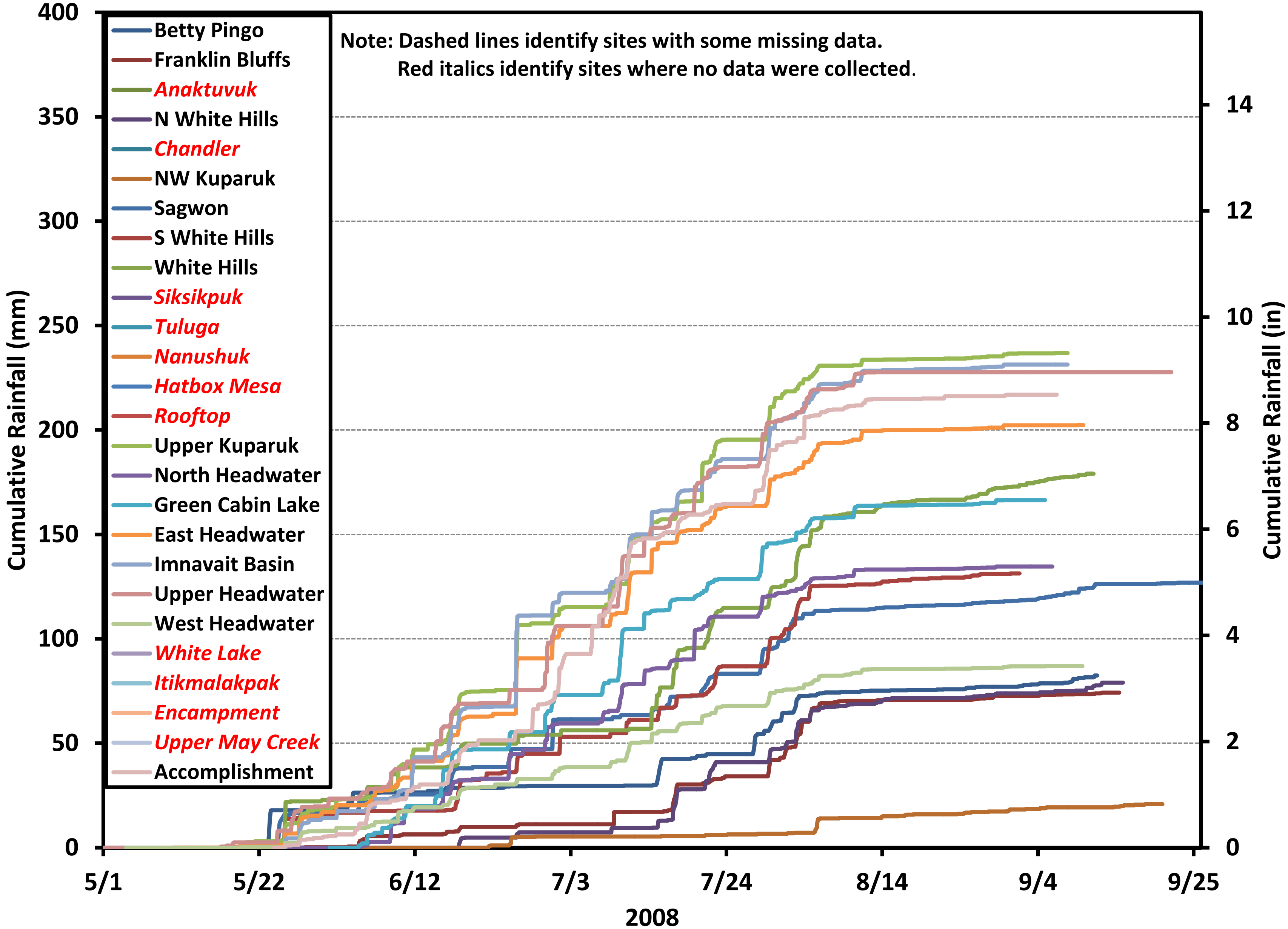
DUM2 - Upper May Creek 1378m (4520 ft)
2009
2010
2011
2012
2013
Cumulative Rainfall (mm)
Cumulative Rainfall (in)
0
50
100
150
200
250
300
350
400
0
2
4
6
8
10
12
14
5/13
5/27
6/10
6/24
7/8
7/22
8/5
8/19
9/2
9/16
9/30



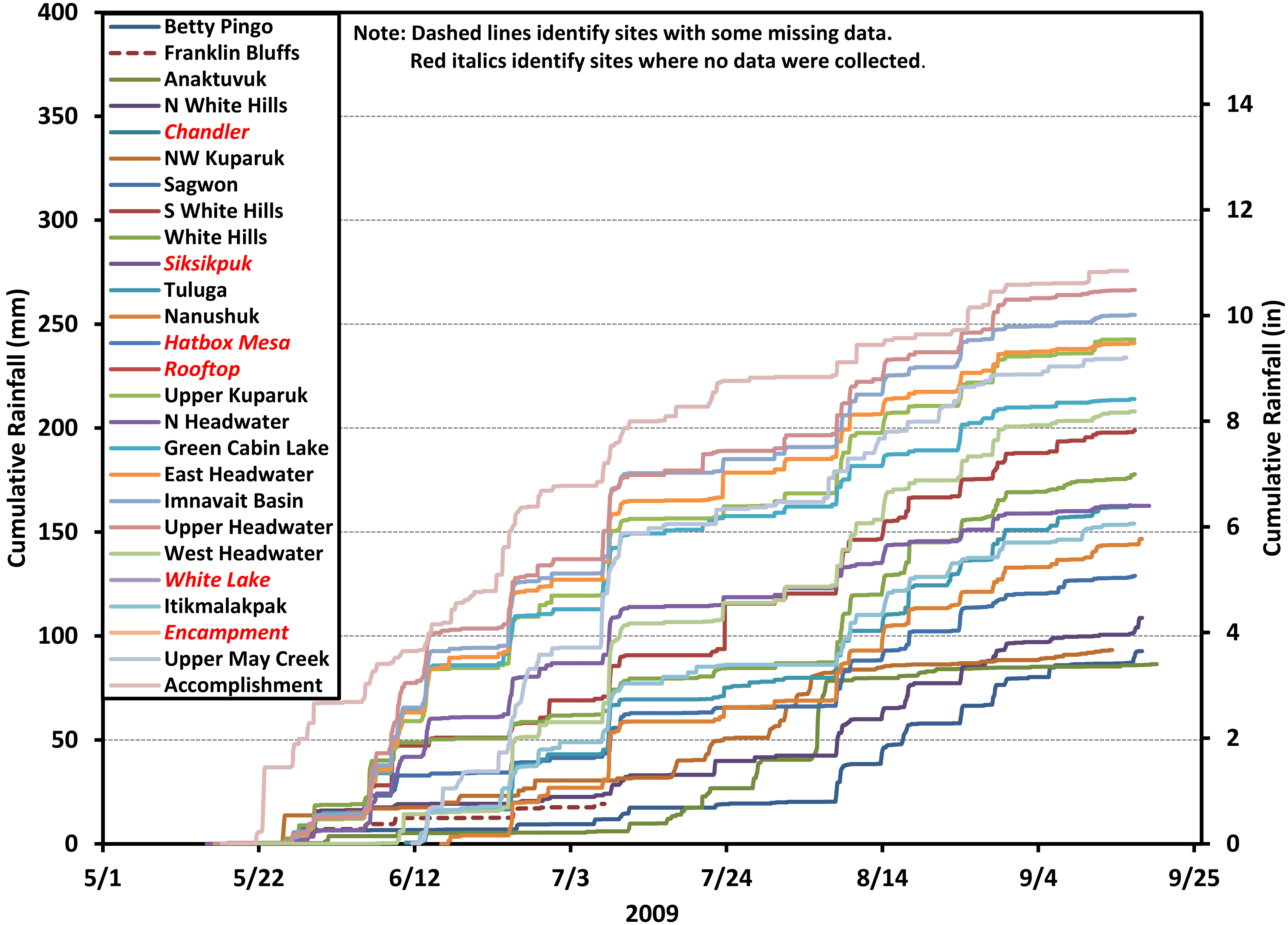
DBM1 - Accomplishment Creek 1474 m (4836 ft)
2006
2007
2008
2009
2010
2011
2012
2013
Cumulative Rainfall (mm)
Cumulative Rainfall (in)
300
250
200
150
100
50
0
10
8
6
4
2
0
5/13
5/27
6/10
6/24
7/8
7/22
8/5
8/19
9/2
9/16



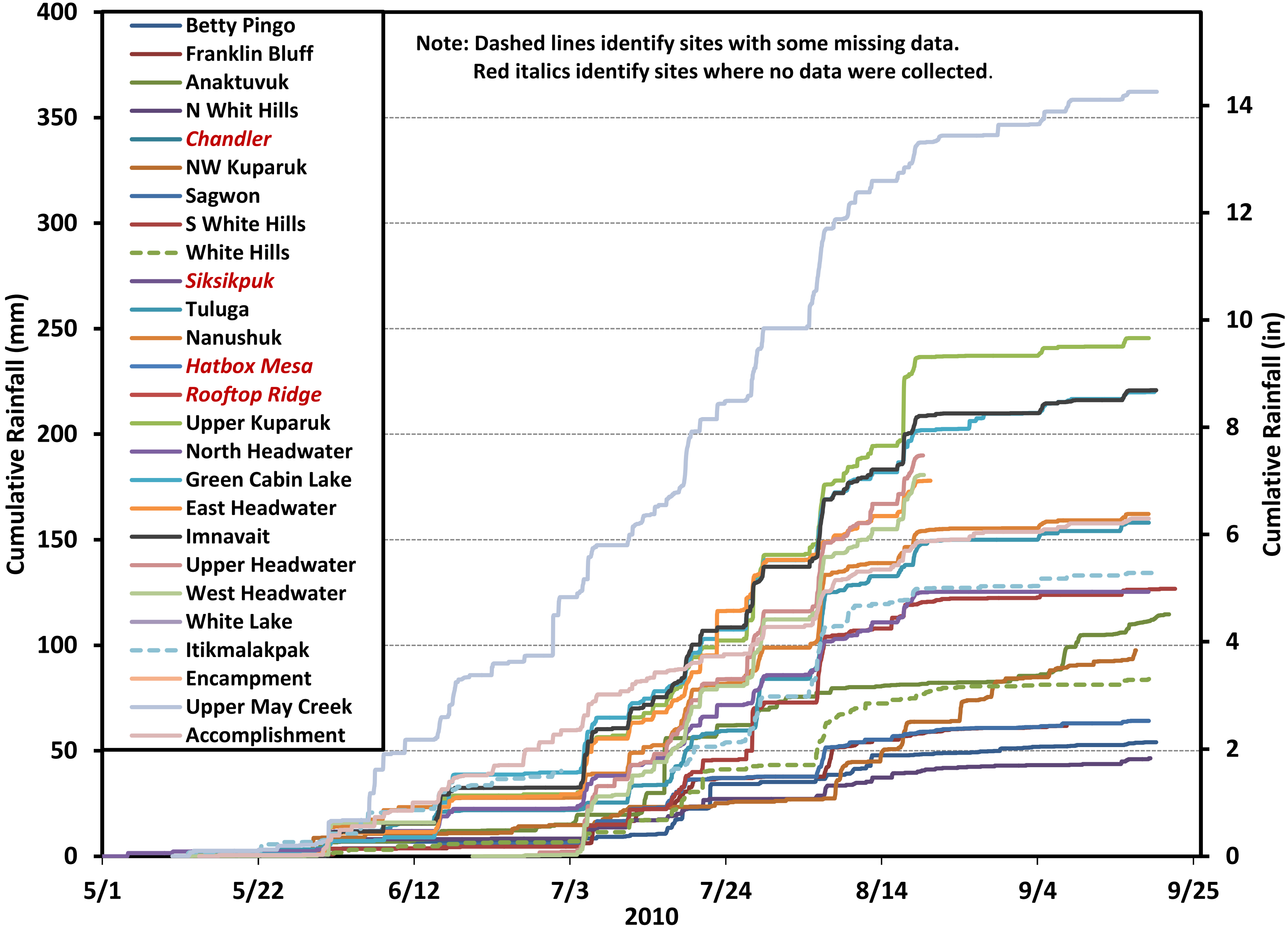
Betty Pingo
Franklin Bluffs
Anaktuvuk
N White Hills
Chandler
NW Kuparuk
Sagwon
S White Hills
White Hills
Siksikpuk
Tuluga
Nanushuk
Hatbox Mesa
Rooftop
Upper Kuparuk
North Headwater
Green Cabin Lake
East Headwater
Imnavait Basin
Upper Headwater
West Headwater
White Lake
Itikmalakpak
Encampment
Upper May Creek
Accomplishment
Note: Dashed lines identify sites with some missing data.
Red italics identify sites where no data were collected.
Cumulative Rainfall (mm)
Cumulative Rainfall (in)
400
350
300
250
200
150
100
50
0
14
12
10
8
6
4
2
0
5/1
5/22
6/12
7/3
7/24
8/14
9/4
9/25
2007

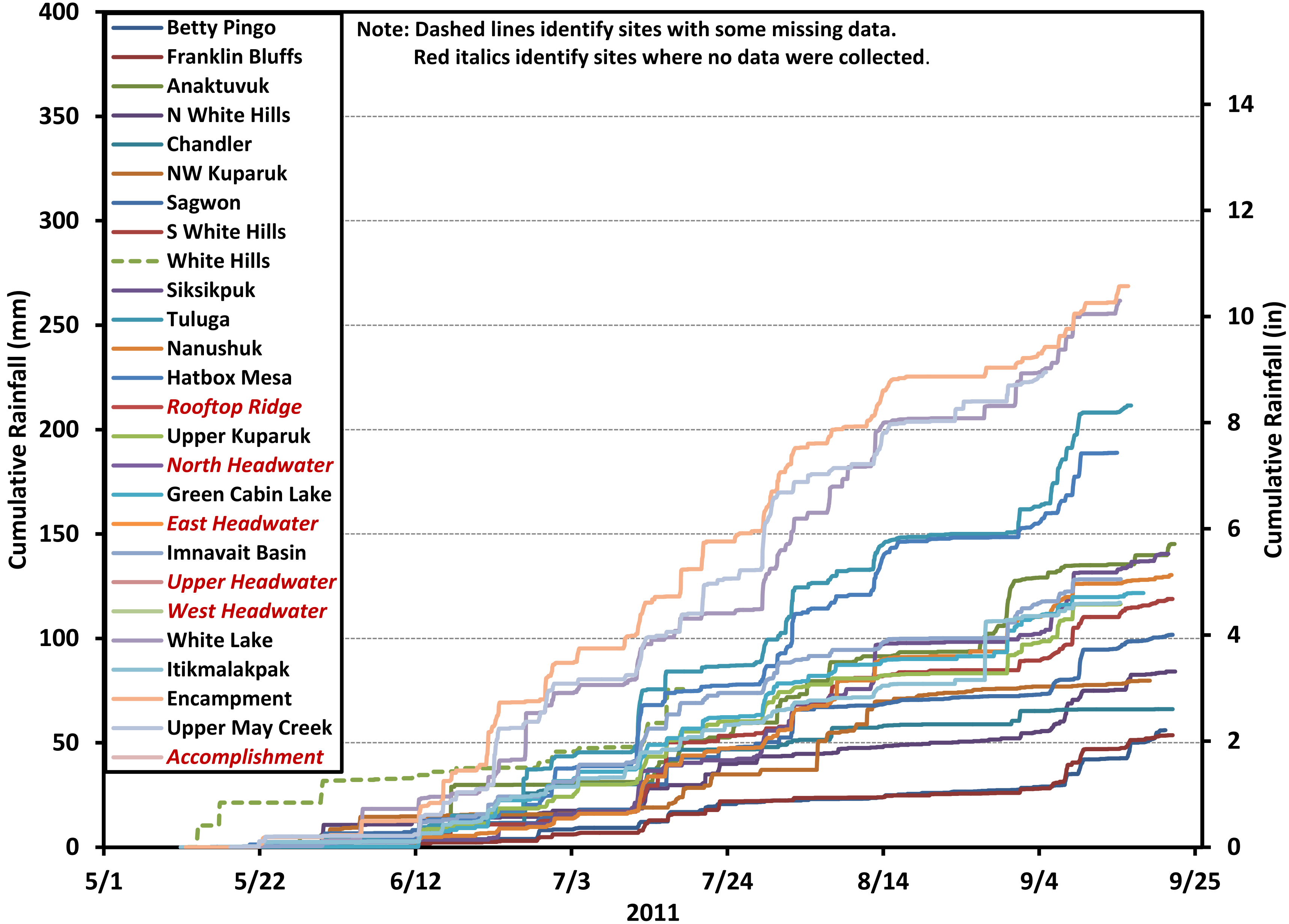


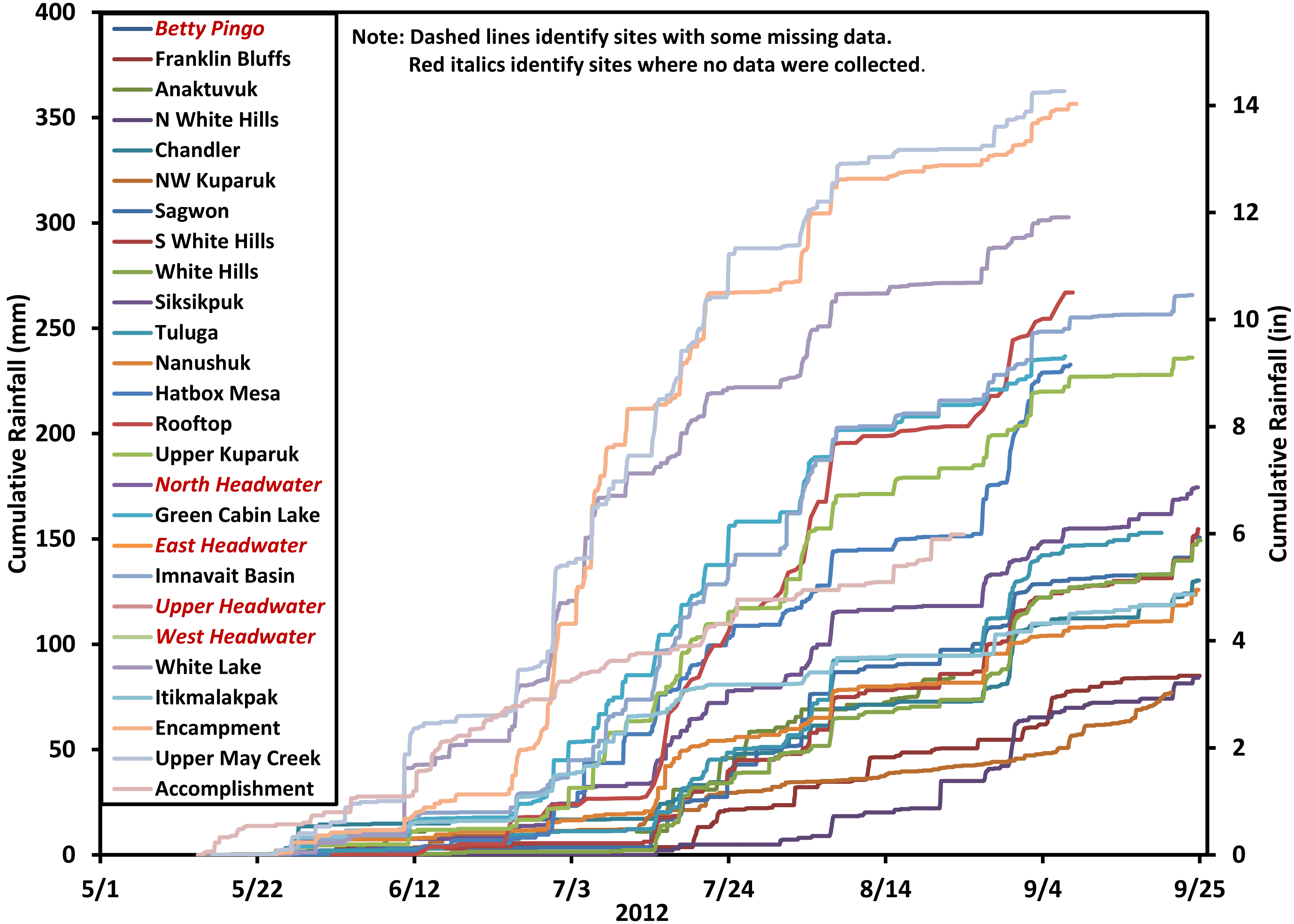
Note: Dashed lines identify sites with some missing data.
Red italics identify sites where no data were collected.
Betty Pingo
Franklin Bluffs
Anaktuvuk
N White Hills
Chandler
NW Kuparuk
Sagwon
S White Hills
White Hills
Siksikpuk
Tuluga
Nanushuk
Hatbox Mesa
Rooftop
Upper Kuparuk
North Headwater
Green Cabin Lake
East Headwater
Imnavait Basin
Upper Headwater
West Headwater
White Lake
Itikmalakpak
Encampment
Upper May Creek
Accomplishment
Cumulative Rainfall (mm)
Cumulative Rainfall (in)
0
50
100
150
200
250
300
350
400
0
2
4
6
8
10
12
14
5/1
5/22
6/12
7/3
7/24
8/14
9/4
9/25
2008



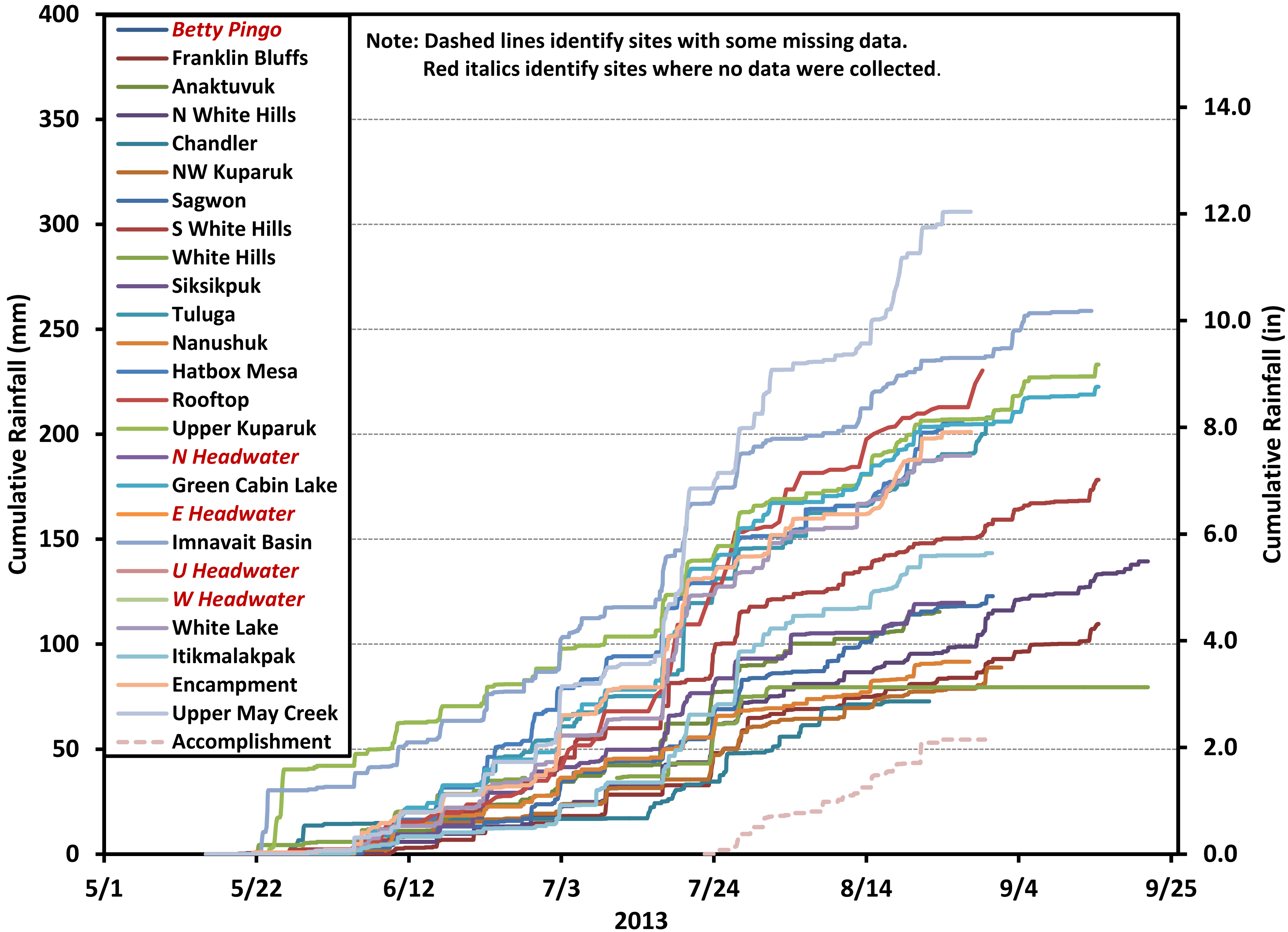
400
350
300
250
200
150
100
50
0
Cumulative Rainfall (mm)
14
12
10
8
6
4
2
0
Cumulative Rainfall (in)
5/1
5/22
6/12
7/3
7/24
8/14
9/4
9/25
2009
Betty Pingo
Franklin Bluffs
Anaktuvuk
N White Hills
Chandler
NW Kuparuk
Sagwon
S White Hills
White Hills
Siksikpuk
Tuluga
Nanushuk
Hatbox Mesa
Rooftop
Upper Kuparuk
N Headwater
Green Cabin Lake
East Headwater
Imnavait Basin
Upper Headwater
West Headwater
White Lake
Itikmalakpak
Encampment
Upper May Creek
Accomplishment
Note: Dashed lines identify sites with some missing data.
Red italics identify sites where no data were collected.


Note: Dashed lines identify sites with some missing data.
Red italics identify sites where no data were collected.
Betty Pingo
Franklin Bluff
Anaktuvuk
N Whit Hills
Chandler
NW Kuparuk
Sagwon
S White Hills
White Hills
Siksikpuk
Tuluga
Nanushuk
Hatbox Mesa
Rooftop Ridge
Upper Kuparuk
North Headwater
Green Cabin Lake
East Headwater
Imnavait
Upper Headwater
West Headwater
White Lake
Itikmalakpak
Encampment
Upper May Creek
Accomplishment
Cumulative Rainfall (mm)
Cumlative Rainfall (in)
400
350
300
250
200
150
100
50
0
14
12
10
8
6
4
2
0
5/1
5/22
6/12
7/3
7/24
8/14
9/4
9/25
2010


Betty Pingo
Franklin Bluffs
Anaktuvuk
N White Hills
Chandler
NW Kuparuk
Sagwon
S White Hills
White Hills
Siksikpuk
Tuluga
Nanushuk
Hatbox Mesa
Rooftop Ridge
Upper Kuparuk
North Headwater
Green Cabin Lake
East Headwater
Imnavait Basin
Upper Headwater
West Headwater
White Lake
Itikmalakpak
Encampment
Upper May Creek
Accomplishment
Note: Dashed lines identify sites with some missing data.
Red italics identify sites where no data were collected.
Cumulative Rainfall (mm)
Cumulative Rainfall (in)
2011
5/1
5/22
6/12
7/3
7/24
8/14
9/4
9/25
0
50
100
150
200
250
300
350
400
2
4
6
8
10
12
14



400
350
300
250
200
150
100
50
0
Cumulative Rainfall (mm)
14
12
10
8
6
4
2
0
Cumulative Rainfall (in)
5/1
5/22
6/12
7/3
7/24
8/14
9/4
9/25
2012
Betty Pingo
Franklin Bluffs
Anaktuvuk
N White Hills
Chandler
NW Kuparuk
Sagwon
S White Hills
White Hills
Siksikpuk
Tuluga
Nanushuk
Hatbox Mesa
Rooftop
Upper Kuparuk
North Headwater
Green Cabin Lake
East Headwater
Imnavait Basin
Upper Headwater
West Headwater
White Lake
Itikmalakpak
Encampment
Upper May Creek
Accomplishment
Note: Dashed lines identify sites with some missing data.
Red italics identify sites where no data were collected.



400
350
300
250
200
150
100
50
0
Cumulative Rainfall (mm)
14.0
12.0
10.0
8.0
6.0
4.0
2.0
0.0
Cumulative Rainfall (in)
5/1
5/22
6/12
7/3
7/24
8/14
9/4
9/25
2013
Betty Pingo
Franklin Bluffs
Anaktuvuk
N White Hills
Chandler
NW Kuparuk
Sagwon
S White Hills
White Hills
Siksikpuk
Tuluga
Nanushuk
Hatbox Mesa
Rooftop
Upper Kuparuk
N Headwater
Green Cabin Lake
E Headwater
Imnavait Basin
U Headwater
W Headwater
White Lake
Itikmalakpak
Encampment
Upper May Creek
Accomplishment
Note: Dashed lines identify sites with some missing data.
Red italics identify sites where no data were collected.

Appendix D – Soil Temperature and Moisture

This section contains a table of soil surface temperature and volumetric soil water content, along with time series plots of soil temperature at depth, soil surface temperature, and soil water content for each station in the Kuparuk Foothills and Umiat Corridor project.

Page D-1 to D-3: Average monthly soil surface temperature (SST) summary (in degrees C and F) for stations in the Kuparuk Foothills and Umiat Corridor projects. *N* indicates number of months used in the analysis.

Page D-4 to D-5: Unfrozen soil water content (volume fraction) summary (in cm^3/cm^3) at 10, 20, 30, or 40 cm below ground surface (bgs) for stations in the Kuparuk Foothills and Umiat Corridor projects. *N* indicates number of months used in the analysis.

Page D-6 to D-10: Soil temperature profiles from soil surface (0 cm) to approximately 150 cm below ground surface (bgs) for stations in the Kuparuk Foothills and Umiat Corridor projects.

Page D-11 to D-16: Soil surface temperature time series plots for stations in the Kuparuk Foothills and Umiat Corridor projects.

Page D-17 to D-21: Unfrozen volumetric soil moisture content (cm^3/cm^3) time series plots at 10, 20, 30, or 40 cm below ground surface (bgs) for stations in the Kuparuk Foothills and Umiat Corridor projects.

Average monthly soil surface temperature (SST) summary (in degrees C and F) for stations in the Kuparuk Foothills and Umiat Corridor projects. *N* indicates number of months used in the analysis.

Soil Surface Temperature	DBM1 - Accomplishment Creek		DFM1 - South White Hills		DFM2 - White Hills		DFM3 - North White Hills		DFM4 - Northwest Kuparuk	
Period of Record	Aug/06 - Aug/13		Sept/06 - Oct/13		Aug/06 - Jun/13		Aug/07 - Oct/13		Oct/06 - Jul/13	
Month	(°C)	(°F)	(°C)	(°F)	(°C)	(°F)	(°C)	(°F)	(°C)	(°F)
October										
Maximum	-0.43	31.23	-0.48	31.14	3.15	37.68	-0.38	31.32	-0.01	31.98
Average	-2.01	28.38	-0.92	30.35	-5.51	22.09	-1.42	29.44	-0.26	31.52
Minimum	-4.09	24.63	-1.58	29.16	-13.06	8.50	-3.63	25.47	-0.76	30.64
n[1]	7		8		4		5		7	
November										
Maximum	-2.18	28.08	-0.96	30.27	-3.76	25.24	-2.00	28.40	-0.27	31.52
Average	-4.10	24.62	-2.19	28.05	-12.62	9.29	-6.14	20.94	-1.33	29.61
Minimum	-6.09	21.04	-3.83	25.11	-19.63	-3.33	-11.99	10.43	-2.97	26.65
n	7		7		4		5		7	
December										
Maximum	-3.50	25.70	-2.38	27.72	-3.98	24.83	-8.22	17.20	-2.36	27.74
Average	-6.28	20.70	-4.26	24.34	-15.85	3.48	-13.10	8.43	-4.70	23.54
Minimum	-9.34	15.19	-6.69	19.96	-25.29	-13.53	-18.46	-1.22	-7.95	17.69
n	7		7		4		5		7	
January										
Maximum	-6.59	20.14	-5.50	22.11	-5.80	21.56	-12.27	9.91	-7.46	18.57
Average	-9.98	14.03	-7.71	18.13	-20.99	-5.79	-19.20	-2.57	-10.23	13.59
Minimum	-13.35	7.97	-10.10	13.82	-31.36	-24.45	-24.09	-11.36	-13.01	8.58
n	7		7		4		4		7	
February										
Maximum	-8.08	17.46	-7.97	17.65	-7.82	17.93	-16.07	3.07	-10.52	13.06
Average	-11.88	10.61	-10.48	13.13	-21.62	-6.92	-20.61	-5.10	-12.68	9.18
Minimum	-15.92	3.35	-12.97	8.65	-31.33	-24.39	-24.72	-12.50	-14.85	5.27
n	7		7		4		4		7	
March										
Maximum	-10.78	12.60	-11.17	11.90	-5.08	22.86	-18.07	-0.53	-12.48	9.53
Average	-13.39	7.90	-12.86	8.85	-23.14	-9.66	-21.89	-7.41	-14.29	6.27
Minimum	-16.41	2.46	-14.09	6.63	-32.90	-27.22	-24.93	-12.87	-15.55	4.01
n	7		7		4		4		7	
April										
Maximum	-5.06	22.89	-7.81	17.95	11.09	51.96	-7.69	18.16	-8.99	15.81
Average	-9.70	14.55	-10.72	12.71	-10.04	13.92	-14.47	5.96	-11.77	10.81
Minimum	-13.61	7.50	-13.00	8.61	-21.76	-7.17	-19.52	-3.14	-14.02	6.76
n	7		7		4		4		7	
May										
Maximum	4.04	39.27	1.34	34.42	26.10	78.98	3.41	38.13	-1.58	29.16
Average	-4.05	24.72	-5.21	22.62	-0.71	30.72	-5.43	22.23	-6.68	19.98
Minimum	-7.92	17.75	-8.54	16.63	-14.73	5.48	-10.59	12.94	-9.66	14.62
n	7		7		4		4		7	
June										
Maximum	10.09	50.16	9.96	49.93	33.57	92.42	10.79	51.41	4.88	40.78
Average	4.70	40.47	3.60	38.47	11.79	53.23	3.95	39.11	0.92	33.66
Minimum	-0.08	31.86	-1.15	29.92	-3.28	26.10	-0.50	31.09	-1.76	28.82
n	7		7		4		4		7	
July										
Maximum	15.13	59.24	12.25	54.04	35.15	95.26	14.02	57.23	7.62	45.71
Average	8.53	47.36	7.85	46.13	14.37	57.87	7.86	46.15	4.67	40.40
Minimum	2.33	36.19	3.56	38.41	0.53	32.95	3.20	37.75	1.84	35.32
n	7		8		4		5		7	
August										
Maximum	7.32	45.18	6.30	43.35	20.57	69.02	7.22	44.99	4.86	40.75
Average	0.80	33.44	1.59	34.86	3.32	37.98	1.88	35.38	1.76	35.16
Minimum	-2.16	28.12	-0.92	30.35	-6.17	20.89	-0.83	30.51	-0.20	31.64
n	8		8		4		5		6	
September										
Maximum	7.32	45.18	6.30	43.35	20.57	69.02	7.22	44.99	4.86	40.75
Average	0.80	33.44	1.59	34.86	3.32	37.98	1.88	35.38	1.76	35.16
Minimum	-2.16	28.12	-0.92	30.35	-6.17	20.89	-0.83	30.51	-0.20	31.64
n	7		8		5		5		7	

Soil Surface Temperature	DUM1 - Itikmalakpak		DUM2 - Upper May Creek		DUM3 - Nanushuk		DUM4 - Tuluga		DUM5 - Encampment Creek	
Period of Record	Jun/09 - Aug/13		Aug/09 - Aug/13		Jun/09 - Aug/13		Jun/09 - Aug/13		Sept/10 - Aug/13	
Month	(°C)	(°F)	(°C)	(°F)	(°C)	(°F)	(°C)	(°F)	(°C)	(°F)
October										
Maximum	1.30	34.34	2.48	36.46	0.19	32.34	-0.38	31.32	-0.17	31.70
Average	0.00	32.00	-4.29	24.28	-0.99	30.22	-1.32	29.62	-2.00	28.40
Minimum	-4.92	23.14	-9.25	15.35	-2.25	27.95	-2.82	26.92	-4.17	24.49
n[1]	4		4		4		3		3	
November										
Maximum	-2.21	28.03	-4.80	23.36	-0.69	30.76	-0.65	30.83	-2.63	27.26
Average	0.00	32.00	-12.25	9.96	-2.08	28.26	-2.21	28.02	-6.68	19.98
Minimum	-4.91	23.17	-20.81	-5.46	-3.60	25.52	-4.04	24.74	-10.51	13.09
n	4		4		4		3		3	
December										
Maximum	-3.97	24.85	-7.41	18.67	-2.04	28.33	-1.91	28.56	-7.28	18.90
Average	0.00	32.00	-18.29	-0.92	-3.61	25.50	-4.04	24.73	-10.86	12.45
Minimum	-7.74	18.06	-27.89	-18.20	-5.44	22.22	-6.52	20.26	-14.38	6.11
n	4		4		4		3		3	
January										
Maximum	-5.49	22.13	-10.38	13.32	-3.77	25.21	-3.59	25.54	-11.02	12.17
Average	0.00	32.00	-21.40	-6.52	-5.26	22.53	-5.53	22.05	-16.15	2.93
Minimum	-9.55	14.80	-32.90	-27.22	-6.89	19.60	-7.82	17.93	-24.66	-12.38
n	4		4		4		3		3	
February										
Maximum	-6.52	20.27	-6.48	20.33	-5.10	22.82	-3.65	25.43	-10.63	12.86
Average	0.00	32.00	-18.93	-2.08	-6.85	19.67	-5.58	21.96	-16.86	1.65
Minimum	-10.94	12.31	-32.30	-26.15	-9.24	15.38	-7.59	18.33	-25.56	-14.01
n	4		4		4		3		3	
March										
Maximum	-7.35	18.77	-12.47	9.56	-7.19	19.05	-6.64	20.06	-12.60	9.32
Average	0.00	32.00	-19.12	-2.42	-8.46	16.76	-7.80	17.96	-18.12	-0.62
Minimum	-11.79	10.78	-26.35	-15.42	-9.73	14.49	-9.17	15.50	-21.31	-6.36
n	4		4		4		3		3	
April										
Maximum	-3.80	25.16	3.70	38.67	-3.92	24.94	-4.40	24.08	-4.84	23.29
Average	0.00	32.00	-12.29	9.88	-6.91	19.56	-6.22	20.80	-11.22	11.80
Minimum	-10.09	13.83	-22.32	-8.18	-9.21	15.42	-8.52	16.66	-18.95	-2.10
n	4		4		4		4		3	
May										
Maximum	19.71	67.47	27.16	80.88	4.29	39.72	7.75	45.95	12.03	53.65
Average	0.00	32.00	0.83	33.50	-2.71	27.12	-1.91	28.56	-3.37	25.93
Minimum	-5.59	21.93	-14.45	5.99	-5.70	21.74	-4.95	23.10	-10.21	13.62
n	4		4		4		4		3	
June										
Maximum	34.09	93.36	32.06	89.71	21.37	70.47	23.46	74.23	19.39	66.90
Average	0.00	32.00	11.91	53.44	7.19	44.94	8.15	46.67	7.58	45.64
Minimum	-1.62	29.08	-2.43	27.63	0.40	32.72	-0.66	30.81	-0.32	31.42
n	5		4		5		5		3	
July										
Maximum	34.12	93.42	31.83	89.30	24.77	76.58	22.17	71.90	18.18	64.72
Average	0.00	32.00	11.16	52.08	10.06	50.11	10.39	50.70	9.10	48.38
Minimum	0.58	33.04	-0.06	31.90	1.30	34.33	1.34	34.42	2.88	37.18
n	5		4		5		5		3	
August										
Maximum	16.21	61.17	17.02	62.63	14.65	58.38	11.34	52.41	10.53	50.95
Average	0.00	32.00	0.53	32.95	2.33	36.19	1.77	35.18	1.89	35.40
Minimum	-4.64	23.64	-7.77	18.01	-2.04	28.32	-3.69	25.35	-2.01	28.38
n	5		5		5		5		3	
September										
Maximum	16.21	61.17	17.02	62.63	14.65	58.38	11.34	52.41	10.53	50.95
Average	0.00	32.00	0.53	32.95	2.33	36.19	1.77	35.18	1.89	35.40
Minimum	-4.64	23.64	-7.77	18.01	-2.04	28.32	-3.69	25.35	-2.01	28.38
n	4		4		4		4		3	

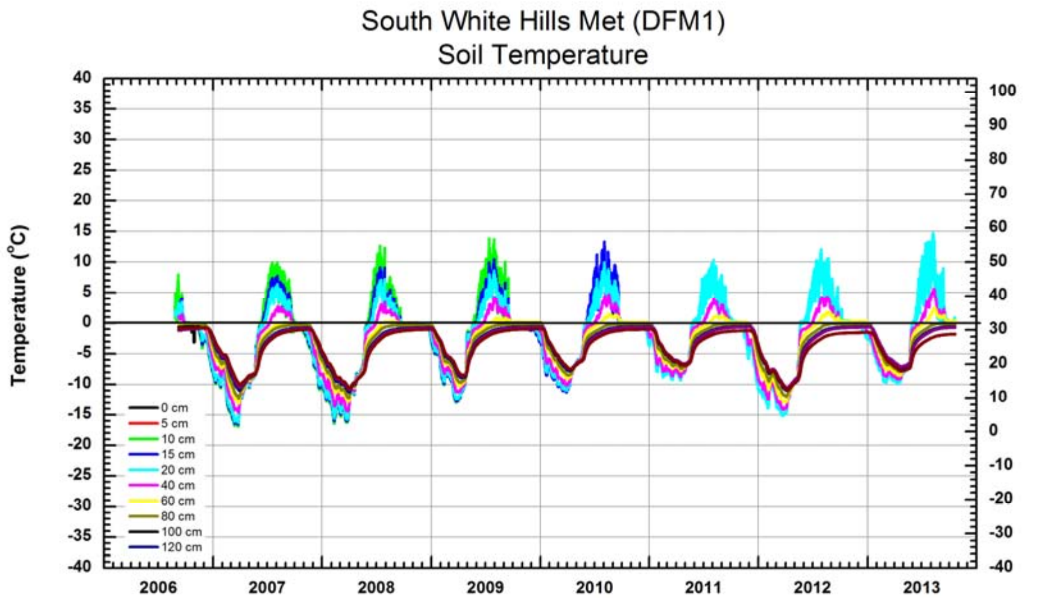
Soil Surface Temperature	DUM6 - White Lake		DUM7 - Hatbox Mesa		DUM8 - Siksikpuk		DUS2 - Anaktuvuk River		DUS3 - Chandler River	
Period of Record	Sept/10 - Aug/13		Sept/10 - Aug/13		Sept/10 - Aug/13		Jun/09 - Aug/13		May/09 - Aug/13	
Month	(°C)	(°F)	(°C)	(°F)	(°C)	(°F)	(°C)	(°F)	(°C)	(°F)
October										
Maximum	-0.96	30.28	0.32	32.58	0.00	32.01	0.36	32.65	0.22	32.40
Average	-2.02	28.36	-0.24	31.57	-0.19	31.67	-2.36	27.75	-1.46	29.37
Minimum	-3.82	25.12	-0.86	30.46	-0.46	31.18	-6.88	19.62	-4.16	24.50
n[1]	3		1		3		4		4	
November										
Maximum	-2.26	27.93	-0.25	31.56	-0.09	31.85	-1.19	29.86	-0.81	30.55
Average	-4.59	23.73	-0.52	31.06	-0.48	31.14	-6.22	20.81	-3.31	26.04
Minimum	-7.57	18.37	-1.04	30.12	-1.13	29.97	-12.20	10.05	-7.35	18.78
n	3		1		3		4		4	
December										
Maximum	-4.90	23.18	-0.71	30.73	-0.59	30.95	-5.15	22.72	-4.31	24.24
Average	-7.40	18.68	-1.30	29.66	-1.22	29.81	-12.64	9.26	-7.29	18.87
Minimum	-10.71	12.73	-2.13	28.16	-2.10	28.23	-19.38	-2.88	-11.17	11.90
n	3		1		3		4		4	
January										
Maximum	-6.53	20.24	-1.86	28.65	-2.10	28.21	-10.66	12.81	-8.31	17.04
Average	-10.08	13.86	-2.95	26.70	-3.31	26.04	-15.96	3.28	-12.32	9.83
Minimum	-14.70	5.54	-4.56	23.78	-5.63	21.88	-21.96	-7.52	-15.65	3.84
n	3		0		3		4		2	
February										
Maximum	-8.53	16.65	-3.45	25.79	-4.67	23.59	-11.93	10.53	-11.71	10.91
Average	-11.30	11.66	-4.66	23.61	-5.89	21.40	-15.76	3.62	-15.07	4.87
Minimum	-16.97	1.46	-6.45	20.39	-7.22	19.00	-20.49	-4.88	-17.03	1.35
n	3		0		3		4		3	
March										
Maximum	-9.91	14.16	-5.59	21.95	-6.56	20.20	-13.68	7.37	-13.43	7.83
Average	-12.26	9.93	-6.76	19.83	-7.54	18.42	-16.01	3.18	-14.69	5.55
Minimum	-14.40	6.07	-7.76	18.04	-8.26	17.14	-18.93	-2.07	-16.10	3.02
n	3		0		3		4		3	
April										
Maximum	-7.69	18.16	-5.89	21.39	-6.11	21.00	-8.22	17.20	-9.65	14.63
Average	-10.75	12.66	-7.00	19.41	-7.19	19.06	-12.77	9.01	-12.92	8.74
Minimum	-14.22	6.40	-7.99	17.62	-8.15	17.33	-17.48	0.54	-15.92	3.35
n	3		0		3		4		2	
May										
Maximum	4.51	40.12	2.90	37.21	0.30	32.53	6.61	43.90	11.11	52.00
Average	-4.75	23.46	-3.45	25.80	-3.66	25.41	-4.82	23.33	-3.70	25.35
Minimum	-9.27	15.32	-6.22	20.81	-6.22	20.80	-10.40	13.27	-7.80	17.96
n	3		0		3		4		4	
June										
Maximum	13.65	56.57	16.77	62.18	10.25	50.44	26.72	80.09	25.87	78.56
Average	5.59	42.07	5.34	41.61	4.19	39.55	8.10	46.58	8.78	47.80
Minimum	-0.99	30.22	-0.72	30.71	-0.40	31.28	-1.13	29.97	-0.31	31.44
n	3		0		3		5		5	
July										
Maximum	13.53	56.35	15.48	59.86	10.89	51.61	31.78	89.21	27.66	81.79
Average	7.47	45.44	7.93	46.27	7.83	46.09	12.10	53.77	12.07	53.73
Minimum	1.69	35.05	1.77	35.19	3.95	39.12	0.11	32.21	2.33	36.20
n	3		0		3		5		5	
August										
Maximum	6.58	43.84	10.03	50.06	6.43	43.57	19.43	66.97	16.60	61.88
Average	0.63	33.13	2.34	36.22	1.85	35.32	3.05	37.49	3.24	37.83
Minimum	-1.86	28.64	-0.57	30.97	-0.06	31.90	-3.33	26.01	-2.22	28.01
n	3		0		3		5		5	
September										
Maximum	6.58	43.84	10.03	50.06	6.43	43.57	19.43	66.97	16.60	61.88
Average	0.63	33.13	2.34	36.22	1.85	35.32	3.05	37.49	3.24	37.83
Minimum	-1.86	28.64	-0.57	30.97	-0.06	31.90	-3.33	26.01	-2.22	28.01
n	3		1		3		4		4	

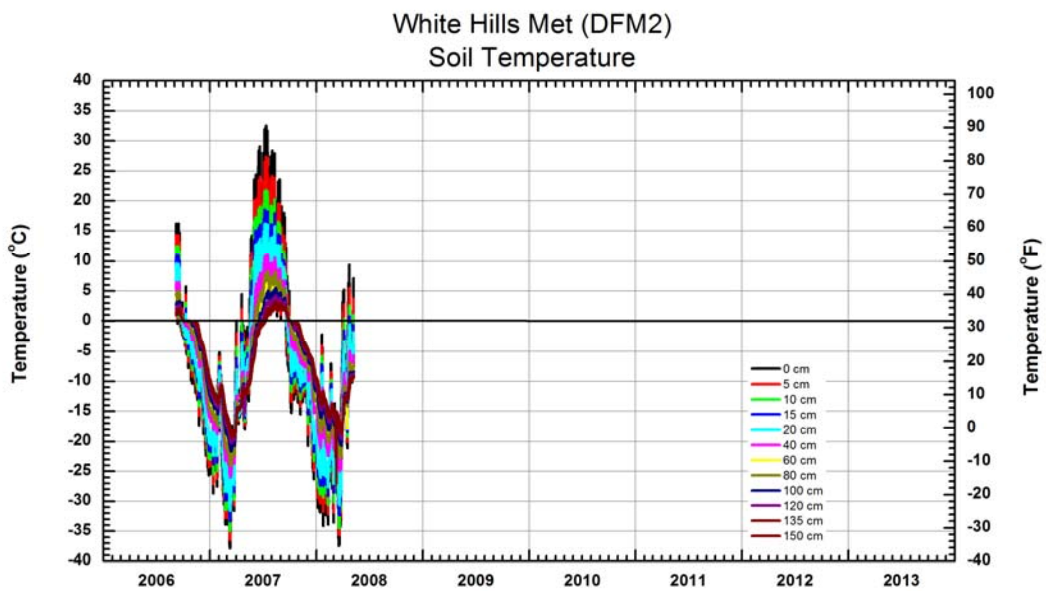
Unfrozen soil water content (volume fraction) summary (in cm^3/cm^3) at 10, 20, 30, or 40 cm below ground surface (bgs) for stations in the Kuparuk Foothills and Umiat Corridor projects. *N* indicates number of months used in the analysis.

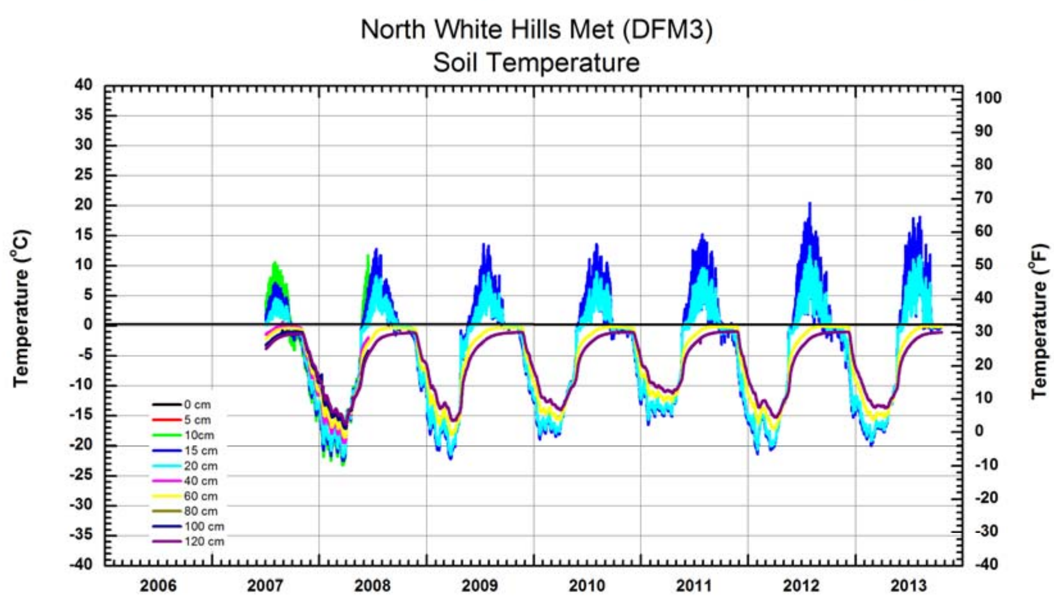
Soil Water Content (cm^3/cm^3)	**S. White Hills DFM1**			**White Hills DFM2**			**N. White Hills DFM3**			**Northwest Kuparuk DFM4**			**Itikmalakpak DUM1**			
Period of Record	**Aug/06 - Aug/13**			**Aug/06 - Jun/13**			**Aug/07 - Aug/13**			**Oct/06 - Jul/13**			**Sept/09 - Aug/13**			
Month	10-cm bgs	20-cm bgs	40-cm bgs	10-cm bgs	20-cm bgs	40-cm bgs	10-cm bgs	20-cm bgs	40-cm bgs	10-cm bgs	20-cm bgs	46-cm bgs	10-cm bgs	20-cm bgs	30-cm bgs	40-cm bgs
October																
Maximum	0.46	0.55	0.53	0.04	0.04	0.04	0.44	0.44	0.18	0.70	0.34	0.61	0.44	0.48	0.52	0.55
Average	0.40	0.51	0.51	0.02	0.02	0.03	0.40	0.42	0.13	0.34	0.32	0.48	0.46	0.48	0.41	0.00
Minimum	0.32	0.46	0.48	0.02	0.02	0.02	0.33	0.35	0.11	0.14	0.29	0.34	0.37	0.42	0.40	0.26
n	8	8	8	8	4	4	7	7	7	7	7	7	4	4	4	4
November																
Maximum	0.29	0.44	0.47	0.02	0.02	0.03	0.35	0.37	0.11	0.14	0.29	0.34	0.36	0.41	0.37	0.18
Average	0.20	0.35	0.42	0.02	0.02	0.02	0.23	0.27	0.10	0.11	0.21	0.25	0.29	0.26	0.14	0.00
Minimum	0.10	0.27	0.35	0.02	0.02	0.02	0.10	0.12	0.08	0.10	0.14	0.17	0.22	0.22	0.20	0.12
n	7	7	7	7	4	4	6	6	6	7	7	7	4	4	4	4
December																
Maximum	0.11	0.27	0.35	0.02	0.02	0.02	0.10	0.14	0.08	0.10	0.14	0.17	0.21	0.21	0.20	0.12
Average	0.09	0.18	0.30	0.02	0.02	0.02	0.09	0.10	0.07	0.08	0.10	0.13	0.18	0.18	0.11	0.00
Minimum	0.08	0.12	0.24	0.01	0.01	0.02	0.08	0.09	0.07	0.07	0.09	0.10	0.15	0.16	0.17	0.11
n	7	7	7	7	4	4	6	6	6	7	7	7	4	4	4	4
January																
Maximum	0.09	0.12	0.24	0.02	0.02	0.02	0.08	0.09	0.06	0.07	0.09	0.10	0.15	0.16	0.17	0.11
Average	0.08	0.11	0.18	0.01	0.01	0.02	0.08	0.09	0.06	0.07	0.08	0.09	0.15	0.16	0.10	0.00
Minimum	0.08	0.10	0.15	0.01	0.01	0.02	0.07	0.08	0.06	0.06	0.07	0.08	0.13	0.15	0.15	0.10
n	7	7	7	4	4	4	6	6	6	7	7	7	4	4	4	4
February																
Maximum	0.08	0.10	0.15	0.02	0.02	0.02	0.07	0.08	0.06	0.07	0.08	0.09	0.13	0.15	0.16	0.10
Average	0.07	0.10	0.14	0.01	0.01	0.02	0.07	0.08	0.06	0.06	0.07	0.08	0.14	0.15	0.10	0.00
Minimum	0.07	0.09	0.13	0.01	0.01	0.02	0.07	0.08	0.06	0.06	0.07	0.08	0.12	0.13	0.14	0.09
n	7	7	7	4	4	4	6	6	6	7	7	7	4	4	4	4
March																
Maximum	0.07	0.09	0.13	0.01	0.02	0.02	0.07	0.08	0.06	0.06	0.07	0.08	0.12	0.13	0.14	0.09
Average	0.07	0.09	0.13	0.01	0.01	0.02	0.07	0.08	0.06	0.06	0.07	0.08	0.13	0.14	0.09	0.00
Minimum	0.07	0.09	0.12	0.01	0.01	0.02	0.07	0.08	0.06	0.06	0.07	0.08	0.11	0.13	0.14	0.09
n	7	7	7	4	4	4	6	6	6	7	7	7	4	4	4	4
April																
Maximum	0.07	0.10	0.13	0.03	0.03	0.03	0.08	0.09	0.06	0.07	0.08	0.08	0.12	0.13	0.14	0.09
Average	0.07	0.09	0.13	0.02	0.02	0.02	0.07	0.08	0.06	0.06	0.07	0.08	0.13	0.14	0.09	0.00
Minimum	0.07	0.09	0.12	0.01	0.01	0.02	0.07	0.08	0.06	0.06	0.07	0.08	0.11	0.13	0.14	0.09
n	7	7	7	4	4	4	6	6	6	7	7	7	4	4	4	4
May																
Maximum	0.23	0.13	0.17	0.06	0.05	0.06	0.10	0.11	0.07	0.15	0.09	0.10	0.17	0.20	0.29	0.31
Average	0.10	0.11	0.14	0.03	0.03	0.03	0.09	0.09	0.06	0.08	0.08	0.09	0.15	0.17	0.14	0.00
Minimum	0.07	0.10	0.13	0.02	0.02	0.03	0.08	0.09	0.06	0.06	0.08	0.08	0.12	0.13	0.14	0.09
n	7	7	7	3	3	3	6	6	6	7	7	7	4	4	4	4
June																
Maximum	0.56	0.57	0.46	0.05	0.05	0.07	0.45	0.17	0.08	0.85	0.24	0.12	0.55	0.61	0.65	0.73
Average	0.46	0.36	0.24	0.04	0.03	0.04	0.17	0.13	0.07	0.54	0.13	0.11	0.42	0.49	0.55	0.00
Minimum	0.22	0.13	0.17	0.03	0.03	0.03	0.11	0.12	0.07	0.15	0.09	0.09	0.16	0.20	0.26	0.29
n	7	7	7	3	3	3	5	5	6	7	7	7	4	4	4	4
July																
Maximum	0.55	0.58	0.55	0.05	0.05	0.05	0.45	0.44	0.15	0.84	0.36	0.61	0.54	0.59	0.63	0.69
Average	0.53	0.57	0.53	0.04	0.03	0.04	0.45	0.40	0.09	0.79	0.33	0.29	0.55	0.59	0.61	0.00
Minimum	0.51	0.55	0.46	0.03	0.03	0.03	0.43	0.18	0.08	0.74	0.23	0.11	0.47	0.52	0.56	0.57
n	7	6	7	2	3	3	4	6	7	6	7	7	4	4	4	4
August																
Maximum	0.54	0.57	0.54	0.05	0.05	0.06	0.45	0.44	0.47	0.81	0.35	0.64	0.53	0.57	0.60	0.60
Average	0.52	0.57	0.54	0.04	0.04	0.04	0.44	0.43	0.33	0.78	0.34	0.63	0.52	0.56	0.57	0.00
Minimum	0.51	0.55	0.53	0.03	0.03	0.04	0.43	0.42	0.16	0.76	0.33	0.61	0.46	0.50	0.54	0.55
n	6	6	7	3	3	3	5	6	7	6	6	6	4	4	4	4
September																
Maximum	0.52	0.56	0.54	0.04	0.04	0.05	0.45	0.45	0.47	0.82	0.35	0.64	0.50	0.54	0.57	0.60
Average	0.50	0.56	0.53	0.03	0.03	0.04	0.44	0.44	0.36	0.80	0.34	0.63	0.51	0.55	0.58	0.00
Minimum	0.45	0.55	0.53	0.02	0.02	0.03	0.42	0.43	0.18	0.69	0.34	0.60	0.44	0.48	0.52	0.55
n	7	8	8	4	4	4	7	7	7	7	7	7	4	4	4	4

Soil Water Content (cm^3/cm^3)	**Nanushuk DUM3**				**Tuluga DUM4**				**Hat Box Mesa DUM7**				**Siksikpuk DUM8**			**Anaktuvuk River DUS2**			
Period of Record	**Sept/09 - Aug/13**				**Sept/09 - Aug/13**				**Sept/09 - Aug/13**				**Sept/10 - Aug/13**			**Sept/09 - Aug/13**			
Month	10-cm bgs	20-cm bgs	30-cm bgs	40-cm bgs	10-cm bgs	20-cm bgs	30-cm bgs	40-cm bgs	10-cm bgs	20-cm bgs	30-cm bgs	40-cm bgs	10-cm bgs	20-cm bgs	30-cm bgs	10-cm bgs	20-cm bgs	30-cm bgs	40-cm bgs
October																			
Maximum	0.26	0.23	0.21	0.24	0.43	0.47	0.50	0.30	0.63	0.82			0.44	0.59	0.92	0.64	0.81	0.64	0.36
Average	0.21	0.20	0.18	0.19	0.41	0.45	0.43	0.22	0.62	0.81			0.44	0.57	0.77	0.57	0.81	0.56	0.23
Minimum	0.17	0.17	0.15	0.15	0.37	0.40	0.35	0.13	0.61				0.43	0.53	0.49	0.52	0.81	0.48	0.14
n	4	4	4	4	3	3	3	3	3	2			3	3	3	4	4	4	4
November																			
Maximum	0.18	0.18	0.15	0.16	0.37	0.40	0.36	0.14	0.62	0.81			0.43	0.55	0.70	0.53	0.81	0.49	0.14
Average	0.15	0.14	0.12	0.11	0.34	0.34	0.30	0.07	0.61	0.79			0.42	0.51	0.51	0.23	0.66	0.37	0.11
Minimum	0.11	0.11	0.09	0.09	0.31	0.30	0.26	0.04	0.60				0.39	0.43	0.24	0.07	0.35	0.23	0.10
n	4	4	4	4	3	3	3	3	3	2			3	3	3	4	4	4	4
December																			
Maximum	0.11	0.11	0.09	0.10	0.31	0.30	0.26	0.04	0.60	0.77			0.39	0.43	0.23	0.07	0.35	0.23	0.10
Average	0.10	0.10	0.08	0.09	0.28	0.27	0.21	0.03	0.57	0.70			0.35	0.32	0.12	0.05	0.13	0.12	0.07
Minimum	0.09	0.09	0.08	0.08	0.24	0.22	0.15	0.02	0.51				0.30	0.21	0.10	0.05	0.06	0.06	0.05
n	4	4	4	4	3	3	3	3	3	2			3	3	3	4	4	4	4
January																			
Maximum	0.09	0.09	0.08	0.09	0.24	0.22	0.15	0.02	0.51	0.48			0.28	0.12	0.09	0.05	0.06	0.06	0.05
Average	0.09	0.09	0.08	0.08	0.20	0.18	0.12	0.02	0.43	0.30			0.17	0.09	0.08	0.04	0.06	0.06	0.05
Minimum	0.08	0.08	0.07	0.08	0.16	0.14	0.10	0.01	0.36				0.10	0.07	0.07	0.04	0.06	0.06	0.05
n	4	4	4	4	3	3	3	3	3	2			3	3	3	4	4	4	4
February																			
Maximum	0.08	0.08	0.07	0.08	0.16	0.14	0.10	0.02	0.36	0.17			0.10	0.07	0.07	0.04	0.06	0.06	0.05
Average	0.08	0.08	0.07	0.08	0.14	0.13	0.09	0.01	0.18	0.15			0.09	0.07	0.07	0.04	0.06	0.06	0.05
Minimum	0.08	0.08	0.07	0.08	0.13	0.12	0.09	0.01	0.22				0.08	0.07	0.07	0.04	0.06	0.06	0.05
n	4	4	4	4	3	3	3	3	3	2			3	3	3	4	4	4	4
March																			
Maximum	0.08	0.08	0.07	0.08	0.13	0.12	0.09	0.01	0.22	0.15			0.08	0.07	0.07	0.04	0.06	0.06	0.05
Average	0.08	0.08	0.07	0.07	0.12	0.11	0.08	0.01	0.13	0.14			0.08	0.07	0.07	0.04	0.06	0.06	0.05
Minimum	0.07	0.07	0.07	0.07	0.11	0.11	0.08	0.01	0.14				0.08	0.06	0.06	0.04	0.06	0.06	0.04
n	4	4	4	4	3	3	3	3	3	2			3	3	3	4	4	4	4
April																			
Maximum	0.08	0.08	0.07	0.08	0.12	0.11	0.09	0.01	0.15	0.15			0.08	0.07	0.07	0.05	0.06	0.06	0.05
Average	0.08	0.08	0.07	0.07	0.11	0.11	0.08	0.01	0.13	0.15			0.08	0.06	0.06	0.04	0.06	0.06	0.05
Minimum	0.07	0.07	0.07	0.07	0.11	0.11	0.08	0.01	0.12				0.08	0.06	0.06	0.04	0.06	0.06	0.04
n	4	4	4	4	4	4	4	4	3	2			3	3	3	4	4	4	4
May																			
Maximum	0.09	0.10	0.10	0.11	0.14	0.14	0.13	0.18	0.13	0.16			0.09	0.08	0.09	0.07	0.08	0.07	0.06
Average	0.08	0.08	0.08	0.09	0.12	0.12	0.10	0.03	0.13	0.15			0.08	0.07	0.07	0.05	0.07	0.06	0.05
Minimum	0.08	0.08	0.07	0.08	0.12	0.11	0.09	0.01	0.12				0.08	0.06	0.06	0.05	0.06	0.06	0.05
n	4	4	4	4	4	4	4	4	3	2			3	3	3	4	4	4	4
June																			
Maximum	0.30	0.31	0.29	0.27	0.16	0.17	0.16	0.19	0.16	0.86			0.13	0.38	0.92	0.44	0.10	0.08	0.06
Average	0.15	0.17	0.17	0.20	0.15	0.15	0.13	0.07	0.14	0.31			0.10	0.13	0.38	0.19	0.09	0.08	0.06
Minimum	0.09	0.10	0.09	0.11	0.14	0.14	0.12	0.05	0.13				0.09	0.08	0.09	0.07	0.08	0.07	0.06
n	4	4	4	4	4	4	4	4	3	2			3	3	3	4	4	4	4
July																			
Maximum	0.36	0.36	0.35	0.30	0.44	0.49	0.36	0.38	0.64	0.84			0.45	0.59	0.00	0.65	0.79	0.33	0.08
Average	0.30	0.29	0.25	0.25	0.24	0.31	0.39	0.20	0.44	0.83			0.30	0.56	0.00	0.51	0.50	0.12	0.07
Minimum	0.23	0.23	0.21	0.24	0.16	0.17	0.16	0.14	0.16				0.12	0.36	0.00	0.43	0.10	0.08	0.06
n	4	4	4	4	4	4	4	4	3	2			3	3	2	4	4	4	4
August																			
Maximum	0.35	0.35	0.36	0.30	0.44	0.50	0.52	0.31	0.63	0.84			0.45	0.59	0.00	0.69	0.80	0.69	0.48
Average	0.28	0.27	0.24	0.26	0.43	0.48	0.51	0.22	0.63	0.83			0.44	0.59	0.00	0.55	0.79	0.61	0.31
Minimum	0.22	0.23	0.21	0.24	0.43	0.47	0.48	0.19	0.62				0.44	0.58	0.00	0.52	0.78	0.33	0.08
n	4	4	4	4	4	4	4	4	3	2			3	3	2	4	4	4	4
September																			
Maximum	0.28	0.29	0.29	0.27	0.43	0.47	0.51	0.31	0.64	0.84			0.44	0.59	0.95	0.65	0.81	0.68	0.52
Average	0.24	0.25	0.22	0.25	0.43	0.47	0.50	0.29	0.63	0.83			0.44	0.59	0.94	0.59	0.81	0.67	0.42
Minimum	0.21	0.23	0.21	0.24	0.42	0.47	0.49	0.27	0.63				0.44	0.59	0.94	0.57	0.80	0.63	0.33
n	4	4	4	4	4	4	4	4	3	1			3	3	2	4	4	4	4

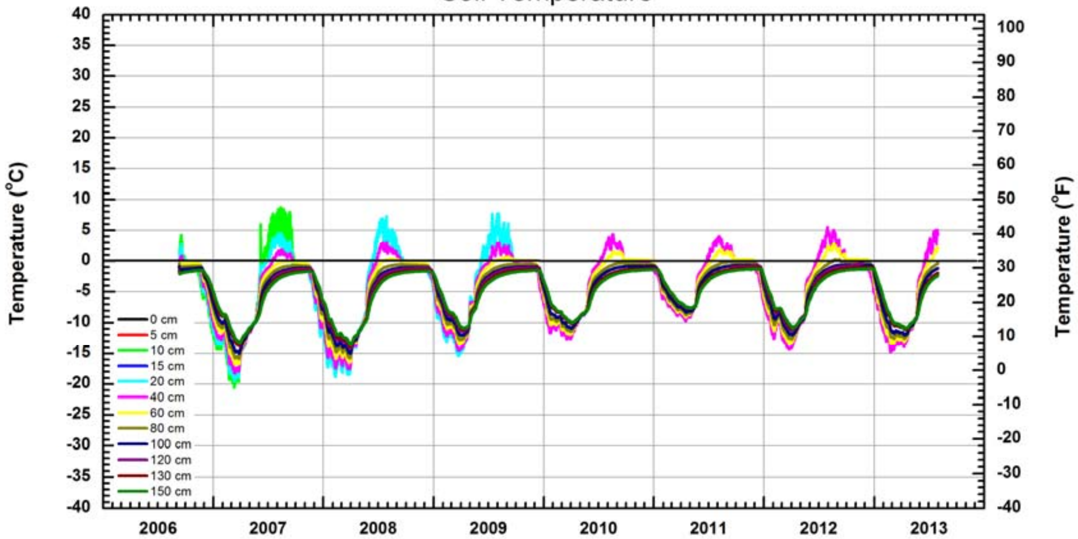
Soil temperature profiles from soil surface (0 cm) to approximately 150 cm below ground surface (bgs) for stations in the Kuparuk Foothills and Umiat Corridor projects:


South White Hills Met (DFM1)
Soil Temperature
Temperature (°C)
Temperature (°F)
0 cm
5 cm
10 cm
15 cm
20 cm
40 cm
60 cm
80 cm
100 cm
120 cm
2006
2007
2008
2009
2010
2011
2012
2013

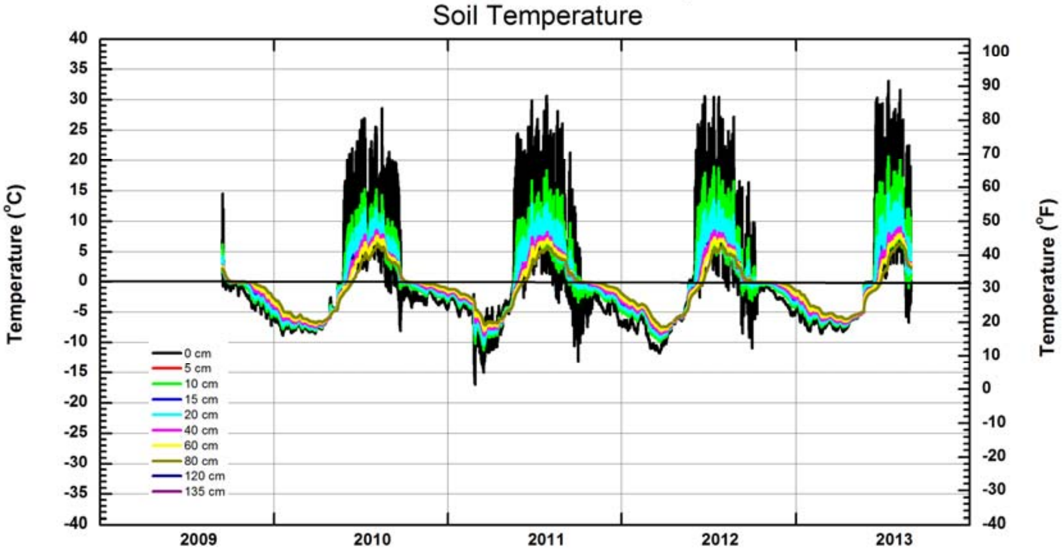

White Hills Met (DFM2)
Soil Temperature
Temperature (°C)
Temperature (°F)
0 cm
5 cm
10 cm
15 cm
20 cm
40 cm
60 cm
80 cm
100 cm
120 cm
135 cm
150 cm
2006
2007
2008
2009
2010
2011
2012
2013


North White Hills Met (DFM3)
Soil Temperature
Temperature (°C)
Temperature (°F)
0 cm
5 cm
10cm
15 cm
20 cm
40 cm
60 cm
80 cm
100 cm
120 cm
2006
2007
2008
2009
2010
2011
2012
2013

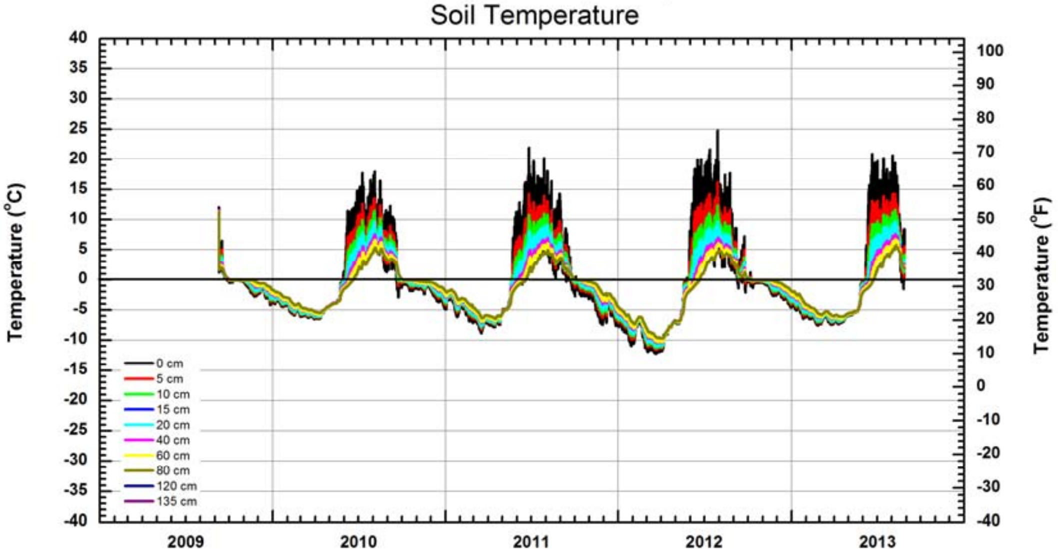
Northwest Kuparuk Met (DFM4)
Soil Temperature

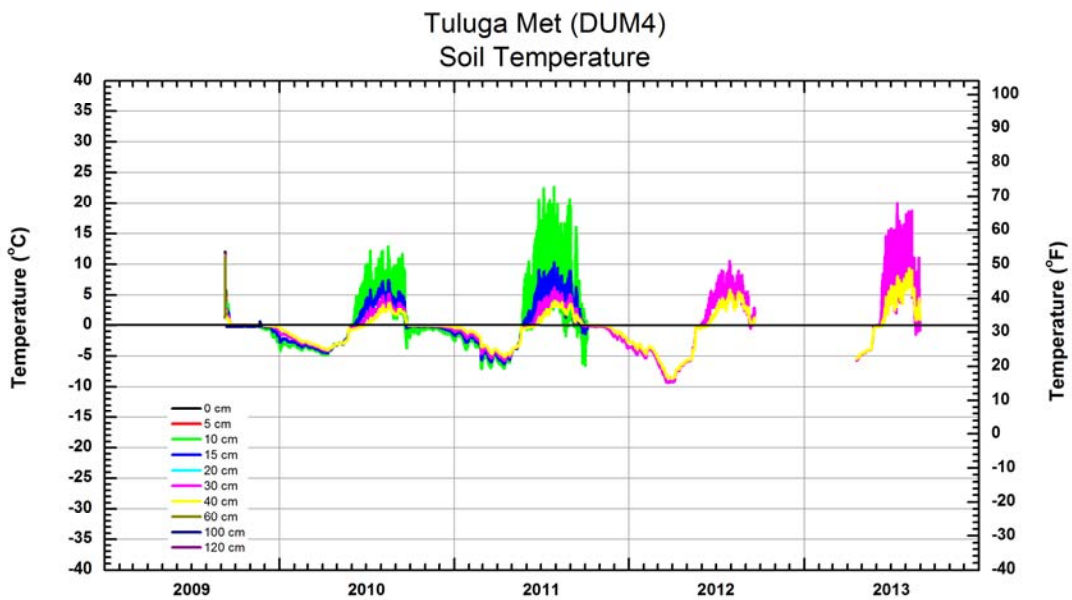


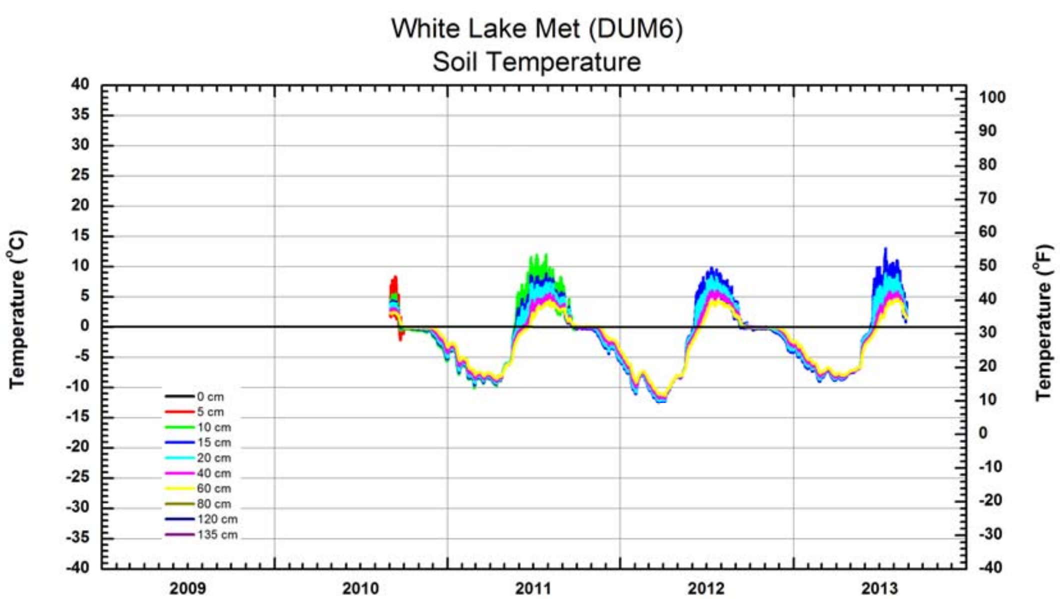
Itikmalakpak Met (DUM1)
Soil Temperature

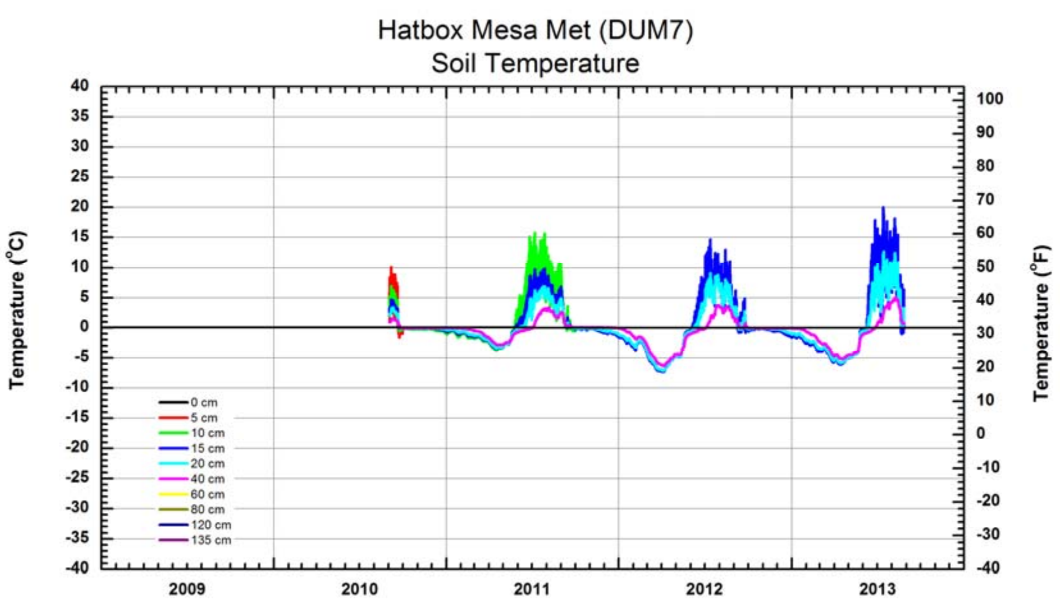


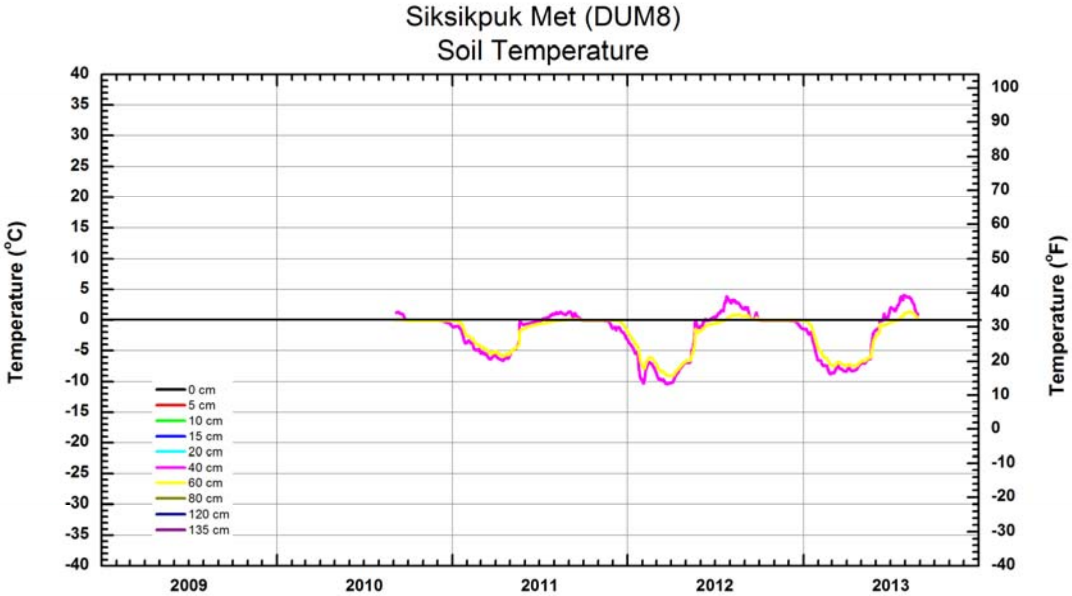
Nanushuk Met (DUM3)
Soil Temperature

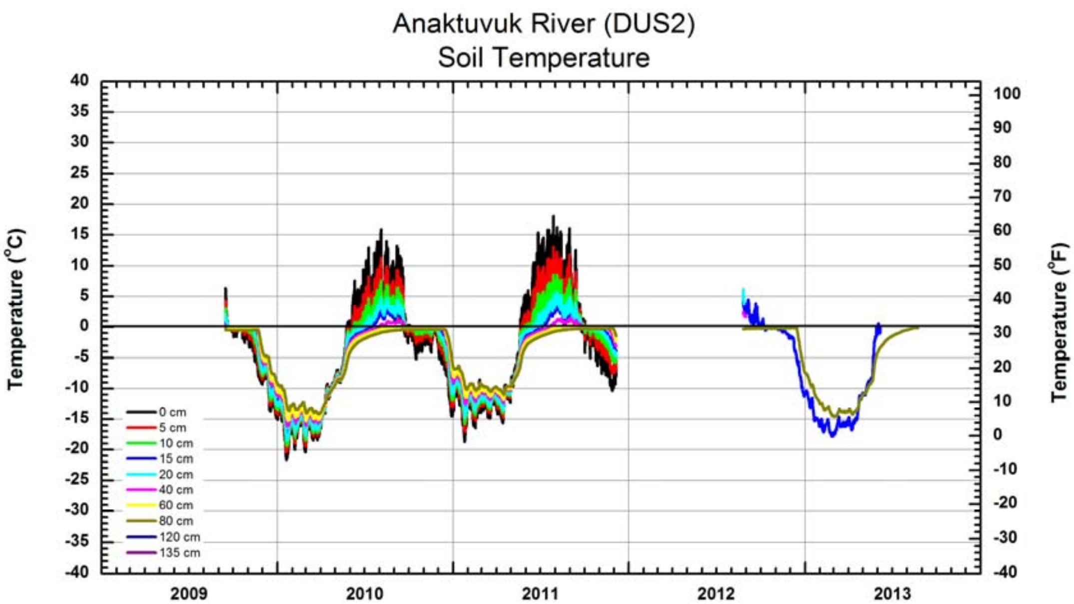



Tuluga Met (DUM4)
Soil Temperature
Temperature (°C)
Temperature (°F)
0 cm
5 cm
10 cm
15 cm
20 cm
30 cm
40 cm
60 cm
100 cm
120 cm
2009
2010
2011
2012
2013

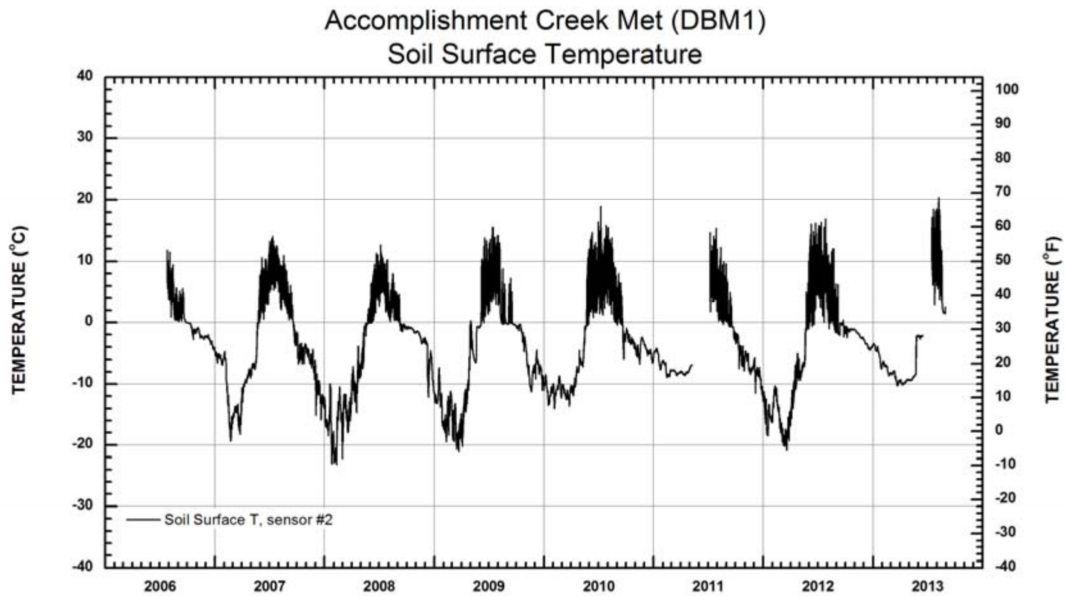

White Lake Met (DUM6)
Soil Temperature
Temperature (°C)
Temperature (°F)
0 cm
5 cm
10 cm
15 cm
20 cm
40 cm
60 cm
80 cm
120 cm
135 cm
2009
2010
2011
2012
2013

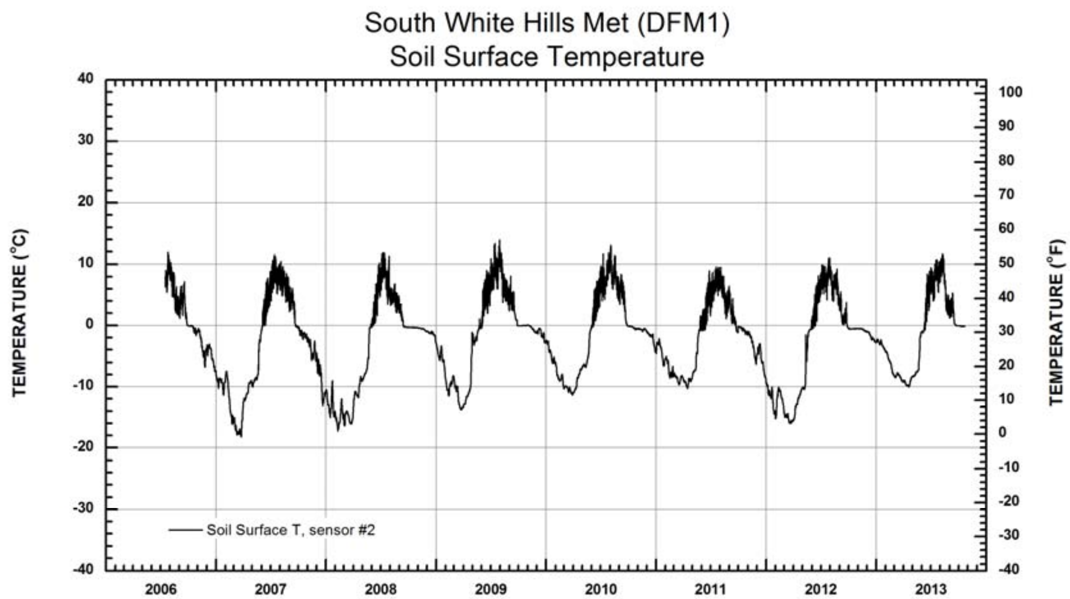

Hatbox Mesa Met (DUM7)
Soil Temperature
Temperature (°C)
Temperature (°F)
0 cm
5 cm
10 cm
15 cm
20 cm
40 cm
60 cm
80 cm
120 cm
135 cm
2009
2010
2011
2012
2013

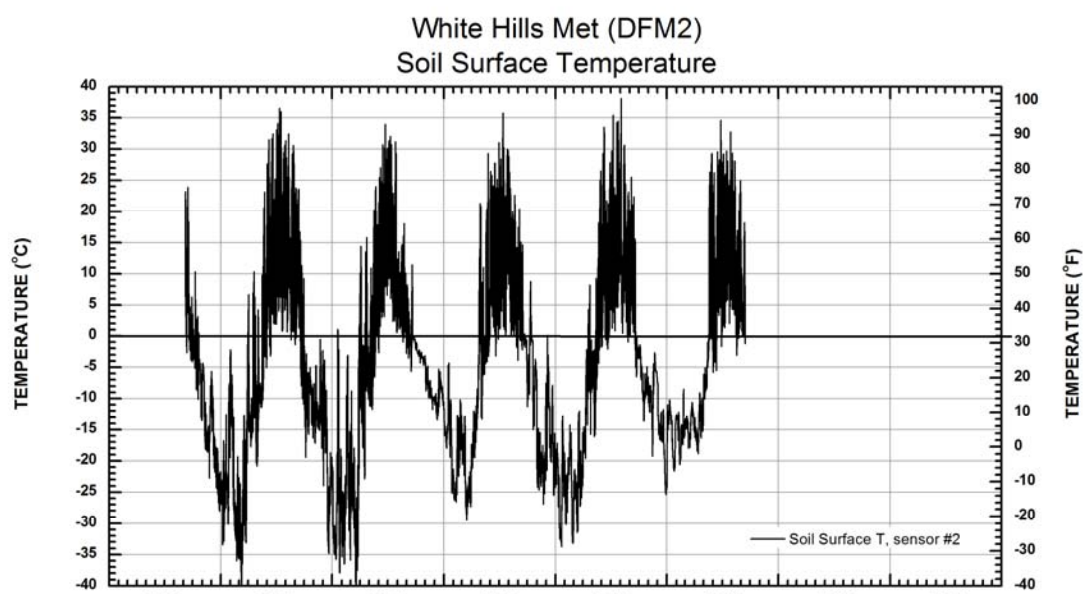

Siksikpuk Met (DUM8)
Soil Temperature
Temperature (°C)
Temperature (°F)
0 cm
5 cm
10 cm
15 cm
20 cm
40 cm
60 cm
80 cm
120 cm
135 cm
2009
2010
2011
2012
2013

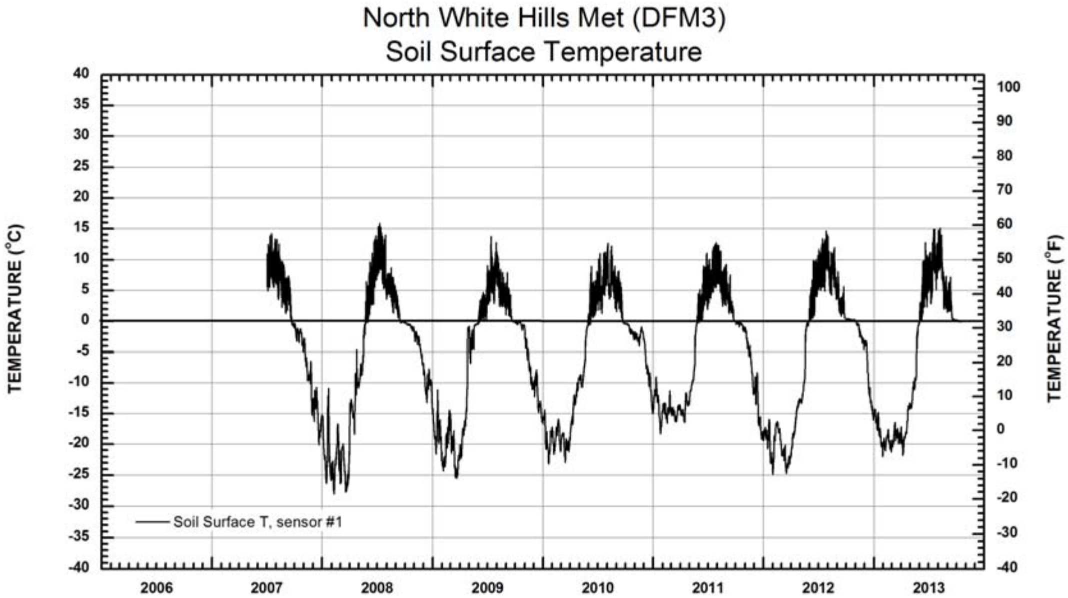

Anaktuvuk River (DUS2)
Soil Temperature
Temperature (°C)
Temperature (°F)
0 cm
5 cm
10 cm
15 cm
20 cm
40 cm
60 cm
80 cm
120 cm
135 cm
2009
2010
2011
2012
2013

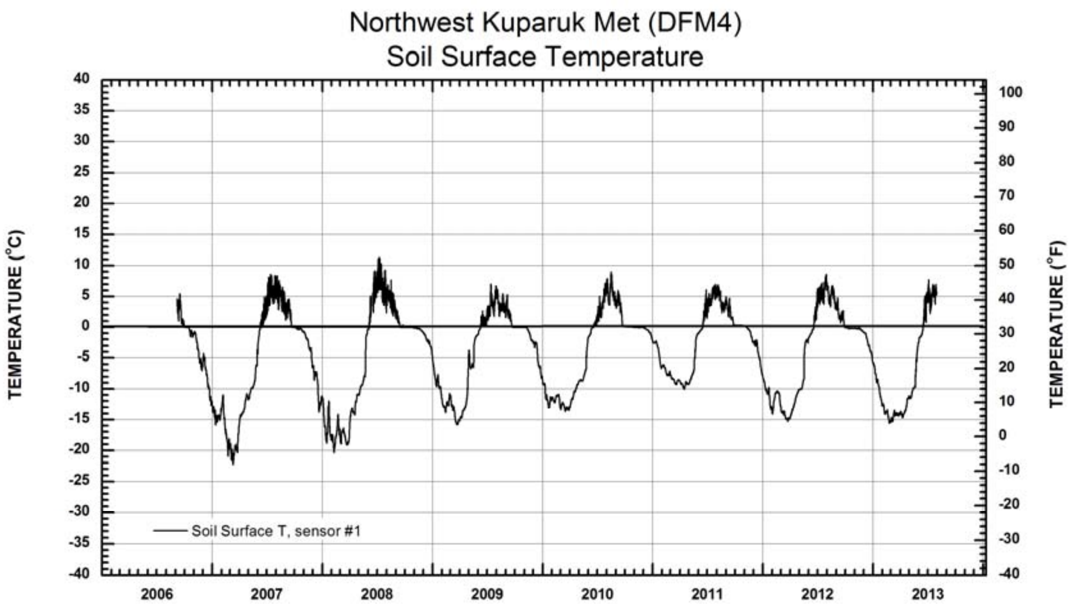
Soil surface temperature time series plots for stations in the Kuparuk Foothills and Umiat Corridor projects:

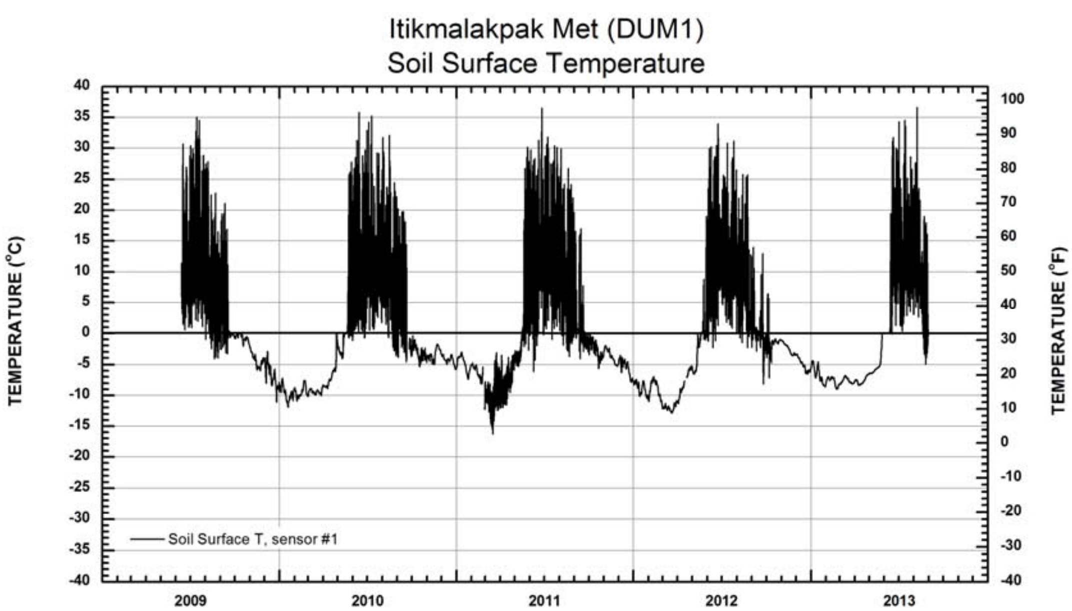

Accomplishment Creek Met (DBM1)
Soil Surface Temperature
TEMPERATURE (°C)
TEMPERATURE (°F)
Soil Surface T, sensor #2
40
30
20
10
0
-10
-20
-30
-40
100
90
80
70
60
50
40
30
20
10
0
-10
-20
-30
-40
2006
2007
2008
2009
2010
2011
2012
2013

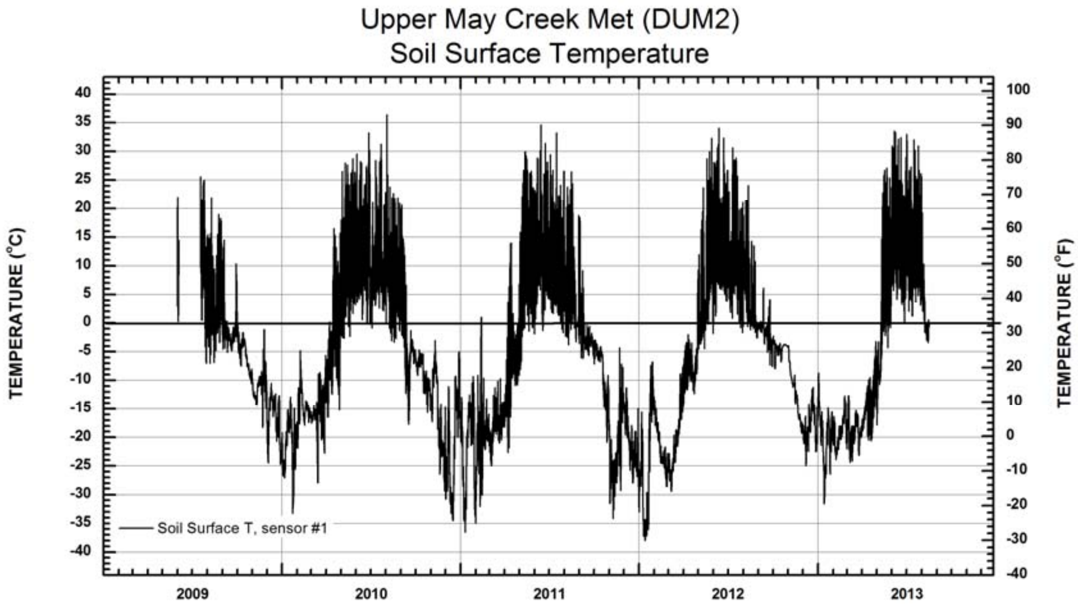

South White Hills Met (DFM1)
Soil Surface Temperature
TEMPERATURE (°C)
TEMPERATURE (°F)
Soil Surface T, sensor #2
40
30
20
10
0
-10
-20
-30
-40
100
90
80
70
60
50
40
30
20
10
0
-10
-20
-30
-40
2006
2007
2008
2009
2010
2011
2012
2013

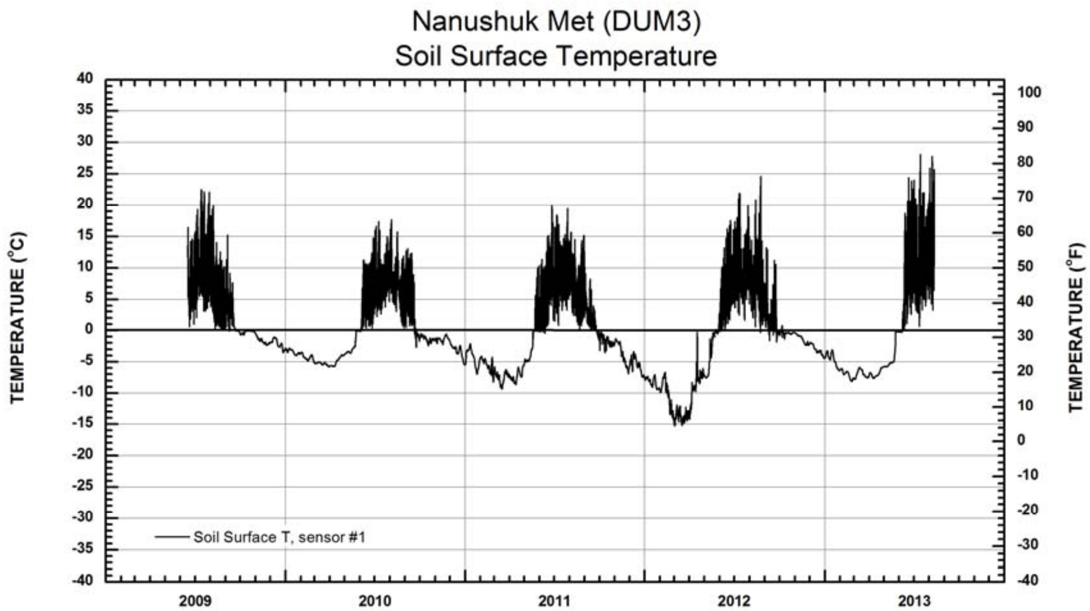

White Hills Met (DFM2)
Soil Surface Temperature
TEMPERATURE (°C)
TEMPERATURE (°F)
Soil Surface T, sensor #2
40
35
30
25
20
15
10
5
0
-5
-10
-15
-20
-25
-30
-35
-40
100
90
80
70
60
50
40
30
20
10
0
-10
-20
-30
-40
2006
2007
2008
2009
2010
2011
2012
2013

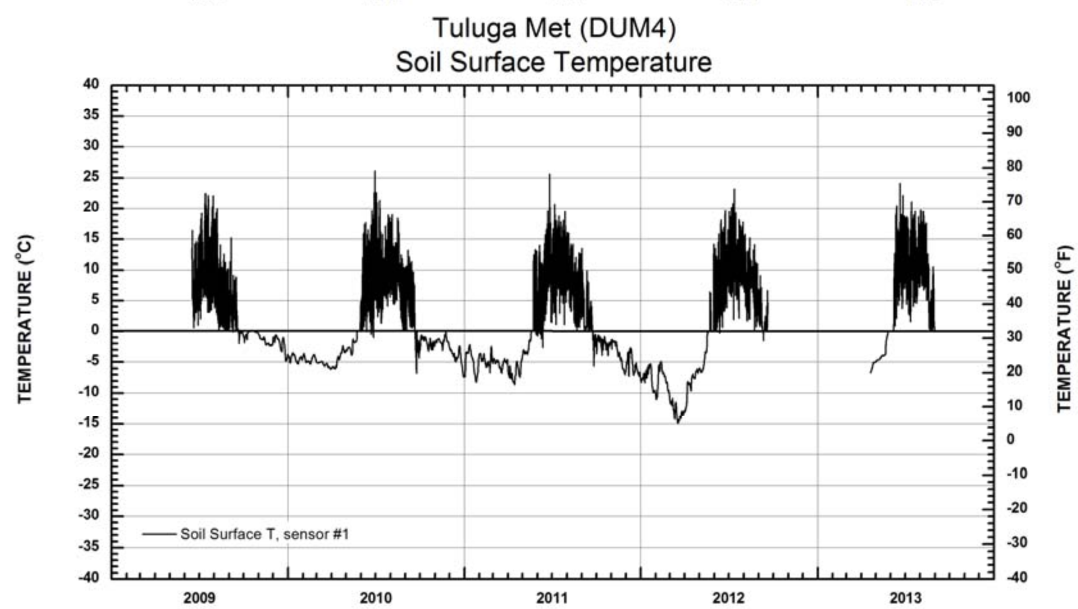

North White Hills Met (DFM3)
Soil Surface Temperature
TEMPERATURE (°C)
TEMPERATURE (°F)
Soil Surface T, sensor #1
2006
2007
2008
2009
2010
2011
2012
2013


Northwest Kuparuk Met (DFM4)
Soil Surface Temperature
TEMPERATURE (°C)
TEMPERATURE (°F)
Soil Surface T, sensor #1
2006
2007
2008
2009
2010
2011
2012
2013

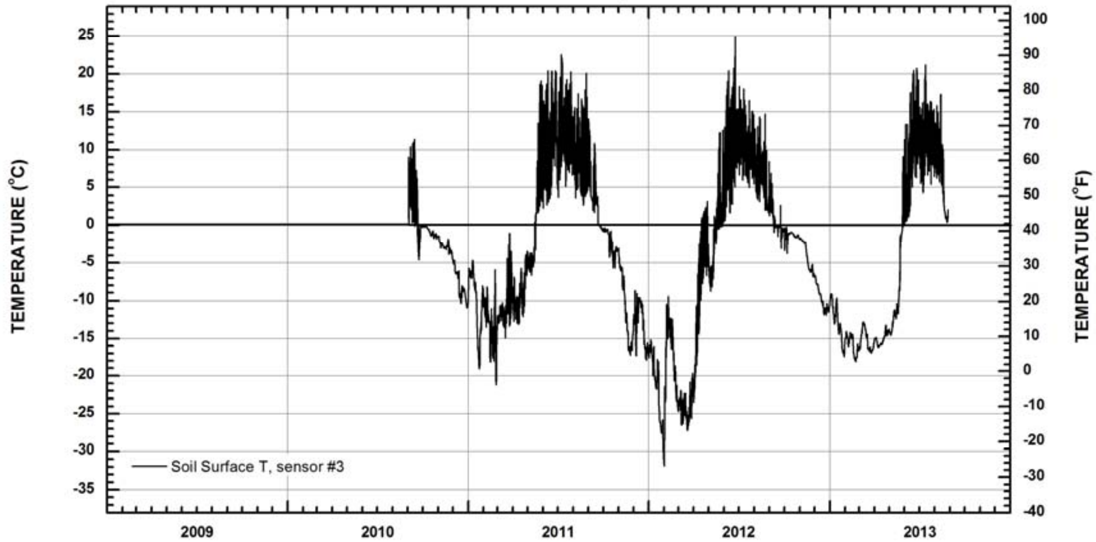

Itikmalakpak Met (DUM1)
Soil Surface Temperature
TEMPERATURE (°C)
TEMPERATURE (°F)
Soil Surface T, sensor #1
2009
2010
2011
2012
2013


Upper May Creek Met (DUM2)
Soil Surface Temperature
TEMPERATURE (°C)
TEMPERATURE (°F)
Soil Surface T, sensor #1
2009
2010
2011
2012
2013

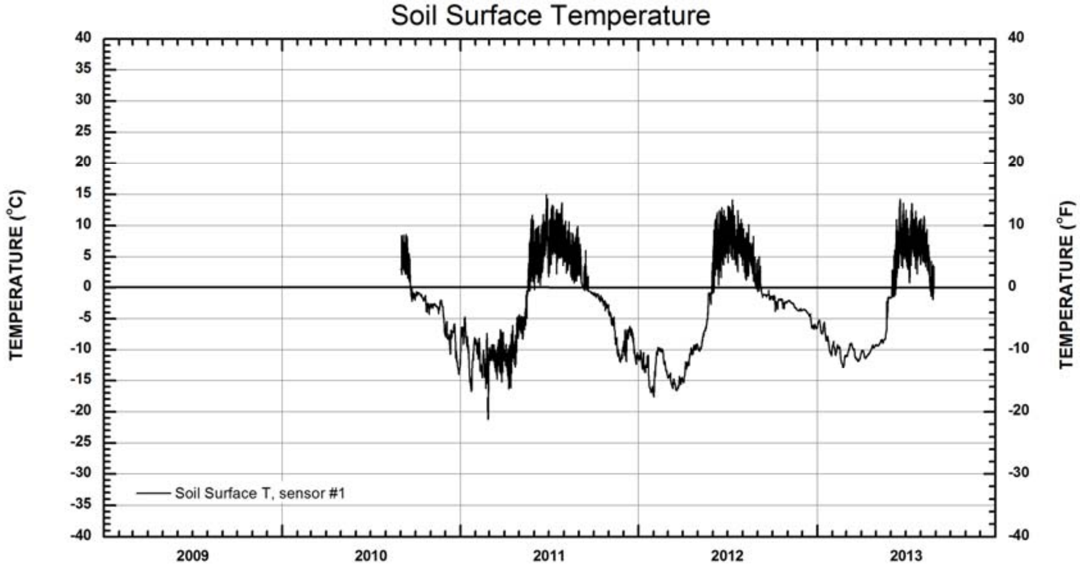

Nanushuk Met (DUM3)
Soil Surface Temperature
TEMPERATURE (°C)
TEMPERATURE (°F)
Soil Surface T, sensor #1
2009
2010
2011
2012
2013


Tuluga Met (DUM4)
Soil Surface Temperature
TEMPERATURE (°C)
TEMPERATURE (°F)
Soil Surface T, sensor #1
2009
2010
2011
2012
2013

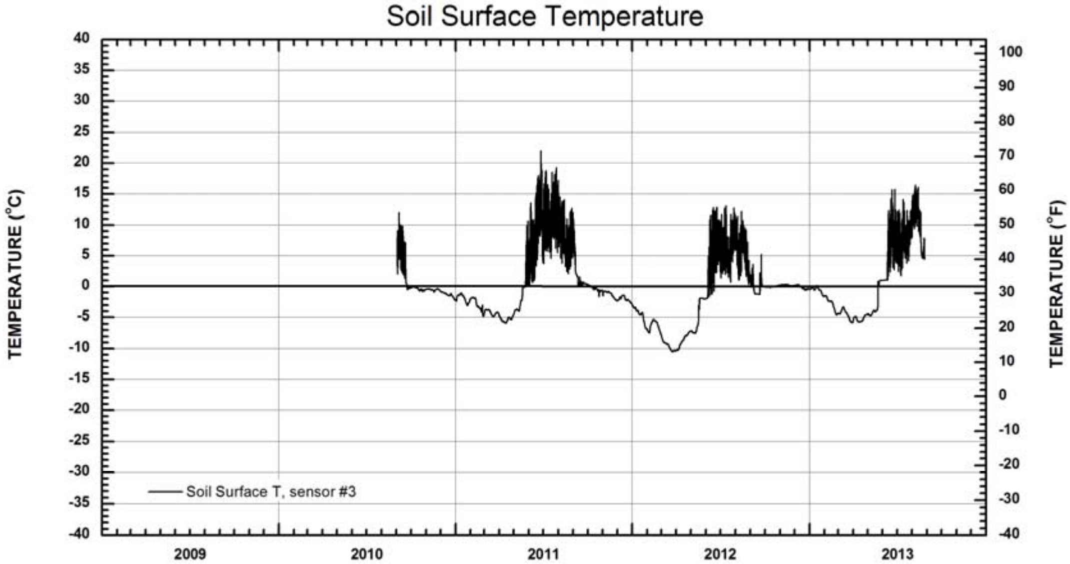
Encampment Creek (DUM5)
Soil Surface Temperature

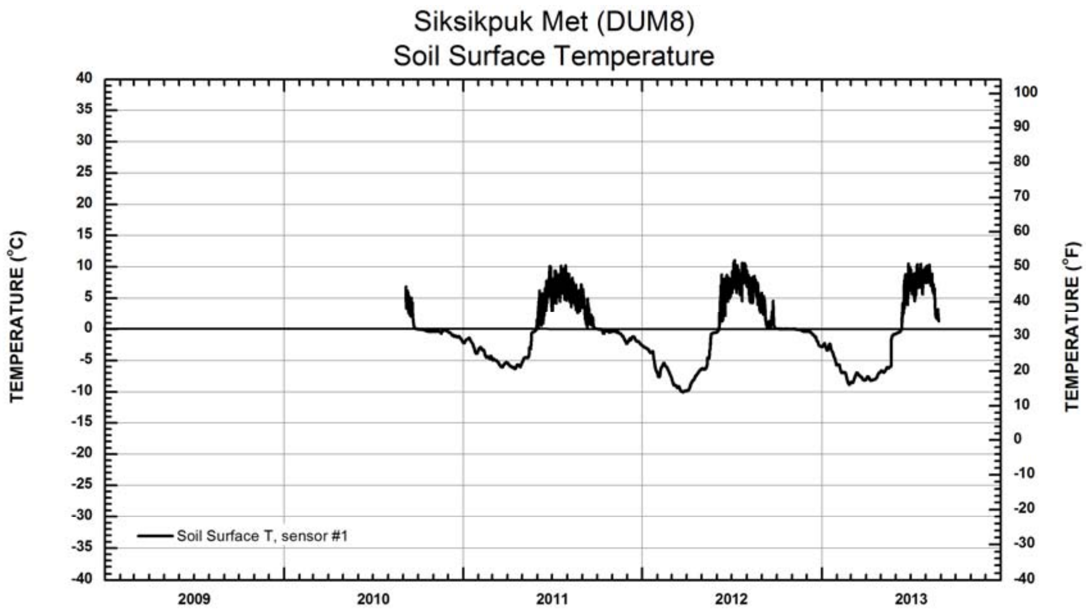


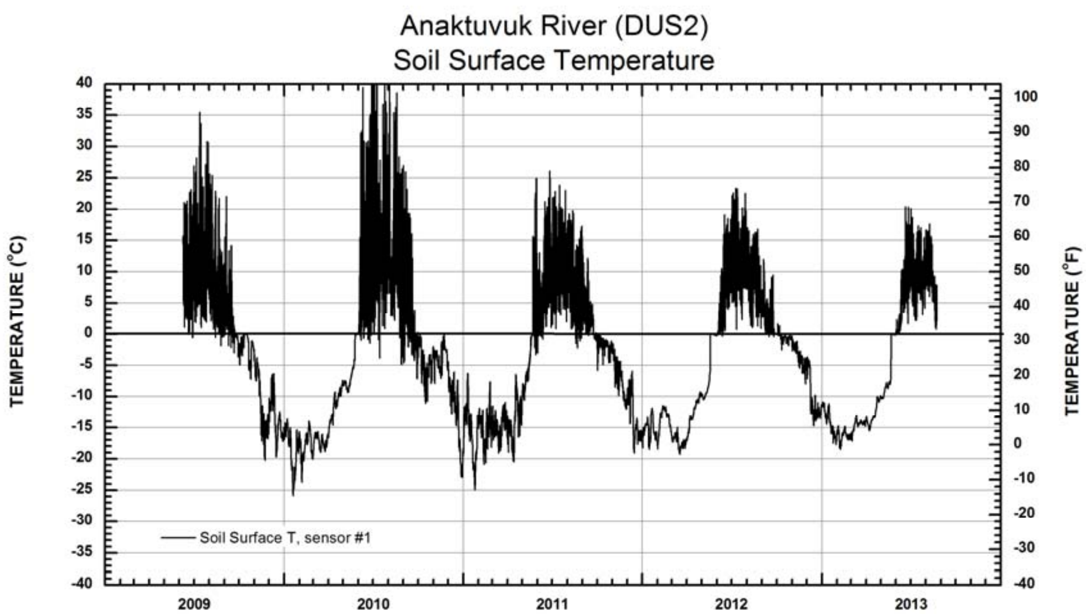
White Lake Met (DUM6)
Soil Surface Temperature

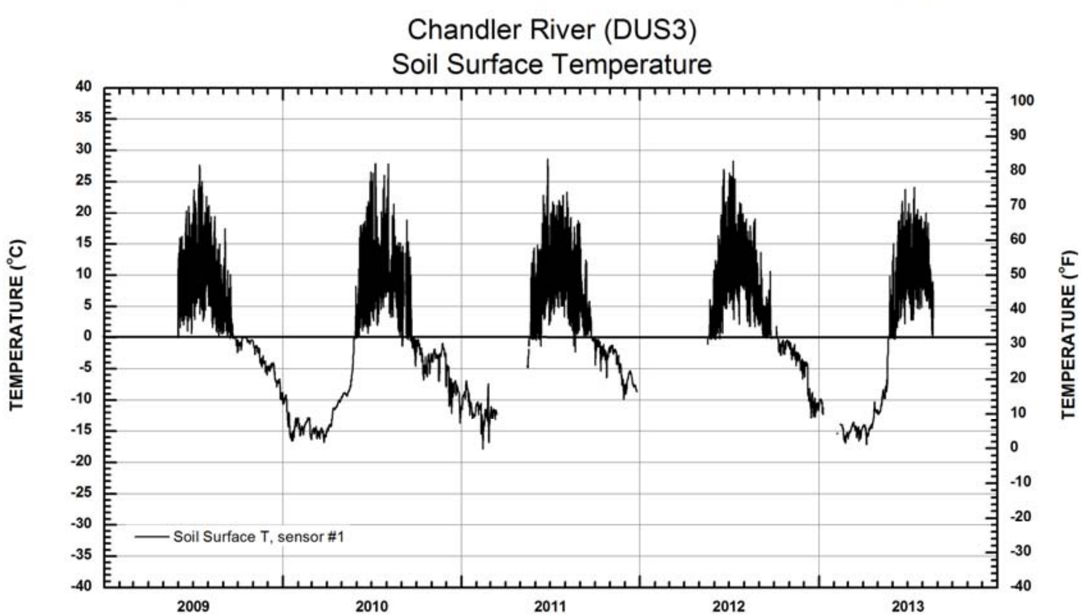


Hatbox Mesa Met (DUM7)
Soil Surface Temperature



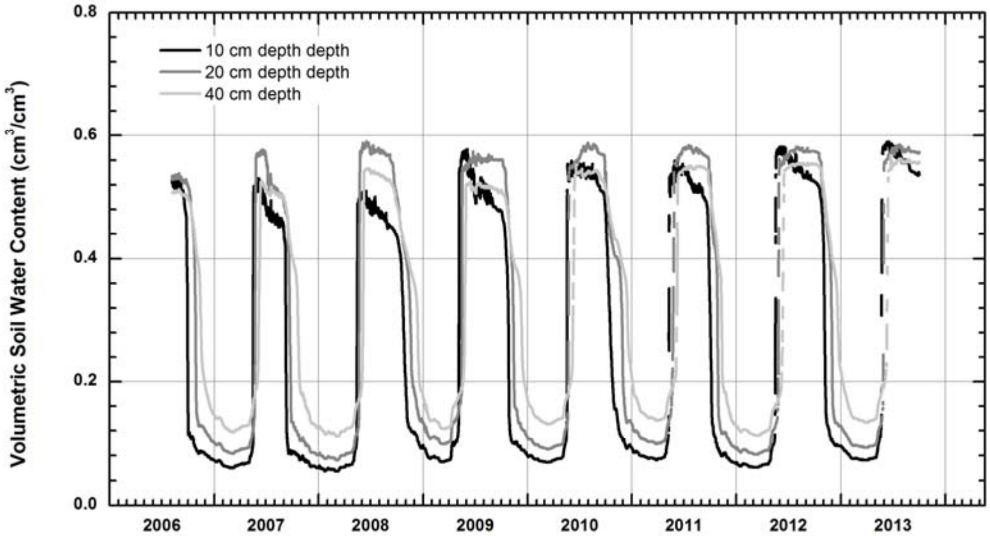

Siksikpuk Met (DUM8)
Soil Surface Temperature
TEMPERATURE (°C)
TEMPERATURE (°F)
Soil Surface T, sensor #1
2009
2010
2011
2012
2013


Anaktuvuk River (DUS2)
Soil Surface Temperature
TEMPERATURE (°C)
TEMPERATURE (°F)
Soil Surface T, sensor #1
2009
2010
2011
2012
2013

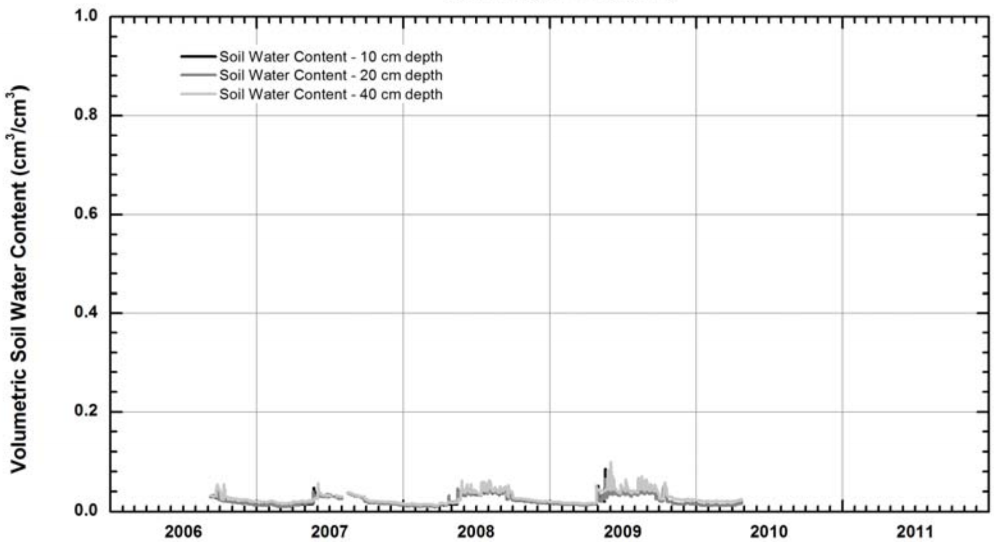

Chandler River (DUS3)
Soil Surface Temperature
TEMPERATURE (°C)
TEMPERATURE (°F)
Soil Surface T, sensor #1
2009
2010
2011
2012
2013

Unfrozen volumetric soil moisture content (cm^3/cm^3) time series plots at 10, 20, 30, or 40 cm below ground surface (bgs) for stations in the Kuparuk Foothills and Umiat Corridor projects:

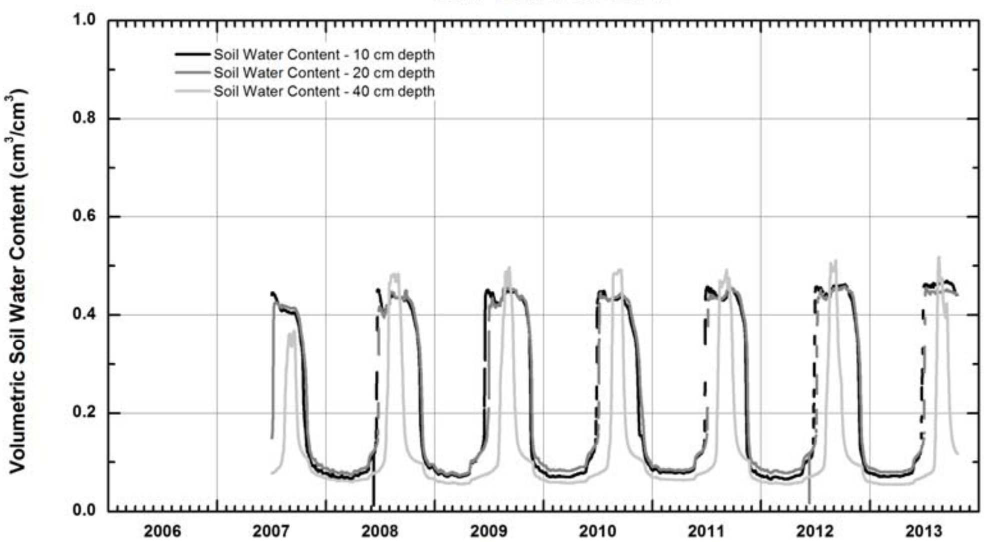
South White Hills Met (DFM1)
Soil Water Content



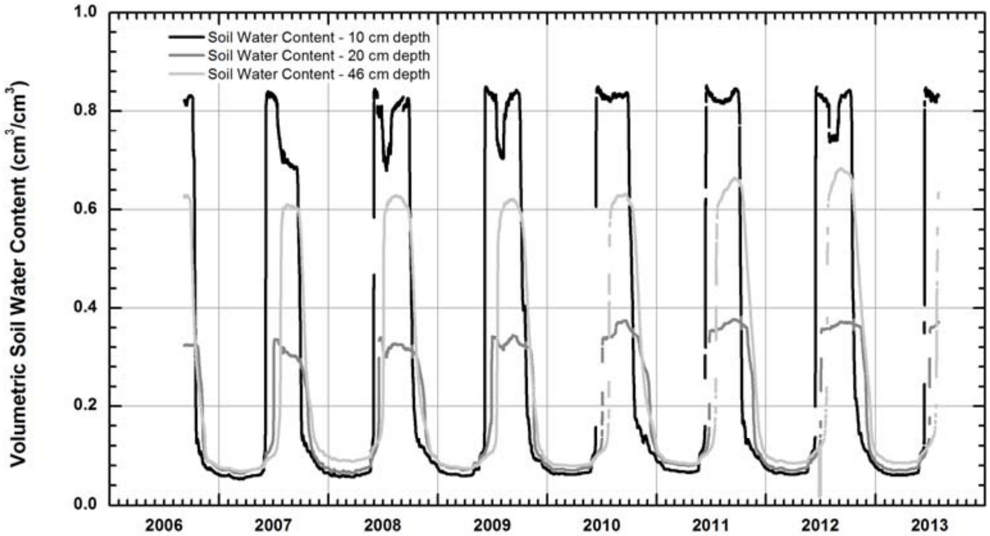
White Hills Met (DFM2)
Soil Water Content



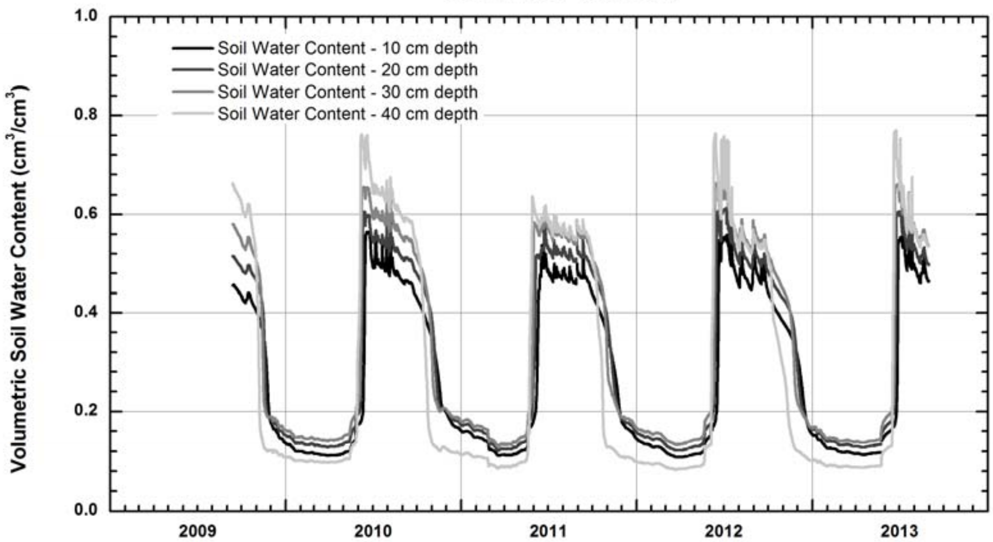
North White HIlls Met (DFM3)
Soil Water Content



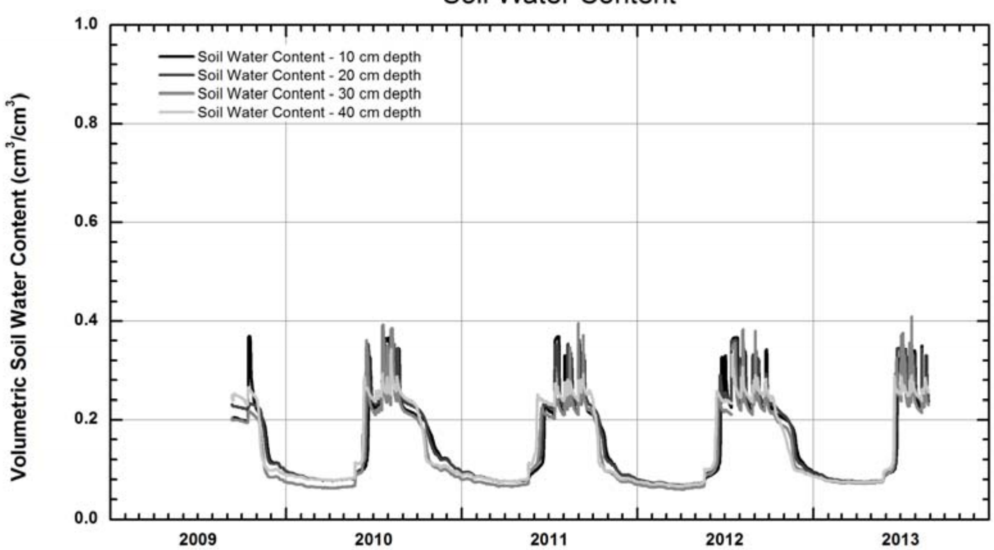
Northwest Kuparuk Met (DFM4)
Soil Water Content

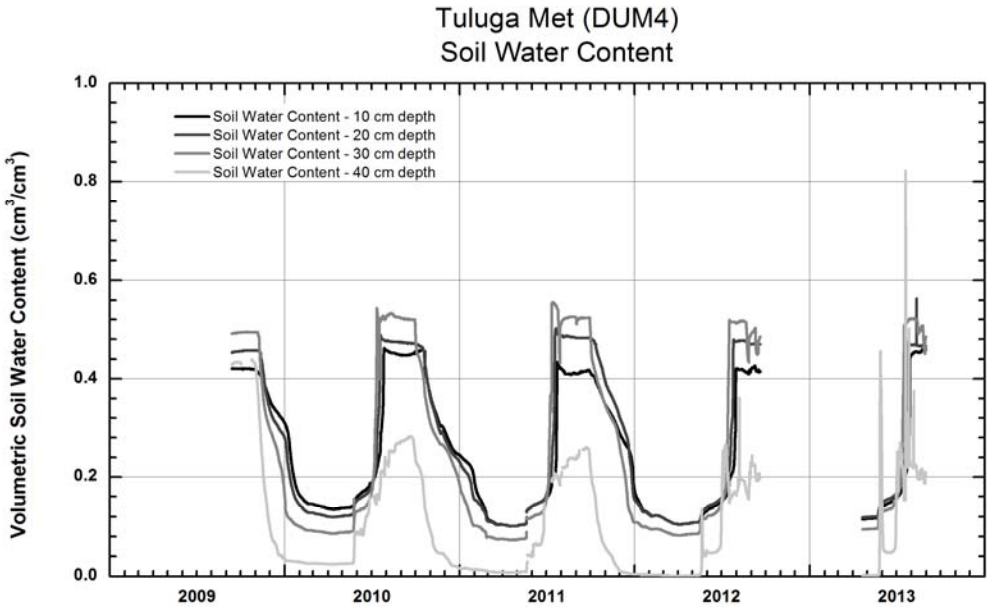


Itikmalakpak Met (DUM1)
Soil Water Content

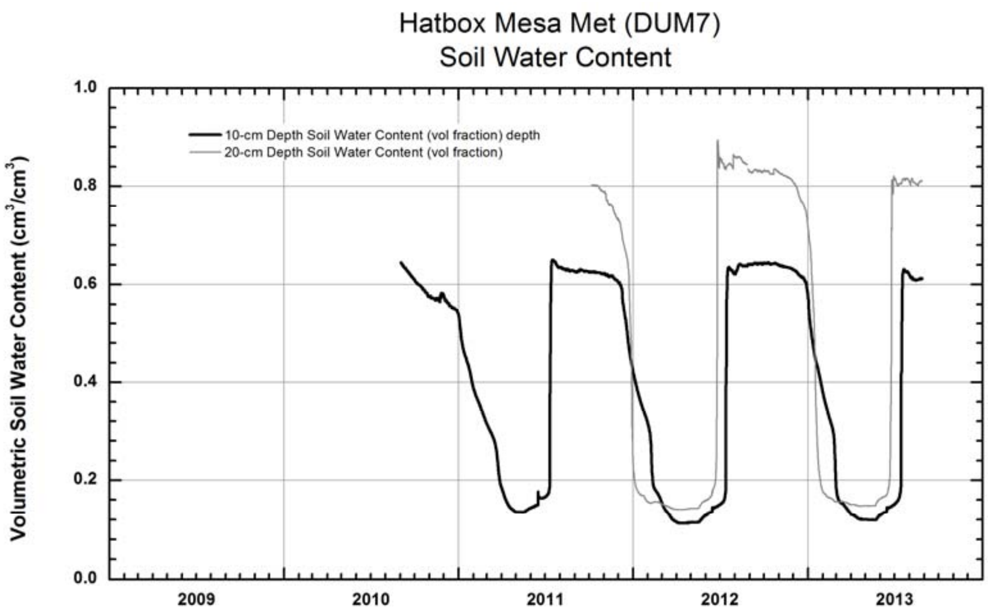


Nanushuk Met (DUM3)
Soil Water Content

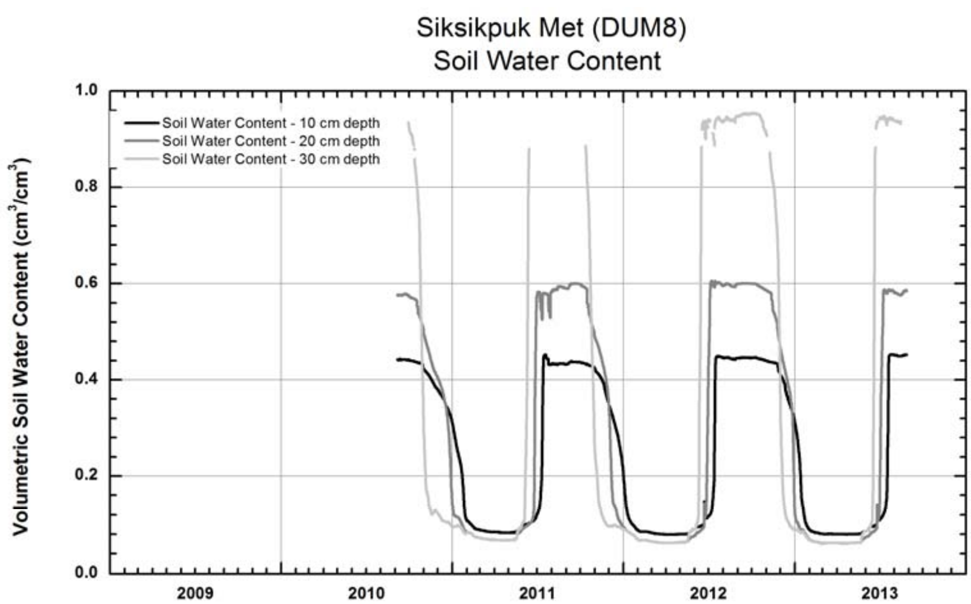




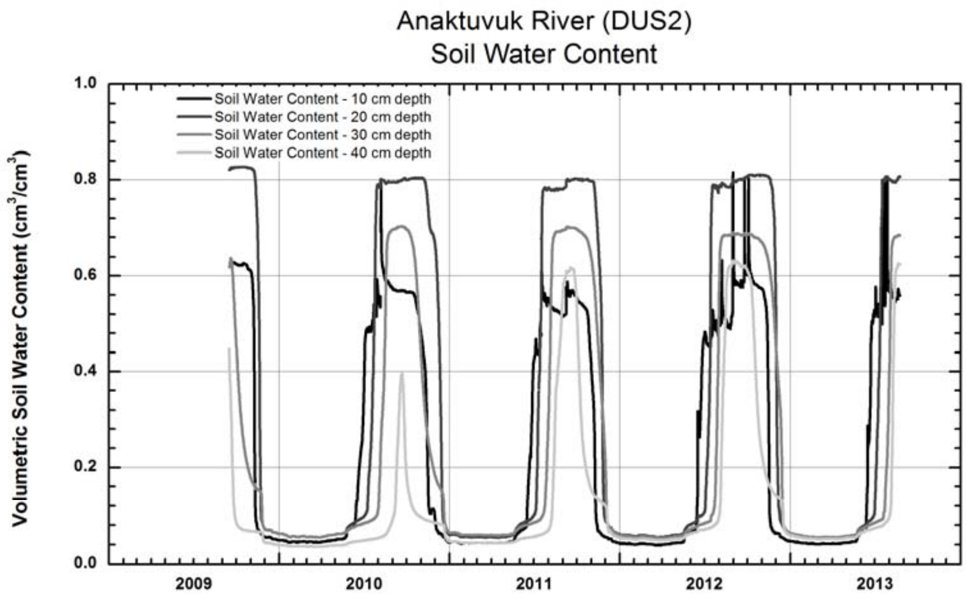
Tuluga Met (DUM4)
Soil Water Content
Soil Water Content - 10 cm depth
Soil Water Content - 20 cm depth
Soil Water Content - 30 cm depth
Soil Water Content - 40 cm depth
Volumetric Soil Water Content (cm³/cm³)
1.0
0.8
0.6
0.4
0.2
0.0
2009
2010
2011
2012
2013



Hatbox Mesa Met (DUM7)
Soil Water Content
10-cm Depth Soil Water Content (vol fraction) depth
20-cm Depth Soil Water Content (vol fraction)
Volumetric Soil Water Content (cm³/cm³)
1.0
0.8
0.6
0.4
0.2
0.0
2009
2010
2011
2012
2013



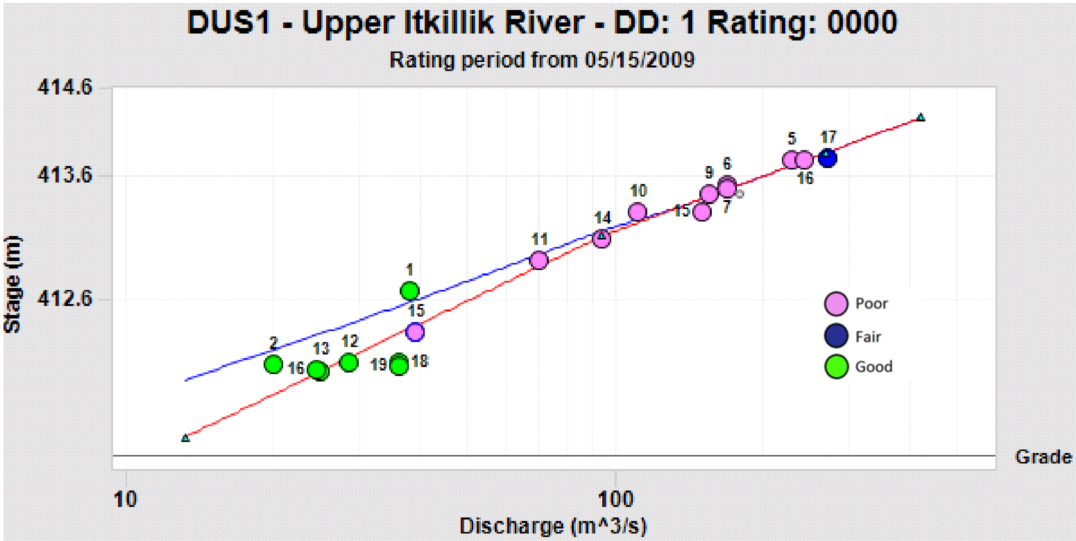
Siksikpuk Met (DUM8)
Soil Water Content
Soil Water Content - 10 cm depth
Soil Water Content - 20 cm depth
Soil Water Content - 30 cm depth
Volumetric Soil Water Content (cm³/cm³)
1.0
0.8
0.6
0.4
0.2
0.0
2009
2010
2011
2012
2013

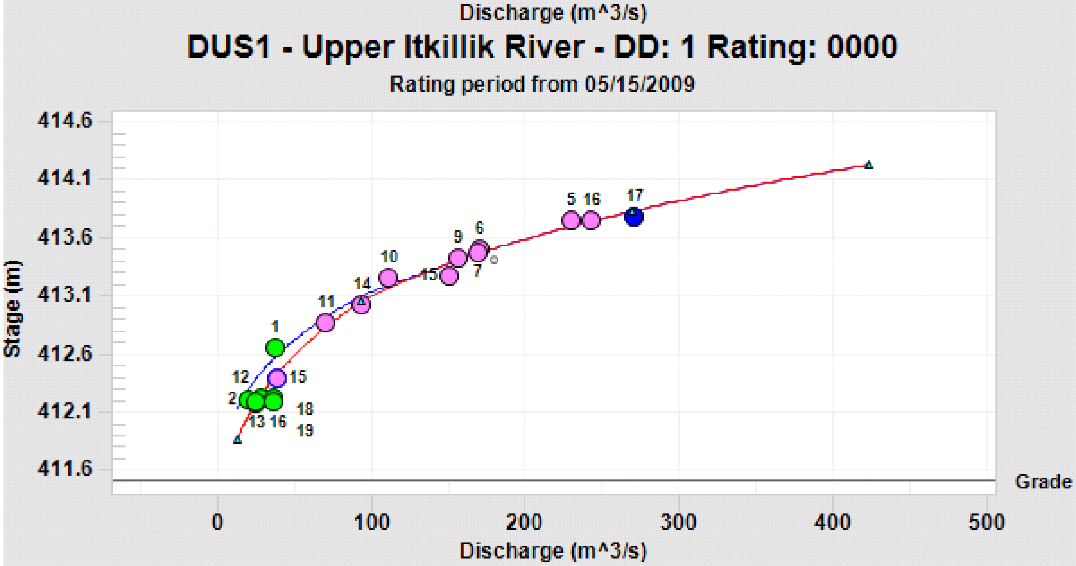

Anaktuvuk River (DUS2)
Soil Water Content
Soil Water Content - 10 cm depth
Soil Water Content - 20 cm depth
Soil Water Content - 30 cm depth
Soil Water Content - 40 cm depth
Volumetric Soil Water Content (cm3/cm3)
1.0
0.8
0.6
0.4
0.2
0.0
2009
2010
2011
2012
2013

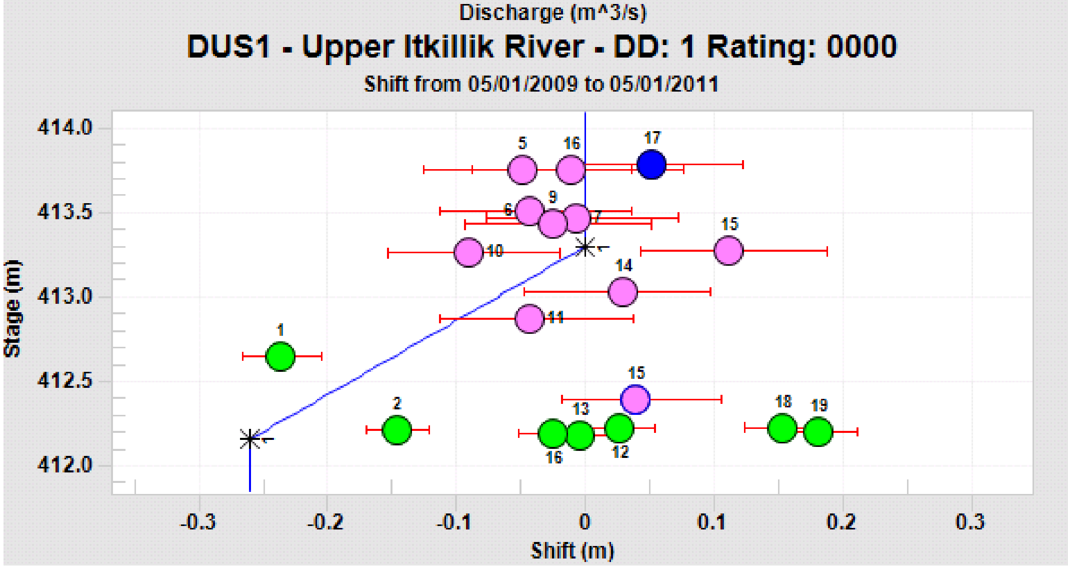
Appendix E – Rating Curves and Discharge Measurement Summaries

This section contains rating curves (in both normal and log normal) and shift diagrams for each river, made in Aquarius software. A quality rating is included with each measurement point. Caution should be taken before using data at very high and low stage/discharge, because the rating curve is extrapolated at these stages as indicated with the triangle (for the rating point) in the rating curve. Rating tables with the expanded rating curves (base rating curve and the shifted rating curve when applicable) are included for each river. ADCP discharge measurement summaries for measurements made on the Itkillik, Anaktuvuk, and Chandler Rivers from 2012 through 2013 are also presented.

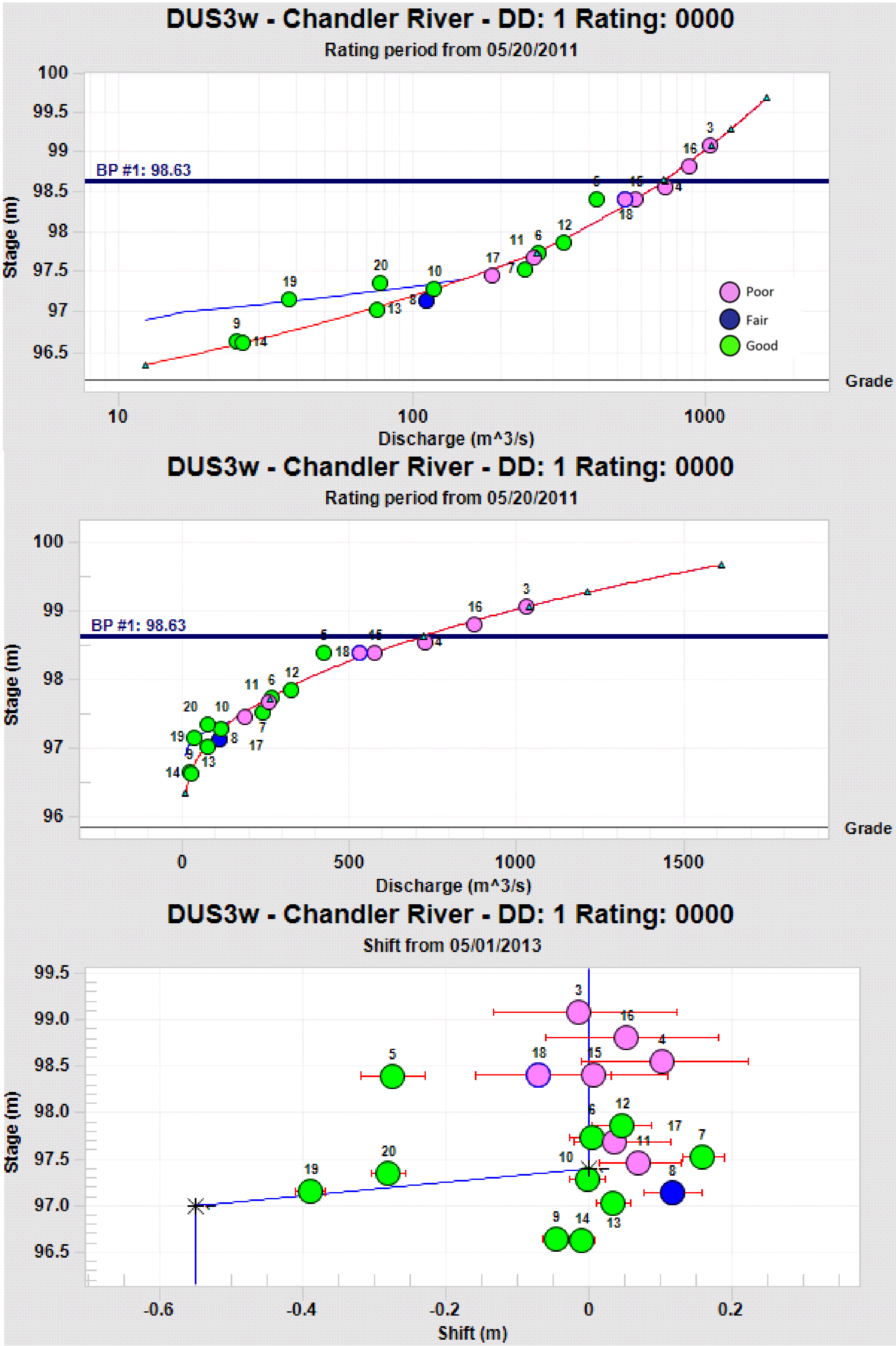
Rating curve and shift diagram for Upper Itkillik River



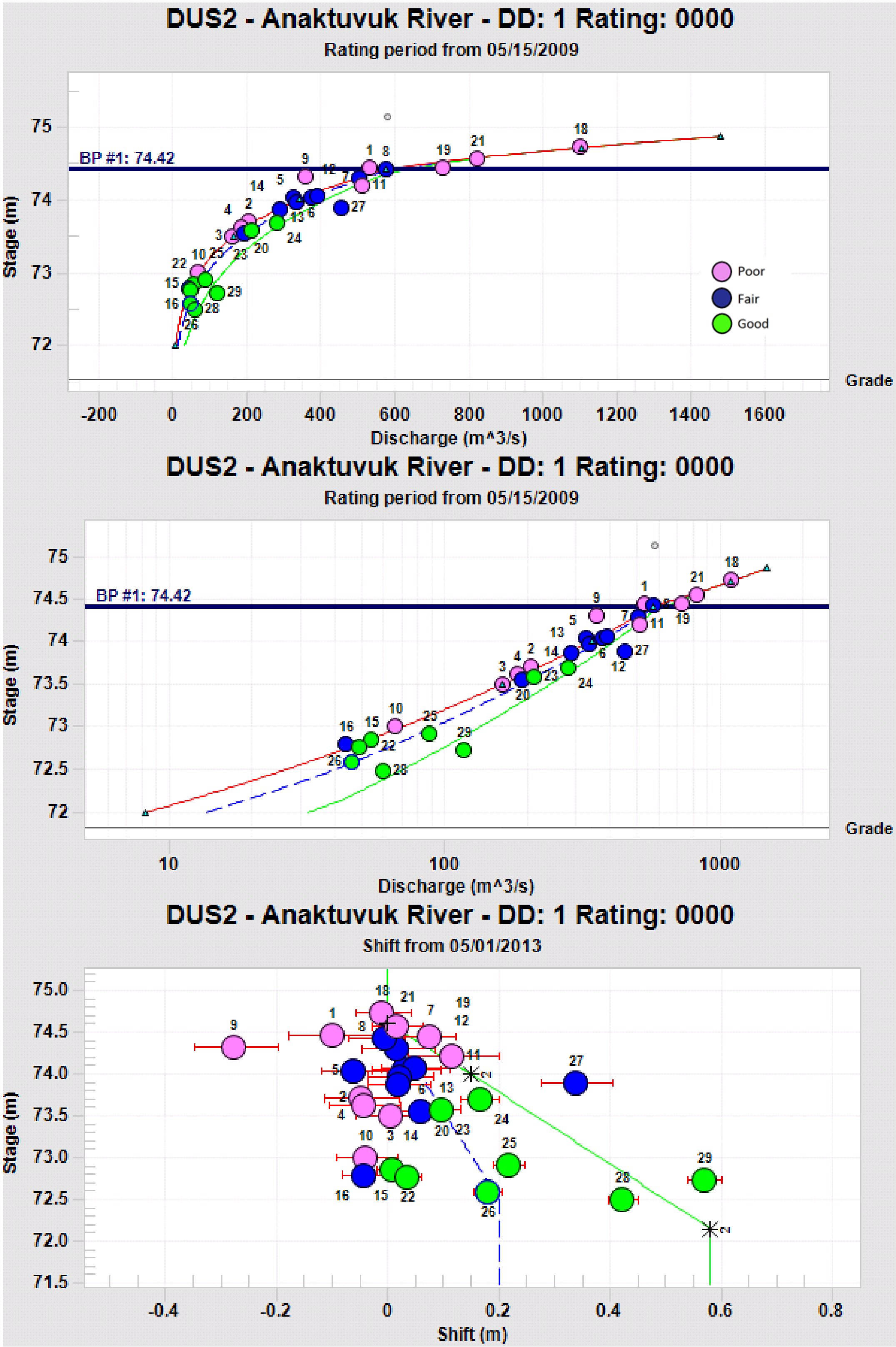




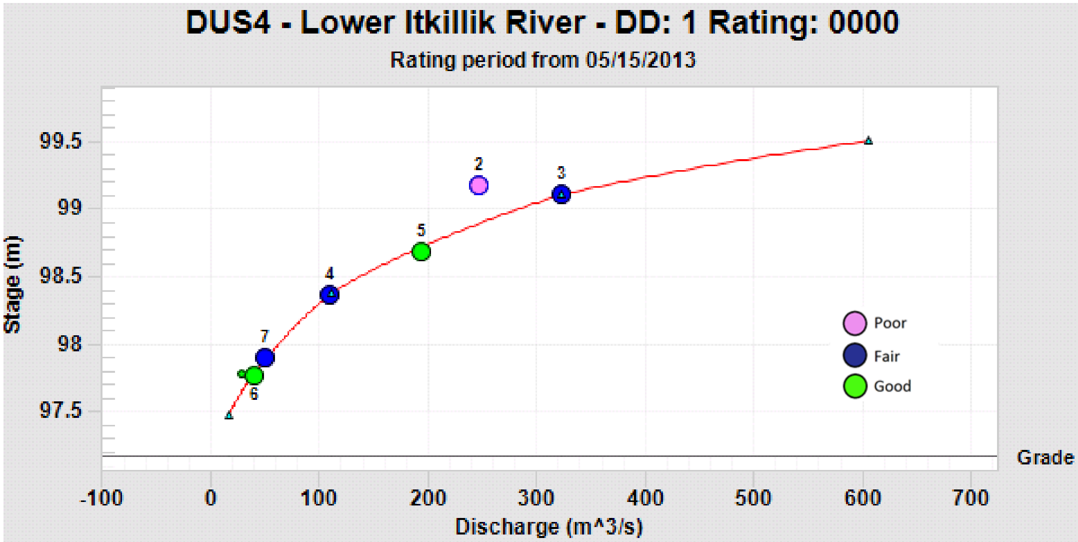
Rating curve and shift diagram for Chandler River

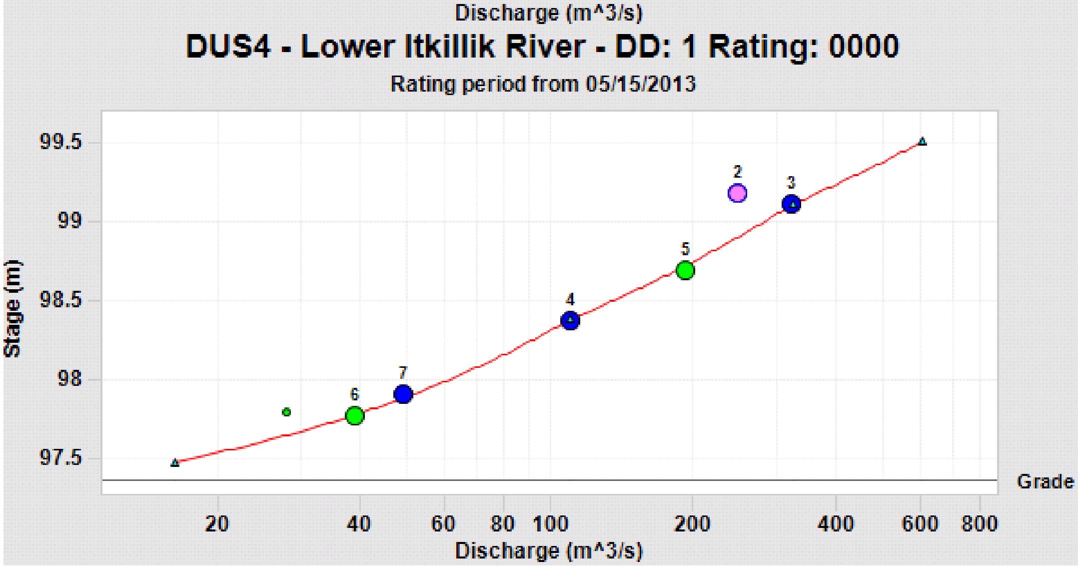


Rating curve and shift diagram for Anaktuvuk River



Rating curve for Lower Itkillik River





Expanded Rating Tables

STATION NUMBER **DUS1** **Upper Itkillik River** SOURCE AGENCY: UAF

LATITUDE 49.28 LONGITUDE -123.11

Date Processed: 04/22/2014 19:45:45 UTC-09:00 By ekyoucha

Rating for Discharge (m^3/s)

RATING ID: 0000 TYPE: Unknown EXPANSION: STATUS: Undefined

Created by ekyoucha on 08/23/2011 @ 19:43:39 UTC, Updated by ekyoucha on 04/23/2014 @ 04:43:16 UTC

Remarks:

Offset1: 410.60

EXPANDED RATING TABLE

Stage (m)	Discharge (m^3/s)										DIFF IN Q PER
	.00	.01	.02	.03	.04	.05	.06	.07	.08	.09	.1 UNITS
411.80								13.19*	13.50	13.82	3.167
411.90	14.14	14.46	14.79	15.13	15.47	15.81	16.17	16.52	16.88	17.25	3.480
412.00	17.62	18.00	18.38	18.76	19.16	19.56	19.96	20.37	20.78	21.20	4.010
412.10	21.63	22.06	22.50	22.94	23.39	23.84	24.30	24.77	25.24	25.72	4.570
412.20	26.20	26.69	27.18	27.69	28.19	28.71	29.23	29.75	30.29	30.82	5.170
412.30	31.37	31.92	32.48	33.04	33.61	34.19	34.77	35.36	35.96	36.57	5.810
412.40	37.18	37.79	38.42	39.05	39.68	40.33	40.98	41.64	42.30	42.97	6.470
412.50	43.65	44.34	45.03	45.73	46.44	47.16	47.88	48.61	49.34	50.09	7.190
412.60	50.84	51.60	52.37	53.14	53.92	54.71	55.51	56.31	57.12	57.94	7.930
412.70	58.77	59.61	60.45	61.30	62.16	63.03	63.90	64.78	65.67	66.57	8.710
412.80	67.48	68.40	69.32	70.25	71.19	72.14	73.10	74.06	75.04	76.02	9.530
412.90	77.01	78.01	79.01	80.03	81.06	82.09	83.13	84.18	85.24	86.31	10.380
413.00	87.39	88.47	89.57	90.67	91.79	92.91	94.04*	95.53	97.03	98.55	12.710
413.10	100.1	101.6	103.2	104.8	106.4	108.0	109.7	111.4	113.0	114.7	16.400
413.20	116.5	118.2	120.0	121.7	123.5	125.4	127.2	129.1	130.9	132.8	18.300
413.30	134.8	136.7	138.7	140.6	142.6	144.7	146.7	148.8	150.8	153.0	20.300
413.40	155.1	157.2	159.4	161.6	163.8	166.1	168.3	170.6	172.9	175.3	22.500
413.50	177.6	180.0	182.4	184.8	187.3	189.7	192.2	194.8	197.3	199.9	24.900
413.60	202.5	205.1	207.7	210.4	213.1	215.8	218.6	221.3	224.1	227.0	27.300
413.70	229.8	232.7	235.6	238.5	241.5	244.5	247.5	250.5	253.6	256.7	30.000
413.80	259.8	263.0	266.2	269.4*	272.6	275.9	279.2	282.5	285.8	289.2	32.800
413.90	292.6	296.1	299.5	303.0	306.6	310.1	313.7	317.4	321.0	324.7	35.800
414.00	328.4	332.2	335.9	339.7	343.6	347.5	351.4	355.3	359.3	363.3	38.900
414.10	367.3	371.4	375.5	379.7	383.8	388.0	392.3	396.5	400.9	405.2	42.300
414.20	409.6	414.0	418.4								

"*" indicates a rating descriptor point

ID	Starting Date	Ending Date	Aging	Comments
----	------------------------	------------------------	-----	----------------------
0000	05/15/2009 12:17:46 UTC-09:00	12/30/2382 12:00:00 UTC-09:00	-1	

STATION NUMBER **DUS1** **Upper Itkillik River** SOURCE AGENCY: UAF

LATITUDE 49.28 LONGITUDE -123.11

Date Processed: 04/22/2014 19:46:46 UTC-09:00 By ekyoucha

Rating for Discharge (m^3/s)

********Shifted for 05/01/2010 00:00:00 UTC-09:00 ********

RATING ID: 0000 TYPE: Unknown EXPANSION: STATUS: Undefined

Created by ekyoucha on 08/23/2011 @ 19:43:39 UTC, Updated by ekyoucha on 04/23/2014 @ 04:43:16 UTC

Remarks:

Offset1: 410.60

EXPANDED RATING TABLE

Stage (m)	Discharge (m^3/s) .00	.01	.02	.03	.04	.05	.06	.07	.08	.09	DIFF IN Q PER .1 UNITS
412.10				13.19	13.50	13.82	14.14	14.46	14.79	15.47	3.743
412.20	15.81	16.17	16.52	17.25	17.62	18.00	18.38	19.16	19.56	19.96	4.560
412.30	20.37	20.78	21.63	22.06	22.50	22.94	23.84	24.30	24.77	25.24	5.350
412.40	25.72	26.69	27.18	27.69	28.19	29.23	29.75	30.29	30.82	31.92	6.760
412.50	32.48	33.04	33.61	34.19	35.36	35.96	36.57	37.18	38.42	39.05	7.200
412.60	39.68	40.33	40.98	42.30	42.97	43.65	44.34	45.73	46.44	47.16	8.200
412.70	47.88	49.34	50.09	50.84	51.60	52.37	53.92	54.71	55.51	56.31	10.060
412.80	57.94	58.77	59.61	60.45	62.16	63.03	63.90	64.78	65.67	67.48	10.460
412.90	68.40	69.32	70.25	72.14	73.10	74.06	75.04	76.02	78.01	79.01	11.630
413.00	80.03	81.06	83.13	84.18	85.24	86.31	88.47*	89.57	90.67	91.79	12.880
413.10	92.91	95.53	97.03	98.55	100.1	103.2	104.8	106.4	108.0	109.7	20.090
413.20	113.0	114.7	116.5	118.2	121.7	123.5	125.4	127.2	130.9	132.8	21.800
413.30	134.8	136.7	138.7	140.6	142.6	144.7	146.7	148.8	150.8	153.0	20.300
413.40	155.1	157.2	159.4	161.6	163.8	166.1	168.3	170.6	172.9	175.3	22.500
413.50	177.6	180.0	182.4	184.8	187.3	189.7	192.2	194.8	197.3	199.9	24.900
413.60	202.5	205.1	207.7	210.4	213.1	215.8	218.6	221.3	224.1	227.0	27.300
413.70	229.8	232.7	235.6	238.5	241.5	244.5	247.5	250.5	253.6	256.7	30.000
413.80	259.8	263.0	266.2	269.4*	272.6	275.9	279.2	282.5	285.8	289.2	32.800
413.90	292.6	296.1	299.5	303.0	306.6	310.1	313.7	317.4	321.0	324.7	35.800
414.00	328.4	332.2	335.9	339.7	343.6	347.5	351.4	355.3	359.3	363.3	38.900
414.10	367.3	371.4	375.5	379.7	383.8	388.0	392.3	396.5	400.9	405.2	42.300
414.20	409.6	414.0	418.4								

"*" indicates a rating descriptor point

ID	Starting Date	Ending Date	Aging	Comments
0000	05/15/2009 12:17:46 UTC-09:00	12/30/2382 12:00:00 UTC-09:00	-1	

STATION NUMBER **DUS2** **Anaktuvuk River** SOURCE AGENCY: UAF

LATITUDE 69 27 50 LONGITUDE 151 10 04
Date Processed: 04/22/2014 19:34:03 UTC-09:00 By ekyoucha
Rating for Discharge (m^3/s)
RATING ID: 0000 TYPE: Unknown EXPANSION: STATUS: Working
Created by ekyoucha on 12/11/2010 @ 01:29:47 UTC, Updated by ekyoucha on 04/18/2014 @ 17:30:49 UTC
Remarks: 2009-2010 Base Rating

Offset1: 69.90 Offset2: 72.50
Breakpoint1: 74.42

EXPANDED RATING TABLE

Stage (m)	Discharge (m^3/s)						DIFF IN Q PER				
	.00	.01	.02	.03	.04	.05	.06	.07	.08	.09	.1 UNITS
72.00		8.240*	8.460	8.685	8.915	9.150	9.390	9.635	9.886	10.14	2.400
72.10	10.40	10.67	10.94	11.22	11.50	11.79	12.09	12.39	12.70	13.01	2.930
72.20	13.33	13.66	13.99	14.33	14.68	15.03	15.39	15.76	16.13	16.51	3.570
72.30	16.90	17.30	17.70	18.12	18.53	18.96	19.40	19.84	20.29	20.76	4.320
72.40	21.22	21.70	22.19	22.69	23.19	23.70	24.23	24.76	25.30	25.85	5.200
72.50	26.42	26.99	27.57	28.16	28.76	29.38	30.00	30.64	31.28	31.94	6.190
72.60	32.61	33.29	33.98	34.68	35.40	36.12	36.86	37.61	38.38	39.15	7.330
72.70	39.94	40.74	41.56	42.39	43.23	44.09	44.96	45.84	46.74	47.65	8.640
72.80	48.58	49.52	50.48	51.45	52.44	53.44	54.46	55.49	56.54	57.61	10.110
72.90	58.69	59.79	60.91	62.04	63.19	64.36	65.55	66.75	67.97	69.21	11.780
73.00	70.47	71.75	73.05	74.36	75.70	77.05	78.43	79.82	81.24	82.67	13.660
73.10	84.13	85.61	87.11	88.63	90.17	91.73	93.32	94.92	96.56	98.21	15.760
73.20	99.89	101.6	103.3	105.1	106.8	108.6	110.4	112.3	114.2	116.1	18.110
73.30	118.0	119.9	121.9	123.9	125.9	128.0	130.1	132.2	134.3	136.5	20.700
73.40	138.7	140.9	143.2	145.5	147.8	150.1	152.5	154.9	157.3	159.8	23.600
73.50	162.3*	164.9	167.5	170.1	172.8	175.5	178.2	181.0	183.8	186.6	27.200
73.60	189.5	192.4	195.4	198.3	201.4	204.4	207.5	210.7	213.9	217.1	30.800
73.70	220.3	223.6	227.0	230.4	233.8	237.2	240.7	244.3	247.9	251.5	34.900
73.80	255.2	258.9	262.7	266.5	270.3	274.2	278.2	282.2	286.2	290.3	39.300
73.90	294.5	298.7	302.9	307.2	311.5	315.9	320.3	324.8	329.4	333.9	44.100
74.00	338.6	343.3*	347.8	352.5	357.1	361.8	366.6	371.4	376.3	381.2	47.600
74.10	386.2	391.2	396.3	401.4	406.6	411.8	417.1	422.5	427.9	433.3	52.700
74.20	438.9	444.4	450.1	455.8	461.5	467.3	473.2	479.1	485.1	491.2	58.400
74.30	497.3	503.4	509.7	516.0	522.3	528.8	535.2	541.8	548.4	555.1	64.600
74.40	561.9	568.7	575.6*	589.1	602.9	617.0	631.3	645.8	660.6	675.7	129.100
74.50	691.0	706.6	722.5	738.7	755.1	771.8	788.8	806.1	823.7	841.6	168.800
74.60	859.8	878.3	897.1	916.2	935.6	955.4	975.4	995.8	1017	1038	199.200
74.70	1059	1081	1103*	1125	1148	1171	1195	1218	1243	1267	233.000
74.80	1292	1318	1343	1369	1396	1423	1450	1478*			

"*" indicates a rating descriptor point

ID	Starting Date	Ending Date	Aging	Comments
0000	05/15/2009 09:24:51 UTC-09:00	12/30/2382 12:00:00 UTC-09:00	-1	Base Rating Curve

STATION NUMBER **DUS2** **Anaktuvuk River** SOURCE AGENCY: UAF

LATITUDE 69 27 50 LONGITUDE 151 10 04

Date Processed: 04/22/2014 19:34:26 UTC-09:00 By ekyoucha

Rating for Discharge (m^3/s)

********Shifted for 06/01/2011 09:54:54 UTC-09:00 ********

RATING ID: 0000 TYPE: Unknown EXPANSION: STATUS: Working

Created by ekyoucha on 12/11/2010 @ 01:29:47 UTC, Updated by ekyoucha on 04/18/2014 @ 17:30:49 UTC

Remarks: 2009-2010 Base Rating

Offset1: 69.90 Offset2: 72.50

Breakpoint1: 74.42

EXPANDED RATING TABLE

Stage (m)	Discharge (m^3/s)										DIFF IN Q PER
	.00	.01	.02	.03	.04	.05	.06	.07	.08	.09	.1 UNITS
71.80		8.240	8.460	8.685	8.915	9.150	9.390	9.635	9.886	10.14	2.400
71.90	10.40	10.67	10.94	11.22	11.50	11.79	12.09	12.39	12.70	13.01	2.930
72.00	13.33	13.66*	13.99	14.33	14.68	15.03	15.39	15.76	16.13	16.51	3.570
72.10	16.90	17.30	17.70	18.12	18.53	18.96	19.40	19.84	20.29	20.76	4.320
72.20	21.22	21.70	22.19	22.69	23.19	23.70	24.23	24.76	25.30	25.85	5.200
72.30	26.42	26.99	27.57	28.16	28.76	29.38	30.00	30.64	31.28	31.94	6.190
72.40	32.61	33.29	33.98	34.68	35.40	36.12	36.86	37.61	38.38	39.15	7.330
72.50	39.94	40.74	41.56	42.39	43.23	44.09	44.09	44.96	45.84	46.74	7.710
72.60	47.65	48.58	49.52	50.48	51.45	52.44	52.44	53.44	54.46	55.49	8.890
72.70	56.54	57.61	58.69	59.79	60.91	62.04	63.19	63.19	64.36	65.55	10.210
72.80	66.75	67.97	69.21	70.47	71.75	73.05	74.36	74.36	75.70	77.05	11.680
72.90	78.43	79.82	81.24	82.67	84.13	85.61	87.11	88.63	88.63	90.17	13.300
73.00	91.73	93.32	94.92	96.56	98.21	99.89	101.6	103.3	103.3	105.1	15.070
73.10	106.8	108.6	110.4	112.3	114.2	116.1	118.0	119.9	121.9	121.9	17.100
73.20	123.9	125.9	128.0	130.1	132.2	134.3	136.5	138.7	140.9	140.9	19.300
73.30	143.2	145.5	147.8	150.1	152.5	154.9	157.3	159.8	162.3	164.9	21.700
73.40	164.9	167.5	170.1	172.8	175.5	178.2	181.0	183.8	186.6	189.5	24.600
73.50	189.5*	192.4	195.4	198.3	201.4	204.4	207.5	210.7	213.9	217.1	30.800
73.60	220.3	220.3	223.6	227.0	230.4	233.8	237.2	240.7	244.3	247.9	31.200
73.70	251.5	251.5	255.2	258.9	262.7	266.5	270.3	274.2	278.2	282.2	34.700
73.80	286.2	290.3	290.3	294.5	298.7	302.9	307.2	311.5	315.9	320.3	38.600
73.90	324.8	329.4	329.4	333.9	338.6	343.3	347.8	352.5	357.1	361.8	41.800
74.00	366.6	371.4*	376.3	376.3	381.2	386.2	391.2	396.3	401.4	406.6	45.200
74.10	411.8	417.1	422.5	422.5	427.9	433.3	438.9	444.4	450.1	455.8	49.700
74.20	461.5	467.3	473.2	479.1	479.1	485.1	491.2	497.3	503.4	509.7	54.500
74.30	516.0	522.3	528.8	535.2	535.2	541.8	548.4	555.1	561.9	568.7	59.600
74.40	575.6	589.1	602.9*	617.0	631.3	631.3	645.8	660.6	675.7	691.0	131.000
74.50	706.6	722.5	738.7	755.1	771.8	771.8	788.8	806.1	823.7	841.6	153.200
74.60	859.8	878.3	897.1	916.2	935.6	955.4	975.4	995.8	1017	1038	199.200
74.70	1059	1081	1103*	1125	1148	1171	1195	1218	1243	1267	233.000
74.80	1292	1318	1343	1369	1396	1423	1450	1478*			

"*" indicates a rating descriptor point

ID	Starting Date	Ending Date	Aging	Comments
0000	05/15/2009 09:24:51 UTC-09:00	12/30/2382 12:00:00 UTC-09:00	-1	Base Rating Curve

STATION NUMBER **DUS2** **Anaktuvuk River** SOURCE AGENCY: UAF

LATITUDE 69 27 50 LONGITUDE 151 10 04

Date Processed: 04/22/2014 19:34:46 UTC-09:00 By ekyoucha

Rating for Discharge (m^3/s)

********Shifted for 05/01/2013 09:54:54 UTC-09:00 ********

RATING ID: 0000 TYPE: Unknown EXPANSION: STATUS: Working

Created by ekyoucha on 12/11/2010 @ 01:29:47 UTC, Updated by ekyoucha on 04/18/2014 @ 17:30:49 UTC

Remarks: 2009-2010 Base Rating

Offset1: 69.90 Offset2: 72.50

Breakpoint1: 74.42

EXPANDED RATING TABLE

Stage (m)	Discharge (m^3/s)						DIFF IN Q PER				
	.00	.01	.02	.03	.04	.05	.06	.07	.08	.09	.1 UNITS
71.40				8.240	8.460	8.685	8.915	9.150	9.390	9.635	2.351
71.50	9.886	10.14	10.40	10.67	10.94	11.22	11.50	11.79	12.09	12.39	2.814
71.60	12.70	13.01	13.33	13.66	13.99	14.33	14.68	15.03	15.39	15.76	3.430
71.70	16.13	16.51	16.90	17.30	17.70	18.12	18.53	18.96	19.40	19.84	4.160
71.80	20.29	20.76	21.22	21.70	22.19	22.69	23.19	23.70	24.23	24.76	5.010
71.90	25.30	25.85	26.42	26.99	27.57	28.16	28.76	29.38	30.00	30.64	5.980
72.00	31.28	31.94*	32.61	33.29	33.98	34.68	35.40	36.12	36.86	37.61	7.100
72.10	38.38	39.15	39.94	40.74	41.56	42.39	43.23	44.09	44.09	44.96	7.460
72.20	45.84	46.74	46.74	47.65	48.58	49.52	49.52	50.48	51.45	52.44	7.600
72.30	53.44	53.44	54.46	55.49	56.54	56.54	57.61	58.69	59.79	59.79	7.470
72.40	60.91	62.04	63.19	63.19	64.36	65.55	66.75	67.97	67.97	69.21	9.560
72.50	70.47	71.75	71.75	73.05	74.36	75.70	75.70	77.05	78.43	79.82	10.770
72.60	81.24	81.24	82.67	84.13	85.61	85.61	87.11	88.63	90.17	90.17	10.490
72.70	91.73	93.32	94.92	96.56	96.56	98.21	99.89	101.6	101.6	103.3	13.370
72.80	105.1	106.8	106.8	108.6	110.4	112.3	112.3	114.2	116.1	118.0	14.800
72.90	119.9	119.9	121.9	123.9	125.9	125.9	128.0	130.1	132.2	132.2	14.400
73.00	134.3	136.5	138.7	140.9	140.9	143.2	145.5	147.8	147.8	150.1	18.200
73.10	152.5	154.9	154.9	157.3	159.8	162.3	164.9	164.9	167.5	170.1	20.300
73.20	172.8	172.8	175.5	178.2	181.0	181.0	183.8	186.6	189.5	192.4	19.600
73.30	192.4	195.4	198.3	201.4	201.4	204.4	207.5	210.7	210.7	213.9	24.700
73.40	217.1	220.3	220.3	223.6	227.0	230.4	233.8	233.8	237.2	240.7	27.200
73.50	244.3*	244.3	247.9	251.5	255.2	255.2	258.9	262.7	266.5	270.3	26.000
73.60	270.3	274.2	278.2	282.2	282.2	286.2	290.3	294.5	294.5	298.7	32.600
73.70	302.9	307.2	311.5	311.5	315.9	320.3	324.8	324.8	329.4	333.9	35.700
73.80	338.6	338.6	343.3	347.8	352.5	352.5	357.1	361.8	366.6	371.4	32.800
73.90	371.4	376.3	381.2	386.2	386.2	391.2	396.3	401.4	401.4	406.6	40.400
74.00	411.8	417.1*	422.5	422.5	427.9	433.3	438.9	438.9	444.4	450.1	44.000
74.10	455.8	455.8	461.5	467.3	473.2	473.2	479.1	485.1	491.2	491.2	41.500
74.20	497.3	503.4	509.7	509.7	516.0	522.3	528.8	528.8	535.2	541.8	51.100
74.30	548.4	548.4	555.1	561.9	568.7	568.7	575.6	589.1	602.9	602.9	68.600
74.40	617.0	631.3	645.8*	645.8	660.6	675.7	691.0	691.0	706.6	722.5	121.700
74.50	738.7	738.7	755.1	771.8	788.8	788.8	806.1	823.7	841.6	841.6	121.100
74.60	859.8	878.3	897.1	916.2	935.6	955.4	975.4	995.8	1017	1038	199.200
74.70	1059	1081	1103*	1125	1148	1171	1195	1218	1243	1267	233.000
74.80	1292	1318	1343	1369	1396	1423	1450	1478*			

"*" indicates a rating descriptor point

ID	Starting Date	Ending Date	Aging	Comments
----	------------------------	------------------------	-----	----------------------
0000	05/15/2009 09:24:51 UTC-09:00	12/30/2382 12:00:00 UTC-09:00	-1	Base Rating Curve

STATION NUMBER **DUS3w Chandler River** SOURCE AGENCY: UAF

LATITUDE 49.28 LONGITUDE -123.11

Date Processed: 04/17/2014 08:41:17 UTC-09:00 By ekyoucha

Rating for Discharge (m^3/s)

RATING ID: 0000 TYPE: Unknown EXPANSION: STATUS: Undefined

Created by ekyoucha on 11/10/2011 @ 18:34:51 UTC, Updated by ekyoucha on 02/24/2014 @ 00:42:13 UTC

Remarks:

Offset1: 94.79 Offset2: 95.29

Breakpoint1: 98.63

EXPANDED RATING TABLE

Stage (m)	Discharge (m^3/s)										DIFF IN Q PER
	.00	.01	.02	.03	.04	.05	.06	.07	.08	.09	.1 UNITS
96.30						12.30*	12.69	13.08	13.49	13.90	4.060
96.40	14.33	14.76	15.21	15.67	16.13	16.61	17.10	17.60	18.12	18.64	4.850
96.50	19.18	19.72	20.29	20.86	21.45	22.04	22.66	23.28	23.92	24.58	6.060
96.60	25.24	25.93	26.62	27.33	28.06	28.80	29.56	30.33	31.12	31.92	7.500
96.70	32.74	33.58	34.43	35.31	36.19	37.10	38.03	38.97	39.93	40.91	9.170
96.80	41.91	42.93	43.96	45.02	46.10	47.20	48.32	49.46	50.62	51.80	11.090
96.90	53.00	54.23	55.48	56.75	58.04	59.36	60.70	62.07	63.46	64.87	13.310
97.00	66.31	67.77	69.26	70.78	72.32	73.89	75.48	77.10	78.75	80.43	15.830
97.10	82.14	83.87	85.63	87.43	89.25	91.10	92.98	94.90	96.84	98.81	18.660
97.20	100.8	102.9	104.9	107.0	109.2	111.4	113.6	115.8	118.1	120.4	21.900
97.30	122.7	125.1	127.5	130.0	132.5	135.0	137.6	140.2	142.8	145.5	25.600
97.40	148.3	151.0	153.8	156.7	159.6	162.5	165.5	168.5	171.6	174.7	29.500
97.50	177.8	181.0	184.3	187.6	190.9	194.3	197.7	201.2	204.7	208.3	34.100
97.60	211.9	215.6	219.3	223.1	226.9	230.8	234.7	238.7	242.7	246.8	39.000
97.70	250.9	255.1	259.4	263.7*	267.1	270.6	274.0	277.5	281.1	284.6	37.300
97.80	288.2	291.9	295.5	299.2	303.0	306.8	310.6	314.4	318.3	322.2	37.900
97.90	326.1	330.1	334.1	338.2	342.3	346.4	350.6	354.8	359.0	363.3	41.500
98.00	367.6	371.9	376.3	380.7	385.2	389.7	394.2	398.8	403.4	408.1	45.200
98.10	412.8	417.5	422.3	427.1	431.9	436.8	441.8	446.7	451.8	456.8	49.100
98.20	461.9	467.1	472.2	477.5	482.7	488.0	493.4	498.8	504.2	509.7	53.300
98.30	515.2	520.8	526.4	532.1	537.8	543.5	549.3	555.2	561.1	567.0	57.800
98.40	573.0	579.0	585.0	591.2	597.3	603.5	609.8	616.1	622.4	628.8	62.300
98.50	635.3	641.8	648.3	654.9	661.6	668.3	675.0	681.8	688.6	695.5	67.200
98.60	702.5	709.5	716.5	723.6*	720.9*	727.3	733.8	740.3	746.8	753.4	57.500
98.70	760.0	766.6	773.3	780.1	786.8	793.6	800.5	807.4	814.3	821.2	68.200
98.80	828.2	835.3	842.3	849.5	856.6	863.8	871.1	878.3	885.7	893.0	72.200
98.90	900.4	907.9	915.3	922.9	930.4	938.0	945.7	953.4	961.1	968.9	76.300
99.00	976.7	984.5	992.4	1000	1008	1016	1024	1033	1041*	1049	80.300
99.10	1057	1065	1074	1082	1090	1099	1107	1116	1124	1133	85.000
99.20	1142	1150	1159	1168	1177	1186	1195	1204	1213*	1222	89.000
99.30	1231	1240	1249	1258	1268	1277	1286	1296	1305	1315	93.000
99.40	1324	1334	1344	1353	1363	1373	1383	1393	1403	1413	99.000
99.50	1423	1433	1443	1453	1463	1473	1484	1494	1505	1515	103.000
99.60	1526	1536	1547	1557	1568	1579	1590	1600	1611*		

"*" indicates a rating descriptor point

ID	Starting Date	Ending Date	Aging	Comments
0000	05/20/2011 09:36:03 UTC-09:00	12/30/2382 12:00:00 UTC-09:00	0	Base Rating for new Water Station

STATION NUMBER **DUS3w Chandler River** SOURCE AGENCY: UAF

LATITUDE 49.28 LONGITUDE -123.11

Date Processed: 04/17/2014 08:41:35 UTC-09:00 By ekyoucha

Rating for Discharge (m^3/s)

********Shifted for 05/01/2013 00:00:00 UTC-09:00 ********

RATING ID: 0000 TYPE: Unknown EXPANSION: STATUS: Undefined

Created by ekyoucha on 11/10/2011 @ 18:34:51 UTC, Updated by ekyoucha on 02/24/2014 @ 00:42:13 UTC

Remarks:

Offset1: 94.79 Offset2: 95.29

Breakpoint1: 98.63

EXPANDED RATING TABLE

Stage (m)			Discharge (m^3/s)					DIFF IN Q PER				
		.00	.01	.02	.03	.04	.05	.06	.07	.08	.09	.1 UNITS
96.80												96.90
12.30	12.69	13.08	13.49	13.90	14.33	14.76	15.21	15.67	16.13	4.310		
97.00		16.61	17.60	19.18	20.29	21.45	23.28	24.58	26.62	28.06	29.56	15.310
97.10		31.92	33.58	35.31	38.03	39.93	42.93	45.02	47.20	50.62	53.00	23.560
97.20		55.48	59.36	62.07	66.31	69.26	72.32	77.10	80.43	83.87	89.25	37.500
97.30		92.98	98.81	102.9	107.0	113.6	118.1	122.7	130.0	135.0	142.8	55.320
97.40		148.3	151.0	153.8	156.7	159.6	162.5	165.5	168.5	171.6	174.7	29.500
97.50		177.8	181.0	184.3	187.6	190.9	194.3	197.7	201.2	204.7	208.3	34.100
97.60		211.9	215.6	219.3	223.1	226.9	230.8	234.7	238.7	242.7	246.8	39.000
97.70		250.9	255.1	259.4	263.7*	267.1	270.6	274.0	277.5	281.1	284.6	37.300
97.80		288.2	291.9	295.5	299.2	303.0	306.8	310.6	314.4	318.3	322.2	37.900
97.90		326.1	330.1	334.1	338.2	342.3	346.4	350.6	354.8	359.0	363.3	41.500
98.00		367.6	371.9	376.3	380.7	385.2	389.7	394.2	398.8	403.4	408.1	45.200
98.10		412.8	417.5	422.3	427.1	431.9	436.8	441.8	446.7	451.8	456.8	49.100
98.20		461.9	467.1	472.2	477.5	482.7	488.0	493.4	498.8	504.2	509.7	53.300
98.30		515.2	520.8	526.4	532.1	537.8	543.5	549.3	555.2	561.1	567.0	57.800
98.40		573.0	579.0	585.0	591.2	597.3	603.5	609.8	616.1	622.4	628.8	62.300
98.50		635.3	641.8	648.3	654.9	661.6	668.3	675.0	681.8	688.6	695.5	67.200
98.60		702.5	709.5	716.5	723.6*	720.9*	727.3	733.8	740.3	746.8	753.4	57.500
98.70		760.0	766.6	773.3	780.1	786.8	793.6	800.5	807.4	814.3	821.2	68.200
98.80		828.2	835.3	842.3	849.5	856.6	863.8	871.1	878.3	885.7	893.0	72.200
98.90		900.4	907.9	915.3	922.9	930.4	938.0	945.7	953.4	961.1	968.9	76.300
99.00		976.7	984.5	992.4	1000	1008	1016	1024	1033	1041*	1049	80.300
99.10		1057	1065	1074	1082	1090	1099	1107	1116	1124	1133	85.000
99.20		1142	1150	1159	1168	1177	1186	1195	1204	1213*	1222	89.000
99.30		1231	1240	1249	1258	1268	1277	1286	1296	1305	1315	93.000
99.40		1324	1334	1344	1353	1363	1373	1383	1393	1403	1413	99.000
99.50		1423	1433	1443	1453	1463	1473	1484	1494	1505	1515	103.000
99.60		1526	1536	1547	1557	1568	1579	1590	1600	1611*		

"*" indicates a rating descriptor point

ID	Starting Date	Ending Date	Aging	Comments
0000	05/20/2011 09:36:03 UTC-09:00	12/30/2382 12:00:00 UTC-09:00	0	Base Rating for new Water Station

STATION NUMBER **DUS4** **Lower Itkillik River at Crossing** SOURCE AGENCY: UAF

LATITUDE 49.28 LONGITUDE -123.11

Date Processed: 04/17/2014 08:36:07 UTC-09:00 By ekyoucha

Rating for Discharge (m^3/s)

RATING ID: 0000 TYPE: Unknown EXPANSION: STATUS: Undefined

Created by ekyoucha on 02/18/2014 @ 22:03:58 UTC, Updated by ekyoucha on 03/15/2014 @ 00:51:57 UTC

Remarks:

Offset1: 97.00

EXPANDED RATING TABLE

Stage (m)	Discharge (m^3/s)										DIFF IN Q PER
	.00	.01	.02	.03	.04	.05	.06	.07	.08	.09	.1 UNITS
97.40									16.30*	16.92	6.250
97.50	17.55	18.19	18.84	19.51	20.18	20.86	21.55	22.25	22.97	23.69	6.870
97.60	24.42	25.16	25.92	26.68	27.45	28.23	29.03	29.83	30.64	31.46	7.870
97.70	32.29	33.13	33.98	34.84	35.71	36.59	37.48	38.38	39.29	40.20	8.840
97.80	41.13	42.07	43.01	43.97	44.93	45.91	46.89	47.88	48.88	49.89	9.780
97.90	50.91	51.94	52.98	54.03	55.09	56.16	57.23	58.32	59.41	60.51	10.710
98.00	61.62	62.75	63.88	65.02	66.16	67.32	68.49	69.66	70.85	72.04	11.620
98.10	73.24	74.45	75.67	76.90	78.14	79.38	80.64	81.90	83.18	84.46	12.510
98.20	85.75	87.05	88.36	89.67	91.00	92.33	93.67	95.03	96.39	97.75	13.380
98.30	99.13	100.5	101.9	103.3	104.7	106.1	107.6	109.0	110.5*	112.5	15.470
98.40	114.6	116.6	118.7	120.9	123.0	125.2	127.4	129.6	131.9	134.1	21.800
98.50	136.4	138.7	141.1	143.4	145.8	148.2	150.6	153.1	155.6	158.1	24.200
98.60	160.6	163.2	165.7	168.3	171.0	173.6	176.3	179.0	181.7	184.5	26.600
98.70	187.2	190.0	192.9	195.7	198.6	201.5	204.4	207.4	210.4	213.4	29.200
98.80	216.4	219.4	222.5	225.6	228.8	231.9	235.1	238.3	241.6	244.8	31.700
98.90	248.1	251.4	254.8	258.1	261.5	265.0	268.4	271.9	275.4	278.9	34.400
99.00	282.5	286.1	289.7	293.3	297.0	300.7	304.4	308.2	312.0	315.8	37.100
99.10	319.6	323.5*	329.1	334.7	340.4	346.2	352.1	358.0	364.0	370.1	56.600
99.20	376.2	382.5	388.7	395.1	401.6	408.1	414.7	421.3	428.1	434.9	65.600
99.30	441.8	448.8	455.9	463.0	470.3	477.6	485.0	492.4	500.0	507.6	73.500
99.40	515.3	523.1	531.0	539.0	547.1	555.2	563.5	571.8	580.2	588.7	82.000
99.50	597.3	606.0*									

"*" indicates a rating descriptor point

ID	Starting Date	Ending Date	Aging	Comments
0000	05/15/2013 13:08:29 UTC-09:00	12/30/2382 12:00:00 UTC-09:00	0	preliminary rating

ADCP Discharge Measurement Summaries

Measurement summaries for each ADCP measurement on the Upper Itkillik, Lower Itkillik, Anaktuvuk, and Chandler Rivers are included. The measurement summary is output from the Winriver II or River Surveyor Live software. Each transect that is used to calculate discharge is included.

Station Number: 1 Meas. No: 24
Station Name: anaktuvuk 7jun2012 Date: 06/07/2012

Party: ey ns	Width: 128.4 m	Processed by: EY
Boat/Motor: achiles 15hp	Area: 195.5 m²	Mean Velocity: 1.43 m/s
Gage Height: 0.000 m	G.H.Change: 0.000 m	Discharge: 278 m³/s

Area Method: Mean Flow	ADCP Depth: 0.070 m	Index Vel.: 0.00 m/s	Rating No.: 1
Nav. Method: DGPS	Shore Ens.:10	Adj.Mean Vel: 0.00 m/s	Qm Rating: G
MagVar Method: Model (19.9°)	Bottom Est: Power (0.1667)	Rated Area: 0.000 m²	Diff.: 0.000%
Depth Sounder: Not Used	Top Est: Power (0.1667)	Control1: Unspecified	
Discharge Method: None		Control2: Unspecified	
% Correction: 0.00		Control3: Unspecified	

Screening Thresholds:		ADCP:	
BT 3-Beam Solution: YES	Max. Vel.: 2.81 m/s	Type/Freq.: StreamPro / 2000 kHz	
WT 3-Beam Solution: NO	Max. Depth: 2.54 m	Serial #: 1180	Firmware: 31.12
BT Error Vel.: 0.10 m/s	Mean Depth: 1.52 m	Bin Size: 12 cm	Blank: 3 cm
WT Error Vel.: 0.30 m/s	% Meas.: 75.68	BT Mode: 10	BT Pings: 2
BT Up Vel.: 0.30 m/s	Water Temp.: None	WT Mode: 12	WT Pings: 6
WT Up Vel.: 3.50 m/s	ADCP Temp.: 8.9 °C		
Use Weighted Mean Depth: YES			

Performed Diag. Test: YES
Performed Moving Bed Test: YES
Performed Compass Calibration: YES Evaluation: NO
Meas. Location: station

Project Name: anaktuvuk7june2012_0.mmt
Software: 2.10

Tr.#		Edge Distance		#Ens.	Discharge						Width	Area	Time		Mean Vel.		% Bad	
		L	R		Top	Middle	Bottom	Left	Right	Total			Start	End	Boat	Water	Ens.	Bins
000	R	14.0	0.50	298	36.3	210	34.8	-0.137	0.040	281	136.0	216.5	15:04	15:10	0.48	1.30	1	3
001	L	14.0	2.50	199	31.0	209	32.9	0.117	1.48	275	122.8	186.1	15:10	15:14	0.57	1.48	1	5
002	R	20.0	2.50	231	31.9	208	32.6	1.20	0.877	275	132.4	197.1	15:16	15:21	0.46	1.39	1	3
003	L	20.0	2.50	172	32.2	213	32.1	1.34	1.47	280	122.3	182.4	15:21	15:25	0.59	1.54	1	6
Mean		17.0	2.00	225	32.8	210	33.1	0.628	0.968	278	128.4	195.5	**Total**	00:21	0.53	1.43	1	4
SDev		3.46	1.00	54	2.38	2.11	1.16	0.746	0.681	3.44	6.9	15.3			0.07	0.10		
SD/M		0.20	0.50	0.24	0.07	0.01	0.03	1.19	0.70	0.01	0.05	0.08			0.13	0.07		

Remarks: WAAS GPS.

Station Number: Meas. No: 25
Station Name: Anaktuvuk Date: 07/27/2012

Party: el,rg	Width: 95.6 m	Processed by: EY
Boat/Motor: kayak	Area: 97.3 m²	Mean Velocity: 0.912 m/s
Gage Height: 0.000 m	G.H.Change: 0.000 m	Discharge: 88.7 m³/s

Area Method: Mean Flow	ADCP Depth: 0.060 m	Index Vel.: 0.00 m/s	Rating No.: 1
Nav. Method: Bottom Track	Shore Ens.:10	Adj.Mean Vel: 0.00 m/s	Qm Rating: G
MagVar Method: Model (19.9°)	Bottom Est: Power (0.1667)	Rated Area: 0.000 m²	Diff.: 0.000%
Depth Sounder: Not Used	Top Est: Power (0.1667)	Control1: Unspecified	
Discharge Method: None		Control2: Unspecified	
% Correction: 0.00		Control3: Unspecified	

Screening Thresholds:		ADCP:	
BT 3-Beam Solution: YES	Max. Vel.: 1.78 m/s	Type/Freq.: StreamPro / 2000 kHz	
WT 3-Beam Solution: NO	Max. Depth: 2.27 m	Serial #: 1180	Firmware: 31.12
BT Error Vel.: 0.10 m/s	Mean Depth: 1.02 m	Bin Size: 8 cm	Blank: 3 cm
WT Error Vel.: 0.30 m/s	% Meas.: 73.21	BT Mode: 10	BT Pings: 2
BT Up Vel.: 0.30 m/s	Water Temp.: None	WT Mode: 12	WT Pings: 6
WT Up Vel.: 2.00 m/s	ADCP Temp.: 13.3 °C		
Use Weighted Mean Depth: YES			

Performed Diag. Test: NO
Performed Moving Bed Test: YES
Performed Compass Calibration: YES Evaluation: NO
Meas. Location: station

Project Name: anak_27july2012_1.mmt
Software: 2.10

Tr.#		Edge Distance		#Ens.	Discharge						Width	Area	Time		Mean Vel.		% Bad	
		L	R		Top	Middle	Bottom	Left	Right	Total			Start	End	Boat	Water	Ens.	Bins
000	L	18.3	3.80	282	11.2	65.8	10.1	0.689	0.884	88.6	95.6	99.7	10:28	10:34	0.27	0.89	0	3
001	R	22.2	4.50	211	11.1	65.8	10.1	1.36	1.11	89.5	97.0	100.8	10:35	10:39	0.32	0.89	3	2
002	L	19.8	3.80	193	11.9	63.9	9.98	0.811	1.44	88.0	94.9	94.2	10:40	10:45	0.33	0.93	0	2
003	R	18.7	4.50	252	11.9	64.0	10.1	0.693	1.75	88.4	94.9	94.4	10:45	10:50	0.27	0.94	0	2
Mean		19.8	4.15	234	11.5	64.9	10.1	0.889	1.30	88.7	95.6	97.3	**Total**	00:22	0.30	0.91	1	3
SDev		1.75	0.40	40	0.430	1.07	0.061	0.322	0.380	0.641	1.0	3.5			0.03	0.03		
SD/M		0.09	0.10	0.17	0.04	0.02	0.01	0.36	0.29	0.01	0.01	0.04			0.10	0.03		

Remarks: No GPS.

Station Number:
Station Name: Anaktuvuk_DSSTN_8-25-12

Meas. No: 26
Date: 08/25/2012

Party: EY, EL, NS	Width: 64.7 m	Processed by: EY
Boat/Motor: Kayak	Area: 81.2 m^2	Mean Velocity: 0.551 m/s
Gage Height: 0.000 m	G.H.Change: 0.000 m	Discharge: 44.7 m^3/s

Area Method: Mean Flow	ADCP Depth: 0.080 m	Index Vel.: 0.00 m/s	Rating No.: 1
Nav. Method: DGPS	Shore Ens.:10	Adj.Mean Vel: 0.00 m/s	Qm Rating: G
MagVar Method: Model (19.9°)	Bottom Est: Power (0.1667)	Rated Area: 0.000 m^2	Diff.: 0.000%
Depth Sounder: Not Used	Top Est: Power (0.1667)	Control1: Unspecified	
Discharge Method: None		Control2: Unspecified	
% Correction: 0.00		Control3: Unspecified	

Screening Thresholds:		ADCP:	
BT 3-Beam Solution: YES	Max. Vel.: 1.68 m/s	Type/Freq.: StreamPro / 2000 kHz	
WT 3-Beam Solution: NO	Max. Depth: 2.05 m	Serial #: 1180	Firmware: 31.12
BT Error Vel.: 0.10 m/s	Mean Depth: 1.25 m	Bin Size: 7 cm*	Blank: 3 cm
WT Error Vel.: 0.32 m/s*	% Meas.: 72.70	BT Mode: 10	BT Pings: 2
BT Up Vel.: 0.30 m/s	Water Temp.: None	WT Mode: 12	WT Pings: 6
WT Up Vel.: 1.75 m/s*	ADCP Temp.: 10.8 °C		
Use Weighted Mean Depth: YES			

Performed Diag. Test: YES
Performed Moving Bed Test: YES
Performed Compass Calibration: YES   Evaluation: NO
Meas. Location: 3/4 mile DS Stn

Project Name: Anaktuvuk_8-25-12_0.mmt
Software: 2.10

Tr.#		Edge Distance		#Ens.	Discharge						Width	Area	Time		Mean Vel.		% Bad	
		L	R		Top	Middle	Bottom	Left	Right	Total			Start	End	Boat	Water	Ens.	Bins
000	L	6.90	1.00	270	5.48	30.5	10.7	0.074	0.018	46.7	65.5	82.6	14:31	14:37	0.19	0.57	1	5
002	L	13.0	1.00	170	4.75	32.8	5.16	0.449	0.039	43.2	64.6	81.4	14:46	14:50	0.26	0.53	1	5
003	*R*	*13.0*	*1.00*	*253*	*5.39*	*35.6*	*5.96*	*0.439*	*0.041*	*47.4*	*64.9*	*80.7*	*14:50*	*14:55*	*0.20*	*0.59*	*0*	*5*
004	*L*	*13.0*	*1.00*	*146*	*4.55*	*31.2*	*5.25*	*0.521*	*0.029*	*41.5*	*63.7*	*79.9*	*14:55*	*14:58*	*0.30*	*0.52*	*1*	*4*
Mean		11.5	1.00	209	5.04	32.5	6.76	0.371	0.032	44.7	64.7	81.2	**Total**	00:26	0.24	0.55	1	5
SDev		3.05	0.00	61	0.461	2.27	2.64	0.201	0.011	2.82	0.7	1.1			0.05	0.03		
SD/M		0.27	0.00	0.29	0.09	0.07	0.39	0.54	0.33	0.06	0.01	0.01			0.22	0.06		

Remarks: gps waas

* - value not consistent for all transects
Discharge for transects in *italics* have a total Q more than 5% from the mean

Station Number:
Station Name: Anaktuvuk at Culverts

Meas. No: 27
Date: 06/05/2013

Party: busey, gieck, lamb, passa	Width: 321.8 m	Processed by: EY
Boat/Motor: achilles/Honda15HP	Area: 445.1 m^2	Mean Velocity: 1.08 m/s
Gage Height: 0.000 m	G.H.Change: 0.000 m	Discharge: 455 m^3/s

Area Method: Mean Flow	ADCP Depth: 0.120 m	Index Vel.: 0.00 m/s	Rating No.: 1
Nav. Method: DGPS	Shore Ens.:10	Adj.Mean Vel: 0.00 m/s	Qm Rating: P
MagVar Method: Model (19.6°)	Bottom Est: Power (0.1667)	Rated Area: 0.000 m^2	Diff.: 0.000%
Depth Sounder: Not Used	Top Est: Power (0.1667)	Control1: Unspecified	
Discharge Method: Distributed		Control2: Unspecified	
% Correction: 1.84		Control3: Unspecified	

Screening Thresholds:		ADCP:	
BT 3-Beam Solution: YES	Max. Vel.: 4.12 m/s	Type/Freq.: Rio Grande / 1200 kHz	
WT 3-Beam Solution: YES	Max. Depth: 4.38 m	Serial #: 12558	Firmware: 10.16
BT Error Vel.: 0.10 m/s	Mean Depth: 1.37 m	Bin Size: 5 cm	Blank: 25 cm
WT Error Vel.: 1.07 m/s	% Meas.: 60.27	BT Mode: 5	BT Pings: 1
BT Up Vel.: 0.30 m/s	Water Temp.: None	WT Mode: 12	WT Pings: 1
WT Up Vel.: 4.00 m/s*	ADCP Temp.: 2.1 °C	WV : 347	WO : 9, 4
Use Weighted Mean Depth: YES			

Performed Diag. Test: YES
Performed Moving Bed Test: YES
Performed Compass Calibration: YES   Evaluation: YES
Meas. Location: station

Project Name: anaktuvuk_culverts_5june2013_
Software: 2.10

Tr.#		Edge Distance		#Ens.	MBT Corrected Discharge						Width	Area	Time		Mean Vel.		% Bad	
		L	R		Top	Middle	Bottom	Left	Right	Total			Start	End	Boat	Water	Ens.	Bins
000	*L*	*4.50*	*2.00*	*714*	*155*	*271*	*54.0*	*3.92*	*2.46*	*486*	*272.1*	*358.6*	*15:29*	*15:41*	*1.24*	*1.36*	*14*	*0*
002	R	*12.0*	*3.00*	*1097*	*98.4*	*296*	*42.6*	*5.84*	*3.49*	*447*	*361.2*	*556.6*	*15:48*	*16:05*	*1.06*	*0.80*	*3*	*0*
004	L	*5.00*	*2.00*	*860*	*145*	*241*	*45.6*	*4.70*	*2.10*	*438*	*254.1*	*325.1*	*16:16*	*16:30*	*1.01*	*1.35*	*15*	*0*
005	R	*7.00*	*2.00*	*1229*	*117*	*289*	*43.0*	*-1.81*	*1.63*	*449*	*400.0*	*540.2*	*16:30*	*16:50*	*0.98*	*0.83*	*4*	*0*
Mean		7.13	2.25	975	129	274	46.3	3.16	2.42	455	321.8	445.1	**Total**	01:20	1.07	1.08	9	0
SDev		3.42	0.50	231	25.9	24.8	5.27	3.41	0.793	21.6	70.0	120.2			0.11	0.31		
SD/M		0.48	0.22	0.24	0.20	0.09	0.11	1.08	0.33	0.05	0.22	0.27			0.11	0.28		

Remarks: beam 3 at 45 degrees
the stage has dropped enough that the gravel bar in the left to right middle of the channel was too shallow for measurements t
times. We had a better idea of how the channel had changed after doing the first run so that is why transects 2,4, and 5 were
better than 0. trans 1 we discovered the lower bound in the config was to shallow. so reset and restarted transect. Transects
to 9 are for Horacio but... stage had dropped enough it wasn't worth it to try for the profiles he wanted.
Post processing notes: Adjusted beam 3 alignment.

* - value not consistent for all transects
Discharge for transects in *italics* have a total Q more than 5% from the mean

Station Number: Meas. No: 28

Station Name: Anaktuvuk River 1 mile DS station Date: 07/13/2013

Party: RG/JH	Width: 66.0 m	Processed by: EY
Boat/Motor: kayak	Area: 59.9 m²	Mean Velocity: 0.997 m/s
Gage Height: 0.000 m	G.H.Change: 0.000 m	Discharge: 59.2 m³/s

Area Method: Mean Flow	ADCP Depth: 0.120 m	Index Vel.: 0.00 m/s	Rating No.: 1
Nav. Method: DGPS	Shore Ens.:10	Adj.Mean Vel: 0.00 m/s	Qm Rating: F
MagVar Method: Model (19.6°)	Bottom Est: Power (0.1667)	Rated Area: 0.000 m²	Diff.: 0.000%
Depth Sounder: Not Used	Top Est: Power (0.1667)	Control1: Unspecified	
Discharge Method: None		Control2: Unspecified	
% Correction: 0.00		Control3: Unspecified	

Screening Thresholds:		ADCP:	
BT 3-Beam Solution: YES	Max. Vel.: 2.26 m/s	Type/Freq.: StreamPro / 2000 kHz	
WT 3-Beam Solution: YES	Max. Depth: 1.56 m	Serial #: 1180	Firmware: 31.12
BT Error Vel.: 0.10 m/s	Mean Depth: 0.911 m	Bin Size: 6 cm	Blank: 3 cm
WT Error Vel.: 0.35 m/s	% Meas.: 66.46	BT Mode: 10	BT Pings: 2
BT Up Vel.: 0.30 m/s	Water Temp.: None	WT Mode: 12	WT Pings: 6
WT Up Vel.: 2.00 m/s*	ADCP Temp.: 13.6 °C		
Use Weighted Mean Depth: YES			

Performed Diag. Test: YES

Performed Moving Bed Test: YES

Performed Compass Calibration: YES Evaluation: YES

Meas. Location: Downstream station 1 mile

Project Name: dus2-2_0_13july2013_eyreview

Software: 2.10

Tr.#		Edge Distance		#Ens.	Discharge						Width	Area	Time		Mean Vel.		% Bad	
		L	R		Top	Middle	Bottom	Left	Right	Total			Start	End	Boat	Water	Ens.	Bins
000	L	14.0	4.00	151	10.9	40.8	7.81	0.680	0.290	60.5	63.2	58.5	14:12	14:15	0.30	1.03	1	3
001	R	11.0	4.00	156	10.8	38.8	7.79	0.598	0.269	58.3	58.8	55.3	14:16	14:19	0.33	1.05	2	3
003	L	14.0	4.00	163	10.4	39.5	7.55	0.806	0.290	58.6	61.9	56.5	14:24	14:28	0.33	1.04	1	4
004	R	10.0	4.00	135	12.0	38.3	8.12	0.831	0.283	59.5	80.0	69.1	14:30	14:32	0.41	0.86	4	2
Mean		12.3	4.00	151	11.0	39.4	7.82	0.729	0.283	59.2	66.0	59.9	**Total**	00:20	0.34	1.00	2	3
SDev		2.06	0.00	12	0.669	1.09	0.232	0.109	0.010	1.02	9.5	6.3			0.05	0.09		
SD/M		0.17	0.00	0.08	0.06	0.03	0.03	0.15	0.03	0.02	0.14	0.11			0.14	0.09		

Remarks: This measurement supercedes the measurement collected on 7/12 because not all flow was measured on 7/12. Channel geometry has changed from 2012. RTK GPS working.

* - value not consistent for all transects

Station Number: Meas. No: 29

Station Name: anaktuvuk_dus2 Date: 08/24/2013

Party: JWH_JAK	Width: 68.3 m	Processed by: EY
Boat/Motor: kayak	Area: 77.1 m²	Mean Velocity: 1.48 m/s
Gage Height: 0.000 m	G.H.Change: 0.000 m	Discharge: 114 m³/s

Area Method: Mean Flow	ADCP Depth: 0.120 m	Index Vel.: 0.00 m/s	Rating No.: 1
Nav. Method: DGPS	Shore Ens.:10	Adj.Mean Vel: 0.00 m/s	Qm Rating: G
MagVar Method: Model (19.6°)	Bottom Est: Power (0.1667)	Rated Area: 0.000 m²	Diff.: 0.000%
Depth Sounder: Not Used	Top Est: Power (0.1667)	Control1: Unspecified	
Discharge Method: None		Control2: Unspecified	
% Correction: 0.00		Control3: Unspecified	

Screening Thresholds:		ADCP:	
BT 3-Beam Solution: YES	Max. Vel.: 2.81 m/s	Type/Freq.: StreamPro / 2000 kHz	
WT 3-Beam Solution: YES	Max. Depth: 2.24 m	Serial #: 1180	Firmware: 31.12
BT Error Vel.: 0.10 m/s	Mean Depth: 1.13 m	Bin Size: 6 cm	Blank: 3 cm
WT Error Vel.: 0.32 m/s	% Meas.: 68.68	BT Mode: 10	BT Pings: 2
BT Up Vel.: 0.30 m/s	Water Temp.: None	WT Mode: 12	WT Pings: 6
WT Up Vel.: 3.00 m/s*	ADCP Temp.: 8.2 °C		
Use Weighted Mean Depth: YES			

Performed Diag. Test: YES

Performed Moving Bed Test: YES

Performed Compass Calibration: YES Evaluation: YES

Meas. Location: 1 mile downstream from station

Project Name: dus2_1_24aug2013.mmt

Software: 2.10

Tr.#		Edge Distance		#Ens.	Discharge						Width	Area	Time		Mean Vel.		% Bad	
		L	R		Top	Middle	Bottom	Left	Right	Total			Start	End	Boat	Water	Ens.	Bins
000	L	10.0	3.00	161	17.9	79.8	15.8	0.735	0.235	114	68.9	79.9	15:20	15:23	0.37	1.43	1	5
001	R	11.5	4.00	127	18.3	79.0	16.8	1.47	0.503	116	68.5	75.8	15:26	15:29	0.45	1.53	1	6
002	L	10.5	3.00	172	18.1	81.1	16.2	0.758	0.376	117	70.5	81.3	15:38	15:41	0.37	1.44	1	5
003	R	11.0	4.00	155	17.3	74.0	16.8	1.29	0.460	110	65.2	71.4	15:43	15:46	0.40	1.54	1	7
Mean		10.8	3.50	153	17.9	78.5	16.4	1.06	0.393	114	68.3	77.1	**Total**	00:26	0.40	1.48	1	6
SDev		0.65	0.58	19	0.444	3.10	0.519	0.371	0.118	3.07	2.2	4.4			0.04	0.06		
SD/M		0.06	0.16	0.13	0.02	0.04	0.03	0.35	0.30	0.03	0.03	0.06			0.09	0.04		

Remarks: RTK GPS

* - value not consistent for all transects

Station Number: 2
Station Name: chandler_culvert_6jun2012

Meas. No: 12
Date: 06/06/2012

Party: ns ey	Width: 149.5 m	Processed by: EY
Boat/Motor: ahilles/15hp	Area: 187.4 m²	Mean Velocity: 1.75 m/s
Gage Height: 0.000 m	G.H.Change: 0.000 m	Discharge: 328 m³/s

Area Method: Mean Flow	ADCP Depth: 0.070 m	Index Vel.: 0.00 m/s	Rating No.: 1
Nav. Method: DGPS	Shore Ens.:10	Adj.Mean Vel: 0.00 m/s	Qm Rating: G
MagVar Method: None (19.7°)	Bottom Est: Power (0.1667)	Rated Area: 0.000 m²	Diff.: 0.000%
Depth Sounder: Not Used	Top Est: Power (0.1667)	Control1: Unspecified	
Discharge Method: None		Control2: Unspecified	
% Correction: 0.00		Control3: Unspecified	

Screening Thresholds:		ADCP:	
BT 3-Beam Solution: YES	Max. Vel.: 3.03 m/s	Type/Freq.: StreamPro / 2000 kHz	
WT 3-Beam Solution: NO	Max. Depth: 3.60 m	Serial #: 1180	Firmware: 31.12
BT Error Vel.: 0.10 m/s	Mean Depth: 1.26 m	Bin Size: 12 cm	Blank: 3 cm
WT Error Vel.: 0.30 m/s	% Meas.: 68.49	BT Mode: 10	BT Pings: 2
BT Up Vel.: 0.30 m/s	Water Temp.: None	WT Mode: 12	WT Pings: 6
WT Up Vel.: 4.00 m/s	ADCP Temp.: 7.0 °C		
Use Weighted Mean Depth: YES			

Performed Diag. Test: YES
Performed Moving Bed Test: NO
Performed Compass Calibration: YES Evaluation: NO
Meas. Location: culverts

Project Name: chandler_6jun2012_0.mmt
Software: 2.10

Tr.#		Edge Distance		#Ens.	Discharge						Width	Area	Time		Mean Vel.		% Bad	
		L	R		Top	Middle	Bottom	Left	Right	Total			Start	End	Boat	Water	Ens.	Bins
000	L	71.0	3.50	202	33.5	213	37.8	44.8	3.01	332	138.6	178.3	11:35	11:40	0.47	1.87	1	11
001	R	46.0	2.00	311	43.2	224	42.5	11.9	0.446	322	159.4	184.2	11:48	11:55	0.39	1.75	1	7
002	L	46.0	2.00	513	39.1	236	40.7	12.1	0.514	329	143.2	195.1	11:56	12:07	0.23	1.69	17	7
004	R	48.0	1.50	258	42.7	224	42.3	18.2	0.473	328	156.7	192.1	12:11	12:16	0.39	1.71	8	8
Mean		52.8	2.25	321	39.6	225	40.8	21.8	1.11	328	149.5	187.4	**Total**	00:40	0.37	1.75	7	8
SDev		12.2	0.87	136	4.45	9.43	2.16	15.7	1.26	4.11	10.1	7.7			0.10	0.08		
SD/M		0.23	0.38	0.42	0.11	0.04	0.05	0.72	1.14	0.01	0.07	0.04			0.28	0.05		

Remarks: streampro WAAS GPS

Station Number:
Station Name: Chandler Culverts

Meas. No: 13
Date: 07/27/2012

Party: el,ns	Width: 75.2 m	Processed by: EY
Boat/Motor: kayak	Area: 94.9 m²	Mean Velocity: 0.804 m/s
Gage Height: 0.000 m	G.H.Change: 0.000 m	Discharge: 76.3 m³/s

Area Method: Mean Flow	ADCP Depth: 0.120 m	Index Vel.: 0.00 m/s	Rating No.: 1
Nav. Method: DGPS	Shore Ens.:10	Adj.Mean Vel: 0.00 m/s	Qm Rating: G
MagVar Method: Model (19.8°)	Bottom Est: Power (0.1667)	Rated Area: 0.000 m²	Diff.: 0.000%
Depth Sounder: Not Used	Top Est: Power (0.1667)	Control1: Unspecified	
Discharge Method: None		Control2: Unspecified	
% Correction: 0.00		Control3: Unspecified	

Screening Thresholds:		ADCP:	
BT 3-Beam Solution: YES	Max. Vel.: 2.76 m/s	Type/Freq.: StreamPro / 2000 kHz	
WT 3-Beam Solution: NO	Max. Depth: 2.24 m	Serial #: 1180	Firmware: 31.12
BT Error Vel.: 0.10 m/s	Mean Depth: 1.26 m	Bin Size: 7 cm	Blank: 3 cm
WT Error Vel.: 0.32 m/s	% Meas.: 71.90	BT Mode: 10	BT Pings: 2
BT Up Vel.: 0.30 m/s	Water Temp.: None	WT Mode: 12	WT Pings: 6
WT Up Vel.: 2.00 m/s	ADCP Temp.: 15.2 °C		
Use Weighted Mean Depth: YES			

Performed Diag. Test: NO
Performed Moving Bed Test: NO
Performed Compass Calibration: YES Evaluation: NO
Meas. Location: culverts

Project Name: Chandler_27July2012_0.mmt
Software: 2.10

Tr.#		Edge Distance		#Ens.	Discharge						Width	Area	Time		Mean Vel.		% Bad	
		L	R		Top	Middle	Bottom	Left	Right	Total			Start	End	Boat	Water	Ens.	Bins
006	L	18.0	1.50	99	10.7	53.6	10.5	0.713	0.097	75.5	78.9	94.0	14:47	14:49	0.60	0.80	1	3
007	R	5.00	1.00	126	11.8	56.8	10.5	0.131	0.037	79.4	70.1	92.6	14:54	14:56	0.48	0.86	1	3
008	L	16.0	1.30	139	11.3	57.4	10.4	0.712	0.082	79.8	77.8	96.0	14:57	15:00	0.41	0.83	1	3
009	*R*	*12.8*	*1.00*	*125*	*9.78*	*47.6*	*8.81*	*0.427*	*0.026*	*66.7*	*75.8*	*95.3*	*15:02*	*15:05*	*0.46*	*0.70*	*1*	*4*
010	*L*	*14.0*	*1.30*	*103*	*11.2*	*58.1*	*10.4*	*0.397*	*0.073*	*80.2*	*74.1*	*93.9*	*15:06*	*15:08*	*0.55*	*0.85*	*1*	*3*
011	R	*11.5*	*1.50*	*158*	*10.9*	*52.7*	*10.3*	*0.128*	*0.021*	*74.1*	*74.7*	*94.8*	*15:09*	*15:12*	*0.41*	*0.78*	*1*	*3*
012	L	*12.4*	*1.50*	*142*	*10.2*	*57.6*	*9.89*	*0.449*	*0.062*	*78.3*	*74.7*	*97.6*	*15:14*	*15:17*	*0.45*	*0.80*	*1*	*3*
Mean		12.8	1.30	127	10.8	54.8	10.1	0.422	0.057	76.3	75.2	94.9	**Total**	00:29	0.48	0.80	1	3
SDev		4.11	0.22	21	0.681	3.81	0.612	0.238	0.029	4.81	2.9	1.6			0.07	0.05		
SD/M		0.32	0.17	0.17	0.06	0.07	0.06	0.56	0.52	0.06	0.04	0.02			0.15	0.07		

Remarks: No ADCP test. WAAS GPS.

Discharge for transects in *italics* have a total Q more than 5% from the mean

Station Number:
Station Name: Chandler Culverts

Meas. No: 14
Date: 08/24/2012

Party: el,ey,ns	Width: 48.9 m	Processed by: EY
Boat/Motor: kayak	Area: 32.2 m²	Mean Velocity: 0.821 m/s
Gage Height: 0.000 m	G.H.Change: 0.000 m	Discharge: 26.5 m³/s

Area Method: Mean Flow	ADCP Depth: 0.045 m	Index Vel.: 0.00 m/s	Rating No.: 1
Nav. Method: DGPS	Shore Ens.:10	Adj.Mean Vel: 0.00 m/s	Qm Rating: G
MagVar Method: Model (19.8°)	Bottom Est: Power (0.1667)	Rated Area: 0.000 m²	Diff.: 0.000%
Depth Sounder: Not Used	Top Est: Power (0.1667)	Control1: Unspecified	
Discharge Method: None		Control2: Unspecified	
% Correction: 0.00		Control3: Unspecified	

Screening Thresholds:		ADCP:	
BT 3-Beam Solution: YES	Max. Vel.: 1.90 m/s	Type/Freq.: StreamPro / 2000 kHz	
WT 3-Beam Solution: NO	Max. Depth: 1.13 m	Serial #: 1180	Firmware: 31.12
BT Error Vel.: 0.10 m/s	Mean Depth: 0.660 m	Bin Size: 5 cm	Blank: 3 cm
WT Error Vel.: 0.38 m/s	% Meas.: 63.79	BT Mode: 10	BT Pings: 2
BT Up Vel.: 0.30 m/s	Water Temp.: None	WT Mode: 12	WT Pings: 6
WT Up Vel.: 2.00 m/s	ADCP Temp.: 12.7 °C		
Use Weighted Mean Depth: YES			

Performed Diag. Test: YES
Performed Moving Bed Test: YES
Performed Compass Calibration: YES   Evaluation: NO
Meas. Location: culverts

Project Name: Chandler_culvert_24Aug2012_(
Software: 2.10

Tr.#		Edge Distance		#Ens.	Discharge						Width	Area	Time		Mean Vel.		% Bad	
		L	R		Top	Middle	Bottom	Left	Right	Total			Start	End	Boat	Water	Ens.	Bins
001	R	8.00	2.50	167	4.80	17.0	4.23	0.291	0.219	26.6	49.3	32.5	13:43	13:46	0.20	0.82	1	3
002	L	8.00	3.00	149	4.82	16.7	4.30	0.371	0.231	26.4	49.7	32.3	13:46	13:50	0.22	0.82	1	3
003	R	9.00	3.00	174	4.69	17.1	4.16	0.598	0.233	26.8	48.1	31.9	13:50	13:53	0.19	0.84	1	4
004	L	9.00	2.50	165	4.71	16.7	3.90	0.616	0.165	26.1	48.4	32.3	13:54	13:57	0.19	0.81	1	3
Mean		8.50	2.75	163	4.76	16.9	4.14	0.469	0.212	26.5	48.9	32.2	**Total**	00:14	0.20	0.82	1	3
SDev		0.58	0.29	11	0.066	0.209	0.173	0.163	0.032	0.299	0.8	0.2			0.01	0.01		
SD/M		0.07	0.10	0.07	0.01	0.01	0.04	0.35	0.15	0.01	0.02	0.01			0.07	0.02		

Remarks: WAAS GPS.

Station Number:
Station Name: Chandler River

Meas. No: 15
Date: 06/01/2013

Party: Gieck & Busey	Width: 145.3 m	Processed by: EY and BB
Boat/Motor: Achilles 15hp	Area: 282.5 m²	Mean Velocity: 2.04 m/s
Gage Height: 0.000 m	G.H.Change: 0.000 m	Discharge: 576 m³/s

Area Method: Mean Flow	ADCP Depth: 0.120 m	Index Vel.: 0.00 m/s	Rating No.: 1
Nav. Method: DGPS	Shore Ens.:10	Adj.Mean Vel: 0.00 m/s	Qm Rating: P
MagVar Method: Model (19.4°)	Bottom Est: Power (0.1667)	Rated Area: 0.000 m²	Diff.: 0.000%
Depth Sounder: Not Used	Top Est: Power (0.1667)	Control1: Unspecified	
Discharge Method: None		Control2: Unspecified	
% Correction: 0.00		Control3: Unspecified	

Screening Thresholds:		ADCP:	
BT 3-Beam Solution: YES	Max. Vel.: 4.55 m/s	Type/Freq.: StreamPro / 2000 kHz	
WT 3-Beam Solution: YES	Max. Depth: 3.35 m	Serial #: 12558	Firmware: 31.12
BT Error Vel.: 0.10 m/s	Mean Depth: 1.97 m	Bin Size: 5 cm	Blank: 3 cm
WT Error Vel.: 1.07 m/s	% Meas.: 60.86	BT Mode: 10	BT Pings: 2
BT Up Vel.: 0.30 m/s	Water Temp.: 1.0 °C	WT Mode: 12	WT Pings: 6
WT Up Vel.: 3.00 m/s	ADCP Temp.: 3.5 °C	WV : 200	WO : 6, 4
Use Weighted Mean Depth: YES			

Performed Diag. Test: YES
Performed Moving Bed Test: YES
Performed Compass Calibration: YES   Evaluation: YES
Meas. Location: Culverts above gauge site

Project Name: chandler_culverts_2013-06-01_
Software: 2.10

Tr.#		Edge Distance		#Ens.	Discharge						Width	Area	Time		Mean Vel.		% Bad	
		L	R		Top	Middle	Bottom	Left	Right	Total			Start	End	Boat	Water	Ens.	Bins
000	R	9.30	1.50	229	137	374	66.4	4.58	0.699	582	123.5	270.7	18:02	18:06	0.96	2.15	0	0
001	L	14.4	3.90	338	179	308	72.9	4.07	3.15	567	171.7	285.8	18:09	18:14	1.16	1.99	6	0
002	R	13.5	3.70	277	140	380	65.4	6.91	1.53	593	142.5	291.4	18:17	18:22	1.18	2.04	0	1
003	L	10.3	4.40	229	149	341	65.4	2.99	3.74	562	143.4	282.3	18:25	18:29	1.34	1.99	9	0
Mean		11.9	3.38	268	151	351	67.5	4.64	2.28	576	145.3	282.5	**Total**	00:26	1.16	2.04	4	0
SDev		2.46	1.28	52	19.4	33.0	3.61	1.66	1.41	14.1	19.8	8.7			0.16	0.08		
SD/M		0.21	0.38	0.19	0.13	0.09	0.05	0.36	0.62	0.02	0.14	0.03			0.14	0.04		

Remarks: 6/5/2013 Update
Beam 3 @ 45 Degrees.

ook several tries to get a decent compass test. Mix of spinning a bit fast, wave action, and flowing ice dodging, water velocities pushing us down river too quickly.

id the transects in the usual place (above culverts). Start the RB up by some coal deposit or something Rob discussed at length. Anyway, neat geology at the start. Then drifted down to the shallows on the left bank. On the left bank motored up a bit so we'd miss the biggest standing waves in the middle of the channel / gravel bar in the middle. Finished a above the marina. High velocities and shallow water were a bit of an issue on this date. Neither of us noticed any caviation around the rio grande (iit was discussed while we were doing the transects) contributing to bad data bins but it's possible.

id not get a good moving bed this day. I would vote for combining the compass calibration in this file with the last loop in the 6/2 data set.

Station Number:
Station Name: chandler River culverts

Meas. No: 16
Date: 06/02/2013

Party: gieck busey	Width: 164.8 m	Processed by: e youcha, b busey
Boat/Motor: achilles 15hp	Area: 372.9 m²	Mean Velocity: 2.34 m/s
Gage Height: 0.000 m	G.H.Change: 0.000 m	Discharge: 872 m³/s

Area Method: Mean Flow	ADCP Depth: 0.150 m	Index Vel.: 0.00 m/s	Rating No.: 1
Nav. Method: Bottom Track	Shore Ens.:10	Adj.Mean Vel: 0.00 m/s	Qm Rating: P
MagVar Method: Model (19.8°)	Bottom Est: Power (0.1667)	Rated Area: 0.000 m²	Diff.: 0.000%
Depth Sounder: Not Used	Top Est: Power (0.1667)	Control1: Unspecified	
Discharge Method: None		Control2: Unspecified	
% Correction: 0.00		Control3: Unspecified	

Screening Thresholds:		ADCP:	
BT 3-Beam Solution: YES	Max. Vel.: 5.39 m/s	Type/Freq.: Rio Grande / 1200 kHz	
WT 3-Beam Solution: YES	Max. Depth: 4.41 m	Serial #: 12558	Firmware: 10.16
BT Error Vel.: 0.10 m/s	Mean Depth: 2.30 m	Bin Size: 25 cm	Blank: 25 cm
WT Error Vel.: 1.07 m/s	% Meas.: 56.10	BT Mode: 5	BT Pings: 1
BT Up Vel.: 0.30 m/s	Water Temp.: None	WT Mode: 12	WT Pings: 1
WT Up Vel.: 5.00 m/s	ADCP Temp.: 6.0 °C	WV : 254	WO : 2, 4
Use Weighted Mean Depth: YES			

Performed Diag. Test: YES
Performed Moving Bed Test: YES
Performed Compass Calibration: NO   Evaluation: NO
Meas. Location: culverts

Project Name: chandler_culverts_2013-06-02_
Software: 2.10

Tr.#		Edge Distance L	Edge Distance R	#Ens.	Discharge Top	Middle	Bottom	Left	Right	Total	Width	Area	Time Start	End	Mean Vel. Boat	Water	% Bad Ens.	Bins
000	R	8.60	2.00	573	201	515	131	8.09	2.67	858	145.3	367.6	17:26	17:29	1.49	2.33	40	2
001	L	22.6	4.60	605	279	414	160	10.9	7.86	872	208.2	397.2	17:31	17:35	1.47	2.19	25	0
002	R	22.6	1.50	495	187	504	129	35.8	1.80	858	141.9	354.8	17:41	17:44	1.47	2.42	34	3
003	L	27.1	5.40	509	219	524	139	13.1	5.69	901	163.6	372.2	17:47	17:50	1.45	2.42	32	1
Mean		20.2	3.38	545	222	489	140	17.0	4.50	872	164.8	372.9	**Total**	00:24	1.47	2.34	33	2
SDev		8.04	1.92	52	40.4	50.9	14.4	12.7	2.79	20.2	30.5	17.8			0.02	0.11		
SD/M		0.40	0.57	0.10	0.18	0.10	0.10	0.75	0.62	0.02	0.18	0.05			0.01	0.05		

Remarks: Beam 3 @ 45 degrees.
ADCP remained on-site between 6/1 and 6/2.
no GPS data.
Got good bottom track data on this day though. Took several attempts to get a good loop test. We dropped the adcp to 26cm below the water surface.
Otherwise very good data. Left bank was over-bank full a little bit I think (kind of hard to tell with a low to the water perspective we shot distance to the traditional bank.

ost Processing Notes (EY): Entered in magnetic declination of 19.75 and beam 3 of 45 degrees. Transducer depth entered of 15 cm from field notes (was 0.000 in Winriver), so Q increased after post processing.
Compass calibration done the previous day and equipment left onsite.

Station Number:
Station Name: Chandler_Culverts_6June2013

Meas. No: 17
Date: 06/06/2013

Party: el/rg	Width: 106.8 m	Processed by: Emily Youcha
Boat/Motor: achilles honda 15hp	Area: 194.9 m²	Mean Velocity: 0.958 m/s
Gage Height: 0.000 m	G.H.Change: 0.000 m	Discharge: 187 m³/s

Area Method: Mean Flow	ADCP Depth: 0.100 m	Index Vel.: 0.00 m/s	Rating No.: 1
Nav. Method: Bottom Track	Shore Ens.:10	Adj.Mean Vel: 0.00 m/s	Qm Rating: F
MagVar Method: Model (19.4°)	Bottom Est: Power (0.1667)	Rated Area: 0.000 m²	Diff.: 0.000%
Depth Sounder: Not Used	Top Est: Power (0.1667)	Control1: Unspecified	
Discharge Method: None		Control2: Unspecified	
% Correction: 0.00		Control3: Unspecified	

Screening Thresholds:		ADCP:	
BT 3-Beam Solution: YES	Max. Vel.: 2.02 m/s	Type/Freq.: Rio Grande / 1200 kHz	
WT 3-Beam Solution: YES	Max. Depth: 3.42 m	Serial #: 12558	Firmware: 10.16
BT Error Vel.: 0.10 m/s	Mean Depth: 1.83 m	Bin Size: 25 cm	Blank: 25 cm
WT Error Vel.: 1.07 m/s	% Meas.: 52.81	BT Mode: 5	BT Pings: 1
BT Up Vel.: 0.30 m/s	Water Temp.: None	WT Mode: 12	WT Pings: 1
WT Up Vel.: 3.00 m/s	ADCP Temp.: 4.5 °C	WV : 254	WO : 2, 4
Use Weighted Mean Depth: YES			

Performed Diag. Test: YES
Performed Moving Bed Test: YES
Performed Compass Calibration: YES   Evaluation: YES
Meas. Location: Culverts

Project Name: chandler_culverts_6june2013_(
Software: 2.10

Tr.#		Edge Distance L	Edge Distance R	#Ens.	Discharge Top	Middle	Bottom	Left	Right	Total	Width	Area	Time Start	End	Mean Vel. Boat	Water	% Bad Ens.	Bins
001	R	20.0	4.00	882	45.7	101	29.9	10.6	0.536	188	95.5	184.5	15:50	15:55	0.43	1.02	2	0
003	L	22.0	3.00	821	46.5	102	30.1	7.48	0.347	187	105.0	198.3	15:58	16:03	0.41	0.94	1	0
006	R	17.5	3.00	1013	52.0	92.8	32.0	7.08	0.190	184	111.7	195.4	16:10	16:16	0.56	0.94	10	0
007	L	17.0	5.00	640	54.3	98.2	30.6	3.58	1.34	188	115.0	201.3	16:18	16:22	0.56	0.93	1	0
Mean		19.1	3.75	839	49.6	98.6	30.7	7.19	0.603	187	106.8	194.9	**Total**	00:32	0.49	0.96	4	0
SDev		2.32	0.96	155	4.17	4.16	0.958	2.88	0.511	1.79	8.6	7.3			0.08	0.04		
SD/M		0.12	0.26	0.18	0.08	0.04	0.03	0.40	0.85	0.01	0.08	0.04			0.17	0.04		

Remarks: WAAS GPS.

ost Processing Notes: Compass Calibration has large error (9 degrees). Suggest using bottom track results.
(Although GPS results are very close anyways). Large portion of Q is estimated (top) because instrument does not measure i shallow water well.

Station Number: Meas. No: 18

Station Name: Chandler Culverts Date: 06/08/2013

Party: el,rg	Width: 144.1 m	Processed by: Ey
Boat/Motor: achilles / honda 15 HP	Area: 307.3 m²	Mean Velocity: 1.74 m/s
Gage Height: 0.000 m	G.H.Change: 0.000 m	Discharge: 533 m³/s

Area Method: Mean Flow	ADCP Depth: 0.160 m*	Index Vel.: 0.00 m/s	Rating No.: 1
Nav. Method: Bottom Track	Shore Ens.:10	Adj.Mean Vel: 0.00 m/s	Qm Rating: F
MagVar Method: Model (19.4°)	Bottom Est: Power (0.1667)	Rated Area: 0.000 m²	Diff.: 0.000%
Depth Sounder: Not Used	Top Est: Power (0.1667)	Control1: Unspecified	
Discharge Method: Proportional		Control2: Unspecified	
% Correction: 1.36		Control3: Unspecified	

Screening Thresholds:		ADCP:	
BT 3-Beam Solution: YES	Max. Vel.: 8.56 m/s	Type/Freq.: Rio Grande / 1200 kHz	
WT 3-Beam Solution: YES	Max. Depth: 3.27 m	Serial #: 12558	Firmware: 10.16
BT Error Vel.: 0.10 m/s	Mean Depth: 2.14 m	Bin Size: 25 cm	Blank: 25 cm
WT Error Vel.: 1.07 m/s	% Meas.: 66.08	BT Mode: 5	BT Pings: 1
BT Up Vel.: 0.30 m/s	Water Temp.: None	WT Mode: 12	WT Pings: 1
WT Up Vel.: 2.50 m/s*	ADCP Temp.: 6.3 °C	WV : 278	WO : 1, 4
Use Weighted Mean Depth: YES			

Performed Diag. Test: YES

Performed Moving Bed Test: YES

Performed Compass Calibration: YES Evaluation: YES

Meas. Location: culverts

Project Name: chandler_culverts_8june2013_(

Software: 2.10

Tr.#		Edge Distance L	Edge Distance R	#Ens.	MBT Corrected Discharge Top	Middle	Bottom	Left	Right	Total	Width	Area	Time Start	Time End	Mean Vel. Boat	Mean Vel. Water	% Bad Ens.	% Bad Bins
000	R	6.00	7.00	374	113	338	46.8	3.96	7.13	509	130.0	284.7	15:35	15:39	1.16	1.79	10	15
003	L	20.0	5.00	397	121	373	55.7	4.60	3.09	557	155.9	329.4	15:45	15:49	1.10	1.69	7	14
004	R	5.50	6.00	379	120	346	51.1	-3.19	3.17	518	131.5	291.4	15:54	15:58	1.25	1.78	7	15
005	L	17.0	4.00	415	133	351	53.6	5.45	2.82	546	159.0	323.7	16:01	16:05	1.17	1.69	7	14
Mean		12.1	5.50	391	122	352	51.8	2.71	4.05	533	144.1	307.3	**Total**	00:30	1.17	1.74	8	15
SDev		7.47	1.29	19	8.39	14.7	3.84	3.97	2.06	22.8	15.5	22.5			0.06	0.05		
SD/M		0.62	0.23	0.05	0.07	0.04	0.07	1.47	0.51	0.04	0.11	0.07			0.05	0.03		

Remarks: Compass Calibration error of 6 degrees. Directional bias appears present in the data. Recommend using bottom track (althou
BT data is close to GPS/WAAS data anyways).

* - value not consistent for all transects

Station Number: Meas. No: 19

Station Name: DUS3 Chandler Water Date: 07/13/2013

Party: RG/JH	Width: 62.9 m	Processed by: EY
Boat/Motor: Kayak	Area: 67.1 m²	Mean Velocity: 0.561 m/s
Gage Height: 0.000 m	G.H.Change: 0.000 m	Discharge: 37.6 m³/s

Area Method: Mean Flow	ADCP Depth: 0.120 m	Index Vel.: 0.00 m/s	Rating No.: 1
Nav. Method: DGPS	Shore Ens.:10	Adj.Mean Vel: 0.00 m/s	Qm Rating: G
MagVar Method: Model (19.4°)	Bottom Est: Power (0.1667)	Rated Area: 0.000 m²	Diff.: 0.000%
Depth Sounder: Not Used	Top Est: Power (0.1667)	Control1: Unspecified	
Discharge Method: None		Control2: Unspecified	
% Correction: 0.00		Control3: Unspecified	

Screening Thresholds:		ADCP:	
BT 3-Beam Solution: YES	Max. Vel.: 1.35 m/s	Type/Freq.: Rio Grande / 1200 kHz	
WT 3-Beam Solution: YES	Max. Depth: 2.24 m	Serial #: 1180	Firmware: 10.16
BT Error Vel.: 0.10 m/s	Mean Depth: 1.07 m	Bin Size: 25 cm	Blank: 25 cm
WT Error Vel.: 0.30 m/s	% Meas.: 70.91	BT Mode: 5	BT Pings: 1
BT Up Vel.: 0.30 m/s	Water Temp.: None	WT Mode: 12	WT Pings: 1
WT Up Vel.: 1.50 m/s	ADCP Temp.: 15.0 °C		
Use Weighted Mean Depth: YES			

Performed Diag. Test: YES

Performed Moving Bed Test: YES

Performed Compass Calibration: YES Evaluation: YES

Meas. Location: at lower PT station

Project Name: dus3-1_0_ekyreview.mmt

Software: 2.10

Tr.#		Edge Distance L	Edge Distance R	#Ens.	Discharge Top	Middle	Bottom	Left	Right	Total	Width	Area	Time Start	Time End	Mean Vel. Boat	Mean Vel. Water	% Bad Ens.	% Bad Bins
000	R	14.0	1.00	141	6.61	27.5	4.70	0.261	0.052	39.1	66.0	65.7	12:03	12:06	0.34	0.59	1	2
001	L	14.0	1.00	167	5.81	26.4	4.85	0.331	0.101	37.5	61.5	65.5	12:08	12:11	0.28	0.57	1	1
002	R	8.00	1.00	169	5.89	25.6	4.69	-0.069	0.031	36.1	62.0	66.3	12:12	12:16	0.31	0.55	1	2
003	L	8.00	1.00	197	5.52	27.1	4.78	0.093	0.070	37.6	62.1	70.9	12:17	12:21	0.26	0.53	1	2
Mean		11.0	1.00	168	5.96	26.6	4.76	0.154	0.064	37.6	62.9	67.1	**Total**	00:17	0.30	0.56	1	2
SDev		3.46	0.00	23	0.465	0.851	0.073	0.179	0.030	1.24	2.1	2.5			0.04	0.03		
SD/M		0.31	0.00	0.14	0.08	0.03	0.02	1.16	0.47	0.03	0.03	0.04			0.12	0.05		

Remarks: RTK GPS working.
Measurement taken at PT station.

Station Number:
Station Name: chandler

Meas. No: 20
Date: 08/25/2013

Party: EB_JAK	Width: 70.2 m	Processed by: EY
Boat/Motor: kayak	Area: 84.1 m²	Mean Velocity: 0.919 m/s
Gage Height: 0.000 m	G.H.Change: 0.000 m	Discharge: 77.3 m³/s

Area Method: Mean Flow	ADCP Depth: 0.100 m	Index Vel.: 0.00 m/s	Rating No.: 1
Nav. Method: Bottom Track	Shore Ens.:10	Adj.Mean Vel: 0.00 m/s	Qm Rating: F
MagVar Method: Model (19.4°)	Bottom Est: Power (0.1667)	Rated Area: 0.000 m²	Diff.: 0.000%
Depth Sounder: Not Used	Top Est: Power (0.1667)	Control1: Unspecified	
Discharge Method: Distributed		Control2: Unspecified	
% Correction: 2.37		Control3: Unspecified	

Screening Thresholds:		ADCP:	
BT 3-Beam Solution: YES	Max. Vel.: 1.96 m/s	Type/Freq.: Rio Grande / 1200 kHz	
WT 3-Beam Solution: YES	Max. Depth: 2.66 m	Serial #: 1180	Firmware: 10.16
BT Error Vel.: 0.10 m/s	Mean Depth: 1.20 m	Bin Size: 25 cm	Blank: 25 cm
WT Error Vel.: 0.30 m/s	% Meas.: 73.72	BT Mode: 5	BT Pings: 1
BT Up Vel.: 0.30 m/s	Water Temp.: None	WT Mode: 12	WT Pings: 1
WT Up Vel.: 2.50 m/s	ADCP Temp.: 6.6 °C		
Use Weighted Mean Depth: YES			

Performed Diag. Test: YES
Performed Moving Bed Test: YES
Performed Compass Calibration: YES Evaluation: YES
Meas. Location: station

Project Name: chandler_1_aug25_2013_eyrev
Software: 2.10

Tr.#		Edge Distance		#Ens.	MBT Corrected Discharge						Width	Area	Time		Mean Vel.		% Bad	
		L	R		Top	Middle	Bottom	Left	Right	Total			Start	End	Boat	Water	Ens.	Bins
000	R	10.0	2.00	135	10.8	56.6	10.0	-0.069	0.214	77.5	67.8	84.6	10:06	10:09	0.40	0.92	2	4
001	L	11.0	3.00	132	9.76	55.4	9.41	-0.292	0.169	74.4	70.1	82.6	10:15	10:18	0.50	0.90	2	4
002	R	11.0	3.50	115	10.9	58.8	8.96	-0.203	0.237	78.8	70.7	84.0	10:19	10:21	0.55	0.94	9	2
003	L	11.0	3.50	187	10.9	56.7	10.5	0.135	0.321	78.5	68.3	82.3	10:24	10:28	0.33	0.95	2	5
004	*R*	*10.0*	*3.50*	*120*	*11.1*	*59.7*	*10.2*	*0.035*	*0.440*	*81.4*	*73.4*	*86.5*	*10:29*	*10:31*	*0.46*	*0.94*	*2*	*3*
005	*L*	*11.0*	*3.50*	*217*	*9.39*	*54.7*	*9.10*	*-0.245*	*0.151*	*73.1*	*70.8*	*84.7*	*10:33*	*10:38*	*0.30*	*0.86*	*0*	*3*
Mean		10.7	3.17	151	10.5	57.0	9.70	-0.107	0.255	77.3	70.2	84.1	**Total**	00:31	0.43	0.92	3	4
SDev		0.52	0.61	41	0.707	1.93	0.632	0.169	0.108	3.04	2.0	1.5			0.10	0.03		
SD/M		0.05	0.19	0.27	0.07	0.03	0.07	1.59	0.42	0.04	0.03	0.02			0.23	0.04		

Remarks:

Discharge for transects in *italics* have a total Q more than 5% from the mean

Station Number:
Station Name: Lower ItkillikStation

Meas. No: 1
Date: 08/28/2012

Party: el,ns,ey	Width: 62.9 m	Processed by: EY
Boat/Motor: Kayak	Area: 40.0 m²	Mean Velocity: 0.708 m/s
Gage Height: 0.000 m	G.H.Change: 0.000 m	Discharge: 27.9 m³/s

Area Method: Mean Flow	ADCP Depth: 0.080 m	Index Vel.: 0.00 m/s	Rating No.: 1
Nav. Method: DGPS	Shore Ens.:10	Adj.Mean Vel: 0.00 m/s	Qm Rating: G
MagVar Method: Model (20.3°)	Bottom Est: Power (0.1667)	Rated Area: 0.000 m²	Diff.: 0.000%
Depth Sounder: Not Used	Top Est: Power (0.1667)	Control1: Unspecified	
Discharge Method: None		Control2: Unspecified	
% Correction: 0.00		Control3: Unspecified	

Screening Thresholds:		ADCP:	
BT 3-Beam Solution: YES	Max. Vel.: 2.28 m/s	Type/Freq.: StreamPro / 2000 kHz	
WT 3-Beam Solution: NO	Max. Depth: 1.32 m	Serial #: 1180	Firmware: 31.12
BT Error Vel.: 0.10 m/s	Mean Depth: 0.634 m	Bin Size: 5 cm*	Blank: 3 cm
WT Error Vel.: 0.38 m/s*	% Meas.: 53.70	BT Mode: 10	BT Pings: 2
BT Up Vel.: 0.30 m/s	Water Temp.: None	WT Mode: 12	WT Pings: 6
WT Up Vel.: 2.50 m/s	ADCP Temp.: 7.1 °C		
Use Weighted Mean Depth: YES			

Performed Diag. Test: YES
Performed Moving Bed Test: YES
Performed Compass Calibration: YES Evaluation: NO
Meas. Location: downstream station 300 ft

Project Name: lower_itkillik_8-28-2012_0_ekyr
Software: 2.10

Tr.#		Edge Distance		#Ens.	Discharge						Width	Area	Time		Mean Vel.		% Bad	
		L	R		Top	Middle	Bottom	Left	Right	Total			Start	End	Boat	Water	Ens.	Bins
000	L	1.00	22.0	130	8.49	13.9	6.23	0.039	0.245	28.9	61.6	34.8	10:46	10:49	0.32	0.83	4	2
001	R	2.00	22.0	157	7.99	13.1	5.39	0.236	0.464	27.2	60.3	35.2	10:49	10:53	0.25	0.77	13	2
002	L	1.00	16.0	187	6.26	16.7	4.17	0.040	1.13	28.3	64.8	44.6	11:01	11:05	0.24	0.63	1	3
003	R	1.00	16.0	169	5.83	16.2	3.97	0.063	1.07	27.1	64.8	45.3	11:07	11:10	0.27	0.60	1	6
Mean		1.25	19.0	160	7.14	15.0	4.94	0.094	0.728	27.9	62.9	40.0	**Total**	00:24	0.27	0.71	4	3
SDev		0.50	3.46	24	1.29	1.74	1.07	0.095	0.441	0.872	2.3	5.8			0.03	0.11		
SD/M		0.40	0.18	0.15	0.18	0.12	0.22	1.01	0.61	0.03	0.04	0.14			0.13	0.16		

Remarks: WAAS GPS. Measurement location is at station near proposed DOT crossing.

* - value not consistent for all transects

Station Number: 1 Meas. No: 0

Station Name: Lower Itkillik Crossing Date: 05/31/2013

Party: busey, gieck, lamb, passa	Width: 132.0 m	Processed by: EY
Boat/Motor: Achilles & 15 HP	Area: 127.9 m²	Mean Velocity: 1.93 m/s
Gage Height: 0.000 m	G.H.Change: 0.000 m	Discharge: 246 m³/s

Area Method: Mean Flow	ADCP Depth: 0.060 m	Index Vel.: 0.00 m/s	Rating No.: 1
Nav. Method: DGPS	Shore Ens.:10	Adj.Mean Vel: 0.00 m/s	Qm Rating: P
MagVar Method: Model (19.4°)	Bottom Est: Power (0.1667)	Rated Area: 0.000 m²	Diff.: 0.000%
Depth Sounder: Not Used	Top Est: Power (0.1667)	Control1: Unspecified	
Discharge Method: None		Control2: Unspecified	
% Correction: 0.00		Control3: Unspecified	

Screening Thresholds:		ADCP:	
BT 3-Beam Solution: YES	Max. Vel.: 3.31 m/s	Type/Freq.: StreamPro / 2000 kHz	
WT 3-Beam Solution: YES	Max. Depth: 1.94 m	Serial #: 1180	Firmware: 31.12
BT Error Vel.: 0.10 m/s	Mean Depth: 0.988 m	Bin Size: 7 cm	Blank: 3 cm
WT Error Vel.: 0.30 m/s	% Meas.: 54.86	BT Mode: 10	BT Pings: 2
BT Up Vel.: 0.30 m/s	Water Temp.: 0.0 °C	WT Mode: 12	WT Pings: 6
WT Up Vel.: 3.50 m/s	ADCP Temp.: 0.8 °C		
Use Weighted Mean Depth: YES			

Performed Diag. Test: YES

Performed Moving Bed Test: YES

Performed Compass Calibration: YES Evaluation: YES

Meas. Location: @ Station.

Project Name: lower_itkillik_1_2013-05-31_0_(

Software: 2.10

Tr.#		Edge Distance		#Ens.	Discharge						Width	Area	Time		Mean Vel.		% Bad	
		L	R		Top	Middle	Bottom	Left	Right	Total			Start	End	Boat	Water	Ens.	Bins
003	L	2.00	6.50	182	42.1	153	45.7	0.927	3.14	245	94.6	120.0	16:29	16:32	0.53	2.04	12	2
004	R	2.00	24.1	242	47.5	126	49.1	0.974	15.6	239	136.0	122.4	16:44	16:49	0.75	1.95	8	2
006	R	8.40	20.0	240	46.6	130	48.1	4.79	14.3	244	135.4	124.2	16:56	17:01	0.62	1.96	11	1
007	L	27.5	25.8	187	46.4	136	45.7	14.4	11.6	254	151.4	139.4	17:02	17:06	0.56	1.82	31	4
008	R	4.00	21.7	195	47.7	130	50.5	2.34	17.5	248	142.3	133.3	17:07	17:11	0.77	1.86	6	2
Mean		8.78	19.6	209	46.0	135	47.8	4.68	12.4	246	132.0	127.9	**Total**	00:41	0.65	1.93	14	3
SDev		10.8	7.66	29	2.27	10.5	2.10	5.65	5.62	5.54	21.8	8.2			0.11	0.09		
SD/M		1.23	0.39	0.14	0.05	0.08	0.04	1.21	0.45	0.02	0.17	0.06			0.17	0.04		

Remarks: First measurement here. Using streamPro wth WAAS. Right to Left Transect looks straightforward. The Left to Right will be tricky, need to ferry straight across basically from the station. Busey & Gieck in the boat.

6/5 update:

Did Loop test using the kayak (Lamb). Ended up tethering the kayak with streampro to the achilles.

Lots of standing waves = bad bins. Fast, shallow water also contributed to bad bins.

ood Right to Left measurement was extremely difficult to get hence the variance on the dscharge summary. Right bank starting point was marginal, very shallow and wind pushed the boat nto the gravel. Then, on the return we were in a bigg stretch of the standing waves. Transects 0, 1,2 were a mix of false starts and kayak attempts.

eam 3 @ 45 Degrees

Post Processing NOtes:

No moving bed test, used GPS GGA/VTG (WAAS) data instead of bottom track due to too many bad bins with bottom track.

Adjusted magnetic declination to +19degrees instead of -19

Station Number: 2 Meas. No: 3

Station Name: Lower Itkillik at crossing Date: 06/02/2013

Party: busey, gieck, lamb, passa	Width: 106.8 m	Processed by: EY
Boat/Motor: kayak	Area: 158.4 m²	Mean Velocity: 2.04 m/s
Gage Height: 0.000 m	G.H.Change: 0.000 m	Discharge: 322 m³/s

Area Method: Mean Flow	ADCP Depth: 0.120 m	Index Vel.: 0.00 m/s	Rating No.: 1
Nav. Method: DGPS	Shore Ens.:10	Adj.Mean Vel: 0.00 m/s	Qm Rating: F
MagVar Method: Model (19.8°)	Bottom Est: Power (0.1667)	Rated Area: 0.000 m²	Diff.: 0.000%
Depth Sounder: Not Used	Top Est: Power (0.1667)	Control1: Unspecified	
Discharge Method: None		Control2: Unspecified	
% Correction: 0.00		Control3: Unspecified	

Screening Thresholds:		ADCP:	
BT 3-Beam Solution: YES	Max. Vel.: 3.22 m/s	Type/Freq.: StreamPro / 2000 kHz	
WT 3-Beam Solution: YES	Max. Depth: 2.45 m	Serial #: 1180	Firmware: 31.12
BT Error Vel.: 0.10 m/s	Mean Depth: 1.49 m	Bin Size: 7 cm	Blank: 3 cm
WT Error Vel.: 0.30 m/s	% Meas.: 71.63	BT Mode: 10	BT Pings: 2
BT Up Vel.: 0.30 m/s	Water Temp.: None	WT Mode: 12	WT Pings: 6
WT Up Vel.: 3.80 m/s	ADCP Temp.: 2.6 °C		
Use Weighted Mean Depth: YES			

Performed Diag. Test: YES

Performed Moving Bed Test: YES

Performed Compass Calibration: NO Evaluation: NO

Meas. Location: station

Project Name: Lower_itkillik_1_2013_06_02_0

Software: 2.10

Tr.#		Edge Distance		#Ens.	Discharge						Width	Area	Time		Mean Vel.		% Bad	
		L	R		Top	Middle	Bottom	Left	Right	Total			Start	End	Boat	Water	Ens.	Bins
001	R	2.00	13.7	205	47.1	229	40.3	1.70	2.37	320	106.0	159.3	11:40	11:44	0.54	2.01	1	4
002	L	4.00	17.1	99	48.2	229	36.7	3.56	4.25	322	110.4	155.4	11:47	11:49	1.03	2.07	6	2
003	R	1.00	11.0	218	45.1	233	39.5	1.23	2.27	321	100.8	160.3	11:49	11:54	0.59	2.00	9	3
004	L	3.00	18.9	93	47.8	232	38.2	3.21	4.46	326	110.1	158.5	11:56	11:58	1.01	2.06	3	3
Mean		2.50	15.2	153	47.0	231	38.7	2.43	3.34	322	106.8	158.4	**Total**	00:17	0.79	2.04	5	3
SDev		1.29	3.52	67	1.41	2.31	1.60	1.13	1.18	2.63	4.5	2.1			0.26	0.03		
SD/M		0.52	0.23	0.44	0.03	0.01	0.04	0.47	0.35	0.01	0.04	0.01			0.33	0.02		

Remarks: 6/5/2013 Notes

Again using Kayak tethered to achilles. busey & gieck in the boat. Fail first transect. We started with a large loop at the left e due to being to close to the lower end of a submerged gravel bar. Ended up adding quite a bit of error to measurement so we followed up with a fifth transect. Still lots of standing waves and shallow / high velocity water but stage was higher on this day and so the data is much better. Pretty much impossible to do a loop test with this stage though. Kayak just hops around and c bottom track consistently. See 5/31 measurement for Compass Calibration. ADCP remained on site for duration of break up season.

Used Kayak paddle to get kayak out into the current.

With higher stage measurement quality was much higher today.

eam 3 @ 45 degrees.

ost processing notes: Adjusted declination to +19. GPS GGA and VTG are good. BT not useful.

Station Number: Meas. No: 4

Station Name: Lower_Itkillik_7June2013 Date: 06/07/2013

Party: el	Width: 67.9 m	Processed by: EY
Boat/Motor: Kayak	Area: 98.4 m²	Mean Velocity: 1.12 m/s
Gage Height: 0.000 m	G.H.Change: 0.000 m	Discharge: 110 m³/s

Area Method: Mean Flow	ADCP Depth: 0.100 m	Index Vel.: 0.00 m/s	Rating No.: 1
Nav. Method: DGPS	Shore Ens.:10	Adj.Mean Vel: 0.00 m/s	Qm Rating: F
MagVar Method: Model (19.8°)	Bottom Est: Power (0.1667)	Rated Area: 0.000 m²	Diff.: 0.000%
Depth Sounder: Not Used	Top Est: Power (0.1667)	Control1: Unspecified	
Discharge Method: Distributed		Control2: Unspecified	
% Correction: 14.05		Control3: Unspecified	

Screening Thresholds:		ADCP:	
BT 3-Beam Solution: YES	Max. Vel.: 3.27 m/s	Type/Freq.: StreamPro / 2000 kHz	
WT 3-Beam Solution: YES	Max. Depth: 2.37 m	Serial #: 1180	Firmware: 31.12
BT Error Vel.: 0.10 m/s	Mean Depth: 1.48 m	Bin Size: 7 cm*	Blank: 3 cm
WT Error Vel.: 0.30 m/s*	% Meas.: 76.18	BT Mode: 10	BT Pings: 2
BT Up Vel.: 0.30 m/s	Water Temp.: None	WT Mode: 12	WT Pings: 6
WT Up Vel.: 3.00 m/s	ADCP Temp.: 7.7 °C		
Use Weighted Mean Depth: YES			

Performed Diag. Test: YES

Performed Moving Bed Test: YES

Performed Compass Calibration: NO Evaluation: NO

Meas. Location: downstream station

Project Name: Lower_Itkillik_Station_7June20

Software: 2.10

Tr.#		Edge Distance		#Ens.	MBT Corrected Discharge						Width	Area	Time		Mean Vel.		% Bad	
		L	R		Top	Middle	Bottom	Left	Right	Total			Start	End	Boat	Water	Ens.	Bins
000	L	1.00	2.00	206	12.8	80.2	12.7	0.378	0.024	106	59.5	96.3	10:09	10:13	0.47	1.10	0	6
001	R	1.00	2.00	177	11.8	84.1	11.6	0.104	-0.040	108	58.3	93.6	10:14	10:18	0.53	1.15	1	11
003	L	1.00	22.0	198	15.2	84.6	11.8	0.165	0.558	112	84.5	95.4	10:22	10:26	0.39	1.18	1	5
004	R	2.00	5.00	209	12.8	84.9	14.3	0.259	-0.038	112	69.4	108.3	10:28	10:33	0.51	1.03	2	10
Mean		1.25	7.75	197	13.1	83.5	12.6	0.227	0.126	110	67.9	98.4	**Total**	00:23	0.48	1.12	1	8
SDev		0.50	9.60	14	1.45	2.21	1.24	0.119	0.290	3.20	12.1	6.7			0.06	0.06		
SD/M		0.40	1.24	0.07	0.11	0.03	0.10	0.53	2.30	0.03	0.18	0.07			0.13	0.06		

Remarks: Possible beam 3 misalignment. GPS data showed some directional bias. adjusted beam 3 -10 degress. Used GPS GGA as reference for Q.

* - value not consistent for all transects

Station Number: Meas. No: 5

Station Name: LowerItkillik_Station_8June2013 Date: 06/08/2013

Party: el	Width: 80.5 m	Processed by: EY
Boat/Motor: achilles 15HP	Area: 129.1 m²	Mean Velocity: 1.50 m/s
Gage Height: 0.000 m	G.H.Change: 0.000 m	Discharge: 193 m³/s

Area Method: Mean Flow	ADCP Depth: 0.130 m*	Index Vel.: 0.00 m/s	Rating No.: 1
Nav. Method: DGPS	Shore Ens.:10	Adj.Mean Vel: 0.00 m/s	Qm Rating: G
MagVar Method: Model (19.8°)	Bottom Est: Power (0.1667)	Rated Area: 0.000 m²	Diff.: 0.000%
Depth Sounder: Not Used	Top Est: Power (0.1667)	Control1: Unspecified	
Discharge Method: None		Control2: Unspecified	
% Correction: 0.00		Control3: Unspecified	

Screening Thresholds:		ADCP:	
BT 3-Beam Solution: YES	Max. Vel.: 3.34 m/s	Type/Freq.: StreamPro / 2000 kHz	
WT 3-Beam Solution: YES	Max. Depth: 2.82 m	Serial #: 1180	Firmware: 31.12
BT Error Vel.: 0.10 m/s	Mean Depth: 1.63 m	Bin Size: 7 cm	Blank: 3 cm
WT Error Vel.: 0.30 m/s	% Meas.: 74.72	BT Mode: 10	BT Pings: 2
BT Up Vel.: 0.30 m/s	Water Temp.: None	WT Mode: 12	WT Pings: 6
WT Up Vel.: 2.00 m/s	ADCP Temp.: 7.9 °C		
Use Weighted Mean Depth: YES			

Performed Diag. Test: YES

Performed Moving Bed Test: YES

Performed Compass Calibration: NO Evaluation: NO

Meas. Location: station

Project Name: loweritkillik_station_8june2013_

Software: 2.10

Tr.#		Edge Distance		#Ens.	Discharge						Width	Area	Time		Mean Vel.		% Bad	
		L	R		Top	Middle	Bottom	Left	Right	Total			Start	End	Boat	Water	Ens.	Bins
000	L	2.00	5.00	181	25.8	147	22.4	0.857	0.045	196	80.7	129.7	09:30	09:34	0.55	1.51	8	4
001	R	3.00	5.00	173	20.1	151	20.1	0.487	-0.071	192	68.4	124.8	09:35	09:39	0.55	1.54	7	8
002	L	2.00	22.0	119	29.5	135	23.5	0.579	5.47	194	94.8	119.1	09:44	09:46	0.96	1.63	1	8
006	R	1.00	2.50	136	23.9	143	22.6	0.060	0.022	190	78.1	142.8	10:07	10:11	0.79	1.33	1	6
Mean		2.00	8.63	152	24.8	144	22.2	0.496	1.37	193	80.5	129.1	**Total**	00:40	0.71	1.50	4	6
SDev		0.82	8.99	30	3.94	6.92	1.45	0.330	2.74	2.70	10.9	10.1			0.20	0.13		
SD/M		0.41	1.04	0.19	0.16	0.05	0.07	0.67	2.00	0.01	0.14	0.08			0.28	0.08		

Remarks: WAAS GPS

* - value not consistent for all transects

Station Number:

Station Name: Dus4 Lower Itkillik

Meas. No: 5

Date: 07/12/2013

Party: RG/JH	Width: 46.5 m	Processed by: EY
Boat/Motor: kayak	Area: 36.8 m²	Mean Velocity: 1.05 m/s
Gage Height: 0.000 m	G.H.Change: 0.000 m	Discharge: 38.6 m³/s

Area Method: Mean Flow	ADCP Depth: 0.120 m	Index Vel.: 0.00 m/s	Rating No.: 1
Nav. Method: DGPS	Shore Ens.:10	Adj.Mean Vel: 0.00 m/s	Qm Rating: G
MagVar Method: Model (19.8°)	Bottom Est: Power (0.1667)	Rated Area: 0.000 m²	Diff.: 0.000%
Depth Sounder: Not Used	Top Est: Power (0.1667)	Control1: Unspecified	
Discharge Method: None		Control2: Unspecified	
% Correction: 0.00		Control3: Unspecified	

Screening Thresholds:		ADCP:	
BT 3-Beam Solution: YES	Max. Vel.: 1.93 m/s	Type/Freq.: StreamPro / 2000 kHz	
WT 3-Beam Solution: YES	Max. Depth: 1.35 m	Serial #: 1180	Firmware: 31.12
BT Error Vel.: 0.10 m/s	Mean Depth: 0.797 m	Bin Size: 7 cm	Blank: 3 cm
WT Error Vel.: 0.32 m/s	% Meas.: 60.34	BT Mode: 10	BT Pings: 2
BT Up Vel.: 0.30 m/s	Water Temp.: None	WT Mode: 12	WT Pings: 6
WT Up Vel.: 1.50 m/s	ADCP Temp.: 11.0 °C		
Use Weighted Mean Depth: YES			

Performed Diag. Test: YES

Performed Moving Bed Test: YES

Performed Compass Calibration: YES Evaluation: YES

Meas. Location: station

Project Name: dus4-1_0_12july2013_eyreview

Software: 2.10

Tr.#		Edge Distance		#Ens.	Discharge						Width	Area	Time		Mean Vel.		% Bad	
		L	R		Top	Middle	Bottom	Left	Right	Total			Start	End	Boat	Water	Ens.	Bins
006	R	0.50	23.0	121	7.79	21.5	4.93	0.045	4.67	38.9	54.0	37.6	11:25	11:28	0.25	1.03	1	2
007	L	0.50	10.0	124	8.43	24.5	5.49	0.044	0.648	39.2	45.7	37.8	11:29	11:31	0.34	1.04	6	3
008	R	1.00	10.0	121	8.09	24.0	5.56	0.261	0.863	38.8	42.0	35.3	11:33	11:36	0.29	1.10	1	2
009	L	0.50	8.00	130	8.27	23.2	5.61	0.039	0.513	37.6	44.2	36.5	11:39	11:41	0.31	1.03	2	1
Mean		0.63	12.8	124	8.15	23.3	5.40	0.097	1.67	38.6	46.5	36.8	**Total**	00:16	0.30	1.05	2	2
SDev		0.25	6.90	4	0.276	1.33	0.315	0.109	2.00	0.706	5.2	1.1			0.04	0.03		
SD/M		0.40	0.54	0.03	0.03	0.06	0.06	1.12	1.20	0.02	0.11	0.03			0.13	0.03		

Remarks: RTK GPS

Station Number: LOW_ITKILL

Station Name: Lower Itkillik

Meas. No: 7

Date: 08/25/2013

Party: EDB JWH	Width: 51.4 m	Processed by: EY
Boat/Motor: Kayak	Area: 40.7 m²	Mean Velocity: 1.23 m/s
Gage Height: 0.000 m	G.H.Change: 0.000 m	Discharge: 49.0 m³/s

Area Method: Mean Flow	ADCP Depth: 0.100 m	Index Vel.: 0.00 m/s	Rating No.: 1
Nav. Method: Bottom Track	Shore Ens.:10	Adj.Mean Vel: 0.00 m/s	Qm Rating: F
MagVar Method: Model (19.8°)	Bottom Est: Power (0.1667)	Rated Area: 0.000 m²	Diff.: 0.000%
Depth Sounder: Not Used	Top Est: Power (0.1667)	Control1: Unspecified	
Discharge Method: None		Control2: Unspecified	
% Correction: 0.00		Control3: Unspecified	

Screening Thresholds:		ADCP:	
BT 3-Beam Solution: YES	Max. Vel.: 3.01 m/s	Type/Freq.: StreamPro / 2000 kHz	
WT 3-Beam Solution: YES	Max. Depth: 1.40 m	Serial #: 1180	Firmware: 31.12
BT Error Vel.: 0.10 m/s	Mean Depth: 0.786 m	Bin Size: 7 cm	Blank: 3 cm
WT Error Vel.: 0.38 m/s	% Meas.: 56.42	BT Mode: 10	BT Pings: 2
BT Up Vel.: 0.30 m/s	Water Temp.: None	WT Mode: 12	WT Pings: 6
WT Up Vel.: 2.00 m/s	ADCP Temp.: 7.4 °C		
Use Weighted Mean Depth: YES			

Performed Diag. Test: YES

Performed Moving Bed Test: YES

Performed Compass Calibration: YES Evaluation: YES

Meas. Location: station

Project Name: low_itkill_1_26aug2013_eyrevie

Software: 2.10

Tr.#		Edge Distance		#Ens.	Discharge						Width	Area	Time		Mean Vel.		% Bad	
		L	R		Top	Middle	Bottom	Left	Right	Total			Start	End	Boat	Water	Ens.	Bins
002	R	0.50	3.00	123	12.1	28.6	7.82	0.066	0.497	49.2	54.5	45.1	14:49	14:51	0.46	1.09	1	3
004	R	0.50	1.50	145	12.3	28.5	7.80	0.038	0.135	48.7	51.3	42.5	15:02	15:05	0.41	1.15	1	3
005	L	0.50	2.50	171	15.5	23.9	8.37	0.041	0.324	48.2	45.9	30.4	15:07	15:10	0.43	1.58	1	5
006	R	0.50	2.50	136	12.3	29.5	7.79	0.037	0.270	49.9	54.1	44.7	15:12	15:15	0.44	1.12	0	2
Mean		0.50	2.38	143	13.1	27.6	7.95	0.046	0.307	49.0	51.4	40.7	**Total**	00:26	0.43	1.23	1	3
SDev		0.00	0.63	20	1.61	2.50	0.286	0.014	0.150	0.736	3.9	6.9			0.02	0.23		
SD/M		0.00	0.26	0.14	0.12	0.09	0.04	0.30	0.49	0.02	0.08	0.17			0.05	0.19		

Remarks: Used bottom track data, GPS data had high COV.

Station Number: 2 | Meas. No: 14
Station Name: itkillik4jun2012 | Date: 06/04/2012

Party: ey, el ns
Width: 59.1 m
Processed by: EY
Boat/Motor: Kayak
Area: 63.0 m²
Mean Velocity: 1.49 m/s
Gage Height: 0.000 m
G.H.Change: 0.000 m
Discharge: 93.9 m³/s

Area Method: Mean Flow
ADCP Depth: 0.060 m
Index Vel.: 0.00 m/s
Rating No.: 1
Nav. Method: Bottom Track
Shore Ens.:10
Adj.Mean Vel: 0.00 m/s
Qm Rating: P
MagVar Method: None (20.3°)
Bottom Est: Power (0.1667)
Rated Area: 0.000 m²
Diff.: 0.000%
Depth Sounder: Not Used
Top Est: Power (0.1667)
Control1: Unspecified
Discharge Method: None
Control2: Unspecified
% Correction: 0.00
Control3: Unspecified

Screening Thresholds:
BT 3-Beam Solution: YES
WT 3-Beam Solution: NO
BT Error Vel.: 0.10 m/s
WT Error Vel.: 0.32 m/s*
BT Up Vel.: 0.30 m/s
WT Up Vel.: 3.50 m/s*
Use Weighted Mean Depth: YES

Max. Vel.: 3.22 m/s
Max. Depth: 1.96 m
Mean Depth: 1.07 m
% Meas.: 72.40
Water Temp.: None
ADCP Temp.: 10.4 °C

ADCP:
Type/Freq.: StreamPro / 2000 kHz
Serial #: 1180 Firmware: 31.12
Bin Size: 7 cm* Blank: 3 cm
BT Mode: 10 BT Pings: 2
WT Mode: 12 WT Pings: 6

Performed Diag. Test: YES
Performed Moving Bed Test: NO
Performed Compass Calibration: NO Evaluation: NO
Meas. Location: culverts

Project Name: Itkillik River 4Jun2012_0.mmt
Software: 2.10

Tr.#		Edge Distance		#Ens.	Discharge						Width	Area	Time		Mean Vel.		% Bad	
		L	R		Top	Middle	Bottom	Left	Right	Total			Start	End	Boat	Water	Ens.	Bins
000	R	2.00	8.00	433	12.7	65.1	12.3	0.246	0.859	91.2	63.3	64.0	18:05	18:14	0.33	1.43	22	6
002	L	2.00	3.50	315	12.2	70.9	13.4	-0.025	0.196	96.6	54.9	62.1	18:41	18:47	0.28	1.56	27	6
Mean		2.00	5.75	374	12.5	68.0	12.8	0.111	0.528	93.9	59.1	63.0	**Total**	00:42	0.31	1.49	25	6
SDev		0.00	3.18	83	0.399	4.07	0.803	0.192	0.469	3.82	5.9	1.4			0.03	0.09		
SD/M		0.00	0.55	0.22	0.03	0.06	0.06	1.73	0.89	0.04	0.10	0.02			0.10	0.06		

Remarks: Only two transects and no moving bed test due to lack of time. GPS/WAAS only on second transect (same as bottom track results). Using bottom track for reference.

* - value not consistent for all transects

Station Number: | Meas. No: 15
Station Name: Itkillik Culverts | Date: 07/28/2012

Party: el,rg
Width: 50.9 m
Processed by: EY
Boat/Motor: kayak
Area: 42.6 m²
Mean Velocity: 0.909 m/s
Gage Height: 0.000 m
G.H.Change: 0.000 m
Discharge: 38.6 m³/s

Area Method: Mean Flow
ADCP Depth: 0.120 m
Index Vel.: 0.00 m/s
Rating No.: 1
Nav. Method: DGPS
Shore Ens.:10
Adj.Mean Vel: 0.00 m/s
Qm Rating: G
MagVar Method: Model (20.3°)
Bottom Est: Power (0.1667)
Rated Area: 0.000 m²
Diff.: 0.000%
Depth Sounder: Not Used
Top Est: Power (0.1667)
Control1: Unspecified
Discharge Method: None
Control2: Unspecified
% Correction: 0.00
Control3: Unspecified

Screening Thresholds:
BT 3-Beam Solution: YES
WT 3-Beam Solution: NO
BT Error Vel.: 0.10 m/s
WT Error Vel.: 0.32 m/s
BT Up Vel.: 0.30 m/s
WT Up Vel.: 1.50 m/s
Use Weighted Mean Depth: YES

Max. Vel.: 1.98 m/s
Max. Depth: 1.88 m
Mean Depth: 0.837 m
% Meas.: 60.37
Water Temp.: None
ADCP Temp.: 13.4 °C

ADCP:
Type/Freq.: StreamPro / 2000 kHz
Serial #: 1180 Firmware: 31.12
Bin Size: 7 cm Blank: 3 cm
BT Mode: 10 BT Pings: 2
WT Mode: 12 WT Pings: 6

Performed Diag. Test: NO
Performed Moving Bed Test: NO
Performed Compass Calibration: YES Evaluation: NO
Meas. Location: culverts

Project Name: Itkillik_28July2012_0.mmt
Software: 2.10

Tr.#		Edge Distance		#Ens.	Discharge						Width	Area	Time		Mean Vel.		% Bad	
		L	R		Top	Middle	Bottom	Left	Right	Total			Start	End	Boat	Water	Ens.	Bins
001	*L*	3.00	10.0	82	8.74	20.4	5.23	0.039	1.41	35.8	49.9	44.2	11:36	11:37	0.58	0.81	1	12
003	R	3.00	12.6	105	8.37	24.2	5.21	0.045	1.19	39.0	53.1	43.5	11:45	11:47	0.31	0.90	1	4
004	L	3.00	13.0	101	8.04	23.6	5.09	0.127	2.19	39.0	51.3	42.0	11:50	11:52	0.32	0.93	1	4
005	R	3.00	13.0	107	7.77	23.2	5.10	0.149	2.46	38.7	49.4	41.8	11:52	11:55	0.29	0.93	1	4
006	*L*	3.00	11.3	91	8.66	25.3	5.30	0.132	1.33	40.7	51.0	41.5	11:55	11:57	0.36	0.98	1	4
Mean		3.00	12.0	97	8.32	23.3	5.19	0.098	1.72	38.6	50.9	42.6	**Total**	00:20	0.37	0.91	1	6
SDev		0.00	1.31	11	0.410	1.83	0.091	0.052	0.569	1.78	1.5	1.2			0.12	0.06		
SD/M		0.00	0.11	0.11	0.05	0.08	0.02	0.53	0.33	0.05	0.03	0.03			0.33	0.07		

Remarks: WAAS/SBAS DGPS used. No adcp test performed.

Discharge for transects in *italics* have a total Q more than 5% from the mean

Station Number: DUS1 Meas. No: 17
Station Name: Upper Itkillik Date: 06/01/2013

Party: JH, NS, EDB
Width: 56.1 m
Processed by: JH
Boat/Motor: Cataraft/15HP
Area: 76.1 m²
Mean Velocity: 1.99 m/s
Gage Height: 0.000 m
G.H.Change: 0.000 m
Discharge: 151 m³/s

Area Method: Mean Flow
Nav. Method: DGPS
MagVar Method: None (19.9°)
Depth Sounder: Not Used
Discharge Method: None
% Correction: 0.00

ADCP Depth: 0.100 m
Shore Ens.:10
Bottom Est: Power (0.1667)
Top Est: Power (0.1667)

Index Vel.: 0.00 m/s
Rating No.:
Adj.Mean Vel: 0.00 m/s
Qm Rating: G
Rated Area: 0.000 m²
Diff.: 0.000%
Control1: Unspecified
Control2: Unspecified
Control3: Unspecified

Screening Thresholds:
BT 3-Beam Solution: YES
WT 3-Beam Solution: YES
BT Error Vel.: 0.10 m/s
WT Error Vel.: 1.07 m/s
BT Up Vel.: 0.30 m/s
WT Up Vel.: 3.00 m/s
Use Weighted Mean Depth: YES

Max. Vel.: 3.94 m/s
Max. Depth: 2.00 m
Mean Depth: 1.36 m
% Meas.: 54.76
Water Temp.: None
ADCP Temp.: 1.6 °C

ADCP:
Type/Freq.: Rio Grande / 1200 kHz
Serial #: 12812
Firmware: 10.16
Bin Size: 5 cm
Blank: 25 cm
BT Mode: 7
BT Pings: 1
WT Mode: 12
WT Pings: 1
WV : 278
WO : 6, 4

Performed Diag. Test: YES
Performed Moving Bed Test: YES
Performed Compass Calibration: YES Evaluation: NO
Meas. Location: culverts/crossing

Project Name: upit_0_jh.mmt
Software: 2.10

Tr.#		Edge Distance		#Ens.	Discharge						Width	Area	Time		Mean Vel.		% Bad	
		L	R		Top	Middle	Bottom	Left	Right	Total			Start	End	Boat	Water	Ens.	Bins
002	R	2.00	7.00	133	43.9	83.8	17.9	0.719	1.54	148	52.8	74.7	13:35	13:37	0.68	1.98	2	0
003	L	2.00	7.00	141	47.8	85.5	19.4	0.741	1.76	155	56.5	77.4	13:37	13:40	0.45	2.00	1	1
004	R	2.00	7.00	134	49.1	79.1	20.1	0.794	1.52	151	58.9	76.1	13:40	13:42	0.53	1.98	3	0
Mean		2.00	7.00	136	46.9	82.8	19.1	0.751	1.61	151	56.1	76.1	**Total**	00:07	0.56	1.99	2	1
SDev		0.00	0.00	4	2.70	3.31	1.10	0.039	0.133	3.69	3.1	1.4			0.12	0.02		
SD/M		0.00	0.00	0.03	0.06	0.04	0.06	0.05	0.08	0.02	0.05	0.02			0.21	0.01		

Remarks: No moving bed text due to difficulty tracking bottom. Use GPS (WAAS).

Station Number: DUS1 Meas. No: 18
Station Name: Upper Itkillik Date: 06/02/2013

Party: JH, EB, NS
Width: 70.4 m
Processed by: JH
Boat/Motor: Cataraft/15HP
Area: 103.9 m²
Mean Velocity: 2.34 m/s
Gage Height: 0.000 m
G.H.Change: 0.000 m
Discharge: 243 m³/s

Area Method: Mean Flow
Nav. Method: DGPS
MagVar Method: None (19.9°)
Depth Sounder: Not Used
Discharge Method: None
% Correction: 0.00

ADCP Depth: 0.100 m
Shore Ens.:10
Bottom Est: Power (0.1667)
Top Est: Power (0.1667)

Index Vel.: 0.00 m/s
Rating No.: 1
Adj.Mean Vel: 0.00 m/s
Qm Rating: F
Rated Area: 0.000 m²
Diff.: 0.000%
Control1: 2-Ice Anchor
Control2: 7-Light Debris
Control3: Unspecified

Screening Thresholds:
BT 3-Beam Solution: YES
WT 3-Beam Solution: YES
BT Error Vel.: 0.10 m/s
WT Error Vel.: 1.07 m/s
BT Up Vel.: 0.30 m/s
WT Up Vel.: 3.00 m/s
Use Weighted Mean Depth: YES

Max. Vel.: 4.93 m/s
Max. Depth: 2.23 m
Mean Depth: 1.48 m
% Meas.: 45.26
Water Temp.: None
ADCP Temp.: 1.2 °C

ADCP:
Type/Freq.: Rio Grande / 1200 kHz
Serial #: 12812
Firmware: 10.16
Bin Size: 10 cm*
Blank: 25 cm
BT Mode: 7
BT Pings: 1
WT Mode: 12*
WT Pings: 1
WV : 175*
WO : 1, 4*

Performed Diag. Test: YES
Performed Moving Bed Test: NO
Performed Compass Calibration: NO Evaluation: NO
Meas. Location: culverts

Project Name: upit_2_jh.mmt
Software: 2.10

Tr.#		Edge Distance		#Ens.	Discharge						Width	Area	Time		Mean Vel.		% Bad	
		L	R		Top	Middle	Bottom	Left	Right	Total			Start	End	Boat	Water	Ens.	Bins
000	R	2.00	12.0	209	72.2	126	37.9	0.950	4.89	242	66.8	99.3	14:06	14:08	0.80	2.44	1	5
001	*L*	*2.00*	*11.0*	*177*	*73.3*	*113*	*37.9*	*1.07*	*4.00*	*230*	*71.6*	*101.8*	*14:08*	*14:10*	*0.84*	*2.26*	*7*	*6*
011	*L*	*2.00*	*10.0*	*319*	*95.8*	*90.7*	*64.0*	*1.25*	*6.50*	*258*	*72.8*	*110.5*	*14:44*	*14:46*	*0.75*	*2.34*	*13*	*1*
Mean		2.00	11.0	235	80.4	110	46.6	1.09	5.13	243	70.4	103.9	**Total**	00:40	0.80	2.34	7	4
SDev		0.00	1.00	74	13.3	18.1	15.1	0.150	1.26	14.4	3.2	5.9			0.05	0.09		
SD/M		0.00	0.09	0.32	0.17	0.16	0.32	0.14	0.25	0.06	0.05	0.06			0.06	0.04		

Remarks: RTK GPS. No moving bed test possible due to loss of bottom track. compass calibration on 6/1 (did not move ADCP setup frc site).

* - value not consistent for all transects
Discharge for transects in *italics* have a total Q more than 5% from the mean

Station Number: DUS1 | Meas. No: 19
Station Name: Upper Itkillik | Date: 06/03/2013

Party: JH, EB, NS	Width: 71.7 m	Processed by: JH
Boat/Motor: Cataraft/15HP	Area: 117.5 m²	Mean Velocity: 2.31 m/s
Gage Height: 0.000 m	G.H.Change: 0.000 m	Discharge: 271 m³/s

Area Method: Mean Flow	ADCP Depth: 0.100 m	Index Vel.: 0.00 m/s	Rating No.: 1
Nav. Method: DGPS	Shore Ens.:10	Adj.Mean Vel: 0.00 m/s	Qm Rating: G
MagVar Method: None (19.9°)	Bottom Est: Power (0.1667)	Rated Area: 0.000 m²	Diff.: 0.000%
Depth Sounder: Not Used	Top Est: Power (0.1667)	Control1: Unspecified	
Discharge Method: None		Control2: Unspecified	
% Correction: 0.00		Control3: Unspecified	

Screening Thresholds:		ADCP:	
BT 3-Beam Solution: YES	Max. Vel.: 5.94 m/s	Type/Freq.: Rio Grande / 1200 kHz	
WT 3-Beam Solution: YES	Max. Depth: 2.64 m	Serial #: 12812	Firmware: 10.16
BT Error Vel.: 0.10 m/s	Mean Depth: 1.64 m	Bin Size: 10 cm	Blank: 25 cm
WT Error Vel.: 1.07 m/s	% Meas.: 56.99	BT Mode: 7	BT Pings: 1
BT Up Vel.: 0.30 m/s	Water Temp.: None	WT Mode: 12	WT Pings: 1
WT Up Vel.: 4.00 m/s	ADCP Temp.: 2.1 °C	WV : 427	WO : 1, 10
Use Weighted Mean Depth: YES			

Performed Diag. Test: YES
Performed Moving Bed Test: YES
Performed Compass Calibration: NO Evaluation: NO
Meas. Location:

Project Name: upit_3_jh.mmt
Software: 2.10

Tr.#		Edge Distance		#Ens.	Discharge						Width	Area	Time		Mean Vel.		% Bad	
		L	R		Top	Middle	Bottom	Left	Right	Total			Start	End	Boat	Water	Ens.	Bins
002	R	2.00	7.00	284	73.1	168	39.7	1.45	1.49	283	70.5	120.1	12:20	12:23	0.76	2.36	3	11
003	L	2.00	3.00	312	78.2	147	37.0	1.31	1.54	265	73.3	118.0	12:23	12:26	0.72	2.25	3	12
004	R	3.00	7.00	265	65.5	158	35.2	2.33	1.92	263	66.9	112.6	12:29	12:31	0.76	2.34	5	10
007	L	3.00	3.00	322	83.3	145	40.5	1.72	1.75	273	76.0	119.4	12:41	12:44	0.64	2.28	4	10
Mean		2.50	5.00	295	75.0	154	38.1	1.70	1.67	271	71.7	117.5	**Total**	00:23	0.72	2.31	4	11
SDev		0.58	2.31	26	7.60	10.4	2.45	0.450	0.198	9.32	3.9	3.4			0.05	0.05		
SD/M		0.23	0.46	0.09	0.10	0.07	0.06	0.26	0.12	0.03	0.05	0.03			0.08	0.02		

Remarks: RTK GPS. Compass calibration 6/1.

Station Number: DUS1 | Meas. No: 20
Station Name: Upper itkillik | Date: 07/11/2013

Party: Gieck-Homan	Width: 49.2 m	Processed by: JH
Boat/Motor: kayak	Area: 40.8 m²	Mean Velocity: 0.893 m/s
Gage Height: 0.000 m	G.H.Change: 0.000 m	Discharge: 36.4 m³/s

Area Method: Mean Flow	ADCP Depth: 0.120 m	Index Vel.: 0.00 m/s	Rating No.: 1
Nav. Method: DGPS	Shore Ens.:10	Adj.Mean Vel: 0.00 m/s	Qm Rating: G
MagVar Method: Model (19.9°)	Bottom Est: Power (0.1667)	Rated Area: 0.000 m²	Diff.: 0.000%
Depth Sounder: Not Used	Top Est: Power (0.1667)	Control1: Unspecified	
Discharge Method: None		Control2: Unspecified	
% Correction: 0.00		Control3: Unspecified	

Screening Thresholds:		ADCP:	
BT 3-Beam Solution: YES	Max. Vel.: 1.81 m/s	Type/Freq.: StreamPro / 2000 kHz	
WT 3-Beam Solution: YES	Max. Depth: 1.72 m	Serial #: 1180	Firmware: 31.12
BT Error Vel.: 0.10 m/s	Mean Depth: 0.832 m	Bin Size: 7 cm	Blank: 3 cm
WT Error Vel.: 0.32 m/s	% Meas.: 61.71	BT Mode: 10	BT Pings: 2
BT Up Vel.: 0.30 m/s	Water Temp.: None	WT Mode: 12	WT Pings: 6
WT Up Vel.: 1.50 m/s	ADCP Temp.: 11.7 °C		
Use Weighted Mean Depth: YES			

Performed Diag. Test: NO
Performed Moving Bed Test: YES
Performed Compass Calibration: YES Evaluation: YES
Meas. Location: Culverts

Project Name: upit_4_jh.mmt
Software: 2.10

Tr.#		Edge Distance		#Ens.	Discharge						Width	Area	Time		Mean Vel.		% Bad	
		L	R		Top	Middle	Bottom	Left	Right	Total			Start	End	Boat	Water	Ens.	Bins
001	R	0.50	13.6	219	8.35	22.7	5.26	0.030	0.960	37.3	52.3	41.7	11:55	12:00	0.17	0.89	0	2
002	L	0.50	12.8	189	7.94	21.7	4.83	0.012	1.10	35.5	52.1	42.3	12:00	12:04	0.22	0.84	1	3
003	R	0.50	7.30	185	8.40	23.1	5.11	0.023	0.459	37.1	45.6	39.0	12:08	12:12	0.20	0.95	1	1
004	L	0.50	7.50	170	8.14	22.4	4.73	0.018	0.460	35.8	46.7	40.3	12:13	12:16	0.28	0.89	2	3
Mean		0.50	10.3	190	8.21	22.5	4.98	0.021	0.744	36.4	49.2	40.8	**Total**	00:20	0.22	0.89	1	3
SDev		0.00	3.37	21	0.214	0.601	0.246	0.008	0.333	0.898	3.6	1.5			0.05	0.05		
SD/M		0.00	0.33	0.11	0.03	0.03	0.05	0.37	0.45	0.02	0.07	0.04			0.21	0.05		

Remarks: WAAS GPS

Station Number: DUS1 Meas. No: 21
Station Name: Upper Itkilik Date: 08/26/2013

Party: JWH, EDB
Boat/Motor: kayak
Gage Height: 0.000 m

Width: 44.5 m
Area: 40.0 m²
G.H.Change: 0.000 m

Processed by: JH
Mean Velocity: 0.914 m/s
Discharge: 36.5 m³/s

Area Method: Avg. Course
Nav. Method: Bottom Track
MagVar Method: None (19.9°)
Depth Sounder: Not Used
Discharge Method: None
% Correction: 0.00

ADCP Depth: 0.100 m
Shore Ens.:10
Bottom Est: Power (0.1667)
Top Est: Power (0.1667)

Index Vel.: 0.00 m/s
Adj.Mean Vel: 0.00 m/s
Rated Area: 0.000 m²
Control1: Unspecified
Control2: Unspecified
Control3: Unspecified

Rating No.: 1
Qm Rating: G
Diff.: 0.000%

Screening Thresholds:
BT 3-Beam Solution: YES
WT 3-Beam Solution: YES
BT Error Vel.: 0.10 m/s
WT Error Vel.: 0.38 m/s
BT Up Vel.: 0.30 m/s*
WT Up Vel.: 1.75 m/s
Use Weighted Mean Depth: YES

Max. Vel.: 1.84 m/s
Max. Depth: 1.52 m
Mean Depth: 0.899 m
% Meas.: 64.03
Water Temp.: None
ADCP Temp.: 7.9 °C

ADCP:
Type/Freq.: StreamPro / 2000 kHz
Serial #: 1180 Firmware: 31.12
Bin Size: 5 cm Blank: 3 cm
BT Mode: 10 BT Pings: 2
WT Mode: 12 WT Pings: 6

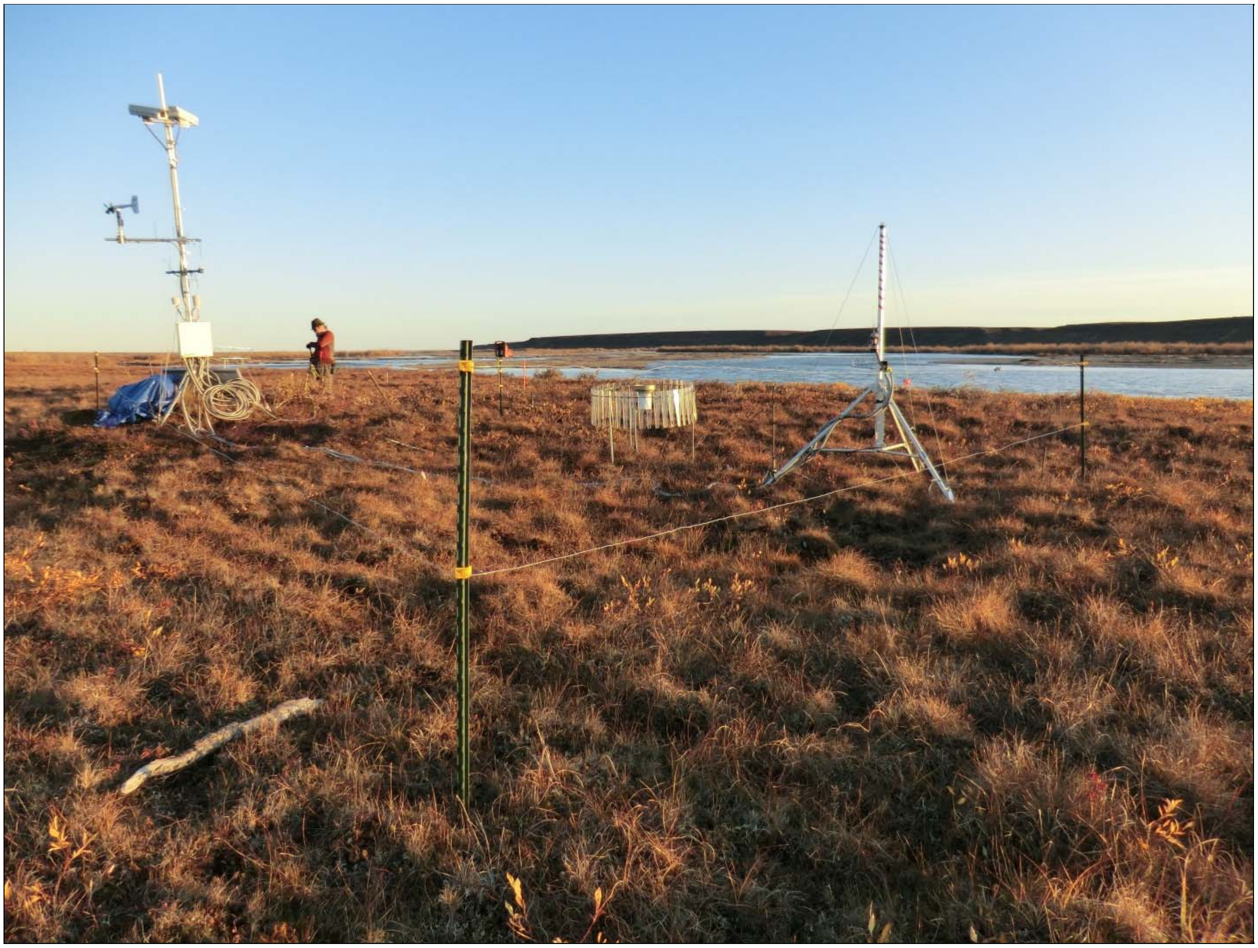
Performed Diag. Test: YES
Performed Moving Bed Test: YES
Performed Compass Calibration: YES Evaluation: YES
Meas. Location: Culvert

Project Name: upit_5_jh.mmt
Software: 2.10

Tr.#		Edge Distance		#Ens.	Discharge						Width	Area	Time		Mean Vel.		% Bad	
		L	R		Top	Middle	Bottom	Left	Right	Total			Start	End	Boat	Water	Ens.	Bins
000	R	0.50	6.00	160	7.45	24.1	5.45	0.015	0.372	37.4	45.1	40.7	15:04	15:07	0.21	0.92	2	1
002	L	1.00	6.00	168	7.25	23.1	5.32	0.048	0.476	36.2	44.4	39.7	15:10	15:13	0.20	0.91	1	3
003	R	1.00	6.00	145	7.17	23.0	5.38	0.053	0.424	36.1	44.3	40.1	15:14	15:17	0.23	0.90	0	1
004	L	1.00	6.00	146	7.30	23.3	5.34	0.077	0.432	36.5	44.0	39.4	15:17	15:20	0.24	0.93	3	2
Mean		0.88	6.00	154	7.29	23.4	5.37	0.048	0.426	36.5	44.5	40.0	**Total**	00:16	0.22	0.91	1	2
SDev		0.25	0.00	11	0.117	0.475	0.058	0.026	0.043	0.582	0.5	0.5			0.02	0.01		
SD/M		0.29	0.00	0.07	0.02	0.02	0.01	0.53	0.10	0.02	0.01	0.01			0.09	0.01		

Remarks: Bottom Track, no GPS.

* - value not consistent for all transects



UNIVERSITY OF ALASKA FAIRBANKS