Hydrologic Insights from a Monitoring Well through a Permafrost Island in a Wetland: Tanana Flats, Alaska

M.G. FERRICK,[1] C.M.COLLINS,[2] AND G. LARSEN[3]

ABSTRACT

The Tanana Flats is a large wetland located between the Alaska Range to the south and the Tanana River to the north. Groundwater beneath the fens of the Flats remains unfrozen year-round, but forests adjacent to and surrounded by the fens grow on relatively warm, ice-rich permafrost that is sensitive to climate warming. A monitoring well was drilled through a permafrost island, adjacent to a fen monitoring station, to determine sub permafrost water temperature, isotopic composition, conductivity, and hydraulic head relative to those of the nearby fen. Well-bottom water temperatures increased monotonically over 17 consecutive months after the drilling, from subfreezing to 1.5°C. Isotopic and conductivity measurements showed that fen water and sub permafrost groundwater form a single hydrologic system, and in-phase seasonal fluctuations indicated rapid and significant water and heat exchange. The predominant permafrost losses observed in the Tanana Flats occur at fen margins where heat transfer from the fens is efficient. However, these results indicate that warm sub permafrost groundwater is the probable heat source to explain degradation that occurs away from fen margins.

Keywords: Tanana Flats; fen wetland; hydrologic sampling and measurement; discontinuous permafrost degradation; deuterium; oxygen-18; conductivity

INTRODUCTION

The Tanana Flats near Fairbanks in interior Alaska, situated between the Alaska Range and the Tanana River, is a lowland fen complex that exceeds 100 km^2 in area (Fig. 1). Water flow through these fens is generally from the foothills in the southeast toward the northwest and the river. Shallow groundwater beneath the fens remains unfrozen year-round, but forests adjacent to and surrounded by the fens grow on ice-rich, discontinuous permafrost with temperatures near 0˚C. The hydrology and permafrost of the Flats are coupled, with frozen ground restricting water movement and thermal effects of surface water and groundwater causing thaw (Woo and Winter, 1993). The permafrost terrain of the Tanana Flats is very sensitive to climate warming, and Jorgenson et al. (2001) have documented recent rapid and widespread degradation. Osterkamp et al. (2000) described the ecological response to warming and degradation of this permafrost as land subsidence, drowning of predominantly birch forests, and fen expansion (Fig. 2). "Birch Island," the permafrost body of interest in this study, is located within the "Upper Fen" (Fig. 3) of the

[1] Formerly with US Army Engineer Research and Development Center–Cold Regions Research and Engineering Laboratory, Hanover, NH, USA, email: michaelgferrick@gmail.com
[2] US Army Engineer Research and Development Center–Cold Regions Research and Engineering Laboratory, Fairbanks, AK, USA.
[3] US Army Garrison Alaska, Fort Richardson, AK, USA.

Flats. Typical of most forested land there, the freeboard of Birch Island above the local fen depends on the continued existence of the permafrost.

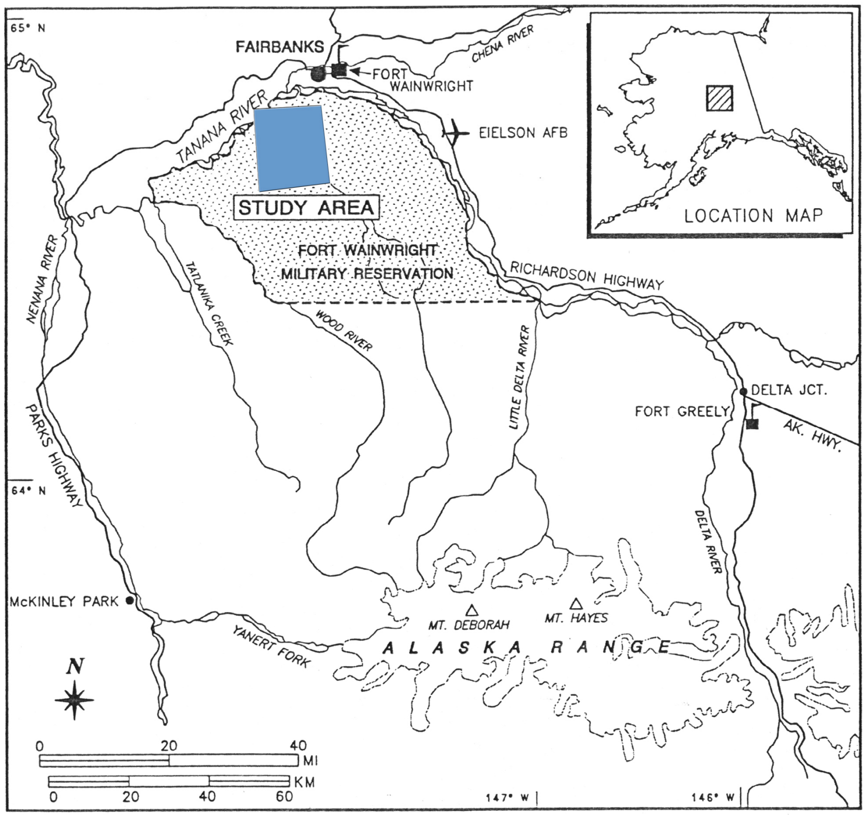


Figure 1. Location map showing the Tanana Flats portion of Fort Wainwright, Alaska, and study area.

Recent permafrost losses seen in the Tanana Flats have occurred predominantly at fen margins where heat transfer from the fen water is efficient. However, the processes responsible for degradation occurring away from fen margins are not clearly understood. The purpose of this study is to develop a better understanding of conditions beneath the permafrost and to determine whether the deeper water there readily exchanges with the surface water of nearby fens. If the fen and the deeper sub permafrost water comprise a single hydrologic system, the sub permafrost temperatures and time scale of interaction with the fen would be related to the quantity of heat supplied to the bottom and interior of the permafrost. For access to the sub permafrost environment of Birch Island, a well was sited in a mixed forest with stable surface conditions, about 50 m from an existing fen monitoring station. Well drilling (Fig. 4) was completed on 31 March 2005 through 7.3 m of permafrost to a depth of 8.8 m, but collapse of coarse sediments at the bottom of the hole limited the well casing to a 5.5-m depth. Development of the well indicated the desired hydraulic connection with groundwater beneath the permafrost, and subsequent sampling has verified the persistence of this connection.

The sub permafrost/fen measurement program presented in this paper included sampling the waters of the fen and well for pH, specific conductance, deuterium and oxygen-18, and measuring in situ temperatures and relative water levels. In addition, air temperature and a near-surface profile of active layer/permafrost temperatures were measured at a distance of 3 m from the well. The purposes of this measurement program were to document the consistency of or differences between the fen and sub permafrost waters through time and the trends in thermal conditions at the bottom of the well, of the stable shallow permafrost, and of the nearby fen. The results and their implications on local hydrology and permafrost degradation are then discussed.

Figure 2. (top) Fen vegetation in foreground and drowning birch forest on degrading permafrost in background, and (bottom) close-up of melting, subsiding permafrost and drowning birch trees.

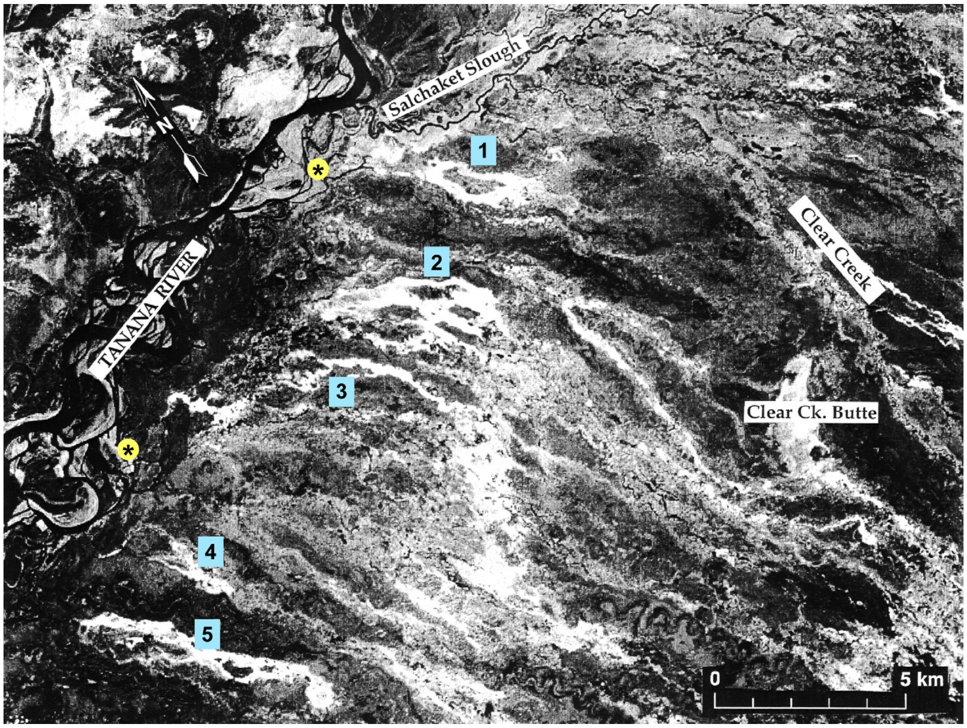


Figure 3. Landsat TM scene of the northwest corner of the Tanana Flats showing the major fen systems (white areas). The Upper Fen (area 1) label is located just above Birch Island. Asterisks (*) indicate primary discharge points from the fens to the Tanana River.

Figure 4. Well drilling through Birch Island permafrost, 30–31 March 2005.

MEASUREMENT METHODS

Hunt et al. (2005) showed that the stable hydrogen and oxygen isotopic composition of water is effective for describing the influence of surface water on groundwater. Multiple samples through time were required to define the seasonal cycle of both deuterium and oxygen-18. Related surface and well water samples had groundwater isotopic compositions intermediate to the extremes of the surface water. These results provide the structure for the water typing study in this paper for both isotopes of water and also for specific conductance (SC). All isotope results presented in this paper represent averages for samples that were triple run by the Alaska Stable Isotope Facility of the Water & Environmental Research Center, University of Alaska–Fairbanks. SC and pH were measured directly in the field or in the laboratory using a YSI model 63 meter with stated accuracies of ±0.1 pH units and ±0.5% of the conductivity reading. A resistance heating element was placed in the well immediately after development to allow periodic thawing and sampling of the frozen water in contact with the permafrost and the unfrozen sub permafrost water.

RESULTS

Air, fen, and well temperatures

Ferrick et al. (2008a) showed that logger temperatures at seven data recording stations in the Tanana Flats closely mimic each other and the air temperatures recorded at the Fairbanks, Alaska airport. Temperatures recorded at the Birch Island well logger were particularly close to those of the airport. Air temperatures transition from summer to winter during September to November and transition back from winter to summer during April and May. Fen profile temperatures are identified as depth measured from the water surface. Table 1 provides a summary of seasonal fen profile temperature extremes for 2004–07, including seasons with partial records. The monitored temperatures over the period of this study indicate that large and rapid changes in the thermal state of the Upper Fen are common.

Figure 5 presents air and fen profile temperatures near Birch Island for April through September 2004. Logger air temperatures at the fen station increased rapidly in early April 2004 to mostly above freezing later in the month, and May temperatures reflect continued gradual warming. The fen profile temperature at 0.25 m remained below freezing until late April, while temperatures at and below 0.5 m were all above freezing in late March. Logger air temperature oscillated about 20°C over most of June–August until decreasing in late August. Temperatures at 0.25 m increased rapidly during June, approached 16°C in late July, and reached an annual peak above 16°C in August. At 0.5 m the temperature also increased rapidly through June to a broad annual peak in July that exceeded 14°C for much of the month. The 1 m temperature increased through June–July to a broad peak at 10.9°C in early August. The 2 m and 3 m temperatures also displayed broad annual peaks progressively later in the season with maximums of 6.4°C and 4.9°C, respectively. Diurnal fluctuations of the air temperature decreased into the fall and were small after mid-October when temperatures remained below freezing. In response, the 0.25 m and 0.5 m profile temperatures decreased rapidly. The temperature at 1 m decreased monotonically from early September through the end of the year, falling below the 2 m and 3 m temperatures and eventually reaching 3.0°C. The 2 m and 3 m temperatures converged toward the end of 2004 at 3.8°C and 3.6°C, respectively.

Logger temperatures reflected mild weather in mid-March 2005, and melt conditions after 6 April. Above freezing low temperatures began on 20 April as part of a strong warming trend. Following the warming of late April through early May, the mean air temperature remained relatively constant into June with large diurnal fluctuations. Instrument replacement in late August 2005 renewed this fen station. As in prior years, air temperature diminished gradually in September and more rapidly from late October into November. The summer maximum and fall minimum profile temperatures given in Table 1 for 2005 reflect the partial data record for the year. Still, the 2005 peak temperatures at 1 m, 2 m, and 3 m were each higher than those in 2004 by 1.5°C, 1.7°C, and 1.5°C, respectively, a consistent and significant increase.

Table 1. Fen profile temperature extremes (˚C) near Birch Island.

Depth (m)	Spring minimum	Date 2004	Summer maximum	Date 2004	Fall minimum	Date 2004
0.25	–1.6	3/31	16.5	8/22		
0.5	0.1	3/26	14.7	7/21		
1	0.7	3/26	10.9	8/2	3.0	12/24
2	1.8	3/26	6.4	9/9	3.8	12/27
3	2.0	3/31	4.9	9/29	3.6	12/28
Depth (m)	Spring minimum	Date 2005	Summer maximum	Date 2005	Fall minimum	Date 2005
0.25						
0.5			12.9	8/24	2.8	10/26
1			12.4	8/24	8.0	11/3
2			8.1	10/21	7.5	11/3
3			6.4	10/29	6.1	11/1
Depth (m)	Spring minimum	Date 2006	Summer maximum	Date 2006	Fall minimum	Date 2006
0.25			out of water		out of water	
0.5			12.0	9/18	–9.3	11/26
0.75			9.3	9/20	–2.6	12/16
1			9.2	9/20	–0.1	12/30
1.5			6.2	9/25	1.1	12/28
2			4.1	9/30	1.9	12/29
3			3.1	10/19	2.5	12/27
Depth (m)	Spring minimum	Date 2007	Summer maximum	Date 2007	Fall minimum	Date 2007
0.25	out of water		out of water			
0.5	–9.7	2/25	out of water			
0.75	–5.1	2/26	out of water			
1	–2.0	3/6	12.8	8/1		
1.5	–0.1	4/17	4.1	8/1		
2	0.4	4/18	1.6	8/1		
3	1.2	6/24	1.3	7/30		

The logger temperature data indicate a continuous warming trend during March through May 2006, with the usual snowmelt period in the latter half of April. A warm June and July followed, with cooler conditions in late August and most of September, and below freezing temperatures and reduced diurnal fluctuations beginning in mid-October. Fen profile temperatures were not available in 2006 until the sensors were again replaced in August, and Table 1 gives the maxima and minima for the partial record. Details of the temperature record at 0.25 m closely resemble those of the logger temperature, indicating that this thermistor was above the water surface. The

1.5 m, 2 m, and 3 m temperatures had successively lower, broader, and later annual peaks relative to shallower depths. Maximum temperatures for 2006 at 1 m, 2 m, and 3 m are lower than those of 2004 by 1.7°C, 2.3°C, and 1.8°C, respectively. Similarly, fall minimum temperatures at these depths are 3.1°C, 1.9°C, and 1.1°C lower than 2004 minimums. Water near the 0.5 m thermistor began to freeze on 23 October, the 0.75 m temperatures became subfreezing on 13 November, and the 1 m temperatures reached freezing at the end of the year.

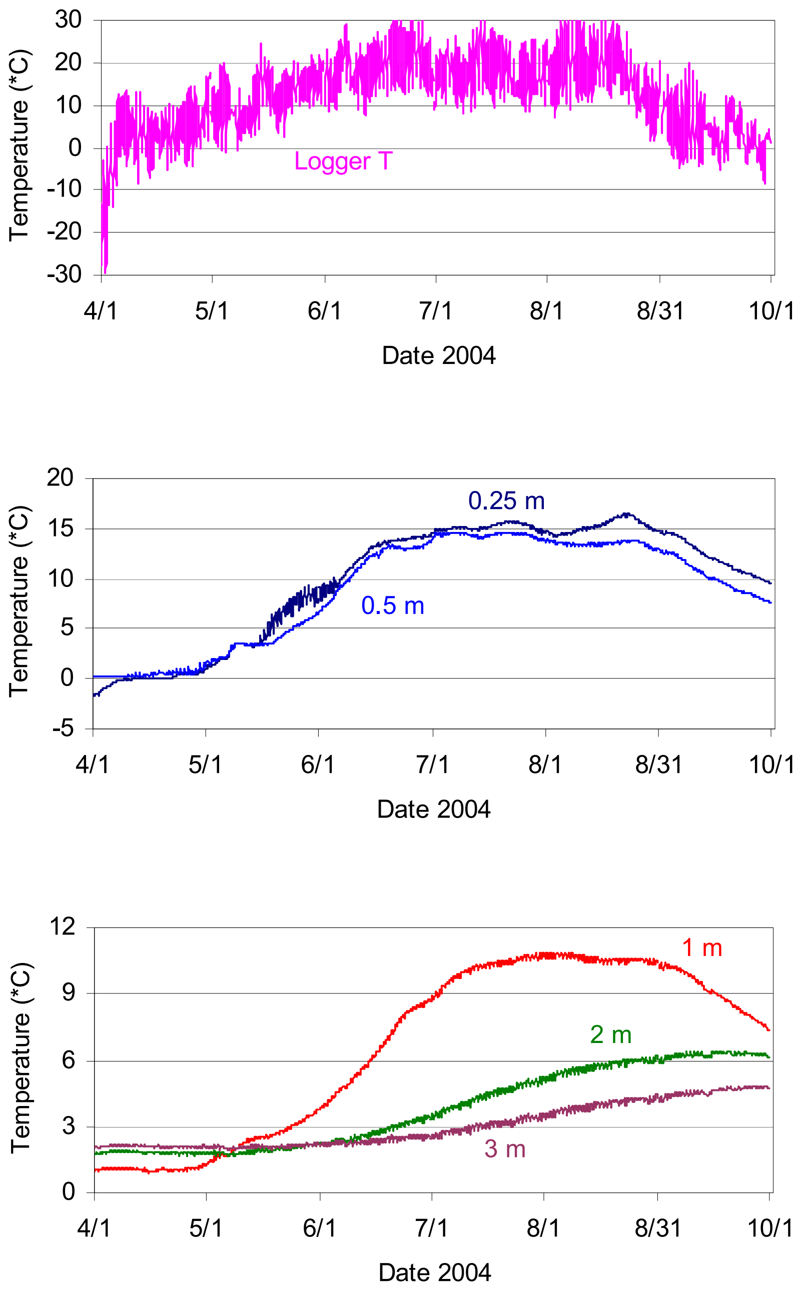


Figure 5. April–September 2004 air and fen profile temperatures near the Birch Island well.

Logger temperatures remained subfreezing from the start of 2007 until the end of March. The shallow profile temperatures followed those of the logger, but were progressively higher with smaller fluctuations as depth increased. Gradual cooling occurred at 1.5–3 m during January–March, with all these temperatures remaining above freezing. The logger, 0.25 m, and 0.5 m temperatures increased together through April and indicated the start of melt early in the month. Large diurnal fluctuations and high temperatures show that the 0.25 m and 0.5 m thermistors were out of the water from mid April through July, while the 0.75 m thermistor remained submerged but very shallow for part of this time. Thaw was complete by 30 April at 0.75 m and by 19 May at 1 m. Subfreezing temperatures at 1.5 m persisted from mid April into July, followed by a relatively rapid temperature increase. Abrupt seasonal temperature decreases at 2 m and 3 m of 0.35°C and 0.13°C, respectively, occurred on 17 April. The 2 m temperature was then almost constant at 0.5°C until 10 July, increasing to 1.6°C by 1 August, while the 3 m temperature remained almost constant at 1.3°C through 1 August. The fen surface temperatures were highly stratified in August 2007, with surface heating restricted to the upper 1 m.

Birch Island air temperatures varied through a range of 73°C over the monitored period of 2005–07. Mid-June through mid-August was the warmest period, with a peak temperature of 29°C in late June 2007, and the minimum temperature for the monitored period in late January

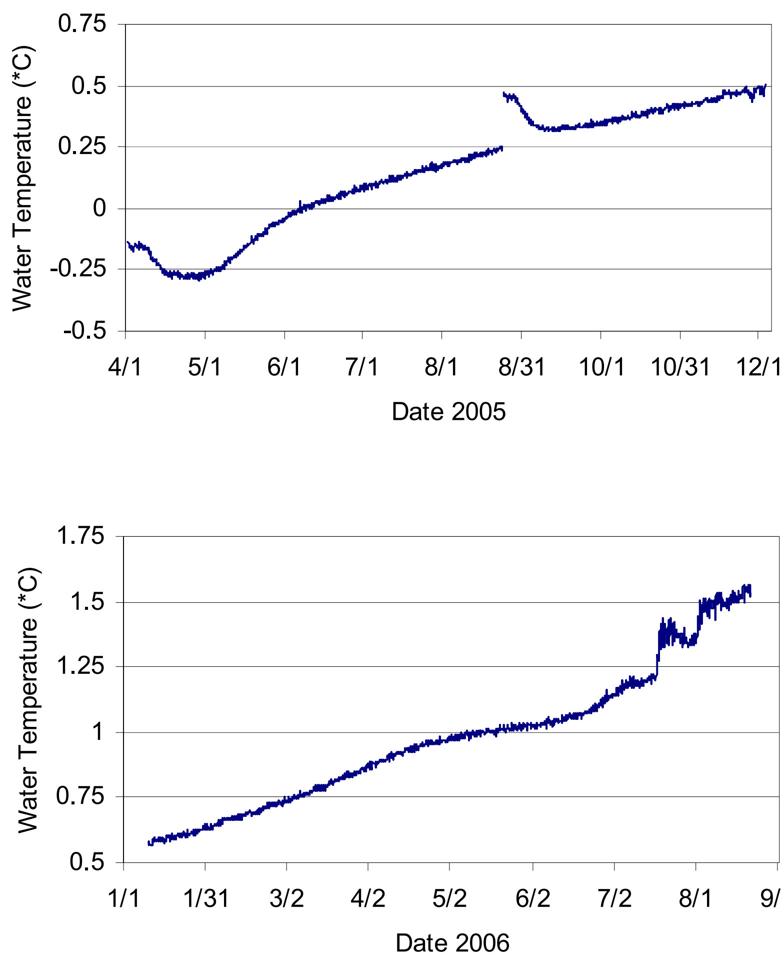


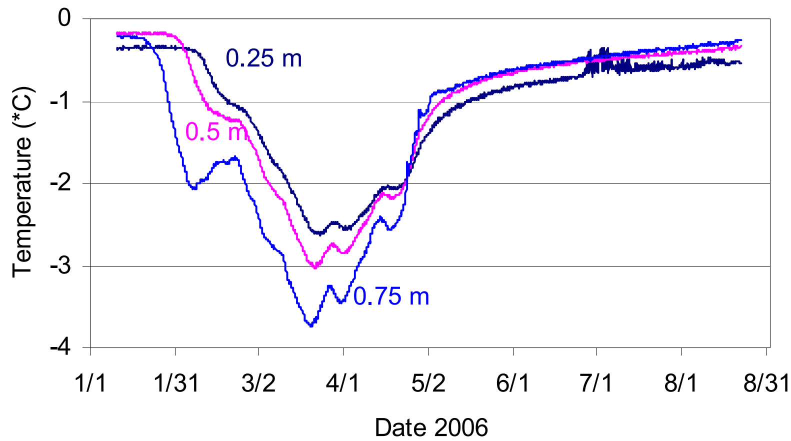
Figure 6. Birch Island well temperature at 5.5 m from the surface, April 2005–August 2006. Note the shift in the temperature scale between 2005 and 2006.

2006 was –44°C. In the weeks after well installation the water at the bottom, 5.5 m from the surface, refroze and the temperature decreased below freezing (Fig. 6). However, on about 1 May 2005 this temperature trend reversed, reaching a thawed state in June. For the period May through July the well temperature increased at an average rate of 0.15°C/month. Thawing of the well for sampling on 24 August disturbed the temperature trend, but by mid-September the natural condition was restored and the temperature increase continued. The average rate of increase for October and November was 0.07°C/month, between 15 January and 15 March 2006 it was 0.10°C/month, and between 1 April and 1 June it was 0.08°C/month, representing a remarkably steady rate for over a year. In mid-July 2006 thermal equilibrium had not yet been established when the water temperature increased sharply, fluctuated for the first time, and then continued to increase. The average rate of increase between 22 June and 22 August 2006 was 0.23°C/month, the highest of the period, and temperature at the bottom of the well exceeded 1.5°C. Over a 17-month monitoring period there was no seasonal reversal in the trend toward higher temperature. The hydraulic connection with groundwater caused by well installation changed the thermal state at the bottom of the well from permafrost to that of the warmer sub-permafrost. These well temperature data have established that groundwater exceeding 1.5°C exists beneath the permafrost of Birch Island. Flow of this groundwater through fractures and imperfections in the permafrost can supply sufficient heat to cause rapid melting and degradation away from fen margins.

Active layer and permafrost temperatures

Ground temperatures about 3 m from the Birch Island well, have generally remained subfreezing throughout the monitored period, indicating a shallow active layer and stable permafrost at the site. Ground temperatures through the fall of 2005 were nearly constant, –0.4°C at 0.25 m, and –0.2°C at 0.5 m and 0.75 m. However, 1 m temperatures were much lower than those nearer the surface, decreasing slowly through the fall from –5°C to –6°C. A rapid temperature decrease at 1 m during January 2006 occurred prior to corresponding decreases at shallower depths, with –9°C recorded in early February (Fig. 7). Shallow temperature responses to this decrease occurred at 0.75 m in late January, at 0.5 m in early February, and at 0.25 m in mid February. Following a midwinter warming, the 1 m temperature minimum of –9.7°C occurred in late March. Increased depth correlated with lower annual minimum temperatures, also in late March, of –2.6, –3.0, and –3.7°C at 0.25, 0.5, and 0.75 m, respectively. Unlike the temperature patterns of the fens that were driven by heat flow to or from the surface (Ferrick et al., 2008a) these winter permafrost temperatures appear to respond to conditions at depth. The ground temperatures all increased strongly through April, with 0.75 m and above exceeding –1°C by mid-May, while the 1 m temperature increased to –6°C and then remained relatively steady into early July. Slow temperature increases at 0.75 m and above continued through late August when all were in the narrow range of –0.55°C to –0.25°C. A series of what appear to be precipitation-event-related temperature increases at 1 m resulted in a maximum of –3.1°C by mid August. Temperature differences between the 1 m and shallower thermistors were significant through the year.

The Birch Island temperature records, not available through the fall and much of the winter, were reestablished in March 2007. The opposite of 2006, shallow permafrost temperatures in late winter of 2007 were clearly dictated by conditions at the surface (Fig. 8). These temperatures were at annual minimums in mid March, with –9.5°C at 0.25 m progressively increasing to –6.1°C at 1 m. Steep temperature increases at all depths and a profile inversion occurred during April. An early June thaw at 0.25 m was followed by a continued increase to 5.0°C by 1 August. Frozen conditions persisted through this period at the deeper thermistors, with maximum temperatures of –0.2°C, –0.4°C, and –0.6°C at 0.5, 0.75, and 1 m, respectively. The reason for the change in direction of heat flow between 2006 and 2007 is not clear, though shallow permafrost out of thermal equilibrium with current surface conditions can persist at this site and could be the cause. Additional thermistors were installed on 1 August 2007 at depths of 1.5, 2, and 3 m to provide a deeper profile to more fully characterize the upper permafrost temperature.



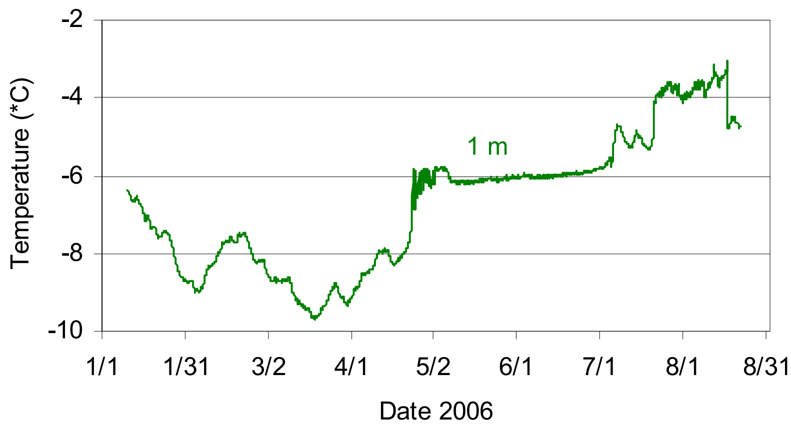


Figure 7. Active layer to permafrost profile temperatures, January–August 2006.

Fen water levels

Water levels of the Upper Fen follow an annual cycle with slow recession during the cold late fall and winter months, and recharge and water level recovery with spring melt. Water levels in May through October vary significantly between years, depending on rainfall during the period. Rainfall and snowmelt induced increases in fen water levels can increase the flow exchange with associated groundwater systems.

Fen water levels at the station near the Birch Island well, for the period of April 2004 through June 2005, are given in Figure 9 and summarized in Table 2. The Upper Fen water level in late winter 2004 was relatively low with no surface outflow. The April melt produced an annual peak, followed by generally decreasing fen water levels through August in response to extremely low rainfall. August had the lowest monthly mean water level and the annual minimum level for 2004. Monthly water level variability, represented by the standard deviation, was greatest in April and generally diminished through the year, with a minimum in November. Monthly maximum water levels decreased monotonically from April through December. The fen water level range in 2004 was 1.05 ft (0.32 m). The general fen water level recession of 2004 continued in 2005 through 21 April (Fig. 9), when the overall minimum of 1.44 ft (0.44 m) occurred. For the tabulated period of 2004–2005, April was the month with the largest stage variability in each year, the overall maximum level in 2004, and the overall minimum level in 2005. In response to spring melt, the

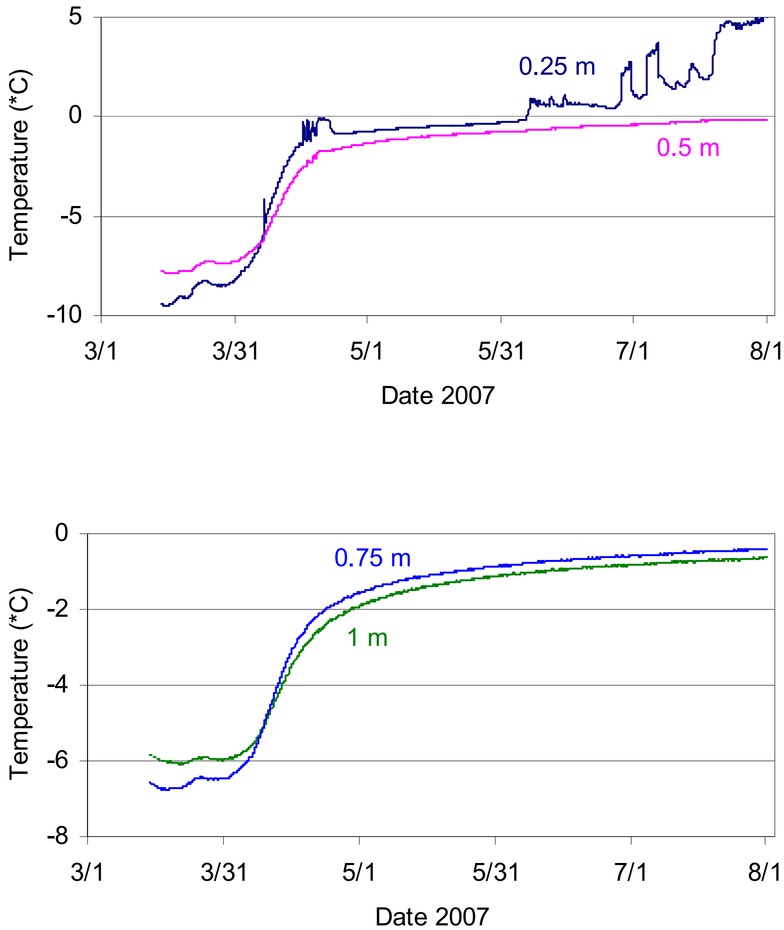


Figure 8. Active layer to permafrost profile temperatures, March–July 2007.

Table 2. Upper Fen water level data summary near Birch Island April 2004–June 2005.

Month	Mean ± Std Dev (ft)	Maximum (ft)	Minimum (ft)
April 2004	2.44 ± 0.20	**2.86**	2.22
May	**2.50** ± 0.07	2.60	**2.39**
June	2.30 ± 0.10	2.44	2.14
July	2.04 ± 0.09	2.16	1.93
August	1.88 ± 0.05	2.00	1.81
September	1.90 ± 0.06	2.00	1.81
October	1.97 ± 0.02	2.00	1.94
November	1.94 ± **0.01**	1.95	1.92
December	1.92 ± 0.01	1.94	1.90
March 2005	1.63 ± 0.06	**1.73**	1.53
April	**1.60** ± **0.21**	2.11	**1.44**
May	2.22 ± 0.07	2.32	1.96
June	2.30 ± 0.10	2.47	2.12

Bold represents an extreme for this period

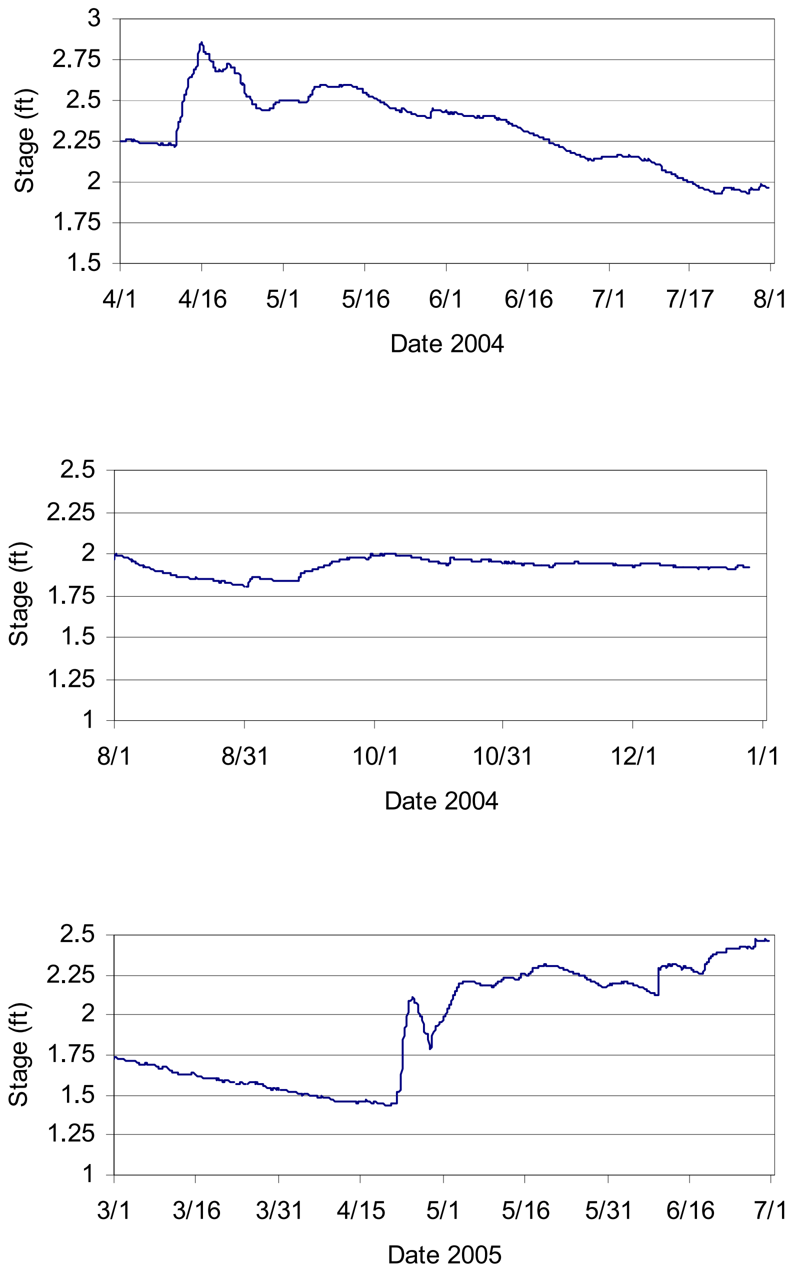


Figure 9. Upper Fen stage near the Birch Island well, April 2004 – June 2005.

stage rapidly increased to a peak of 2.11 ft (0.64 m) on 25 April 2005. The stage increase during early May to a peak of 2.31 ft (0.70 m) on the 19th was followed by a gradual decrease to 2.12 ft (0.65 m) on 10 June. The April and May peak stages of 2005 were lower than those of 2004 by 0.75 ft (0.23 m) and 0.29 ft (0.09 m), respectively. However, an extended rise in water levels during June and July 2005 produced a peak stage of at least 3.0 ft (0.91 m), 0.5 ft (0.15 m) higher than the maximum of 2004. In just over two months a significant hydrologic deficit was replaced by high water.

Rainfall was recorded together with stage at this fen station starting in late August 2006, and through 2 August 2007 most rainfalls were very light, with only 6 events in late May through July that exceeded 1 cm. The fen stage had small amplitude variability, but remained very stable throughout the almost year-long period. Most of the 0.5 ft (0.15 m) net decrease in stage occurred during the winter, followed by very little stage response to melt or the few summer rainfalls.

Well water levels

The water level in the well was drawn down during initial development and sampling, prior to installation of a Druck pressure transducer near the bottom. In response to this drawdown, the initial record showed a water level of 1.13 m on 1 April 2005 which gradually increased to 1.68 m on 8 April. Freezing on 9–10 April ended the reliable record of the sensor. A pair of replacement Drucks, installed on 26 August 2005, indicated a flat stage response for about a week before freezing began. After freezing in mid September, the data from these two sensors were smooth with nearly identical trends through August 2006. Piezometric pressure decreased through the winter to a minimum on 1 April, just prior to melt. The trend then reversed with a smooth rise to a mid-June peak, followed by a recession through August. Though these seasonal changes were typical, it is not known whether the frozen sensors properly represented the piezometric pressure trends of the well, and no water level data were obtained in the adjacent fen during this period for comparison. After thawing the well on 22 August 2006, a survey found equal water levels of the well and the fen, supporting the hypothesis of a direct hydraulic connection. After sample removal for water analysis, 400 g of table salt was injected to prevent freezing of the subsequent replacement Druck.

On 1 August 2007 there was no ice in the permafrost zone of the well, indicating that over the prior year the water level had not equilibrated with the adjacent fen. The fen water level decreased through the winter to a minimum on 21 March, followed by an increase of 0.39 m through 27 June, a period of about 95 days. The water level in the well decreased progressively from 0.25 m on 15 March 2007 to 0.09 m on 19 May and then smoothly increased through 1 August to 0.45 m, an increase of 0.36 m in about 75 days. Direct comparison indicates similar increases in levels at similar rates in both locations, with about a two month lag between changes in the fen and the response of the well. There was no indication of well sensor freezing in the data, and it was not frozen on 1 August. Water level recovery following the 1 August sampling was very slow, even though the level was more than 3 m below that of the local fen. The hydraulic conductivity near the well screen was clearly diminished in 2007 relative to that prior to injection of the salt. Our hypothesis is that the developing thaw near the well bottom has caused a significant reduction in hydraulic conductivity and compromised the connection with the groundwater.

Chemical characterization of well and fen waters

The solutes in fen water are concentrated during winter as a result of exclusion from the growing ice cover. This trend is reversed with the melt of snow and ice in the spring which causes a large and rapid dilution. Specific conductance (SC) and pH measurements of the fen near Birch Island made between 2002 and 2007 are summarized with corresponding well data in Table 3.

Table 3. Water chemistry comparison at Birch Island: fen – well.

Date	fen pH	fen SC (µS/cm)	well pH	well SC (µS/cm)
Aug 2002	6.9–7.2	240–280		
Apr 2003	6.5	710		
July 2003	6.7–6.9	290–360		
Mar 2004	7.0–7.1	563–682		
Aug 2004		284		
Mar 2005			7.4–7.5	505–575
Aug 2005	6.6	374	7.3	290–295
Aug 2006	6.7	221	7.9–8.0	236–269
Aug 2007	6.5	200	7.0	67,000

SC of both the groundwater below Birch Island and nearby fen water fluctuate greatly through the year. Samples obtained from the fen and well in late winter (March–April) provide a SC range of 505–710 µS/cm, while for summer samples (July-August) the range is 200–374 µS/cm. The pH of the fen ranges between 6.5 and 7.2, while the well range is slightly higher at 7.0–8.0, with neither displaying a seasonal trend. The August 2005, 2006 and 2007 common samplings consistently indicate more alkaline water in the well relative to the fen, but equivalent SC prior to the injection of salt. The salt injection following the August 2006 sampling, intended to prevent the well bottom Druck from freezing, was clearly evident in the August 2007 SC measurement. Comparable and seasonally in–phase SC data support the hypothesis of a connection between fen and sub–permafrost waters and indicate a large seasonal or shorter–term exchange between them.

Isotopic characterization of well and fen waters

Table 4 and Figure 10 give Birch Island well and fen isotope data for samples obtained in March and August over the period of 2004 to 2007. The $\delta^{18}O$ ranges for the well and fen samples were –17.2 to –19.9 and –16.5 to –19.5, respectively, with related δD ranges of –146 to –163 for the well and –138 to –156 for the fen. The slightly greater depletion of the groundwater well samples relative to the fen samples may indicate that the seasonal signatures were not completely captured by our limited temporal sampling (Hunt et al., 2005) that did not include the important spring melt period. The mostly negative deuterium excess *d* calculated for the fen samples ranged between –13.5 and 0.7 while that for the well samples ranged between –8.0 and 5.9. Ferrick et al. (2008b) found that fen samples from the post melt period had a mean d = 7.8, comparable to local precipitation, while at other times *d* was generally negative. However, like groundwater emerging at the surface below the Upper Fen in August 2005, positive *d* of the August 2006 well samples may reflect the signature of April melt water. This correspondence would suggest an exchange period of about 4 months between the fen and the sub permafrost groundwater. The linear regression through the Birch Island well samples of Figure 10 is also a good representation of the fen samples. The reduced slope relative to meteoric water, characteristic of evaporation, would not be expected for relatively deep groundwater unless that water actively exchanges with water at the surface. These isotope results also indicate that the fen water and the sub-permafrost groundwater represent a single component of the hydrologic system.

Table 4. Water isotope comparison at Birch Island: fen –well.

Date	fen			well		
	$\delta^{18}O$	δD	d	$\delta^{18}O$	δD	d
March 2004	-17.5 -16.8	-149 -148	-8.7 -13.5			
Aug 2004	-16.5	-138	-6.0			
March 2005				-17.9 -18.4 -18.9 -18.8	-149 -152 -155 -152	-5.1 -4.3 -3.3 -1.9
Aug 2005	-19.5	-156	0.7	-18.7 -17.2	-149 -146	0.3 -8.0
Aug 2006	-17.2 -17.3	-144 -142	-6.9 -3.9	-19.7 -19.7 -19.9	-154 -155 -153	2.8 2.8 5.9
Aug 2007	-17.1	-138	-1.3	-19.6 -19.7	-162 -163	-5.4 -5.1
Ave ± Stdev	-17.4±0.9	- 145±6		- 19.0±0.8	-154±5	

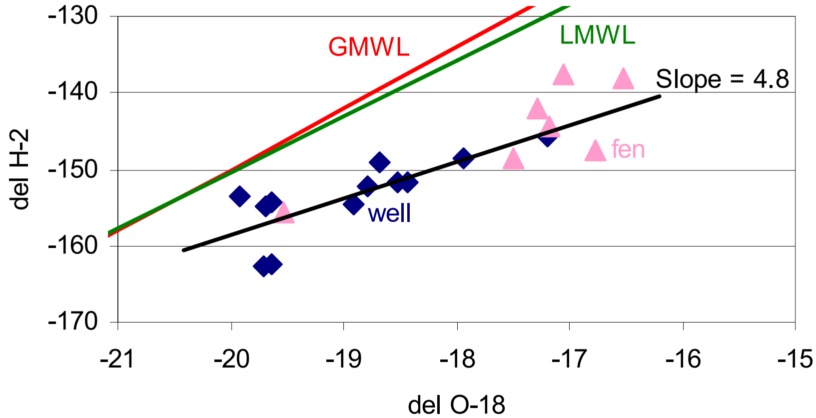


Figure 10. Birch Island well and nearby fen isotope data for March and August samples obtained during the period 2004–07, compared to the global (slope = 8) and local meteoric water lines (GMWL, LMWL). The well data regression with a reduced slope = 4.8 relative to meteoric water is extended through the fen data to show correspondence.

CONCLUSIONS

Birch Island, contained within the Upper Fen of the Tanana Flats, had air temperatures that varied through a range of 73°C during the period of this study. The monitored fen temperatures over the study period indicated that large and rapid changes in the thermal state of the Upper Fen are common. Measured well bottom water temperatures indicated corresponding sub permafrost water temperatures of at least 1.5°C. Local shallow permafrost temperatures at the 0.5 m depth and below remained subfreezing throughout this period, indicating a shallow active layer at the well site and stable permafrost, in contrast to many other locations in the Flats. Unlike the temperature patterns of the fens that were consistently driven by heat flow to or from the surface, the winter 2006 permafrost temperatures responded to conditions at depth. However, 2007 permafrost temperatures were different, being more typically dictated by conditions at the surface. The data do not identify a reason for the anomalous behavior, though it may occur during periods when the permafrost is not in thermal equilibrium with surface conditions.

A direct hydraulic connection with sub-permafrost groundwater was established following well drilling through the Birch Island permafrost in March 2005. After thawing the well on 22 August 2006, the water levels of the well and fen were found to be equal. Also, data from the Birch Island well and fen station pair over a period of several months in 2007 indicated that well water levels responded to changing levels in the adjacent fen.

Solutes in the fen water are concentrated during winter, a result of exclusion from growing ice, and spring melt causes a large and rapid dilution of these solutes. Specific conductance of the well and nearby fen samples exhibited comparable large, in-phase seasonal variations each year. The deuterium–oxygen-18 linear regression for groundwater samples from beneath Birch Island was also a good representation of the local fen samples. It had a reduced slope relative to meteoric water, characteristic of evaporation. However, evaporation of relatively deep groundwater can only occur with an active exchange of water to and from the surface. These SC and isotope relationships support a direct connection between fen and sub–permafrost waters as a single component of the hydrologic system with an exchange period of a few months.

Most of the losses of permafrost in the Tanana Flats have occurred at fen margins, caused by heat transfer from the warm fen water. However, monitoring of the Birch Island well has provided insight into less well understood processes that cause melting and degradation on the interior of permafrost features. Groundwater flowing beneath the permafrost or through fractures and imperfections, at temperatures exceeding 1.5°C, can readily supply sufficient heat to cause melt and land subsidence away from fen margins.

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