Snow Survey Data for the Kuparuk Foothills Hydrology Study: Spring 2008

Dalton Hwy and Trans-Alaska pipeline, photo by Ken Irving

by

Sveta Berezovskaya, Jeff Derry, Douglas Kane, Rob Gieck, Michael Lilly, and Dan White

June 2008

Kuparuk Foothills Hydrology Project
Report No. INE/WERC 08.14
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Sveta Berezovskaya¹, Jeff Derry², Douglas Kane¹, Rob Gieck¹, Michael Lilly², and Dan White¹

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Report Number INE/WERC 08.14

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DISCLAIMER

The content 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 (AKDOT&PF) and supplemented by data from a National Science Foundation grant. This work does not constitute a standard, specification, or regulation.

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 other project sponsors.
## Conversion Factors

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<tr>
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<td>kilopascal (kPa)</td>
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<tr>
<td>Slugs per cubic foot (slug/ft³)</td>
<td>515.464</td>
<td>Kilograms per cubic meter (kg/m³)</td>
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</table>
UNITS

For the purpose 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 variable 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

<table>
<thead>
<tr>
<th>Abbreviation</th>
<th>Definition</th>
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<tr>
<td>AAS</td>
<td>Alaska’s Arctic Slope</td>
</tr>
<tr>
<td>ADOT&amp;PF</td>
<td>Alaska Department of Transportation and Public Facilities</td>
</tr>
<tr>
<td>F</td>
<td>Fahrenheit (°F).</td>
</tr>
<tr>
<td>ft</td>
<td>feet</td>
</tr>
<tr>
<td>GWS</td>
<td>Geo-Watersheds Scientific</td>
</tr>
<tr>
<td>kg</td>
<td>kilograms</td>
</tr>
<tr>
<td>km²</td>
<td>square kilometers</td>
</tr>
<tr>
<td>m</td>
<td>meters</td>
</tr>
<tr>
<td>NGVD</td>
<td>National Geodetic Vertical Datum</td>
</tr>
<tr>
<td>NRCS</td>
<td>Natural Resources Conservation Service</td>
</tr>
<tr>
<td>NWIS</td>
<td>National Water Information System</td>
</tr>
<tr>
<td>QA</td>
<td>quality assurance</td>
</tr>
<tr>
<td>QC</td>
<td>quality control</td>
</tr>
<tr>
<td>Slug</td>
<td>slug</td>
</tr>
<tr>
<td>SWE</td>
<td>snow water equivalent</td>
</tr>
<tr>
<td>UAF</td>
<td>University of Alaska Fairbanks</td>
</tr>
<tr>
<td>USGS</td>
<td>U.S. Geological Survey</td>
</tr>
<tr>
<td>WERC</td>
<td>Water and Environmental Research Center</td>
</tr>
<tr>
<td>WWW</td>
<td>World Wide Web</td>
</tr>
<tr>
<td>YSI</td>
<td>Yellow Springs Instruments</td>
</tr>
</tbody>
</table>
ACKNOWLEDGEMENTS

This project was funded by grant ADN #2562123, Alaska Department of Transportation and Public Facilities. Ken Irving, Dan Reichardt, Emily Youcha, Amy Tidwell, Robert Gieck, Bob Busey, Greta Myerchin, Bill Schnabel and many others participated in snow water equivalent data collection. Peter Prokein assisted with map preparation. Additional snow data is obtained by the National Science Foundation, Office of Polar Programs, Arctic Observing Network (AON) project (OPP-0335941, OPP-9814984, and OPP-009615).
Snow Survey Data for the Kuparuk Foothills Hydrology Study:
Spring 2008

1. INTRODUCTION

This report follows 2006 and 2007 snow survey data reports (Kane et al, 2006, Berezovskaya et al., 2007) and discusses snow conditions that were observed during 2008 end-of-winter snow surveys in the study area of the Kuparuk River basin. Field studies primarily focused on maximum snow water equivalent (SWE) accumulation during the 2007 - 2008 winter and the subsequent snow melt period. Field activities started at the end of April because the snowpack at that point in time reflects all precipitation falling during the period from October to April (less sublimation), with usually 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 the net 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 impacts the amount of soil desiccation that occurs within the organic layer overlying permafrost (Kane et al., 1978). Snowmelt is also a major hydrological event each year. Peak discharge is highest for many rivers on the North Slope, particularly for the basins of the Sagavanirktok, Colville and Kuparuk Rivers, during the snowmelt period. 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 Foothills in May and melting is usually complete within a month. Due to extremely high snowpack heterogeneity, knowledge of 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 2008 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. STUDY AREA

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 (8140 km²). 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 a 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).

Sedge tussocks and mosses that cover much of northern Alaska are the dominant vegetation type. 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

Snow surveys are made at designated stations throughout the domain to determine the depth, as well as 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, generally the last week of April. Our observations in the Foothills show that the onset of ablation is typically in May. The end of April is a good time to capture the end-of-winter SWE. Also, March, April and May are often the months of lowest precipitation and, therefore, there isn’t much accumulation between the surveys and ablation.
Figure 2. Location map of 2008 snow survey sites and meteorological stations in the vicinity of the Kuparuk River basin with detailed information for the Upper Kuparuk (inset).
In addition to snow surveys, snow depths are collected continuously throughout the winter at meteorological stations, which are equipped with snow depth sensors. Snow depth sensor readings can be collected in near real time or downloaded in the field directly from a data logger.

### 3.1 Snow Survey

Our snow surveys include 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 with snow depth being more variable than density (Benson and Sturm, 1993). Usually, double sampling yields an areal SWE estimate with a lower variance than is possible by collecting snow cores only. 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 a fiberglass tube (“Adirondack”) with an inside area of 35.7 cm², equipped with metal teeth on the lower end to cut through dense layers of snow. The advantage of the Adirondack for shallow snowpack is that it has a larger diameter than many other types of snow tubes and thus provides a larger sample for the shallow Arctic snowpack. To obtain a complete snow core, the Adirondack 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. Five snow cores are usually taken to estimate average snow density.

We use constant 50 m lengths 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

\[ SWE = \frac{SD \cdot \rho_s}{\rho_w} \]  \hspace{1cm} (1)

where \( \rho_s \) is average snow density from the 5 snow core samples, \( \rho_w \) is water density and \( SD \) is an average of 50 snow depths.

3.2 Snow Ablation

Starting with the 2007 Kuparuk Foothills snow survey data report, we summarized long-term snowmelt observations, which have been conducted continuously since 1985 to 2007 (Table 1) from previously funded National Science Foundation, Office of Polar Programs projects.

Table 1. Summary of snow ablation sites.

<table>
<thead>
<tr>
<th>Site Name</th>
<th>Period of Record</th>
<th>Comments</th>
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</thead>
<tbody>
<tr>
<td>Betty Pingo</td>
<td>1993 to 2008</td>
<td>Surveyed near NRCS Wyoming gauge</td>
</tr>
<tr>
<td>Franklin Bluffs</td>
<td>1988 to 2008</td>
<td>Surveyed near Met site 1988 to 1998 (with some missing years), snow site moved west 700 meters along access road 1999 to 2008.</td>
</tr>
<tr>
<td>Happy Valley</td>
<td>1999 to 2008</td>
<td>Survey site 150 meters west of Dalton Highway from Happy Valley Airfield.</td>
</tr>
<tr>
<td>Imnavait Basin</td>
<td>1985 to 2008</td>
<td>Snow ablation measured at 4 sites on west facing slope at mid-basin 1985 to 1988, at a 6 site mid-basin transect 1989 to 1997 and at a 6 site transect along UTM 612800 northing from 1999 to 2008.</td>
</tr>
<tr>
<td>Sagwon Hill</td>
<td>1988 to 2008</td>
<td>Adjacent to the Sagwon Meteorological Site</td>
</tr>
<tr>
<td>West Dock</td>
<td>1999 to 2008</td>
<td>150 meters east of West Dock - GC1 Road approximately one mile south of West Dock Meteorological Site.</td>
</tr>
</tbody>
</table>
3.2.1 Observation from 1985 to 2007

Measurement methods have changed over time as techniques have been modified to improve sampling accuracy and as the study area has expanded. From 1985 to 1992 snow water equivalents were estimated from 10 randomly collected snow cores. These cores were sampled using Adirondack tubes and weighed using 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 Adirondack mechanical scale and after 1999, digital scales were used. Following Rovansek et al. (1993), the double sampling technique was adopted in 1996 and continues to be used through today (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: Adirondack snow tube, avalanche probes, T-handled graduated probes, MagnaProbe, as well as ski poles and rods with added graduated scales.

A number of observational sites have also changed over time (Table 1). In 1985, snow water equivalent and ablation were observed only in the Imnavait Creek Basin. Sagwon Hill (SH) and Franklin Bluffs (FR) sites were added in 1986 (although measurements were often lacking). Snow surveys at the Sagwon site were usually made just east of the meteorological site. The Franklin Bluffs sampling 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. The Betty Pingo site on the Prudhoe 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.
Imnavaït Creek basin (IB) differs from others in that it has the longest period of recorded and detailed observations. Several sites were sampled across the basin to capture basin average snow water equivalent. From 1985 through 1997 the Imnavaït 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 the west facing slope adjacent to 4 runoff plots (Hinzman, 1990). In 1989, 2 additional sites were added, one in the valley bottom and one on the east facing slope of the basin. To provide consistent identification of sites, the transect was aligned with 7612800 northing (NAD27, UTM6) since 1999.

3.2.2 Observations from 2008

During the 2008 snowmelt season, SWE observations were taken at the Upper Kuparuk station (UKmet), Happy Valley (HV), Sagwon Hill (SH), Franklin Bluffs (FR), Betty Pingo (Betty), West Dock (WD) and at the six sites across the Imnavaït basin (IB1-IB6). Sites are visited daily or every other day to capture the net volumetric decrease in SWE. We take the 5 snow densities and 50 snow depths at each site. 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

Each of the four meteorological stations - DFM1, DFM2, DFM3, DFM4 - located in the Kuparuk Foothills Project is equipped with one of two kinds of snow-depth sensors, the Campbell Scientific Sonic Ranger 50 (SR50) or SR50(A). The only difference between the SR50 and SR50(A) is the housing encasing the ultrasonic sensor. The sensor emits a 50 kHz sound pulse and measures the time the pulse take to return to the sensor. Ultrasonic sensors can measure the distance to any reflective surface like the ground or water, but sensitivity of the SR50(A) is designed for measuring distance to a snow surface.

The method for measuring snow depth with the SR50(A) 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-ground and distance-to-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 a depth-depth of 10 inches under the sensor.

The ultrasonic pulse has a measurement cone width of 22º from the bottom of the sensor. The SR50(A) records measurements at one minute intervals and reports hourly averages.

4. ACCURACY OF OBSERVATIONS

This section reports the problems of measuring and processing observational snow data, so reported dataset can be used properly.

4.1 Snow Water Equivalent

Snow density and SWE are estimated using snow core sampling. 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 Adirondack in diameter) captures snow density within 5% of snow pit estimates. Our field comparison of Adirondack to snow pit density gives 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, true value. 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

While end-of-winter snow surveys provide areal average snow depth accounting for spatial snowpack heterogeneity, the SR50(A) measures snow depth directly under the sensor during the entire winter. Snow sensor data used in conjunction with snow survey data can enhance and expand the information gained with each sampling method.

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 22° angles around sensor, and one directly underneath) on the ground are 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.

Post-processing adjustments to data may vary according to the error tolerance and goals of the investigation, for this project 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.
- Smooth the data and omit smaller, sporadic, data values. If the difference between a data point and the prior data point is greater than 1.5 cm, and/or if the difference between a data point and the following data point is greater than 1.5 cm, then replace the data point with the average of the prior 5 hours and following 5 hours data values. 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.
High frequency, small amplitude, noise is inherent in ultrasonic snow-depth sensors and can be an impediment to accurate snow accumulation measurements (Brazenec, 2005). 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 distance readings. Inaccuracies can be caused by poor calibration and/or neglecting periodic maintenance requirements. Physically related errors include wind and/or blowing snow creating spurious data readings, difficulty in establishing a zero point due to tussocks, low shrubs, grass, etc., and changes in sensor height due to ground heave and wildlife curiosities.

5. SPATIAL DISTRIBUTION OF SNOW SURVEY 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 1,120 m) in the Kuparuk River basin (Appendix A1-A3).

There are two distinctly different snow regimes across the Kuparuk basin, uplands and coastal plain (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 an 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 alone is not always representative for this purpose, because most of the snow survey sites in the mountains are located in the valley bottoms where helicopter can safely access the site.

We also list the lake sites that are visited for the purpose of chemistry data collection (e.g. Chambers et. al., 2006). Snow surveys are always conducted on the lake surface, because the lake snow is thinner, denser, harder, and has less snow water equivalent than snow on surrounding tundra (Sturm and Liston, 2003). If time allows, snow surveys are also taken on the surrounding tundra. Lake snow data collection is not applied for the long-term SWE analysis since different lakes are visited every year. However, lake snow parameters (depth, density,
distribution and thermal properties) are critical input to the physical models to account appropriately for ice thickness and heat losses (Sturm and Liston, 2003). Snow survey measurements were taken on the lake surface of 4 lakes in 2008 (Appendix A3 and Appendix B3).

Overall, 113 sites were visited in 2008. This number includes 84 sites within the frame of the Foothills project (80 snow survey sites and 4 lake sites) and 29 sites within the Bullen Point project (26 snow survey sites and 3 lake sites). Eight of the Foothills project sites are located in the Mountains, 42 sites are in the Foothills and 30 sites are on the Coastal Plain.

6. SNOW SURVEY DATA

The average of Coastal Plain snow density (0.415 slug ft\(^{-3}\), 214 kg m\(^{-3}\)) is less than Foothills density (0.455 slug ft\(^{-3}\) / 235 kg m\(^{-3}\)) and Mountains density (0.480 slug ft\(^{-3}\), 248 kg m\(^{-3}\)) (Appendix B1-B3).

The average Coastal Plain SWE is (3.6 in, 9.1 cm), and snow depth is (14.5 in, 36.9 cm). The Foothills average SWE is (3.7 in, 9.4 cm), and snow depth average is (15.3 in, 38.9 cm). The Mountains average SWE (1.4 in, 3.5 cm) and snow depths average is (6.3 in, 16.1 cm) and is generally lower than those at the Coastal Plain and Foothills. Figure 3 and Figure 4 show the snow depth and SWE at each snow survey site in the AAS. Overall, average end-of-winter SWE tends to be the highest in the Foothills (3.7 in, 9.4 cm) and lowest in the Mountains (1.4 in, 3.5 cm) (Figures 3 and 4, Table 2).
Figure 3. End of winter snow depth (cm) collected from snow survey sites at the North Slope of Alaska in spring 2008. The colored circles represent the snow depth class that minimizes the sum of squared difference from the mean within the class. Dashed lines indicate the approximate boundary between the Mountains, Foothills, and Coastal Plains regions.
Figure 4. End of winter snow water equivalent (cm) collected from snow survey sites at the North Slope of Alaska in spring 2008. The colored circles represent the snow water equivalent class that minimizes the sum of squared difference from the mean within the class. Dashed lines indicate the approximate boundary between the Mountains, Foothills, and Coastal Plains regions.
Table 2. The Kuparuk River snow water equivalent: 2000-2008.

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<th>Foothills SWE cm</th>
<th>Number of sites</th>
<th>Coastal Plain SWE cm</th>
<th>Number of sites</th>
<th>Kuparuk basin SWE cm</th>
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The Mountains and Foothills have less end-of-winter SWE in 2008 compared to the previous years (55% and 81% of the 2006 and 2007 SWE). The Coastal Plain has a similar SWE in 2007, 102% of the 2006 and 2007 end-of-winter SWE (Table 3). The Foothills have the highest 9-year SWE average (11.1 cm) versus 8.4 cm for the Mountains and 9.4 cm for the Coastal Plain. This database is starting to be long enough that we can start to get an understanding of variability from year-to-year (Table 3).

† Note the 2007 and 2006 Coastal Plain and Basin averages are slightly different from those reported in Kane et al., 2006 and Berezovskaya et al., 2007. This table contains averages only from ‘long-term’ snow survey sites, i.e. lake snow survey sites are excluded from 2006 and 2007 averages.
Table 3. Maximum, minimum, and average snow water equivalent in the Coastal Plain, Foothills, and Mountainous regions of the Kuparuk River Basin (2000-2008, n=9).

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Table 4. 2008 snow water equivalent analysis.

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* not enough data

Long-term snow surveys on the AAS have been maintained by the US Department of Agriculture (USDA) since the 1970s. The USDA Natural Resources Conservation Service (NRCS) reports that the Arctic Coast SWE in 2008 (average from 2 snow courses) accounts for 65% of the long-term average SWE and the Dalton highway has received 60% of the long-term average SWE (McClure R., 2008).

Our dataset covers a relatively short period of time (2000-2008) compared to the NRCS, but has a much larger spatial extent. The number of sites in specific regions in general has increased in time (Table 2). End-of-winter SWE over the Kuparuk river watershed in 2008 accounts for 76 % of the 9-year average SWE (Table 4). Foothills and Coastal Plain end-of-winter SWE in 2008 represent 84 % and 97 % respectively of the 9-year average SWE (Table 4).
7. SONIC SNOW DEPTH DATA

All four meteorological stations in the Kuparuk River Basin reported continuous, good quality sensor snow depth from the accumulation and ablation season (Figure 5-7). The White Hills (DFM2) sensor data is not shown because there was no snow reported at the site this year. This station is located on top of a ridge, where snow is eroded due to persistent strong winds.

Sonic snow-depth records at the other three stations are adjusted to account for field observations and anomalous data points (Section 3.3). Transition periods, particularly the transition from fall to winter, are difficult periods to ascertain accurate snow depths. For instance, the South White Hills and Northwest Kuparuk stations (DFM1 and DFM4) reported sensor snow depths that agreed very well with measured snow depths when sites were visited on May 17 (Figure 5, Figure 7). Yet, data indicated a snow depth of 10 cm (3.9 in) the first of October when there was no snow on the ground. This is likely due to the vegetation at these sites – grass and tundra can create a false surface which the ultrasonic sensor measures. Typically, however, snow is quickly captured by the vegetation and accumulates to the top of the vegetation height during the first snow events of the season. Data is corrected for these erroneous readings during the beginning of the season when reporting in real-time.

Since snow-depth sensor measurements are made at a point, knowledge of the representativeness of sensor data with the surrounding area is useful. Snow depths from snow surveys conducted near the stations show snow depth variability within 30 cm to 76 cm (11.8 in to 29.9 in) for the South White Hills, 0 cm to 65 cm (0 cm to 25.6 in) for the North White Hills, and 18 cm to 42 cm (7.1 in to 16.5 in) for the Northwest Kuparuk station (Figure 5, Figure 6, Figure 7). For North White Hills and South White Hills, sensor readings reflect the lowest depths measured from the snow surveys (Figure 5 and Figure 6). The opposite is true for the Northwest Kuparuk site where snow survey depths range from 18 cm to 42 cm (7.1 in to 16.5 in) while sensor values reported 41 cm (16.1 in) (Figure 7). For South White Hills and North White Hills stations, sensor data is in the 0.08 and 0.01 quantile respectively (the percentage of data that falls below the given sensor value compared to the 50 snow survey depths). For Northwest Kuparuk, sensor data is in
the 1.00 quantile. These comparisons are informative when making inferences about the surrounding area when inspecting data in real-time throughout the season.

The advantage of snow sensor information is its high temporal resolution, which can capture the timing and magnitude of snow events. Records show that snow accumulation began approximately in the middle of October at all of the Kuparuk meteorological sites. The beginning of the snow season was largely uneventful from October to January with snow depth slowly increasing or remaining relatively constant. South White Hills and Northwest Kuparuk report an event the first week of March that deposited 10 -15 cm (3.9 – 5.9 in) of snow. All stations show similar responses to snow events the month of April with accumulation occurring the second and last week of the month. The maximum snow depth during the winter is in the range between approximately 44 cm to 50 cm (17.3 in to 18 in) at the South White Hills and Northwest Kuparuk stations on May 1st, 2008. The maximum depth for the North White Hills station was recorded at 25 cm (10 in) also on May 1st, 2008.

Figure 5. Hourly SR50 sensor snow depths measured over the winter, observed snow depth under the sensor, and snow survey depths measured near sensor at the South White Hills meteorological station.
Figure 6. Hourly SR50 sensor snow depths measured over the winter, observed snow depth under the sensor, and snow survey depths measured near sensor at the North White Hills meteorological station.

Figure 7. Hourly SR50 sensor snow depths measured over the winter, observed snow depth under the sensor, and snow survey depths measured near sensor at the Northwest Kuparuk meteorological station.
8. ABLATION DATA

Historical ablation data are reported in Appendix C. The ablation window varies greatly depending on meteorological conditions and snowpack depth. The start of spring snowmelt usually occurs in the southern Foothills first (Imnavait Basin, Upper Kuparuk sites), and a week or two later snow starts melting on the Coastal Plain (Franklin Bluffs, Betty Pingo and West Dock). Onset of ablation in 2008 varied from May 15th at the Innnavait Basin and Upper Kuparuk sites to May 21st – May 25th at northern sites, with an average of 6 days to complete the melt (Figure 6). Snowpacks across the entire Kuparuk River basin melted within three weeks from May 15th to May 30th, 2008.

Figure 8. Net volumetric decrease in SWE. Snow ablation curves at the Foothills are shown as dashed lines and on the Coastal Plain as solid lines.

The Innnavait 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 (~80% of catchment) 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. Ten days were required to complete ablation in the Imnait watershed.

9. SUMMARY

Observed end-of-winter 2008 Kuparuk basin SWE is less than the 9-year average (76 %). This is caused by low Foothills and Mountains SWE, whereas the Coastal Plain has an average SWE close to the 9-year average (97%). Snowpacks across the entire Kuparuk River basin melted within three weeks from May 15th to May 30th, 2008.

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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

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Appendix A3. Elevation and coordinates of the sites located on the Coastal Plain (A) and Lake Sites (B).

Table A. Coastal Plain.

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Appendix B3. Summary for the sites located on the Coastal Plain (A) and Lake Sites (B).

### Table A. Coastal Plain.

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2 Lake sites are separated because most of them do not represent repeated yearly measurements.
APPENDIX C. HISTORICAL ABLATION DATA
Appendix C1. Snow water equivalent (cm) in the Imnavait Creek basin (basin average).

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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 | 08 |
|-------------|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|
| 120         |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    | 7.3 |
| 121         |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |
| 122         |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |
| 123         |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |
| 124         |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |
| 125         |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |
| 126         |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |
| 127         |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |
| 128         |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |
| 129         |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |
| 130         |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    | 16.4|
| 131         |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |
| 132         |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |
| 133         |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    | 22.0|
| 134         |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |
| 135         |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |
| 136         |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |
| 137         |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |
| 138         |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |
| 139         |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |
| 140         |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |
| 141         |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |
| 142         |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |
| 143         |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |
| 144         |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |
| 145         |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |
| 146         |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |
| 147         |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |
| 148         |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |
| 149         |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |
| 150         |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |
| 151         |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    | 24.3|
| 152         |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |
| 153         |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    | 11.7|
| 154         |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |
| 155         |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    | 12  |
| 156         |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    | 4.1 |
| 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 | 90 | 91 | 92 | 93 | 94 | 95 | 96 | 97 | 98 | 99 | 00 | 01 | 02 | 03 | 04 | 05 | 06 | 07 | 08 |
|-------------|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|
| 120         |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |
| 121         |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |
| 122         |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |
| 123         |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |
| 124         |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |
| 125         |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |
| 126         |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |
| 127         |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |
| 128         |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |
| 129         |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |
| 130         |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |
| 131         |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |
| 132         |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |
| 133         |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |
| 134         |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |
| 135         |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |
| 136         |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |
| 137         |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |
| 138         |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |
| 139         |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |
| 140         |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |
| 141         |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |
| 142         |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |
| 143         |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |
| 144         |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |
| 145         |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |
| 146         |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |
| 147         |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |
| 148         |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |
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| 156         |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |
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| 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  | 08  |
|-------------|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|
| 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 |
| 135         |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     | 8.3 |
| 136         |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     | 12.0 |
| 137         |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     | 15.6 |
| 138         |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     | 8.7 |
| 139         |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     | 4.7 |
| 140         |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     | 14.5 |
| 141         |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     | 13  |
| 142         |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     | 3.3 |
| 143         |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     | 19.1 |
| 144         |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     | 9.1 |
| 145         |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     | 1.0 |
| 146         |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     | 12.3 |
| 147         |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     | 0    |
| 148         |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     | 7.0 |
| 149         |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     | 11  |
| 150         |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     | 6.6 |
| 151         |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     | 14.7 |
| 152         |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     | 14.6 |
| 153         |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     | 13.4 |
| 154         |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     | 2.3  |
| 155         |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     | 1.3  |
| 156         |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     | 0.7  |
| 157         |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     | 0.7  |
| 158         |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     | 7.7  |
| 159         |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     | 0.7  |
| 160         |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     | 0.7  |
| 161         |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     | 7.7  |
| 162         |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     | 0.7  |
| 163         |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     | 0.7  |
### Appendix C6. Snow water equivalent (cm) at the Betty Pingo (BP) 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 | 08 |
|-------------|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|
| 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 |
| 134         |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |
| 135         |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    | 5.8 |
| 136         |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |
| 137         |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    | 7.3 |
| 138         |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    | 7.3 |
| 139         |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    | 6.3 |
| 140         |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    | 6.1 |
| 141         |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    | 5.8 |
| 142         |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    | 4.3 |
| 143         |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    | 4.2 |
| 144         |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    | 10 |
| 145         |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    | 10 |
| 146         |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    | 12 |
| 147         |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    | 12 |
| 148         |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    | 11 |
| 149         |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    | 5.5 |
| 150         |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    | 3.8 |
| 151         |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    | 0.8 |
| 152         |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    | 0.1 |
| 153         |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    | 0.1 |
| 154         |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    | 0.1 |
| 155         |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    | 3.4 |
| 156         |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    | 9.7 |
| 157         |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    | 6.6 |
| 158         |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    | 4.2 |
| 159         |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    | 3.4 |
| 160         |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    | 1.4 |
| 161         |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    | 0.9 |
| 162         |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |
| 163         |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |
### Appendix C7. Snow water equivalent (cm) at the West Dock (WD) site

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