Snow Survey Data for the Kuparuk Foothills Hydrology Study: Spring 2007

Spring snowpack during dusk, UAF Staff

by

Sveta Berezovskaya, Jeff Derry, Douglas Kane, Robert Geick, Michael Lilly, Dan White

July 2007

Kuparuk Foothills Hydrology Project

Report No. INE/WERC 07.17

Water and Environmental Research Center

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A report on research sponsored by the

Alaska Department of Transportation and Public Facilities

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Recommended Citation:

Berezovskaya, S.L., Derry, J.E., Kane, D.L., Geick, 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.

Fairbanks, Alaska
July 2007

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DISCLAIMER

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UNITS, CONVERSION FACTORS, 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 (mm)
mile (mi)	1.609	kilometer (km)
	Area	
Acre	43559.826	square feet (ft^2)
Acre	0.407	hectare (ha)
square foot (ft^2)	2.590	square mile (mi^2)
square mile (mi^2)	2.590	square kilometer (km^2)
	Volume	
gallon (gal)	3.785	liter (L)
gallon (gal)	3785	milliliter (mL)
cubic foot (ft^3)	23.317	liter (L)
Acre-ft	1233	cubic meter (m^3)
	Velocity and Discharge	
foot per day (ft/d)	0.3048	meter per day (m/d)
Square foot per day (ft^2/d)	.0929	square meter per day (m^2/d)
cubic foot per second (ft^3/s)	0.02832	cubic meter per second (m^3/sec)
	Hydraulic Conductivity	
foot per day (ft/d)	0.3048	meter per day (m/d)
foot per day (ft/d)	0.00035	centimeter per second (cm/sec)
meter per day (m/d)	0.00115	centimeter per second (cm/sec)
	Hydraulic Gradient	
foot per foot (ft/ft)	5280	foot per mile (ft/mi)
foot per mile (ft/mi)	0.1894	meter per kilometer (m/km)
	Pressure	
pound per square inch (lb/in^2)	6.895	kilopascal (kPa)

UNITS

For the purposes of this report, both English and Metric (SI) units were employed. The choice of "primary" units employed depended on common reporting standards for a particular property or parameter measured. Whenever possible, the approximate value in the "secondary" units was also provided in parentheses. Thus, for instance, snow density was reported in kilograms per cubic meter (kg m^{-3}) followed by the approximate value in slugs per cubic feet (slug ft^{-3}) in parentheses.

Vertical Datum:

In this report, "sea level" refers to the National Geodetic Vertical Datum of 1929 (NGVD of 1929), a geodetic datum derived from a general adjustment of the first-order level nets of both the United States and Canada, formerly called *Sea Level Datum of 1929*.

Horizontal Datum:

The horizontal datum for all locations in this report is the North American Datum of 1983.

Abbreviations, Acronyms, And Symbols

AAS	Alaska's Arctic Slope
ADOT&PF	Alaska Department of Transportation and Public Facilities
F	Fahrenheit (^oF).
ft	feet
GWS	Geo-Watersheds Scientific
kg	kilograms
km^2	square kilometers
m	meters
NGVD	National Geodetic Vertical Datum
NRCS	Natural Resources Conservation Service
NWIS	National Water Information System
QA	quality assurance
QC	quality control
Slug	slug
UAF	University of Alaska Fairbanks
USGS	U.S. Geological Survey
WERC	Water and Environmental Research Center
WWW	World Wide Web
YSI	Yellow Springs Instruments

ACKNOWLEDGEMENTS

This project was funded by grant ADN #2562123, Alaska Department of Transportation and Public Facilities. Ken Irving, Dan Reichardt, Amy Tidwell, Jessica Cherry, Beisheng Ye, Joel Homan and many others participated in snow water equivalent data collection. Peter Prokein assisted with maps preparation. Logistical support was provided by BP Exploration (Alaska) Inc. Alaska. The Department of Natural Resources provided beneficial background data in the study area.

Snow Survey Data for the Kuparuk Foothills Hydrology Study: Spring 2007

1. INTRODUCTION

This report discusses snow conditions that were observed during 2007 end-of-winter snow survey in the study area of the Kuparuk River basin. Field studies primarily focused on maximum snow water equivalent (SWE) accumulation during the 2006 - 2007 winter and the following snow melt. Field activities start at the end of April, because the snowpack virtually binds all precipitation falling during the period from October to April with no winter melt occurring on the Alaska's Arctic Slope (AAS) (Benson et al., 1986). Deficiencies in determining snow precipitation and sublimation imply that measurements of snow accumulated on the ground provide the most reliable observational component of winter water budget.

Assessment of maximum snow accumulation is critical input to snow hydrology studies. Seasonal snowpack constitutes winter detention storage for precipitation, induces considerable differences in surface energy balance and results in soil desiccation of the organic layer overlying permafrost (Kane et al., 1978). Water contained in snowpack ensures that snowmelt is a major hydrological event each year. Peak discharge, resulting from snowmelt, is the highest for many rivers on the North Slope, particularly for the basins of the Sagavanirktok, Canning and Kuparuk Rivers. These rivers drain a large area that extends from the Brooks Range through the Northern Foothills and across the coastal plain before discharging into the Arctic Ocean. Snow starts contributing to runoff in the southern mountainous province in May and usually within a month melt is complete. Due to extremely high snowpack heterogeneity, knowledge on SWE spatial distribution is critical for understanding a river basin's hydrologic response during ablation.

This report presents snow water equivalent observational data for the eastern part of the Alaskan Arctic. It summarizes 2007 data collection procedure, accuracy of observations and their spatial distribution.

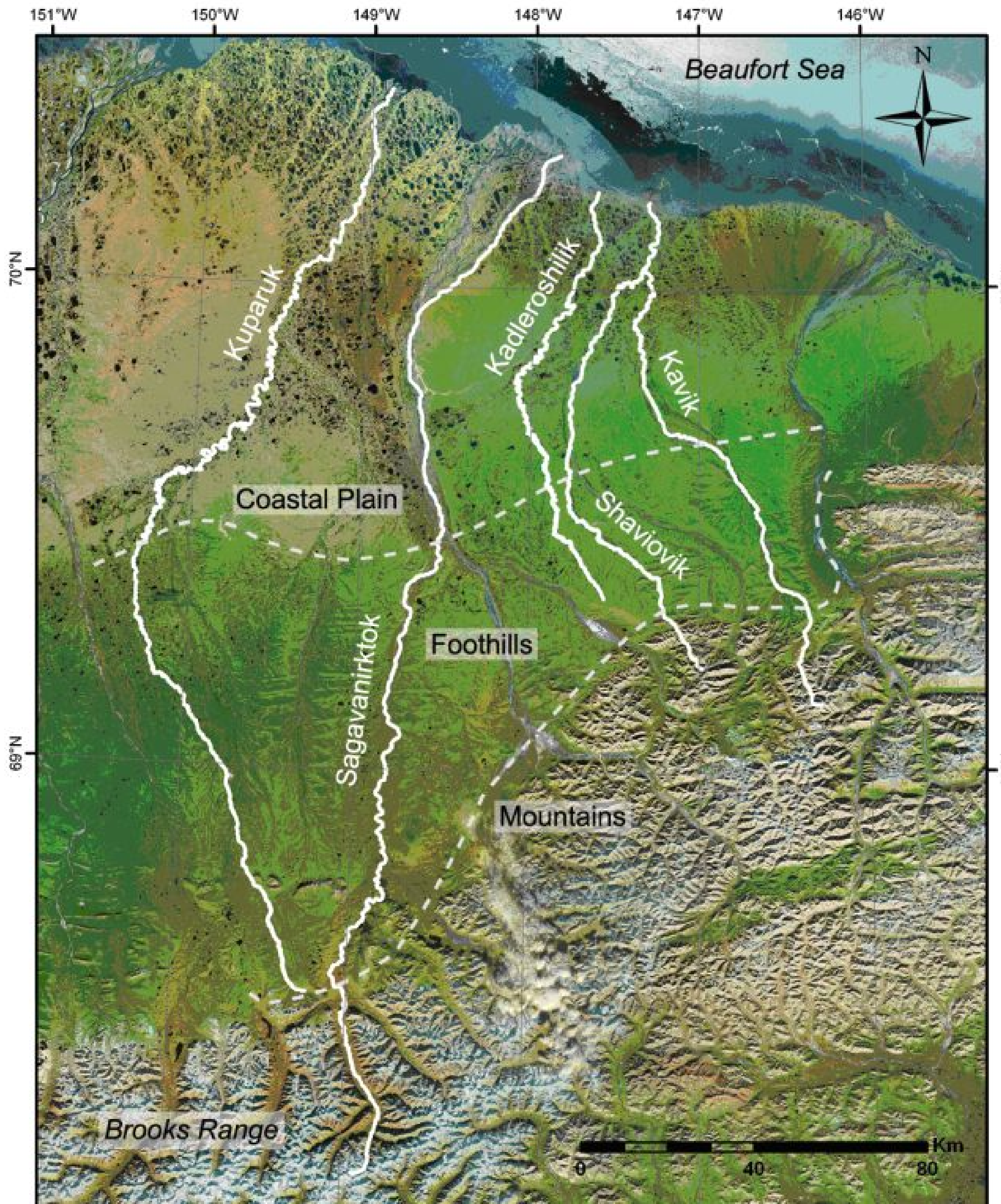

Figure 1. Geographical map of study area. Solid lines show major rivers; dashed lines represent approximate boundaries of the Coastal Plain, Foothills and Mountains regions.

2. AREA OF OBSERVATIONS

The study domain covers an 80 by 230 km region of the AAS that is bounded by the Brooks Range on the south and the Arctic Ocean on the north and includes the Kuparuk River basin (8 140 km^2). The southern and northern boundaries of the domain are at 68° 28' and 70° 30' N latitude, respectively. The western and eastern boundaries of the domain are approximately at 150° 30' and 148° 30' W longitude, respectively. The total elevation range within the Kuparuk River basin is sea level to 1464 m (0 to 4800 ft). The topography is characterized by flat northern portion, generally referred to as "*Coastal Plain*", followed by gently rolling hills and valleys extending to the south (*"Foothills"*) and mountain ridges of the Brooks Range (*"Mountains"*) (Figure 1).

Vegetation falls within a large region of sedge tussocks and mosses that cover much of northern Alaska. Occasional groupings of willows, approximately 40 cm high, occur in hillside water tracts and in the valley bottom. Riparian areas in the foothills are covered with shrubs (up to 2 m tall) and even trees in some areas (maximum 8 to 10 m). The surface organic soils vary from live organic material at the surface to partially decomposed organic matter between 10 and 20 cm in depth. Silt, overlying a glacial till, makes up the mineral soil in the glaciated area (Kane et al, 1989). Overall, the topography and vegetation of the domain are representative of the AAS region.

3. SAMPLING METHODS

Our snow surveys are made at designated stations throughout the domain to determine the depth, vertically integrated density and water equivalent (Figure 2). Most of the sites, except for ablation measurements (see section 3.2), are visited once a year near the peak of snow accumulation, the last week of April. Our observations in the Foothills showed that snow never melts before last week of April. Also, March, April and May are typically the months of lowest precipitation and, therefore, there is not much accumulation between the surveys and ablation.

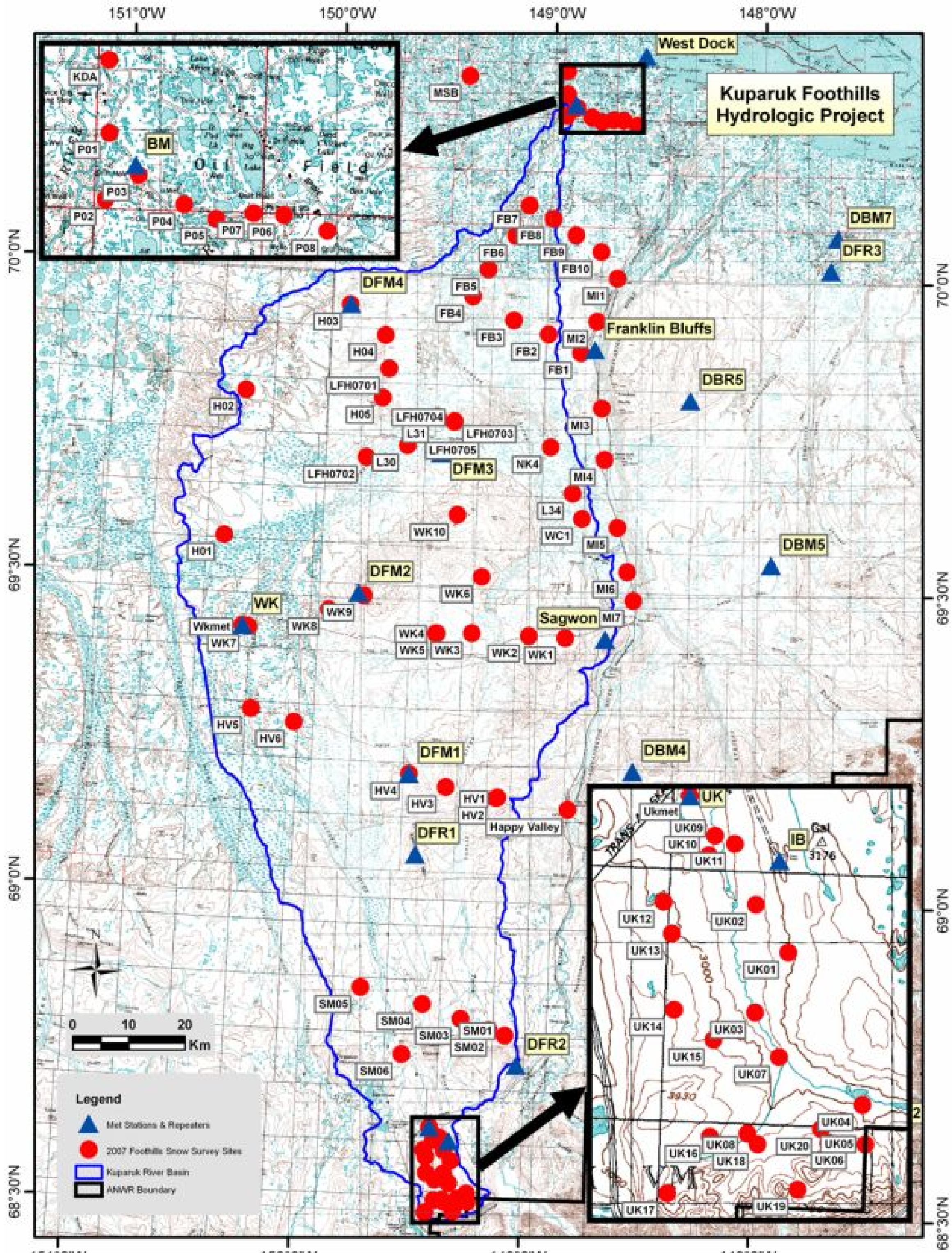

Figure 2. Location map of 2007 snow survey sites and meteorological stations.

In addition, meteorological stations are equipped with snow sensors that operate during the cold season and collect snow depth data at a point. Data can be collected in near real time or in the field directly from data logger.

3.1 Snow Survey

Our snow survey includes gravimetric SWE sampling and snow depth measurements collected over a 25 m by 25 m area; this technique is often referred to as “double sampling”. The Alaskan snowpack is extremely heterogeneous (Benson and Sturm, 1993). Usually, double sampling yields an areal SWE estimate with a lower variance than is possible by collecting snow cores only, because considerably more snow depths than SWE measurements can be made in a time increment. Rovansek et al. (1993) showed that double sampling provides improved SWE estimates and recommended sampling 12 to 15 snow depths for each snow core. However, this optimal ratio of snow depths to water equivalent appeared to vary greatly (from 1 to 23), depending on weather and snow conditions. Currently, we use an optimal ratio of 10; that is, 50 depths accompany five snow cores.

Snow cores are sampled using fiberglass tube (“Adirondak”) with an inside area of 35.7 cm^2, equipped with metal teeth on the lower end to cut through dense layers of snow. The advantage of the Adirondak for shallow snowpack is that it has a larger diameter than many other types of snow tubes and thus provides a larger sample. To obtain a complete snow core, the Adirondak tube is pushed vertically through the snow while turning until soil is encountered; at this point the snow depth is recorded. The tube is then driven further into the organic layer and tipped sideways, retaining a vegetation plug that ensures the complete snow column was sampled. The vegetation plug is then removed and the snow is collected to be weighed later, in the laboratory. This procedure allows estimating both average snow density and snow water equivalent.

We use constant 50 m length for the snow depth course with a 1 m sampling interval along an L-shaped transect. Twenty five depth measurements are made on each leg of the L; this strategy is used to account for the presence of snowdrifts in the area of measurement. The directions of measurement are chosen randomly. Snow depth measurements are collected using a T-shaped graduated rod (T-probe). The probe is simply pushed through the snow to the snow-ground interface.

Snow water equivalent is defined as

$$SWE = (SD * \rho_s) / \rho_w \quad (1)$$

where ρ_s is snow density, averaged from the 5 snow core samples, ρ_w is water density and SD is an average of 50 snow depths.

3.2 Snow Ablation

In addition to 2007 ablation data description, this report summarizes snowmelt observations conducted continuously since 1985 on a north-south transect along the Dalton Hwy.

3.2.1 Observation from 1985 to 2006

Measurement methods have changed over time as techniques have been modified to improve sampling accuracy. From 1985 to 1992 water equivalents were estimated from 10 randomly collected snow cores. These cores were sampled using Adirondak tubes and weighed using their mechanical scales, calibrated in inches of water. To overcome difficulties weighing samples in frequent high wind conditions, cores were often placed in zip-lock bags in the field and weighed indoors out of the wind using the Adirondak mechanical scale and after 1999 digital scales. Following Rovansek et al. (1993), double sampling technique was adopted in 1996 and continues to be used through the present (section 3.1). During the transition period (1993-1995), 5 to 20 snow cores were taken along with fifty snow depths. Snow depths have been measured using a variety of devices such as: Adirondak snow tube, avalanche probes, T-handled graduated probes, MagnaProbe, ski poles and rods with added graduated scales.

Number of observational sites has also changed over the time (Table 1). In 1985, the only sites where snow water equivalent and ablation were observed, were in the Imnavait Creek Basin. Sagwon Hill (SH) and Franklin Bluffs (FR) sites were added in 1986. Snow surveys at the

Sagwon site were made near the meteorological site, usually just east of the 3 or 10 meter tower away from the NRCS Wyoming snow gauge leeward drift. The Franklin Bluffs site was located from 1986 through 1998 adjacent to the meteorological site 1 km east of the Dalton Highway. In 1999 the snow survey and ablation site was moved west approximately 300 meters from the highway. Betty Pingo Site on the Pruhoe Bay Oilfield was established in 1992. This snow survey site is located near the NRCS Wyoming snow gauge about 200 meters north of the Kuparuk Pipeline Road between P-Pad and Gathering Center 2. Upper Kuparuk, Happy Valley and West Dock snow survey and ablation sites were added in 1999.

Table 1. Summary of snow ablation sites.

Site Name	Period of Record	Comments
Betty Pingo	1993 to 2007	Surveyed near NRCS Wyoming gauge
Franklin Bluffs	1987 to 2007	Surveyed near Met site 1983 to 1998, snow site moved west 700 meters along access road 1999 to 2007.
Happy Valley	1999 to 2007	Survey site 150 meters west of Dalton Highway near Happy Valley Airfield.
Imnavait Basin	1985 to 2007	Snow ablation measured at 4 sites on west-facing slope at mid basin 1985 to 1988, and at a 6 site mid-basin transect 1989 to 1997 and at a 6 sites transect along UTM 612800 northing.
Sagwon Hill	1987 to 2007	Adjacent to the Sagwon Meteorological Site
West Dock	1999 to 2007	150 meters east of West Dock - GC1 Road approximately one mile south of West Dock Meteorological Site.
Upper Kuparuk	1999 to 2007	Adjacent to the Upper Kuparuk Meteorological Site

Imnavait Creek basin (IB) differs from others in that it has the longest period of records and detailed observations. There were always several sites sampled across the basin to capture basin average snow water equivalent. From 1985 through 1997 Imnavait Basin snow water equivalent was determined from a transect made across the basin perpendicular to the stream channel. At this time snow ablation was tracked only at west-facing slope adjacent to 4 runoff plots (Hinzman, 1990). In 1989, 2 additional sites were added in the valley bottom and on the east-facing slope of the basin. To provide consistent identification of sites, the transect runs at 7612800 northing (NAD27, UTM6) since 1999.

3.2.2 Ablation observations in 2007

Snow ablation at all sites, described above (section 3.2.1), is observed to date. During 2007 snow melt, SWE observations were conducted at the Upper Kuparuk station (UKmet), Sagwon Hill (SH), Franklin Bluffs (FR), Betty Pingo (Betty), Happy Valley (HV), West Dock (WD) and at six sites across the Imnavait basin (IB1-IB6). Snow courses using double sampling technique (see section 3.1) have been made daily or every other day to capture the net volumetric decrease in SWE. The only difference from the end of winter snow survey is that the snow depth course has an assigned location, because of numerous repeated measurements.

3.3 Snow-Depth Sensors

Ten meteorological stations located on the North Slope/ Kuparuk Foothills Project are equipped with a Sonic Ranger 50 (SR50) snow depth sensors. Four of these stations are established by the Kuparuk River/ Foothills project (DFM1, DFM2, DFM3, DFM4) (Figure 2). Other stations are maintained by WERC as part of the NSF project. The SR50 probe uses ultrasonic pulses to measure the distance from the sensor to the snow surface. Basically, the SR50 sends out an ultrasonic pulse and times how long it takes to sense the pulse echo. Although the SR50 can measure the distance to any reflective surface like the ground or water, the sensitivity of the SR50 is designed for use in measuring distance to a snow surface.

The basic idea for measuring snow depth with the SR50 is simple subtraction. When there is no snow on the ground, the distance measured is the sensor's height above the ground. When snow has accumulated under the sensor the distance measured is to the snow surface. The difference between distance to the ground and distance to the snow surface yields snow depth. For example, if the sensor's height above the ground is 50 inches and 10 inches of snow accumulates, the new distance to surface will be 40 inches. Hence, 40 inches subtracted from 50 inches gives depth of the snow under the sensor of 10 inches.

The SR50 sampling method is point data that typically records measurements at hourly intervals. Thus, the SR50 has a low spatial coverage yet a high temporal resolution, while snow survey data has at higher spatial coverage yet at low temporal resolution. Snow sensor data used in conjunction with snow survey data can enhance and expand the limitations of each sampling method.

4. ACCURACY OF OBSERVATIONS

The problems of measuring and processing any observational data are critical to realize and address. This section provides an accuracy assessment of our observations, so the data can be utilized properly.

4.1 Snow-Water Equivalent

Core SWE often underestimates the water amount contained in the snowpack (our observations, personal communication with M. Sturm). In attempting to quantify underestimation in shallow tundra snowpack conditions, Woo et al. (1997) showed that a larger tube diameter increases the accuracy of density determination; he also showed that the Canadian sampler (similar to the Adirondak in diameter) captures snow density within 5% of snow pit estimates. Our comparison of Adirondak to snow pit density give similar results.

The accuracy of a single snow depth measurement is difficult to quantify. In the area of well-developed organics on top of the mineral soils, snow depth is often overestimated (Berezovskaya and Kane, 2007). While measuring, the probe can easily penetrate low-density organic material, so this additional depth is often inadvertently incorporated into the snow depth measurement. Any type of correction to existing snow depth records is difficult to perform, because the error varies strongly from observer to observer, as well as depending on the snow and soil conditions at each site.

Whereas snow depths show a systematic overestimation error, snow core densities tend to be close to, or to underestimate, SWE. The difficulty in SWE accuracy interpretations is that actual, accurate SWE is unknown. Comparing different sampling methods, Berezovskaya and Kane (2007) concluded that SWE of the tundra snow estimated with double sampling technique has error of ± 10 %.

4.2 Snow-Depth Sensors

Diligent field practices are essential for accurate measurements. After the sensor is installed and subsequently every time the station is visited, the distance from the bottom of the sensor to five points (four distances at 20º angles around sensor, and one directly underneath) on the ground is measured. When snow is on the ground, five depth measurements and the distance from the sensor to the snow surface are obtained. This information is crucial for post processing data correction.

Adjustments to data may vary according to the error tolerance and goals of the investigation, for this report QA/QC procedures are outlined below:

- Establish a baseline value that represents no snow on the ground.
- Manually review data (graphically), and replace erroneous values with the average from the first and last data value that is deemed reasonable.
- Adjust data to fit observed values in the field.
- Lastly, smooth the data and omit smaller, sporadic, data values. If the difference between a data point and the prior data point is greater than 1.5cm, and/or the difference between a data point and the following data point is greater than 1.5cm, then replace the data point

with the average of the prior 5 hours and following 5 hours of data. A 10-hour average helped smooth out blowing snow events and cold periods that may have altered readings.

- As to avoid an abrupt transition during accumulation and/or ablation periods, incrementally adjust data over a period of days.

Potential inherent errors exist. For example, since the speed of sound in air is affected by the temperature of the air it is traveling in, an air temperature measurement is required to correct the distance reading. Inaccuracies can be caused by poor calibration and/or neglecting periodic maintenance requirements. Physically related errors include blowing snow creating spurious data readings, difficulty in establishing a zero point due to tussocks, low shrubs, grass, etc., ground heave altering sensor height, changes in sensor height and angle as well as cable breakages due to wildlife curiosities.

5. SPATIAL DISTRIBUTION OF SNOW SITES

Snow survey sites are chosen to represent snow characteristics over a wide range of vegetation and terrain conditions. Snow water equivalents are measured at elevations from sea level to 3674 ft (0 to ~1120 m) in the Kuparuk River basin (Appendix A1-A3).

There are two distinctly different snow regimes across the Kuparuk basin, uplands and coastal (Liston and Sturm, 2002). To determine regional SWE, snow sites are classified as the Coastal Plain and uplands, the latter is separated into Foothills and Mountains. The coastal sites are the sites located below elevation isoline of 500 ft (152 m) and those above are referred to as uplands sites. Uplands snow sites are, in turn, separated into foothills and mountains based on elevation and surrounding topography (Appendix A1-A3). Elevation only is not representative for this purpose, because in the mountains most of the snow survey sites are located in the valley bottoms where helicopter can safely access the site.

Overall, 141 sites were visited in 2007. This number includes 100 sites within the frame of the Foothills project and 41 sites within the Bullen Point project. 7 of the Foothills project sites are located in the Mountains, 45 sites are in the Foothills and 48 sites are on the Coastal Plain.

6. SUMMARY OF SNOW OBSERVATIONS

Average of Coastal Pain snow densities (0.458 slug ft^{-3} / 236 kg m^{-3}) are similar to the Foothills (0.460 slug ft^{-3} / 237 kg m^{-3}) and less than the Mountains (0.504 slug ft^{-3} / 260 kg m^{-3}) (Appendix B1-B3).

The average of Coastal Plain SWE is 3.2 in (8.2 cm), and snow depth is 14.0 in (35.5 cm). Foothills average snow water equivalent is 4.6 in (11.6 cm), and snow depth average is 19.3 in (49.0 cm). Mountains average snow water equivalent (2.5 in / 6.3 cm) and snow depths (9.7 in / 24.7 cm) are generally lower than those at the Coastal Plain and Foothills. By the end of April Foothills have the highest SWE accumulation and Mountains have the lowest average SWE.

Observations at the Coastal Plain have then been corrected for the heavy snowfalls in early May (section 8). The adjusted average Coastal Plain SWE is 3.6 in (9.1 cm). SWE data before and after storm are listed in Appendix B4.

Overall, snow accumulation over domain is less than average, 90 % of 8-years average (2000-2007) and higher than last year (108 %) (Table 2). Mountains, Foothills and Coastal Plain regions have accumulated 70 %, 102 % and 96 % of average SWE (Table 3). There is only one other source of long-term SWE records collected by NRCS along the Dalton highway. NRCS reports 73 % of average snow accumulation for the Coastal Plain in 2007 (McClure R., 2007).

Table 2. The Kuparuk River snow water equivalent: 2000 – 2007.

YEAR	Mountains			Foothills			Coastal Plain			Kuparuk basin		
	SWE		Number of sites	SWE		Number of sites	SWE		Number of sites	SWE		Number of sites
	cm	in		cm	IN		cm	in		cm	in	
2000	9.3	3.7	2	12.3	4.8	36	9.9	3.9	20	10.5	4.1	58
2001	8.3	3.3	3	11.8	4.6	36	8.4	3.3	36	9.5	3.7	75
2002	6.6	2.6	2	11	4.3	32	9.4	3.7	34	9	3.5	68
2003	14.7	5.8	3	12.2	4.8	36	11.2	4.4	32	12.7	5.0	71
2004	8.8	3.5	3	11.3	4.4	28	9.2	3.6	14	9.8	3.9	45
2005	11.6	4.6	1	11.4	4.5	33	8.9	3.5	26	10.6	4.2	60
2006	6.7	2.6	7	8.9	3.5	39	9.5	3.7	41	8.4	3.3	87
2007	6.3	2.5	7	11.5	4.5	43	8.2	3.2	50	9.1	3.6	100
Average	9.0	3.6		11.3	4.5		9.3	3.7		9.9	3.9	

Table 3. 2007 snow water equivalent analysis.

Region	Number of sites	SWE		Percent of last year	Percent of average
		Cm	in		
Mountains	7	6.3	2.5	94	70
Foothills	45	11.5	4.5	129	102
Coastal Plain		8.1	3.2	85	87
	48	(9.1*)	(3.6*)	(94*)	(96*)
The Kuparuk River basin	100	8.6	3.4	102	87
		(9.0*)	(3.6*)	(108*)	(90*)

* indicates an adjusted SWE (see section 8)

7. SUMMARY OF SONIC SNOW-DEPTH MEASUREMENTS

Three out of eight meteorological stations had continuous, good quality snow sensor data from the accumulation and ablation 2006-2007 season: Northwest Kuparuk (DFM4), the North White Hills (DFM3), and the South White Hills (DFM1) stations (Figure 3-5). DFM 2 station records have not been analyzed, because sensor indicated no snow. This station is located on the top of the ridge, where snow is eroded due to persisting strong winds. Sonic snow depth records at the other three stations were adjusted to account for field observations and anomalous data points (section 3.3). As an example, the Northwest Kuparuk Station demonstrates data before and after it was corrected for periods when no snow was on the ground as well as differences with observed snow depth (Figure 5). Correction procedure for South White Hills station did not help to reduce the noise in February to May records, so the data should be interpreted with caution. Possible reasons for this noise can be attributed to snow being blown into or under the sensor, obstructions on the ground, sensor malfunction and calibration issues.

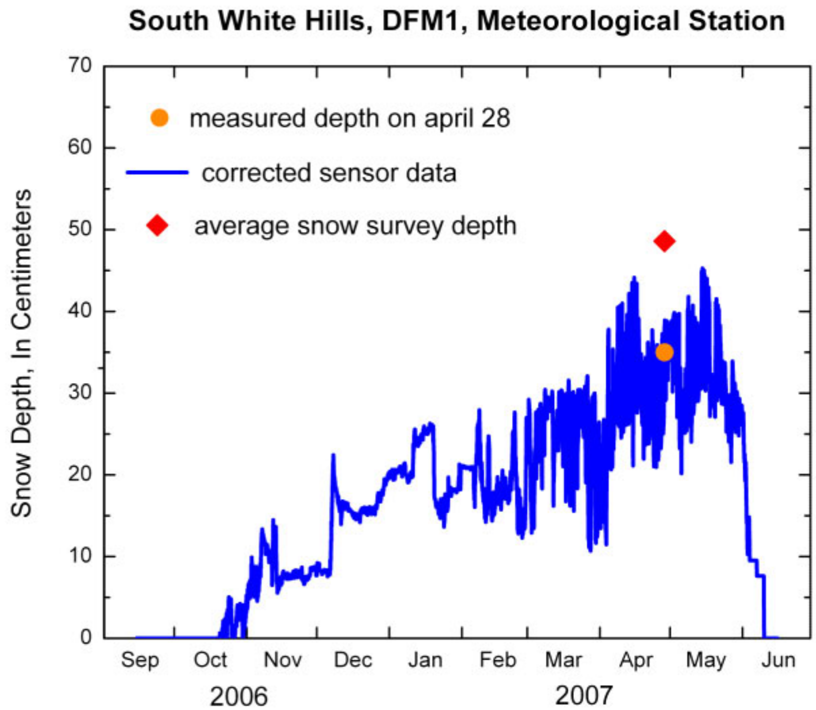

Figure 3. Corrected snow depth from Sonic Range S50 sensor installed at the South White Hills, DFM1 meteorological station.

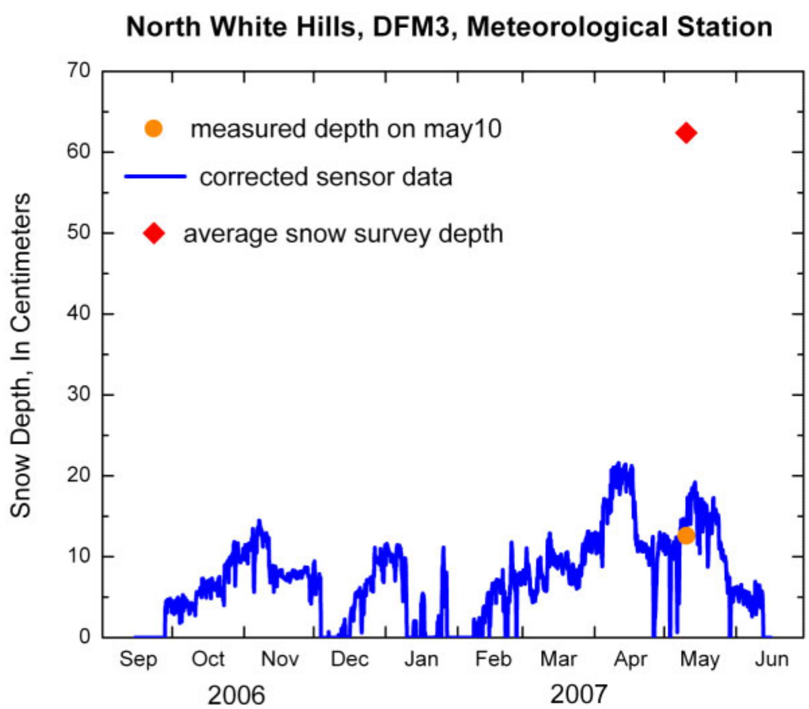

Figure 4. Corrected snow depth from Sonic Range S50 sensor installed at the North White Hills, DFM3 meteorological station.

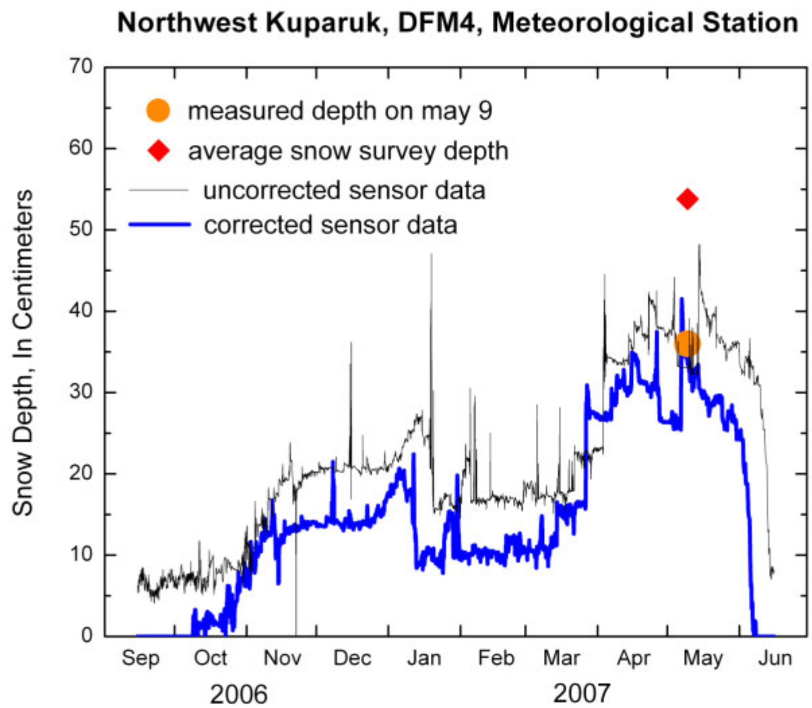

Figure 5. Corrected snow depth from Sonic Range S50 sensor installed at Northwest Kuparuk, DFM4 meteorological station..

The maximum snow depth during the winter was about 20 cm at the North White Hills station and about 40 cm at the Northwest Kuparuk and South White Hills stations. Sonic sensor measurements are made at a point, so they are not always representative of surrounding snow cover depth. Fifty snow depth measurements taken at the nearest snow survey sites in May 2007 provide snow depth variability within 37 to 89 cm for the North White Hills, 32 to 76 cm for the Northwest Kuparuk, and 29 to 70 cm for the South White Hills. Sensor depth measurements are either close to the lower range or slightly less (North White Hills) than the minimum observed snow survey depth.

The advantage of snow sensor information is its high temporal resolution, which can capture the timing and relative magnitude of snow events. Our records show that snow accumulation began approximately at the end of September 2006 for the North White Hills site and early to mid-October 2006 for the Northwest Kuparuk and South White Hills sites. Several major snow deposition and erosion events can be distinguished during the 2006 - 2007 season (Figure 3-6). Significant snow accumulation at the Northwest Kuparuk and South White Hills occurred last week of October, 2006 and, then, first week of December, 2006. During the week of January 8-15 2007, the Northwest Kuparuk's snow depth decreased by 50% and North White Hills decreased by 95%. Decrease in snow depth is usually caused by strong winds that scour snow from open exposed areas (i.e. ridges and windward slopes) and deposit in the lee of the bluffs and other topographical or vegetation obstructions. All stations show snow accumulation during late March – early April and, then a response of various magnitudes to the late spring storm occurring approximately from May 6 to May 10, 2007. For all three stations, snow was no longer on the ground by June 8 to 12, 2007.

8. SUMMARY OF SPRING STORM

Following the initiation of April snow surveys, a storm event occurred approximately from May 5 to May 8, 2007. It brought heavy snowfalls and caused an additional snow accumulation throughout the Coastal Plain. The dominant wind direction was the northeast. Snow accumulation occurred from May 6 to May 8 in the Kuparuk River basin, roughly a day later than sites located in the Bullen Point Region to the east. Inclement weather before, during, and after the storm delayed accessing coastal survey sites via helicopter the majority of the first part of May.

To assess the storm impact on maximum SWE, we compared observations collected before and after this storm (Table 4). The difference was used 1) to localize the area of impact and 2) to adjust maximum winter snow accumulation (Appendix B4).

The evaluation considers the change in SWE at snow survey sites and meteorological stations. To convert snow sensor depth to SWE, an average density of 230 kg/m^3 from snow surveys taken near the same time and location is used. Data show a large spatial extent of the storm affecting survey sites; West Dock, Betty Pingo, Franklin Bluffs, as well as meteorological stations DFM 4 and DFM 3. An accumulation gradient from north to south is seen for the Coastal Plain (Table 4), with higher accumulation in the north decreasing towards the south.

Data also show a transitional zone in this north/south gradient occurring in the White Hills (WK10 site) and Sagwon Hills. Gradual SWE increase in the foothill and mountain areas (Upper Kuparuk and Imnavait Creek) is unlikely caused by the same storm extended into the upland areas. Through the direct snow observations, we would localize the area of spring storm impact to the Coastal Plain only.

Table 4. Observed SWE before and after spring storm. Sites listed in order by location going from north to south. Stations in bold indicate location is on the Coastal Plain.

Site	Data	SWE before storm		SWE after storm		Difference
	source	Date	cm	Date	cm	%
West Dock	Snow survey	4/24	5.8	5/13	6.5	11
Betty Pingo	Snow survey	4/25	6.5	5/13	9.3	30
DFM 4	Snow sensor	5/6	5.9	5/9	7.9	26
Franklin Bluffs	Snow survey	4/27	6.6	5/17	8.7	24
DFM 3	Snow sensor	5/5	2.5	5/8	3.0	15
WK 10	Snow survey	4/29	12.4	5/9	8.5	-46
Sagwon	Snow survey	4/25	7.5	5/17	7.3	-3
DFM1	Snow sensor	5/5	6.9	5/9	7.5	9
Happy Valley	Snow survey	4/25	7.3	5/17	8.1	10
Upper Kuparuk	Snow survey	4/24	11.9	5/16	14.2	16
Imnavait Creek	Snow transect	4/25	12.3	5/12	11.3	-9

The SWE increase on the Coastal Plain as a result of the storm ranges from 11 % to 30%. Snow surveys conducted prior to the storm event were grouped relative to their position to the West Dock, Betty Pingo, Franklin Bluffs, DFM4 and DFM3 sites (Figure 2). Correction factor, derived as a ratio of SWE measured after storm to SWE measured before storm, was applied to each group (Appendix B4). Adjusted SWE result in an average SWE for the Coastal Plain to be 8.9 cm (3.5 in), or a 9 % increase.

9. SUMMARY OF ABLATION OBSERVATIONS

The ablation window varies greatly depending on meteorological conditions and snowpack depth. The start of spring snowmelt usually occurs in the southern part first (Imnavait Basin, Upper Kuparuk sites) and a week or two later snow starts melting on a coastal plain (Franklin Bluffs, Betty Pingo and West Dock). Onset of ablation in 2007 varies from May 14th, 2007 at the Imnavait Basin and Upper Kuparuk to May 27th – May 30th, 2007 at northern sites with an average of 5 days to complete the melt (Figure 6). The Imnavait Basin ablation curve differs in that it is an average of six sites across the basin. Within a few days of sustained melt the entire watershed becomes a patchwork of snow covered and bare tundra. The west-facing slope melts off sooner than the rest of the watershed, because it retains less snow and has more direct solar radiation in the afternoon when air temperatures are highest (Hinzman et al., 1996). In contrast, the east-facing slope has deeper snowpack and receives its maximum irradiance in the morning while convective heat transfer is smaller. 10 days were required to complete ablation in the Imnavait watershed. Snowpack across the entire Kuparuk River basin melted off within three weeks from May 14th to June 5th, 2007.

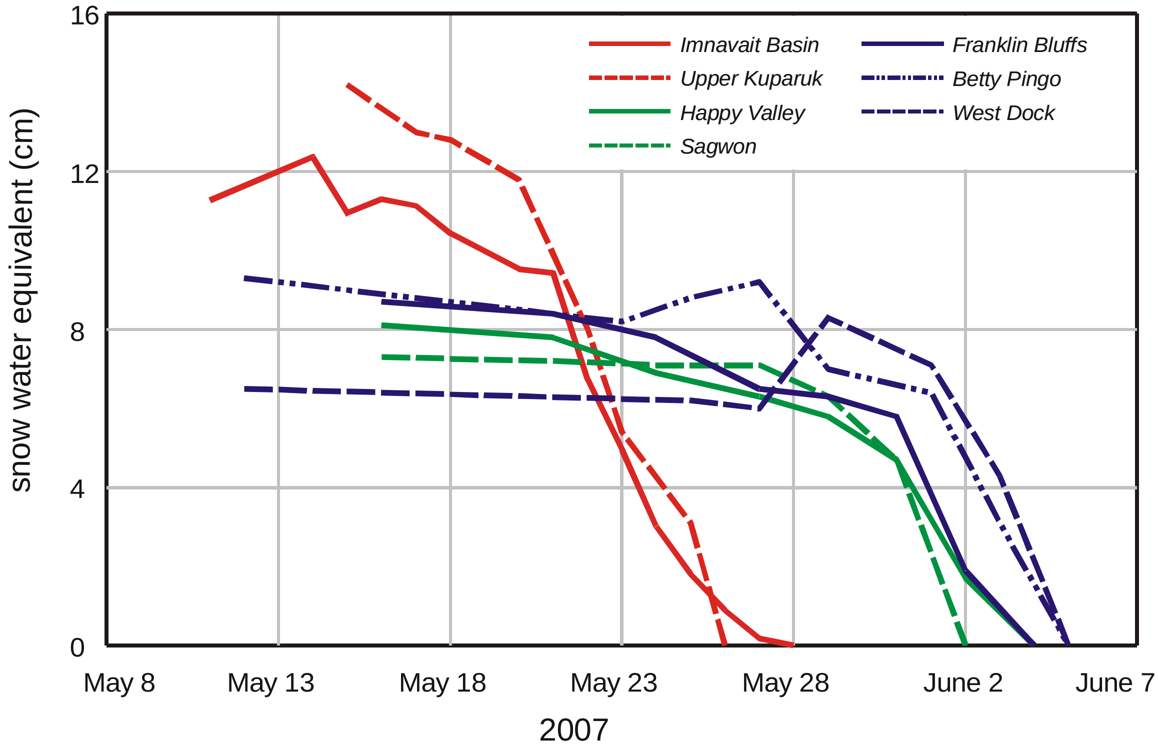

Figure 6. Snow ablation curves at the foothills (red and green lines) and on the coastal plain (blue lines). Imnavait basin shows SWE, averaged from six sites across the basin.

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APPENDIX A. LIST OF THE SNOW SURVEY SITES IN 2007

Appendix A1. Elevation and coordinates of the sites located in the Mountains

№	ID	ELEV m	LAT decimal degree	LON decimal degree
1	UK05	1021	68.5200	-149.227
2	UK06	1050	68.5199	-149.262
3	UK14	1027	68.5638	-149.411
4	UK16	1045	68.5207	-149.373
5	UK17	1109	68.5007	-149.411
6	UK19	1115	68.5037	-149.289
7	UK20	1024	68.5247	-149.269

Appendix A2. Elevation and coordinates of the sites located in the Foothills

№	ID	ELEV m	LAT decimal degree	LON decimal degree
1	UK01	912	68.5849	-149.306
2	UK02	834	68.6010	-149.338
3	UK03	827	68.5639	-149.335
4	UK04	908	68.5335	-149.231
5	UK07	848	68.5489	-149.311
6	UK08	968	68.5222	-149.338
7	UK09	763	68.6241	-149.379
8	UK10	801	68.6173	-149.384
9	UK11	796	68.6215	-149.360
10	UK12	904	68.6007	-149.425
11	UK13	937	68.5899	-149.416
12	UK15	951	68.5540	-149.373
13	UK18	981	68.5187	-149.328
14	Ukmet	778	68.6374	-149.404
15	SM01	732	68.7879	-149.087
16	SM02	680	68.7956	-149.158
17	SM03	651	68.8122	-149.284
18	SM04	612	68.8336	-149.456
19	SM05	568	68.8565	-149.733
20	SM06	609	68.7521	-149.539
21	Happy Valley	314	69.1519	-148.839
22	HV1	365	69.1682	-149.155
23	HV2	353	69.1667	-149.162
24	HV3	386	69.1816	-149.390
25	HV4	308	69.2007	-149.558
26	HV5	179	69.2937	-150.284
27	HV6	218	69.2756	-150.087
28	Wkmet	159	69.4259	-150.342
29	WK1	218	69.4265	-148.872
30	WK2	226	69.4278	-149.038
31	WK3	174	69.4291	-149.298
32	WK4	203	69.4269	-149.461
33	WK5	197	69.4269	-149.457
34	WK6	195	69.5199	-149.262
35	WK8	173	69.4576	-149.953
36	WK9	401	69.4826	-149.797
37	WK10	214	69.6173	-149.384
38	Sagwon	275	69.4262	-148.691
39	H02	172	69.8020	-150.384
40	IB	897	68.6134	-149.318
41	MI6	179	69.5344	-148.599
42	MI7	177	69.4887	-148.568
43	DFR1	508	69.0726	-149.515
44	DFM2	337	69.4865	-149.821
45	DFM1	293	69.2007	-149.558

Appendix A3. Elevation and coordinates of the sites located on the Coastal Plain

№	ID	ELEV m	LAT decimal degree	LON decimal degree
1	West Dock	5	70.3602	-148.570
2	Franklin Bluffs	71	69.8886	-148.775
3	FB1	71	69.8828	-148.839
4	FB2	64	69.9108	-148.992
5	FB3	58	69.9316	-149.156
6	FB4	52	69.9676	-149.351
7	FB5	42	70.0113	-149.283
8	FB6	38	70.0667	-149.160
9	FB7	32	70.1160	-149.101
10	FB8	34	70.0960	-148.987
11	FB9	34	70.0710	-148.878
12	FB10	40	70.0451	-148.758
13	P01	12	70.2955	-148.937
14	P02	15	70.2614	-148.940
15	P03	11	70.2744	-148.891
16	P04	12	70.2601	-148.821
17	P05/Betty	15	70.2532	-148.772
18	P06	12	70.2562	-148.670
19	P07	12	70.2566	-148.716
20	P08	12	70.2486	-148.604
21	MI1	48	70.0032	-148.679
22	MI2	60	69.9336	-148.768
23	MI3	90	69.7950	-148.736
24	MI4	90	69.7130	-148.716
25	MI5	140	69.6050	-148.649
26	H01	113	69.5687	-150.448
27	H03	124	69.9467	-149.920
28	H04	77	69.9000	-149.750
29	H05	90	69.8000	-149.750
30	L30	73	69.7255	-149.626
31	L31	73	69.7730	-149.492
32	L34	116	69.6576	-148.858
33	NK4	101	69.7307	-148.966
34	WC1	127	69.6179	-148.812
35	WK7	137	69.4243	-150.315
36	DFM3	84	69.7149	-149.470
37	DFM4	124	69.9475	-149.917
38	KDA	3	70.3326	-149.941
39	MSB	3	70.1931	-149.237
40	LFH0701-L	87	69.8468	-149.727
41	LFH0701	87	69.8468	-149.727
42	LFH0703-L	83	69.7660	-149.416
43	LFH0703	83	69.7660	-149.416
44	LFH0702-L	97	69.7038	-149.813
45	LFH0702	97	69.7038	-149.813
46	LFH0705-L	95	69.7495	-149.256
47	LFH0705	95	69.7495	-149.256
48	LFH0704	83	69.7667	-149.413

APPENDIX B. AVERAGE SNOW DENSITY, SNOW DEPTH AND SNOW WATER EQUIVALENT

Appendix B1. Summary for the sites located in the Mountains

№	ID	SWE		SNOW DEPTH		SNOW DENSITY	
		cm	in	cm	in	kg/m^3	$slug/ft^3$
1	UK05	4.3	1.7	23.7	9.3	179	0.347
2	UK06	4.9	1.9	16.4	6.5	301	0.584
3	UK14	7.4	2.9	31.5	12.4	233	0.452
4	UK16	3.2	1.3	10.7	4.2	299	0.580
5	UK17	4.8	1.9	17.3	6.8	278	0.539
6	UK19	8.9	3.5	32.4	12.8	276	0.535
7	UK20	10.4	4.1	41.0	16.1	253	0.491
	Average	**6.3**	**2.5**	**24.7**	**9.7**	**260**	**0.504**

Appendix B2. Summary for the sites located in the Foothills.

№	ID	SWE		SNOW DEPTH		SNOW DENSITY	
		cm	in	cm	in	kg/m^3	slug/ft^3
1	UK01	10.2	4.0	43.2	17.0	235	0.456
2	UK02	10.1	4.0	44.8	17.6	227	0.440
3	UK03	12.6	5.0	58.1	22.9	216	0.419
4	UK04	6.0	2.4	22.0	8.7	272	0.528
5	UK07	12.9	5.1	59.3	23.3	217	0.421
6	UK08	3.0	1.2	11.1	4.4	268	0.520
7	UK09	11.3	4.4	47.8	18.8	236	0.458
8	UK10	16.3	6.4	72.2	28.4	255	0.495
9	UK11	13.3	5.2	56.4	22.2	237	0.460
10	UK12	7.7	3.0	32.5	12.8	237	0.460
11	UK13	10.6	4.2	39.9	15.7	266	0.516
12	UK15	10.6	4.2	40.1	15.8	265	0.514
13	UK18	6.0	2.4	24.2	9.5	247	0.479
14	Ukmet	11.9	4.7	62.3	24.5	191	0.371
15	SM01	11.0	4.3	38.2	15.0	287	0.557
16	SM02	10.9	4.3	41.6	16.4	263	0.510
17	SM03	9.9	3.9	43.3	17.0	227	0.440
18	SM04	13.4	5.3	56.6	22.3	237	0.460
19	SM05	11.6	4.6	57.5	22.6	202	0.392
20	SM06	13.7	5.4	67.9	26.7	202	0.392
21	Happy Valley	18.6	7.3	70.0	27.6	266	0.516
22	HV1	18.3	7.2	78.0	30.7	235	0.456
23	HV2	11.7	4.6	55.1	21.7	213	0.413
24	HV3	17.2	6.8	68.8	27.1	250	0.485
25	HV4	15.3	6.0	61.6	24.3	250	0.485
26	HV5	18.8	7.4	87.1	34.3	216	0.419
27	HV6	12.3	4.8	49.8	19.6	248	0.481
28	Wkmet	7.8	3.1	41.7	16.4	188	0.365
29	WK1	10.0	3.9	48.0	18.9	209	0.405
30	WK2	8.8	3.5	47.6	18.7	186	0.361
31	WK3	23.1	9.1	90.4	35.6	255	0.495
32	WK4	6.1	2.4	37.3	14.7	164	0.318
33	WK5	31.4	12.4	93.3	36.7	336	0.652
34	WK6	14.2	5.6	47.0	18.5	302	0.586
35	WK8	8.7	3.4	38.1	15.0	230	0.446
36	WK9	3.8	1.5	17.8	7.0	214	0.415
37	WK10	12.4	4.9	58.2	22.9	230	0.446
38	Sagwon	7.5	3.0	31.3	12.3	213	0.413
39	H02	5.9	2.3	25.1	9.9	233	0.452
40	IB	11.9	4.7	44.5	17.5	267	0.518
41	MI6	11.5	4.5	45.9	18.1	252	0.489
42	MI7	8.8	3.5	40.0	15.7	219	0.425
43	DFR1	10.5	4.1	47.0	18.5	224	0.435
44	DFM2	0.8	0.3	2.8	1.1	271	0.526
45	DFM1	10.4	4.1	48.6	19.1	215	0.417
	Average	**11.5**	**4.5**	**48.8**	**19.2**	**237**	**0.460**

Appendix B3. Summary for the sites located on the Coastal Plain.

№	ID	SWE		SNOW DEPTH		SNOW DENSITY	
		cm	in	cm	in	kg/m^3	$slug/ft^3$
1	West Dock	5.8	2.3	23.3	9.2	248	0.481
2	Franklin Bluffs	6.6	2.6	27.6	10.9	239	0.464
3	FB1	15.1	5.9	57.9	22.8	260	0.504
4	FB2	7.8	3.1	38.2	15.0	200	0.388
5	FB3	8.8	3.5	43.1	17.0	230	0.446
6	FB4	11.3	4.4	49.6	19.5	230	0.446
7	FB5	9.6	3.8	41.2	16.2	230	0.446
8	FB6	7.9	3.1	40.6	16.0	190	0.369
9	FB7	6.5	2.6	36.2	14.3	180	0.349
10	FB8	14.4	5.7	49.3	19.4	290	0.563
11	FB9	8.3	3.3	36.3	14.3	230	0.446
12	FB10	10.1	4.0	45.7	18.0	220	0.427
13	P01	6.1	2.4	18.4	7.2	331	0.642
14	P02	3.7	1.5	21.3	8.4	176	0.341
15	P03	6.5	2.6	29.0	11.4	224	0.435
16	P04	5.5	2.2	22.1	8.7	250	0.485
17	P05/BettyP	6.7	2.6	30.0	11.8	224	0.435
18	P06	3.3	1.3	11.4	4.5	289	0.561
19	P07	3.8	1.5	25.1	9.9	153	0.297
20	P08	4.5	1.8	19.1	7.5	236	0.458
21	MI1	5.2	2.0	21.0	8.3	249	0.483
22	MI2	7.1	2.8	30.4	12.0	235	0.456
23	MI3	5.1	2.0	15.2	6.0	339	0.658
24	MI4	5.4	2.1	28.6	11.3	189	0.367
25	MI5	7.0	2.8	32.5	12.8	215	0.417
26	H01	10.6	4.2	37.8	14.9	281	0.545
27	H03	8.0	3.1	47.3	18.6	170	0.330
28	H04	20.0	7.9	84.3	33.2	240	0.466
29	H05	9.5	3.7	40.0	15.7	240	0.466
30	L30	9.4	3.7	45.4	17.9	210	0.407
31	L31	9.8	3.9	46.6	18.3	210	0.407
32	L34	4.1	1.6	27.0	10.6	150	0.291
33	NK4	4.7	1.9	18.2	7.2	260	0.504
34	WC1	6.9	2.7	28.5	11.2	240	0.466
35	WK7	9.9	3.9	47.7	18.8	207	0.402
36	DFM3	16.7	6.6	62.4	24.6	270	0.524
37	DFM4	11.6	4.6	53.8	21.2	220	0.427
38	KDA	6.4	2.5	24.3	9.6	265	0.514
39	MSB	4.5	1.8	12.0	4.7	378	0.733
40	LFH0701-L	8.1	3.2	26.2	10.3	310	0.601
41	LFH0701	10.2	4.0	36.6	14.4	280	0.543
42	LFH0703-L	8.1	3.2	24.4	9.6	330	0.640
43	LFH0703	6.3	2.5	28.5	11.2	220	0.427
44	LFH0702-L	9.4	3.7	27.4	10.8	340	0.660
45	LFH0702	7.7	3.0	36.4	14.3	210	0.407
46	LFH0705-L	8.6	3.4	32.1	12.6	270	0.524
47	LFH0705	12.3	4.8	44.7	17.6	280	0.543
48	LFH0704	5.3	2.1	19.5	7.7	274	0.532
	Average	**8.1**	**3.2**	**34.3**	**13.5**	**244**	**0.473**

Appendix B4. Adjusted SWE for the sites located on the Coastal Plain.

№	ID	SWE		CORRECTION FACTOR	ADJUSTED SWE	
		cm	in		cm	in
1	West Dock	5.8	2.3	1.12	6.5	2.6
2	Franklin Bluffs	6.6	2.6	1.32	8.7	3.4
3	FB1	15.1	5.9	not applicable	15.1	5.9
4	FB2	7.8	3.1	not applicable	7.8	3.1
5	FB3	8.8	3.5	not applicable	8.8	3.5
6	FB4	11.3	4.4	not applicable	11.3	4.4
7	FB5	9.6	3.8	not applicable	9.6	3.8
8	FB6	7.9	3.1	not applicable	7.9	3.1
9	FB7	6.5	2.6	not applicable	6.5	2.6
10	FB8	14.4	5.7	not applicable	14.4	5.7
11	FB9	8.3	3.3	not applicable	8.3	3.3
12	FB10	10.1	4.0	not applicable	10.1	4.0
13	P01	6.1	2.4	1.43	8.7	3.4
14	P02	3.7	1.5	1.43	5.3	2.1
15	P03	6.5	2.6	1.43	9.3	3.7
16	P04	5.5	2.2	1.43	7.9	3.1
17	P05/BettyP	6.7	2.6	1.43	9.6	3.8
18	P06	3.3	1.3	1.43	4.7	1.9
19	P07	3.8	1.5	1.43	5.4	2.1
20	P08	4.5	1.8	1.43	6.4	2.5
21	MI1	5.2	2.0	1.32	6.9	2.7
22	MI2	7.1	2.8	1.32	9.4	3.7
23	MI3	5.1	2.0	1.32	6.7	2.7
24	MI4	5.4	2.1	0.0	5.4	2.1
25	MI5	7.0	2.8	1.32	9.2	3.6
26	H01	10.6	4.2	1.10	11.7	4.6
27	H03	8.0	3.1	not applicable	8.0	3.1
28	H04	20.0	7.9	not applicable	20.0	7.9
29	H05	9.5	3.7	not applicable	9.5	3.7
30	L30	9.4	3.7	not applicable	9.4	3.7
31	L31	9.8	3.9	not applicable	9.8	3.9
32	L34	4.1	1.6	not applicable	4.1	1.6
33	NK4	4.7	1.9	not applicable	4.7	1.9
34	WC1	6.9	2.7	not applicable	6.9	2.7
35	WK7	9.9	3.9	not applicable	9.9	3.9
36	DFM3	16.7	6.6	not applicable	16.7	6.6
37	DFM4	11.6	4.6	not applicable	11.6	4.6
38	KDA	6.4	2.5	1.43	9.2	3.6
39	MSB	4.5	1.8	1.43	6.4	2.5
40	LFH0701-L	8.1	3.2	1.34	10.9	4.3
41	LFH0701	10.2	4.0	1.34	13.7	5.4
42	LFH0703-L	8.1	3.2	1.19	9.6	3.8
43	LFH0703	6.3	2.5	1.19	7.5	3.0
44	LFH0702-L	9.4	3.7	1.19	11.2	4.4
45	LFH0702	7.7	3.0	1.19	9.2	3.6
46	LFH0705-L	8.6	3.4	not applicable	8.6	3.4
47	LFH0705	12.3	4.8	not applicable	12.3	4.8
48	LFH0704	5.3	2.1	1.19	6.3	2.5
	Average	**8.1**	**3.2**		**9.1**	**3.6**

Sites that were sampled after storm are marked as “not applicable”, i.e. correction is not needed.

APPENDIX C. HISTORICAL ABLATION DATA

Appendix C1. Snow water equivalent (cm) in the Imnavait Creek basin (basin average).

Day of Year	85	86	87	88	89	90	91	92	93	94	95	96	97	98	99	00	01	02	03	04	05	06	07
120											14												
121																							
122										8													
123				7.5																			
124							8.2																
125																							
126										4.6	6.8												
127																					12		
128	10.6									1.7	5.3												
129	10.3		10	6.9		9.9	1.1												15.7	12.0			
130	9.7		8.8	5.1			0.3			1.3	1.3								14.4				
131	7.9		8.6	4.8			0.2												14.9				
132			7.6	1.9		7.8	0.14												14.3				11.3
133	8.1		7.4	0.4		6.9	0.12		10.1				12.5		6.9				14.4		5.7	9.6	
134	7.5		7.5	0.0		6.5	0.06			0.1			10.5		5.7				14.4	9.3	4.5		
135				0.0		4.9	0						11.0	9.5	5.1		13	12.4	15.1	8.2	3.3	6.8	12.4
136			7.7			3.6				0	0		7.3	8.7	3.9			12.2	15.1	7.8	1.4		11.0
137			7.5		13	1.8			5.8			10.1	5.8	6.5	3.6			12.6	15.4	6.0	2.1	4.0	11.3
138	8.0		6.9			1.1			0.7				5.3	6.2	3.2		13	12.1	14.8	4.3		3.4	11.1
139	7.3		5.2		12.3	0.4			0.1				4.5	4.2	2.2	11.2	14	11.2	15.2	2.0	1.8	2.9	10.4
140	6.9		3.9		12.0	0.02			0.0			10.2	3.7	1.5	1.1	10.7		11.1	15.4	2.1	2.1	1.3	
141	6.2		2.6		12.0	0.0							2.8	1.5	0.6	10.2	14	9.3	18.5	1.8	1.0	0.3	9.5
142	6.2		1		11.4								2.2	0.1	0.4	9.2		7.0	18.4	1.1	0.9	0.5	9.4
143	5.7		0.2		10.7							10.2	1.9	0.0		9.5	14	5.4	16.4	0.2	0.8	0.1	6.7
144	4.4		0.0		10.5			15.3				9.0	1.4			9.3		0.5	15.3	0.0	0.4	0.0	5.0
145	1.8				9.3							6.6	0.7			8.0	14	0.0	17.1		0.2		3.0
146	0.9				8.6			14.6				4.8	0.4			7.5	13		17.3		0.1		1.8
147	0.6	11.4			7.6			13.9				2.6	2.5			7.3	12		15.1		0.0		0.9
148	0.3	11.2			4.5			13.9					2.2			6.4	12		15.3				0.2
149	0.1	10.2			2.0			14.1				1.6	2.2			3.9	12		14.5				0.0
150	0.0	10.2			0.0			13.7				0.4	0.8			0.2	9.6		12.8				
151		8.9						13.0					0.6			0.01	4.6		11.4				
152		7.4						10.8				0.0	0.0			0.0	6.0		11.7				
153		5.1						9.7									5.9		7.2				
154		4.1						8.8									3.1		3.6				
155		2.3						7.5									2.2		0.4				
156		0.3						5.8									0.8		0.0				
157		0.0						5.1									0.2						
158								5.2									0.0						
159								4.0															

160								**2.7**															
161								**1.0**															
162								**0.0**															
163																							

Appendix C2. Snow water equivalent (cm) at the Upper Kuparuk (UK) site

Day of Year	85	86	87	88	89	90	91	92	93	94	95	96	97	98	99	00	01	02	03	04	05	06	07
120																15		10	14	18	18		12
121																							
122																							
123																							
124																							
125																							
126																							
127																							
128																							
129																			17.4				
130																			17.0				
131																			15.3		13.0		
132																			12.3		11.5		
133															11.9							12.4	
134															9.1			12.9		16.4	6.0		
135															4.3		17	12.5	18.3	17.0	13.2		
136															3.0			15.3	17.4			8.0	14.2
137															2.5						9.1	7.8	
138															0.0			15.2	18.1	11.5		6.4	13.0
139																	14		18.7	9.8	7.2	4.5	13
140																20.5	16			7.7	8.1	1.8	
141																		12.6		9.2	5.5	0.0	11.8
142																	17				0.3		
143																		5.8		5.9			8.0
144																	17		17.6				5.4
145																		0	17.9	1.1			
146																	18		17.3	0.5			3.1
147																	15						0.0
148																	13		15.2				
149																	15						
150																	13.3		13.1				
151																17.2	10.1						
152																	13.7		12.3				
153																17	9.7		10.6				
154																			7.9				
155																17	0						
156																16							
157																9.8							
158																4.8							
159																1.3							

160																**0**							
161																							
162																							
163																							

Appendix C3. Snow water equivalent (cm) at the Happy Valley (HV) site.

Day of Year	85	86	87	88	89	90	91	92	93	94	95	96	97	98	99	00	01	02	03	04	05	06	07
120																	14	15	13	23	24		7.3
121																							
122																							
123																							
124																							
125																							
126																							
127																							
128																							
129																							
130																			16.4				
131																							
132																							
133																						22.0	
134																		13.1					
135																					28.3		
136																		12.5					
137																							8.1
138																		9.6					
139																15.3				17.4		22.0	
140															7.4		19	6.7			30.0		
141																			17.7	14.9			
142															10			0.8				14.1	7.8
143																		0.0	11.1	14.7	28.6		
144																						13	
145																			20.2	8.2			6.9
146																	14				26.7	8.2	
147																							
148																			11.0		21	7	6.3
149																				0			
150																16.0					19	4.2	5.8
151																			24.3				
152																	11.7				13	0	4.7
153																13			4.4				
154																	9.2				10		1.7
155																12							
156																	4.1				4.3		0
157																11							
158																	0						
159																2.3							

160																							
161																**0**							
162																							
163																							

Appendix C4. Snow water equivalent (cm) at the Sagwon (SH) site.

Day of Year	85	86	87	88	89	90	91	92	93	94	95	96	97	98	99	00	01	02	03	04	05	06	07
120				8.1	23	11	15		14			21	12			10	6.4	10	8.1	11	5.5		7.5
121																							
122																							
123																							
124																							
125																							
126																							
127							4.4																
128						5.0																	
129				5.4																			
130																							
131																							
132																							
133				3.9			4.19															6.0	
134																		7.9					
135			5.2													7.9					3.6		
136																		7.7					
137				3.9												7.7							7.3
138				4.4														3.3					
139												1.0				3.3				8.2		0.0	
140						1.1								1.7	5.8		8.1	0.0			4.3		
141				3.9												0.0			8.4	4.8			
142															7.7								7.2
143																			10.2	4.9	3.4		
144				3.8									1.1		4.1								
145					14.9				5.8											2.8			7.1
146				3.7													6.6				2.9		
147																							
148				3.7															9.2		2.2		7.1
149																				2.8			
150				2.6																	0.3		6.3
151																			2.0				
152				2.4													5.7			2.3	0		4.7
153																							
154				1.8													1.8			1.3			0
155																							
156				1.7													0.5			0.5			
157																	0.0						
158																				0			
159																							

160																							
161																							
162																							
163																							

Appendix C5. Snow water equivalent (cm) at the Franklin Bluffs (FR) site

Day of Year	85	86	87	88	89	90	91	92	93	94	95	96	97	98	99	00	01	02	03	04	05	06	07
120				9.3		4.7	11.3		12.7					6.5		10		8.5	12		12	10	6.6
121																							
122																							
123																							
124										6.1													
125																							
126											7.0												
127																							
128						5.6																	
129				2.7																			
130																			10.2				
131																							
132																							
133																							
134							10.7											8.3					
135			8.5																		12.0		
136								8.0										6.5					
137																			15.6				8.7
138																		4.7	17.6				
139												6.9							19.5			8.1	
140														7.1		14.5	13	3.3	19.1	9.1	11.5		
141							10.9	6.7											12.5				
142				5.4										9.1				1.0	12.3		12.8	5.5	8.4
143																		0.0					
144							8.6							8.2					10.0			1.8	
145					22.3				14					9.6					9.2	2.9			7.8
146				4.9										9.1							12.3	0	
147							8.6							8					11.4				
148				4.0										8.6					9.4		11		6.5
149													22.9	7.8						2.9			
150				3.4										6.9					7.3		8		6.3
151							2.8							6.7		14.7			14.6				
152				1.6										4.7			13.4			2.3	6		5.8
153														2.9					2.6				
154				0.8										1.9			9.6			1.3	2.7		1.9
155														1.4		14			0.5				
156				0.7										0.7			7.7			0.4	0.4		0
157					7.7									0			5.5		0	0.4			
158				0												9.2	4.5			0	0		
159																8.2	3.5						

160																**3.5**	**2**						
161																**2**	**0**						
162																**1.2**							
163																**0.3**							

Appendix C6. Snow water equivalent (cm) at the Betty Pingo (BM) site

Day of Year	85	86	87	88	89	90	91	92	93	94	95	96	97	98	99	00	01	02	03	04	05	06	07
120																						12	
121																							
122																							
123																							
124																							
125																							
126											6.6												
127																							
128																							
129											7.6												
130											7.1												
131											6.3												
132											6.0												
133											6.0							9					9.3
134											5.9												
135											5.8				9.9								
136																		8.9					
137										7.3			12.8					8.3	10.9				
138													12.7					6.3	10.0		7.0		
139												4.7	12.9					5.4	11.5	8.1			
140										7.2		4.4	13.3					4.5	12.7		9.5		
141										6.8		4.6	13.2		9.3	12.8	8.3	4.5	12.6				
142												4.3	12.6		8.5			2.7	12.7				
143										4.2		2.8	11.8					0.6	11.3				
144									10	3		1.9	11.3		9.2			0.0	9.5	2.7		6.3	8.2
145									10	1.8	5.8	1.4	13.0		7.5								
146									12	0.9	5.1	1.8	12.3		8.1				11.1		10.8	2.6	8.8
147									12	0.6	4.1	0.7	13.3		8.5				11.8				
148									11	0.8	3.7	0.4			7				11.8			0	9.2
149									5.5	0.4	3				7.2				11.5	2.6			
150									3.8	0.1	2.1				7				9.8		5.5		7
151										0	1.3				6.8				10.1	2.6	4.4		
152									0		0				5.7	14.9	8.8		8.9		4.2		
153											0				5.7				7.1	1.9			6.4
154															4.5		4.1		6.5	1.3	3		
155															3.4				1.9	1.1	2.4		3.1
156													9.7		2.9		3.4		0.0	0.6	1.1		
157													6.6		2.6	8.4	2			0	0.2		0
158													4.2			6.7	1.2						
159													3.4			6.2	0.9						

160													**1.4**			**3.8**	**0.7**						
161													**0.9**			**1.7**	**0**						
162																**0.3**							
163																**0.0**							

Appendix C7. Snow water equivalent (cm) at the West Dock (WD) site

Day of Year	85	86	87	88	89	90	91	92	93	94	95	96	97	98	99	00	01	02	03	04	05	06	07
120																6.5	5.7	7.3	18	7	6.3		5.8
121																							
122																							
123																							
124																							
125																							
126																							
127																							
128																							
129																							
130																							
131																							
132																							
133																		7.7					6.5
134																							
135																					3.7	8.8	
136																		7.6					
137																		7.7	7.3				
138																		6.5	9.4			7.3	
139																		4.8					
140																		4.3	14.6	8.2	4.9		
141															10.6		6.3	4.3	11.2				
142															8.9			3.1	9.3				
143																		1.0					
144															12			0.0	11.2				
145															9.6					2			
146															11				9.2		3.8		6.2
147															11				7.3			4	
148															11				8.9				6.0
149															9.1				6.6			0	
150															11				10.3	2.4	3.3		8.3
151															8.9	6.2					2		
152															8		6.3		14.1	2.4	1		
153															6.8				5.7				7.1
154															7.6		4.2		4.9	1	0.6		
155															5.6				4.0	1	0.2		4.3
156															4.7	7.2	2.8			0.8			
157															4.7	6.8	1.7		0.4	0.4			0
158															3.4	5.4	0.9						
159															2.8	3.4	0.4						

160															**3.3**	**1.6**	**0.4**						
161															**1.6**	**0.7**	**0.2**						
162															**0.5**	**0.6**	**0**						
163															**0**	**0**							