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Chum Salmon Spawning Habitat on the Snake River: A Feasibility Study

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To

Norton Sound Research and Restoration Initiative

C/o

The Alaska Department of Fish and Game

Commercial Fisheries Division, AYK Region

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ABSTRACT

Chum salmon spawning habitat was mapped and habitat characteristics were documented in a feasibility study on the Snake River, while testing and developing methods for future habitat research. The Snake River, which is located in Norton Sound, Alaska, is a relatively shallow river in an Arctic tundra environment and can be subject to significant harvest pressure and also potential human impacts through development and mining. Aerial surveys demonstrated that the chum salmon spawning habitat coincided with the areas of felt leaf willow and areas of open water in winter, both of which are indicators of upwelling water. The aerial surveys also showed that the majority of the chum salmon spawning habitat, areas of felt leaf willow and areas of unfrozen river were all located upstream from the confluence of Glacier Creek. Local knowledge interviews confirmed the lack of chum salmon spawning habitat downstream from the Nome-Teller Highway, located at the interface between the Snake River valley, which has a more confined surface aquifer and the coastal plain, which allows water to drain away from the river and therefore has very little upwelling. These interviews also reiterated the importance of upwelling to viable chum salmon spawning habitat. A comparison of the habitat characteristics in high and medium density spawning habitat revealed that most characteristics measured were similar, however the high density spawning habitat had a higher river discharge than the medium density spawning habitat. The cross sectional profiles demonstrated that a combination of maximum water depth and gradient are important characteristics for ideal spawning habitat within a site. Future studies would benefit from thorough data collection through at least one complete annual spawning cycle, although winter fieldwork poses logistical challenges. Also, more in-depth research into temperature, upwelling, and dissolved oxygen profiles, as well as substrate characterization may provide additional insight into the factors contributing to ideal chum salmon spawning habitat in this Arctic environment.

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INTRODUCTION

Freshwater habitat quality and availability is critical to the success of spawning salmon, and in an area with declining or depressed chum salmon returns, as in the Nome Subdistrict of Norton Sound (Subdistrict 1), it is imperative to understand the factors that contribute to ideal spawning habitat. Approximately 95-99% of salmon that survive to adulthood home to their natal site to spawn (Quinn 2005). The quality of spawning habitat is dependent on many factors, including temperature, stream discharge, and water quality, and specific site selection within a spawning area is dependent on environmental cues such as substrate composition, cover, water quality and water quantity (Bjornn and Reiser 1991). Species-specific site selection has been linked to differences in hyporheic water flow, as Chinook salmon spawn in areas of downwelling (Geist et al. 2002), while chum salmon spawn in areas of upwelling (Geist et al. 2002; Maclean 2003), and also is influenced by substrate size and water flow as larger salmon can move larger gravel and withstand higher flow than smaller species of salmon (Quinn 2005). Within-species site selection relies on subtle changes in the environmental cues which differentiate between ideal spawning habitat and poor spawning habitat and salmon may be evolutionarily tuned to these subtle differences, especially in a harsh, unforgiving Arctic environment.

Freshwater habitat requirements for salmon have not been well studied in Arctic environments, where tundra is the primary ground cover and rivers may freeze to the substrate in winter months. In these environments, salmon are dependent on upwelling areas for spawning success because this hyporheic flow remains just above freezing during the winter months, and therefore prevents eggs deposited in these areas from freezing. This hyporheic flow also remains colder than the surrounding river temperature during the summer, which therefore influences development rates of deposited eggs (Quinn 2005). Upwelling also contributes to the dissolved oxygen content of the water in the spawning areas, which becomes especially critical in winter when water flow under the ice is significantly reduced or not present. Insufficient levels of dissolved oxygen have been linked to mortality and developmental delays in salmonid embryos (Quinn 2005). In fact, even when groundwater flow is present, the spatial variability in dissolved oxygen has been shown to be principally responsible for limiting the area of favorable incubation habitat in chum salmon in Interior Alaska (Maclean 2003). Therefore, chum salmon use these key environmental factors, including hyporheic flow, temperature and dissolved oxygen, as well as other habitat characteristics when determining spawning site selection and variations in these environmental cues can be used to identify ideal spawning habitat conditions for chum salmon.

Projects documenting habitat use and characteristics for chum salmon have management applications, and also may provide valuable information for future enhancement, restoration or research projects. Specifically on the Snake River in the Nome Subdistrict of Norton Sound, there is only limited information documenting the location and characteristics of chum salmon spawning habitat, yet there is potential for significant harvest pressure on this stock, and the stock has experienced significant declines in recent years. By determining the factors that constitute ideal chum salmon spawning habitat on the Snake River, these conditions can be used to find additional, unused spawning habitat to support possible future restoration activities, and can be used as a benchmark when restoring habitat that has become undesirable for chum salmon spawning due to human influences or other impacts. Therefore, the purpose of the present study is to document utilized chum salmon spawning habitat and habitat characteristics on the Snake River while testing and developing methodologies for future habitat research.

METHODS

Study area

The Snake River (Figure 1) was selected to study and map chum salmon spawning habitat because of its relatively easy access due to local roads and trails and because it is located in the Nome Subdistrict, which has experienced the greatest declines of chum salmon in Norton Sound (Kohler 2003). The Snake River flows 43 km South from the confluence of the North Fork and Goldbottom Creek. It is a prehistorically glaciated fourth order river that is surrounded by tundra and willows and has a hydrograph driven by spring runoff and snowmelt. Average discharge of the Snake River in 2002 and 2003 was 72 cfs and 215 cfs, respectively, with minimum discharge recorded at 36.4 cfs in 2002 and a maximum discharge measured at 315 cfs in 2003 (Kroeker and Dunmall 2003, 2004).

1) Document available chum spawning habitat on the Snake River:

a) Interview Local Area Biologists

Charlie Lean, a former Alaska Department of Fish and Game Norton Sound Area Management Biologist who is currently with the Norton Sound Economic Development Corporation, was interviewed on March 31, 2006 to document and map his knowledge of current and historic chum salmon spawning habitat, and areas of upwelling on the Snake River. Jim Menard, the current Norton Sound Area Management Biologist for the Alaska Department of Fish and Game, was interviewed on April 18, 2006 to document his knowledge of chum salmon spawning sites on the Snake River.

b) Conduct Aerial Reconnaissance

Aerial surveys were completed with Charlie Lean using a helicopter at peak chum salmon spawning on July 25, 2005, on the Snake River. Stream reaches used by spawning chum salmon were marked with a GPS. A relative index of spawner density (none, low, medium, high) was developed to allow later comparison of stream reaches. Aerial surveys were also completed with Charlie Lean on November 4, 2005, after the first snowfall and freeze, to document areas of open water and felt-leaf willow. For all aerial surveys, spawning areas, areas of open water and areas of felt leaf willow were marked on maps using different colored pens. These maps were then used to generate the GIS maps. Digital photographs were taken during the aerial surveys.

Stream reaches that were identified as spawning locations were marked on GIS maps using USGS NAD27 (Alaska) datum. Areas of open water and felt-leaf willow were also marked on GIS maps.

2) Determine the characteristics of chum salmon spawning habitat on the Snake River;

From the aerial surveys: the two high-density spawning locations were identified as Boulder Creek (GPS location 03W 0477492 / 7168292) and Glacier Creek (GPS location 03W 0477887 / 7163606) and the two medium-density spawning locations were identified as Bangor Creek (GPS locations 03W 0479005 / 7171695) and just downstream of Rowe's cabin (GPS location 03W 0478976 / 7171128). Although attempts were made to count the number of redds and the number of spawning chum salmon in each location, an accurate count proved to be impossible due to depth of water, glare on the water surface, and fish movements. Therefore, a relative comparison of densities was made based on general observations.

a) Habitat Characteristics:

i) Discharge: River discharge measurements were completed using a Swoffer 2100 flow meter attached to a top-set wading rod. Water velocity and water depth were measured at a minimum of ten stations at regular intervals across the width of the river at each of the four sites. The sites for discharge measurements were reasonably representative of the habitat at each of the four locations, and were devoid of deep pools, excessive turbulence and back eddies. Water velocity measurements were completed on August 3, 2005 at the Bangor Creek location, and on August 10, 2005 at all of the Bangor Creek, Rowe's Cabin, Boulder Creek and Glacier Creek locations. Water velocity measurements were completed again on October 26, 2005 at the Bangor Creek and Boulder Creek locations. Winter discharge measurements were attempted at Boulder Creek on March 16, 2006, at Bangor Creek on March 23, 2006, by drilling a series of holes in the ice with an auger across the width of the river, and measuring the flow of water under the ice (Figure 2).

Figure 2. Winter discharge measurements were attempted at Boulder Creek on March 16, 2006. Note the recent overflow at the base of the high bank.

Discharge (Q, in cubic feet per second) was calculated using the following formula (from McMahon et al. 1996):

$$Q = w_1 d_1 v_1 + w_2 d_2 v_2 + \ldots + w_n d_n v_n$$

Where: w = width;
d = depth;
v = velocity.

ii) Physical parameters: Percent oxygen saturation, salinity, water temperature, dissolved oxygen, and conductivity were measured on August 7, 2005 at the Bangor Creek, Rowe's cabin, Boulder Creek, and Glacier Creek locations using a YSI DO 200 meter. Gradient was measured at each location using a Suunto clinometer (model PM5/360PC). Wolman pebble counts were attempted at two locations, but accurate categorization of substrate by this method proved to be impossible due to the relatively high depth of the water in spawning areas. Hyporheic and instream water temperature probes (Onset Hobo 32kilobyte temperature dataloggers) were deployed on August 18, 2005 at the Boulder Creek and Glacier Creek locations and on September 3, 2005 at the Bangor Creek location. The hyporheic temperature probes were installed in a capped, perforated steel pipe (60cm long), which was driven into the substrate approximately 45cm using a sledgehammer. Sediment was removed from the pipe by blowing into a plastic pipe inserted into the steel pipe until the water flowing out of the top of the steel pipe ran clear. The temperature probes were attached to a steel cable, which was attached to the cap and allowed the probes to hang freely in the pipe at a depth of approximately 40cm into the substrate. The instream temperature probes were attached to the outside of this steel pipe using a steel cable, and flowed freely in the river at the level of the substrate. Dissolved oxygen and water and air temperature measurements were completed at the Bangor Creek and Boulder Creek locations on October 26, 2005 and again at Boulder Creek on March 16, 2006 and Bangor Creek on March 23, 2006. Snow and ice depth measurements were collected at Boulder Creek on March 16, 2006 and at Bangor Creek on March 23, 2006.

Figure 3. Timothy Kroeker installing a hyporheic temperature probe at the Bangor Creek site.

iii) Upwelling: Upwelling or vertical hydraulic gradient (VHG, measured in centimeters) was measured by placing three piezometers into the substrate in spawning habitat at each of the Bangor Creek, Boulder Creek and Glacier Creek sites. The piezometers were constructed of clear plastic pipe (2.2cm outside diameter, 2.0cm inside diameter), and had two rows of 2cm long slits, spaced 1cm apart cut into the bottom 10cm of the pipe. The piezometers were 60cm in overall length, and had a cone fitted on the bottom end to ease placement into the substrate. Individual piezometers were driven into the riverbed by inserting a steel drive rod into the piezometer and manually pounding the piezometer into the substrate. Once the piezometer was in place, the drive rod was removed and a standpipe was added to extend the piezometer above the river surface. Air was blown into the standpipe and the pipe was then quickly removed to suck out any sediment in the piezometer shaft. The standpipes were removed between measurements and the piezometers were capped with a plastic

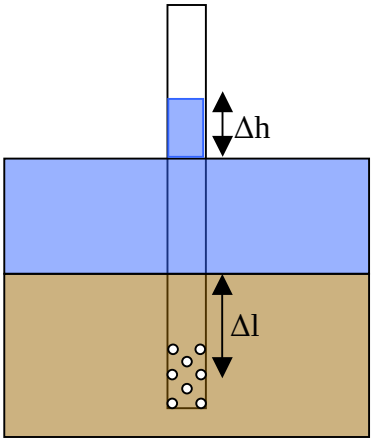

Figure 4. Sketch of a piezometer, where brown represents the substrate, blue represents the water, and Δh and Δl are depicted under upwelling conditions.

plug.

Measurements of upwelling were conducted when possible, as high water and ice conditions made upwelling measurements challenging. At the Bangor Creek site, piezometer 1 (P1), the most upstream piezometer, was placed immediately downstream of the uppermost spawning redd, P2 was placed in slightly less well used spawning material, and P3 was placed on the outer limit of spawning activity at the Bangor Creek. At the Boulder Creek site, P1, the most upstream piezometer, was placed immediately adjacent to a high density spawning site, P2 was placed within spawning activity, further downstream from P1, and P3 was placed at the downstream margin of high density spawning activity. At the Glacier Creek site, P1, the most upstream piezometer, was placed immediately upstream of the majority of spawning activity, P2 was placed in the majority of the spawning activity, but close to the bank because of water level restrictions, and P3 was placed at the downstream margin of the observed spawning activity.

Upwelling, or vertical hydraulic gradient (VHG) was calculated at each site based on the following formula:

$$VHG = \Delta h / \Delta l$$

Where: Δh is the difference in head between the water level in the piezometer and the level of the stream surface (cm), and
Δl is the depth from the streambed surface to the middle of the perforated interval (from Baxter et al. 2003, see Figure 4).

iv) Cross Sectional Profiles: Cross sectional profiles were completed by the Kawerak Transportation Department on August 7, 2005 at each of the Boulder Creek, Glacier Creek, Bangor Creek and Rowe's Cabin locations. At each location, a minimum of five transects were completed across the width of the river and a "Total Base Station" (Nikon) was used to collect the CAD (Computer Aided Drafting) survey data points at each change in depth profile at each transect. Unfortunately, during data analysis it was realized that the data points collected from the Boulder Creek and Glacier Creek sites were not accessible due to a downloading error. However, the surveys measurements from the Bangor Creek and Rowe's Cabin sites were compiled and cross sectional profiles of the river were developed for those sites. In addition, the

Figure 5. Ken Waterman and Charlie Lean taking survey measurements to develop the cross sectional profiles at the Bangor Creek location, August 7, 2005.

distance between the transects and the change in elevation were used to calculate the gradient between transects and the overall gradient for each of the Bangor Creek and Rowe's Cabin sites.

Habitat characteristics, including wetted width, bank height, substrate type, flow characterization (glide, pool, riffle), and gradient were measured for the entire section of the Snake River from the Nome-Teller bridge to the confluence of Glacier Creek and the Snake River during July. The lengths of each habitat type was measured using hip chain, and a GPS location was taken at the beginning of each change in habitat type. The substrate type was categorized as percent boulder, cobble, gravel and fine material by a relative comparison between sites, where boulder was defined as any rock greater than 30cm in diameter, cobble was any rock 10-30 cm in diameter, gravel was any rock 1-10cm in diameter, and fines were anything less than 1cm in diameter. The depths of the habitat types were taken within a representative section of that habitat type, except the depth of the riffles was always taken at the crest of the riffle. For the purposes of these measurements, the right bank was defined as the bank on the right side, looking upstream and all depth measurements began at the right bank side of the river.

Figure 6. Chum salmon spawning at the Glacier Creek site, August 7, 2005.

RESULTS

1) Document available chum spawning habitat on the Snake River:

a) Interview Local Area Biologists

From the March 31, 2006 interview with Charlie Lean:

The chum salmon spawning habitat on the Snake River is closely tied with the historic geological activity in that region. Winter water flow is the determinant of suitable spawning habitat and chum salmon are amazing in their ability to detect areas that will provide upwelling during the winter months. Downstream of the Nome-Teller Highway (near Gold Pan Gulch), the river is not suitable for chum salmon spawning because it has a sandy bottom and little or no upwelling. Historically, Snake River was covered by a glacier, which pushed sediment from the valley to a terminal moraine. The terminal moraine is located in an arc, with the base of the arc extending to approximately ½ mile downstream from the Teller Highway, immediately upstream from Gold Pan Gulch (Figure 7).

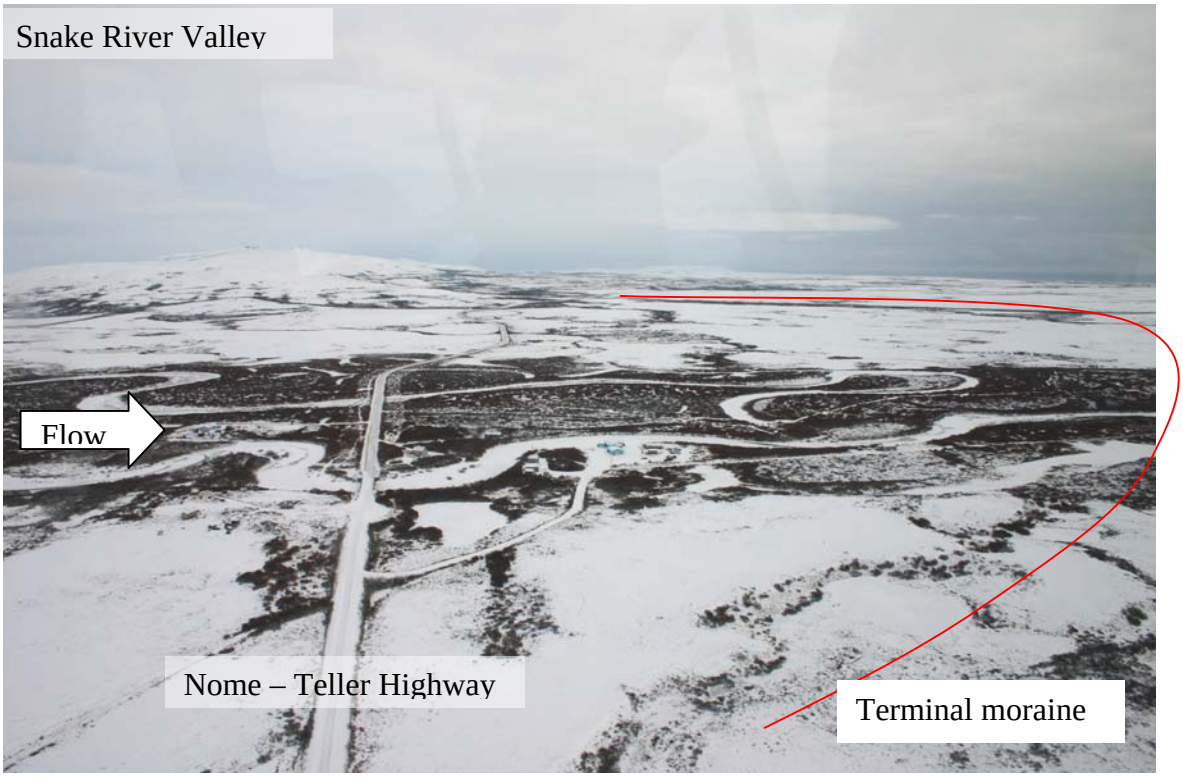

Figure 7. An aerial view of the Snake River at the Nome-Teller Bridge. Nome is located in the background, on the right hand side of the photo.

When the glacier receded, waves washed the sediment back into the Snake River valley. Also two former beach lines cross the Snake River: the 72' beach line, which coincides with Gold Pan Gulch and the 24' beach line, which runs through the City of Nome. As the depth to bedrock increases, as it does in these areas that have been subject to sedimentation, the chance for

upwelling diminishes. During the winter, water gradually weeps away into the soils overlaying the bedrock and in fact, open portions of the river diminish or disappear downstream of Sunset Creek in the winter months. This disappearance of the river demonstrates low flow in the riparian gravel downstream of Sunset Creek, and spawning activity in this area would be subject to freeze down and low oxygen levels. Therefore, the Snake River downstream of the Nome-Teller Highway is not suitable chum salmon spawning habitat because it has an unsuitable substrate (sand), low or no upwelling, and low oxygen levels in the winter.

Upstream from the Nome-Teller Highway, there are several tributaries that have formed notable alluvial fans, and it is at the base of these alluvial fans where the prime chum salmon spawning habitat is located on the Snake River (Figure 8). Four major tributaries of the Snake River have year-round flow: Glacier Creek, Boulder Creek, Bangor Creek and the North Fork and these tributaries represent major water sources in the winter. In recent years, it is less common for chum salmon to make it to the North Fork, but it represented good habitat in the past. The secondary habitat possibilities are where the meanders have undergone shortcuts or meander lobes have been formed, as long as sufficient winter water flows.

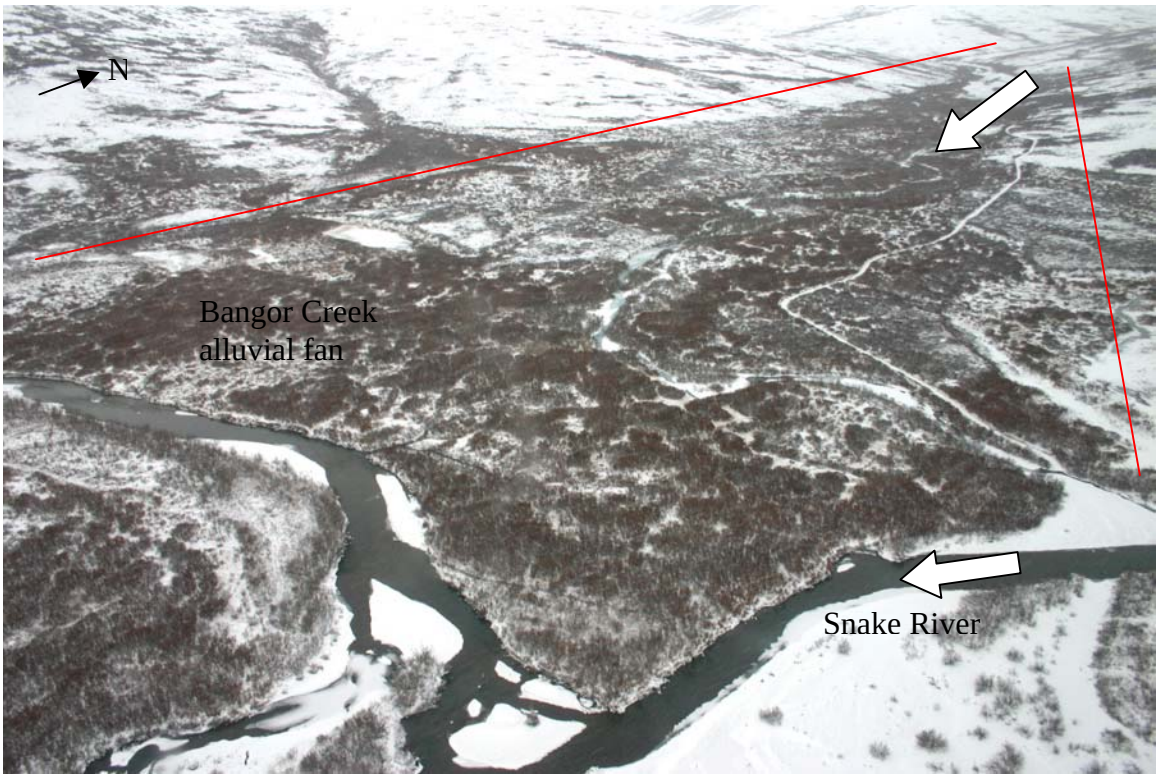

Figure 8. An aerial view of the Bangor Creek alluvial fan, looking up the Bangor Creek valley.

Chum salmon have never been observed spawning in the tributaries to the Snake River, but rather are core mainstem spawners and key into areas of upwelling. The Glacier Creek alluvial fan is the first prime habitat that the chum salmon encounter as they swim upstream. The Boulder Creek alluvial fan consistently has the highest density of spawning chum salmon in Snake River over long-term (20 years of) observation. The Boulder Creek alluvial fan not only provides spawning habitat, it also provides a ripening or resting opportunity for chum salmon

bound for locations further upstream. Historically, just downstream from the Boulder Creek confluence, four subsistence camps were present, dating from the early 1970's or earlier. These subsistence camps are evidence of the previous abundance of chum salmon and the more liberal regulations once in place for management.

From the April 18, 2006 interview with Jim Menard:

The chum salmon spawn in areas of upwelling, and are generally found in larger concentrations in the mainstem of the Snake River at the mouth of the tributaries. Very few chum salmon are seen spawning downstream of the Nome-Teller Bridge, although there is a hole where they tend to hold just downstream of that bridge. The Boulder Creek and Glacier Creek confluences are major areas for chum salmon spawning, and there are several other smaller areas scattered along the mainstem, one of which is at the confluence of Russel Creek, and another is immediately downstream from the confluence of Lindblom Creek.

b) Conduct Aerial Reconnaissance

The information gathered from the aerial reconnaissance on July 25, 2005 and November 4, 2005 was mapped using ArcView 9.1 by the Sitnasuak Native Corporation Land Management Department. The maps developed showed that the locations of chum salmon spawning areas overlapped the felt leaf willow locations and the areas of open water (Figures 9 and 10). The maps also demonstrated that there were more areas of frozen river downstream from the confluence of Glacier Creek to the mouth of the Snake River than there were upstream from that location (Figures 11 and 12). Similarly, there were more areas of felt leaf willow upstream from the confluence of Glacier Creek than there were downstream from that location (Figures 13 and 14). The maps also showed that the majority of the spawning sites, and all of the high and medium density spawning sites, were found upstream from the confluence of Glacier Creek (Figures 15 and 16).

2) Determine the characteristics of chum salmon spawning habitat on the Snake River;

Precipitation influences the chum salmon spawning habitat on the Snake River by affecting river discharge, turbidity, and water temperature. Therefore, the precipitation recorded at the Snake River weather station, which is located at the Snake River enumeration camp (GPS Coordinates 03W 0473824 / 7157118), complements a description of chum salmon spawning habitat on the Snake River. The Snake River weather station is part of the Environmental Condition Monitoring Project (Kroeker and Dunmall 2006). In 2005, the amount of precipitation recorded in June was 19.60 mm, in July was 44.20 mm, in August was 78.40 mm, and in September was 159.00 mm.

Temperature also is an important factor for chum salmon spawning habitat and spawning success. The air temperature recorded at the Snake River weather station is shown in Figure 17 and the instream water temperature recorded at the Snake River enumeration camp is shown in Figure 18. Temperatures were also recorded at each of the Bangor Creek, Glacier Creek, Boulder Creek and Rowe's Cabin sites when the sites were visited, however the temperature probes deployed at each of these sites in August 2005 to record both instream and gravel water

temperatures were not downloaded due to the snow and ice conditions persisting through April 2006.

a) General Characteristics:

Bangor Creek

The Bangor Creek site, located downstream from the confluence of Bangor Creek and the Snake River, was determined to be a medium-density site because there were comparatively few chum salmon observed spawning at that location during the aerial survey on July 25. The Bangor Creek location was categorized as a glide, however a small pool was noted on the North shore, upstream side (yellow star, Figure 19). There were no boulders, and the entire site was defined as 5% cobble, 60% gravel and 35% sand. The gravel was concentrated on the North side of the sampling site, while the sand was concentrated on the South side of the sampling site. All spawning activity was noted on the North side of the site. Medium-sized (approximately 3 feet high) willows covered the North bank, while the South shore was a beach.

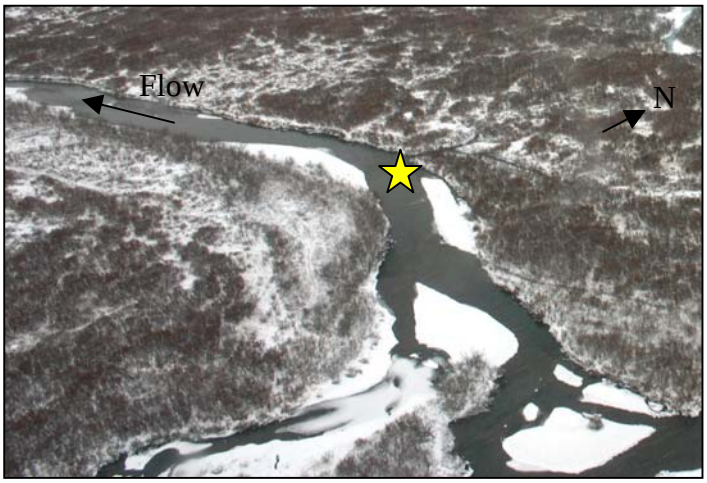

Figure 19. An aerial view of the Bangor Creek sampling site, looking downstream. The pool is identified by the yellow star.

Boulder Creek

The Boulder Creek site, located at the confluence Boulder Creek and the Snake River, was determined to be a high-density site because there were comparatively many chum salmon observed spawning at that location during the aerial survey on July 25. The Boulder Creek location was categorized as a glide, however a large pool noted on the West shore, upstream side (red oval, Figure 20). There were no boulders, and the entire site was defined as 5% cobble, 50% gravel and 45% sand. The gravel was concentrated on the West side of the sampling site, while the sand was concentrated on the East side of the sampling site. All spawning activity was noted on the West side of the site. Chum salmon were also observed to be holding at the extreme upstream portion of this site (yellow star, Figure 20). Sockeye salmon were also observed holding, and perhaps spawning at this site. Medium-sized willows covered the West bank, while the East bank was a beach.

Figure 20. An aerial view of the Boulder Creek sampling site, looking upstream.

Glacier Creek:

The Glacier Creek site, immediately downstream of the confluence of Glacier Creek and the Snake River, was determined to be a high-density site because of the comparatively many chum salmon observed spawning at this site during the aerial survey on July 25 (Figure 22). The Glacier Creek location was categorized as a glide, and had a large pool at the upstream end, on the East side. There were no boulders or cobble present, and the entire site was defined as 50% gravel and 50% sand. The gravel was concentrated on the East side of the sampling site, while the sand was concentrated on the West side of the site. Within the pool, however, the substrate contained more sand than in the glide portion and the furthest upstream portions of the pool had high concentrations of sand (90%) and very little gravel (10%). Chum salmon were observed to be holding in the pool. Also, sockeye and coho salmon were later observed holding in this same location. There was a large back eddy at the extreme upstream portion of the pool. Tall (approximately 6 feet high) willows thickly covered the East bank, while the West bank was a beach.

Figure 21. An aerial view of the Boulder Creek sampling site, looking west. Note the relatively high density of fish present, and the spawning redds.

Figure 22. An aerial view of the Glacier Creek site, looking west. Note the relatively high density of fish present, and the spawning redds.

Rowe's Cabin:

The Rowe's Cabin site, on the downstream side of a tight bend in the Snake River, was defined as a medium-density site because there were comparatively few chum salmon observed spawning at this site during the July 25 aerial survey (Figure 23). The Rowe's Cabin site was categorized as a glide, and it had a large pool on the downstream end, on the North side. There were no boulders or cobble present, and the entire site was defined as 40% gravel and 60% sand. The gravel was concentrated on the North side, upstream from the pool, and the sand was

concentrated on the South side and in the pools. Chum salmon were observed spawning at the immediate margins (both upstream and downstream) of the pool, as well as on the North side of the site, upstream from the large pool. Tall willows thickly covered the North bank, and extended across the thin piece of land separating the bend in the river. The South bank was a wide beach. Woody debris (branches) was found in the water on the North side of the site.

Figure 23: An aerial view of the Rowe's Cabin site, looking west. The habitat characteristic measurements were taken within the section outlined by the red oval, and the pool is on the Southern edge of that oval.

b) Habitat Characteristics:

Serial measurements of habitat characteristics were taken at Bangor Creek, a medium density spawning site, and at Boulder Creek, a high density spawning site, to allow for comparison of these parameters between sites of differing spawning density at different times of the year. A point measurement of habitat characteristics was taken on one day at all four sites to allow for comparison between sites.

i) Discharge: The Snake River discharge at the Bangor Creek and Boulder Creek site increased as summer progressed into fall, corresponding to precipitation events in the Snake River valley (Table 1). Between August 3 and August 10, 27.60 mm of rain were recorded at the Snake River weather station (Kroeker and Dunmall 2006). This rainfall translated into an almost doubling of the river discharge measurement at Bangor Creek (Table 1). Similarly, the precipitation that occurred during September (in the form of rain) and October (in the form of both rain and snow) resulted in the highest water levels and therefore highest discharge measurements to occur during the October measurement at both the Bangor Creek and Boulder Creek sites (Table 1). Discharge measurements were attempted during the winter, however water flow

Figure 24. Liana Tobin, Timothy Kroeker and Clifford Tocktoo taking discharge measurements at Bangor Creek, August 3, 2005. The view is looking downstream at the mainstem of the Snake River, from the North bank.

under the ice was too low to measure. When discharge measurements were taken at all four sites within one day, the Glacier Creek site had the highest discharge measurement, followed by the Boulder Creek, Rowe's Cabin and Bangor Creek sites (Table 1).

ii) Physical parameters: The physical parameters measured were very similar between the different sites. Also, the percent oxygen saturation remained similar at each of the Bangor Creek and Boulder Creek sites, regardless of what time of year it was measured (Table 2). Water temperature at each of the four sites was similar during the summer, ranging from 8.9 to 9.4^{o}C, and it dropped to near zero during the fall and winter measurements (Table 2). Conductivity measured at each of the four sites ranged from 159.0 to 169.1µS (Table 2). The gradient at all four sites was 1%. Ice depth measurements, collected at Bangor Creek on March 23, 2006, and Boulder Creek on March 16, 2006, demonstrated a thinner layer of ice covering slightly deeper water at the Boulder Creek site, when compared to the Bangor Creek site (Table 2). There was a small amount of snow on top of the ice at the Bangor Creek site, and none at the Boulder Creek site (Table 2).

Figure 25. Chum salmon spawning at Bangor Creek, on the Snake River, August 3, 2005.

iii) Upwelling: A comparison of the upwelling measurements between sites revealed that Bangor Creek consistently had the highest levels of upwelling overall, although the level of upwelling varied greatly depending on where the piezometers were placed at each site (Table 3). Serial measurements of the same piezometers on different dates demonstrated consistency in the level of upwelling measured at each piezometer, except at the Glacier Creek site. The inconsistency in the Glacier Creek measurements may be due to extremely high water conditions during the second measurement, which made accurate measurements challenging. At Bangor Creek, the piezometers with the largest upwelling measurements were the ones placed in close proximity to the observed spawning activity (P1 and P2), however at Boulder Creek, the piezometer with the largest upwelling measurement was the one placed at the downstream margin of the observed high density spawning activity (P3). At Glacier Creek, the piezometer placed immediately upstream of the majority of the spawning activity measured the highest amount of upwelling (P1), and the piezometer placed in the spawning activity measured no upwelling (P2). This may be due to the fact that P2 was placed close to the bank because of deep water elsewhere, and therefore was inadvertently out of the upwelling zone. Upwelling measurements were attempted during the winter months, however the piezometers were lost under the ice, despite having GPS locations and the use of a metal detector (Table 3).

The hyporheic temperature probe at the Glacier Creek site, which is part of the Environmental Condition Monitoring Project (Kroeker and Dunmall 2006), has demonstrated that hyporheic flow does occur at the Glacier Creek site. This temperature probe has been deployed since July 2002, and data are available to August 2005 (Figure 26). This gravel probe is located in active chum salmon spawning habitat, immediately downstream from P1, which also measured the largest amount of upwelling at this site. The hyporheic temperature remained above zero throughout the winter months at the Glacier Creek site location, and slightly cooler than the instream flow during the summer months, indicating subsurface flow is present at this location.

iv) Cross Sectional Profiles: The cross sectional profiles developed for the Bangor Creek (Figure 27) and Rowe's Cabin (Figure 28) sites demonstrate the change in substrate profile associated with viable spawning habitat. The overall gradient at the Bangor Creek site was 0.85% and it was 0.83% at the Rowe's Cabin site. This is similar to the gradients measured using the clinometer (1% at all sites). At the Bangor Creek site, the majority of the chum salmon spawning occurred between Transect (Section) 2 and Transect 4, corresponding to the Transects with a combination of the highest gradient and greatest maximum depth. At the Rowe's Cabin site, the majority of the chum salmon spawning occurred between Transect (Section) 2 and Transect 4, although there was some spawning occurring between Transects 1 and 2 as well as between Transects 4 and 5, again corresponding to the Transects with a combination of the highest gradient and greatest maximum depth. Therefore, simply having a deep site (as in Transect 1 at both sites) or an acceptable gradient (as between Transects 4 and 5 at both sites) does not constitute ideal habitat within a site. The ideal spawning habitat at both sites corresponds to a combination of maximum depth and maximum gradient. The profiles also correspond well to the observations of chum salmon spawning on the deepest side of the river at each site, where the greatest concentration of gravel was present.

Habitat characteristics, including wetted width, bank height, substrate type, flow characterization (glide, pool, riffle), and gradient were collected for the entire section of the Snake River from the Nome-Teller bridge to the confluence of Glacier Creek and the Snake River (Table 4). This section of the Snake River is dominated by glides, and has occasional pools (with depths greater than 1m), usually located on the outer bank side of a turn in the river. Several side channels contained juvenile fish, which were presumably salmonids as they were noted to have parr marks. Most of the instream vegetation noted was in the form of slime on the rocks at the bottom of the river, while there were occasional branches located in the pools. The outer bank at bends in the river was generally willow growing on top of mud and sand, which was eroding into the river, while the inner bank was usually a beach, and consisted of fine sand. Dead chum salmon were noted on the stream edge in five locations, and live chum salmon were noted in the river in two locations. Pink salmon were also observed in the river.

DISCUSSION

As a feasibility study, this project successfully mapped chum salmon spawning habitat and collected information that allowed a preliminary comparison of habitat characteristics in high and medium density chum salmon spawning locations on the Snake River, while developing and testing methods for future research. The aerial surveys allowed a detailed map of the chum

salmon spawning locations on the Snake River to be produced, and corresponded well to the local knowledge of the former and current Alaska Department of Fish and Game Area Management Biologists to obtain a comprehensive picture of historic and current chum salmon spawning activity on the Snake River. This map of chum salmon spawning locations can be used as a benchmark to determine impacts of development on chum salmon, and can also be used to direct restoration or mitigation efforts associated with that development. Managers can also use the map to direct harvest or human impacts away from spawning locations. These aerial surveys also highlighted that the spawning locations overlapped with open water and felt leaf willow areas, which are suggested indicators of upwelling water, and also showed additional areas of open water and felt leaf willow that are not currently being used as spawning areas by chum salmon. These additional areas provide direction for future research to determine if they are viable chum salmon spawning habitat, which can then be used to assist in determining the overall carrying capacity for chum salmon on the Snake River, based on available versus utilized habitat. This information can also be used to assist possible future restoration activities.

A preliminary comparison of habitat characteristics between spawning locations of differing densities demonstrates that the highest density spawning sites (including those categorized as high and medium) all have a 1% gradient, upwelling present, and the spawning occurs in the areas within the sites with a higher percentage of gravel. As well, the cross sectional profiles at the Bangor Creek and Rowe's Cabin sites demonstrate that a combination of maximum water depth and gradient are important characteristics for ideal spawning habitat within a site. Water flow is a source of the variation in spawning density between the high and medium density sites measured, although significantly more in-depth study is required. The only parameter measured in the summer that differed between the high and medium density sites was the river discharge, which was higher in the high density spawning sites than in the medium density spawning sites. The fact that the ice depth was smaller at the high density location suggests that winter water flow is greater at this location, compared to the medium density location. Discharge may be related to the amount of subsurface flow, which is necessary for egg survival in harsh Arctic conditions. However, it is impossible to adequately compare the subsurface flow between the sites without more in-depth study of temperature and upwelling measurements at each site.

Although the piezometer measurements demonstrated upwelling at all spawning locations sampled, the relative amount of upwelling varied within and between sites. Previous studies have distinguished between subsurface flow and groundwater flow, which both may be contributing to upwelling on the Snake River, by temperature profiles (Leman 1993). Groundwater is characterized by having a constant temperature year-round, whereas subsurface flow is generally warmer in the summer and colder in the winter than groundwater (Leman 1993). The hyporheic temperature profile developed for the Glacier Creek site suggests that the hyporheic flow at that location is influenced by subsurface flow, and not groundwater, although they may be mixing to some extent (Figure 26). It is also likely that the subsurface flow is from Glacier Creek, which empties into the Snake River immediately upstream from the chum salmon spawning site, as well as from the mainstem Snake River. A spawning site supplied by groundwater, as opposed to subsurface flow, results in a more constant development of embryos throughout the winter season, while a spawning site influenced by subsurface flow results in a latent period of embryo development during the coldest months, and therefore a longer emergence time than those embryos that developed in groundwater (Leman 1993). This may be

a significant distinction in chum salmon spawning later in the season, or fall runs of chum salmon, which occur in the Port Clarence district, just North of Norton Sound. Additionally, spawning sites influenced by subsurface flow may have temperature differences of several degrees within a few meters, which exposes developing embryos even within a spawning site to different developmental conditions (Merritt and Raymond 1983). While spawning sites that are influenced by either groundwater or subsurface flow generally do not freeze during winter, those that are dependent on subsurface flow are at a higher risk of mortality due to desiccation during times of low flow (Leman 1993). A more detailed temperature profile for spawning sites of differing density would provide insight into groundwater versus subsurface water influenced spawning sites, and provide information regarding the source of the subsurface flow, whether it is water from the mainstem or the tributaries. This distinction may help to identify factors influencing the differences in spawning density found on the Snake River.

Dissolved oxygen is another important factor in influencing spawning success, and therefore future studies would benefit from more in-depth study of this parameter between sites. Although surface dissolved oxygen was found to be similar between sites of different spawning density, intergravel dissolved oxygen was not measured. Intergravel dissolved oxygen has been shown to be an additional factor influencing favorable spawning habitat in chum salmon in Interior Alaska (Maclean 2003).

Substrate composition influences both dissolved oxygen and temperature because fine materials in the substrate prevent adequate water flow, which in turn lowers the available dissolved oxygen for the developing embryos, and may create a temperature stratification due to lower mixing potential with stream water (Malcolm et al. 2002). At all of the sites studied, the spawning activity took place on the side of the river with the highest concentration of gravel. However, sand still represented a significant proportion of the substrate composition within the spawning areas. In areas that have less subsurface flow, including the Snake River downstream from the Nome Teller Highway, the higher concentration of fine materials may be further limiting upwelling potential. The temperature probe collecting instream water temperature data at the Snake River enumeration camp site, located roughly halfway between the Nome-Teller Highway bridge and the mouth of the Snake River, recorded freezing temperatures on the river bottom, indicating no subsurface flow, although flowing water in river kept the temperature from going far below freezing. Future studies could determine the influence of these fine materials on the spawning success of the sites by investigating water temperature and dissolved oxygen at different substrate depths.

Winter habitat characteristic measurements posed a significant logistical problem that must be considered in future studies. All areas selected for in-depth study were spawning areas, and therefore were associated with open water in winter. This open water made travel dangerous and measurements were occasionally impossible due to safety concerns. Also, discharge measurements were not possible during winter due to the low water levels and low flows experienced under the ice. Fall discharge measurements were challenging as well because the flow meter froze each time it was lifted out of the water. Winter conditions also made dissolved oxygen measurements challenging because the membrane would freeze once the probe was lifted out of the water, making subsequent measurements inaccurate. However, the importance of

winter measurements supercedes the difficulties associated with winter fieldwork because of the critical habitat differences which may only be observed during the colder temperatures.

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Table 1. Discharge (measured in cubic feet per second (cfs)) at four sites on the Snake River.

Site	Date	Discharge(cfs)
Bangor Creek	8/3/05	37.5
	8/10/05	66.8
	10/26/05	86.9
	3/23/06	n/a*
Boulder Creek	8/10/05	82.8
	10/26/05	115.0
	3/16/06	n/a*
Glacier Creek	8/10/05	135.6
Rowe's Cabin	8/10/05	74.7

* water flow under the ice was too small to measure

Table 2. Dissolved oxygen, surface water temperature, conductivity, salinity, ice depth, maximum water depth under the ice and maximum snow depth on top of the ice at sites on the Snake River.

Site	Date	Water Temperature (^{o}C)	Dissolved Oxygen (%)	Conductivity (uS)	Salinity (ppt)	Ice depth (m)	Water Depth (m)	Snow Depth (m)
Bangor Cr	8/7/05	8.9	95.8	169.1	-	-	-	-
	10/26/05	0.6	110.0	-	-	-	-	-
	3/23/06	0.3	98.3	-	-	0.53	0.52	0.05
Boulder Cr	8/7/05	9.1	100.9	164.6	0.1	-	-	-
	10/26/05	0.3	112.0	-	-	-	-	-
	3/16/06	0.0	95.0	-	-	0.10	0.60	0.00
Glacier Cr	8/7/05	9.4	100.4	159.0	0.1	-	-	-
Rowe's Cabin	8/7/05	8.9	97.3	169.0	0.1	-	-	-

Table 3. Vertical hydraulic gradient (VHG) at sites on the Snake River in 2005. A total of three piezometers (P1, P2, P3) were placed at each site.

			VHG	
Site	Date	P1	P2	P3
Bangor Creek	9/3/05	0.067	0.077	0.037
	10/26/05	-	-	0.040
	3/23/06*	-	-	-
Boulder Creek	8/18/05	0.027	0.037	0.048
	9/3/05	0.013	0.027	0.040
	10/26/05	-	-	0.048
	3/16/06*	-	-	-
Glacier Creek	8/18/05	0.064	0.000	0.021
	9/3/05	0.013	-	-

* Piezometers were lost under the ice

Table 4. Habitat measurements, including habitat type, length of section, relative % composition of substrate, relative % composition of available cover, wetted width (WW), bank full width (BFW), right bank height (RBH), left bank height (LBH), bank full height (BFH), mean depth of the river at ¼, ½, and ¾ distance from the right bank, and gradient, for the entire section of the Snake River from the Nome-Teller Highway to the confluence of Glacier Creek.

				% Substrate				% Cover				Measurements					Mean Depth (cm)			
Date	GPS (03W)	Habitat Type	Length (m)	Boulder	Cobble	Gravel	Fine	Cut Bank	Deep Pool	Instream Veg	Outstream Veg	WW (m)	BFW (m)	RBH (cm)	LBH (cm)	BFH (cm)	1/4	1/2	3/4	Grad-ient %
7/11	047559 7160037	GLIDE	162.0	0	0	60	40	10	50	5	20	17	37	180	115	180	120	68	50	3%
7/11	0475707 7160041	RIFFLE	103.5	0	0	60	40	10	5	5	10	25	64	110	50	75	35	45	25	1%
7/20	0475673 7160115	GLIDE	174.5	0	0	50	50	5	0	15	10	19	39	40	200	200	25	50	85	1%
7/20	0475583 7160251	RIFFLE	72.0	0	10	60	30	5	5	10	5	18	48	50	115	115	50	40	25	1%
7/20	0475648 7160275	GLIDE	214.0	5	30	50	15	5	10	40	45	18	37	30	160	200	40	50	60	1%
7/20	0475792 7160452	RIFFLE	79.0	0	40	40	20	5	20	10	50	20	80	85	30	160	40	45	30	1%
7/20	0475758 7160528	GLIDE	103.0	0	20	70	10	5	0	10	20	19	40	120	110	180	15	50	70	1%
7/20	0475701 7160602	RIFFLE	97.0	5	20	60	15	5	0	5	30	23	48	70	150	200	35	50	40	1%
7/21	0475660 7160705	GLIDE	47.0	0	10	70	20	10	5	5	40	15	95	120	110	160	30	80	110	1%
7/21	0475665 7160744	RIFFLE	28.0	0	30	50	20	0	0	5	5	16	107	200	180	180	30	35	80	1%
7/21	0475684 7160764	GLIDE	52.0	5	30	50	15	5	20	5	60	16	92	200	65	170	50	70	70	1%
7/21	0475728 7160786	RIFFLE	63.0	15	30	50	5	0	20	20	10	25	93	200	110	240	47	62	130	1%

Table 4. Continued.

				% Substrate				% Cover				Measurements					Mean Depth (cm)			
Date	GPS (03W)	Habitat Type	Length (m)	Boulder	Cobble	Gravel	Fine	Cut Bank	Deep Pool	Instream Veg	Outstream Veg	WW (m)	BFW (m)	RBH (cm)	LBH (cm)	BFH (cm)	1/4	1/2	3/4	Grad-ient %
7/21	0475791 7160778	GLIDE	401.0	10	50	30	10	5	5	10	50	28	45	90	80	120	60	20	20	1%
7/21	0476083 7160715	RIFFLE	146.0	5	60	30	5	0	0	5	10	24	86	80	70	90	12	20	35	1%
7/21	0476051 7160854	GLIDE	303.0	5	10	60	25	0	5	5	40	25	51	70	40	170	70	80	40	1%
7/21	0476051 7161158	POOL	32.0	5	5	10	80	0	95	0	0	25	44	65	40	110	200	200+	110	
7/21	0476040 7161190	RIFFLE	14.0	5	30	50	15	0	0	0	5	20	34	90	50	100	60	70	35	1%
7/21	0476035 7161190	POOL	87.0	35	10	40	15	10	55	10	25	11	26	50	110	110	85	200+	140	1%
7/21	0475975 716147	GLIDE	52.0	5	80	10	5	5	0	20	60	17	26	80	85	130	40	45	50	1%
7/21	0475972 7161308	RIFFLE	199.0	40	40	10	10	5	0	5	50	15	22	40	50	100	40	50	55	-1%
7/22	0476021 7161494	POOL	93.0	25	10	15	50	0	30	5	25	20	43	30	110	120	28	40	120	%
7/22	0476070 7161541	GLIDE	31.0	0	20	70	10	0	0	10	20	16	27	25	100	110	20	55	70	%
7/22	0476221 7161434	GLIDE	145.0	10	40	30	20	15	10	15	60	15	47	105	45	160	25	40	55	%
7/22	0476257 7161466	RIFFLE	43.0	20	40	35	5	10	0	20	30	32	39	110	150	120	60	30	30	
7/22	0476362 716103	GLIDE	172.0	10	60	20	10	10	5	15	70	10	34	100	80	100	90	70	30	
7/22	0476353 7161702	RIFFLE	87.0	0	30	60	10	40	0	5	10	20	42	60	40	100	20	20	25	

Table 4. Continued.

				% Substrate				% Cover				Measurements					Mean Depth (cm)			
Date	GPS (03W)	Habitat Type	Length (m)	Boulder	Cobble	Gravel	Fine	Cut Bank	Deep Pool	Instream Veg	Outstream Veg	WW (m)	BFW (m)	RBH (cm)	LBH (cm)	BFH (cm)	1/4	1/2	3/4	Grad-ient %
7/23	0476340 7161741	GLIDE	33.0	0	40	5	55	10	0	20	40	17	26	55	80	80	30	10	40	
7/23	0476336 7161763	RIFFLE	24.0	0	10	80	10	20	0	10	40	17	20	50	115	115	32	20	15	
7/23	0476333 7161786	GLIDE	73.0	0	0	40	60	30	0	30	20	15	18	60	100	100	17	38	50	
7/23	0476321 7161830	RIFFLE	60.0	0	10	80	10	30	0	10	10	20	26	40			25	10	28	
7/23	0476346 7161877	GLIDE	37.0	0	5	80	15	10	15	30	40	6	9	80	70	80	5	60	90	
7/23	0476390 7161930	RIFFLE	125.0	0	10	80	10	5	0	15	40	48	51	120	40	120	28	5	8	
7/23	0476501 7161961	GLIDE	168.0	0	15	75	10	10	40	10	15	16	30	50	70	70	30	75	150	
7/23	0476669 7162014	RIFFLE	22.0	0	5	90	5	20	0	5	30	21	60	30	70	70	10	20	60	
7/23	476702	GLIDE	450.0	0	5	20	75	20	5	20	35	29	32	130	70	130	30	60	85	
7/23	0476923 716674	RIFFLE	85.0	10	40	30	20	70	0	5	5	20	42	40	60	60	60	30	10	
7/23	0476983 7161628	GLIDE	112.0	0	5	30	65	10	5	10	30	20	31	160	60	160	65	150	170	
7/23	0477032 7161579	RIFFLE	18.0	0	5	65	30	0	0	0	20	22	46	20	30	30	10	15	90	
7/23	0477051 7161584	GLIDE	621.0	5	10	60	25	5	5	15	20	21	27		40		38	50	60	

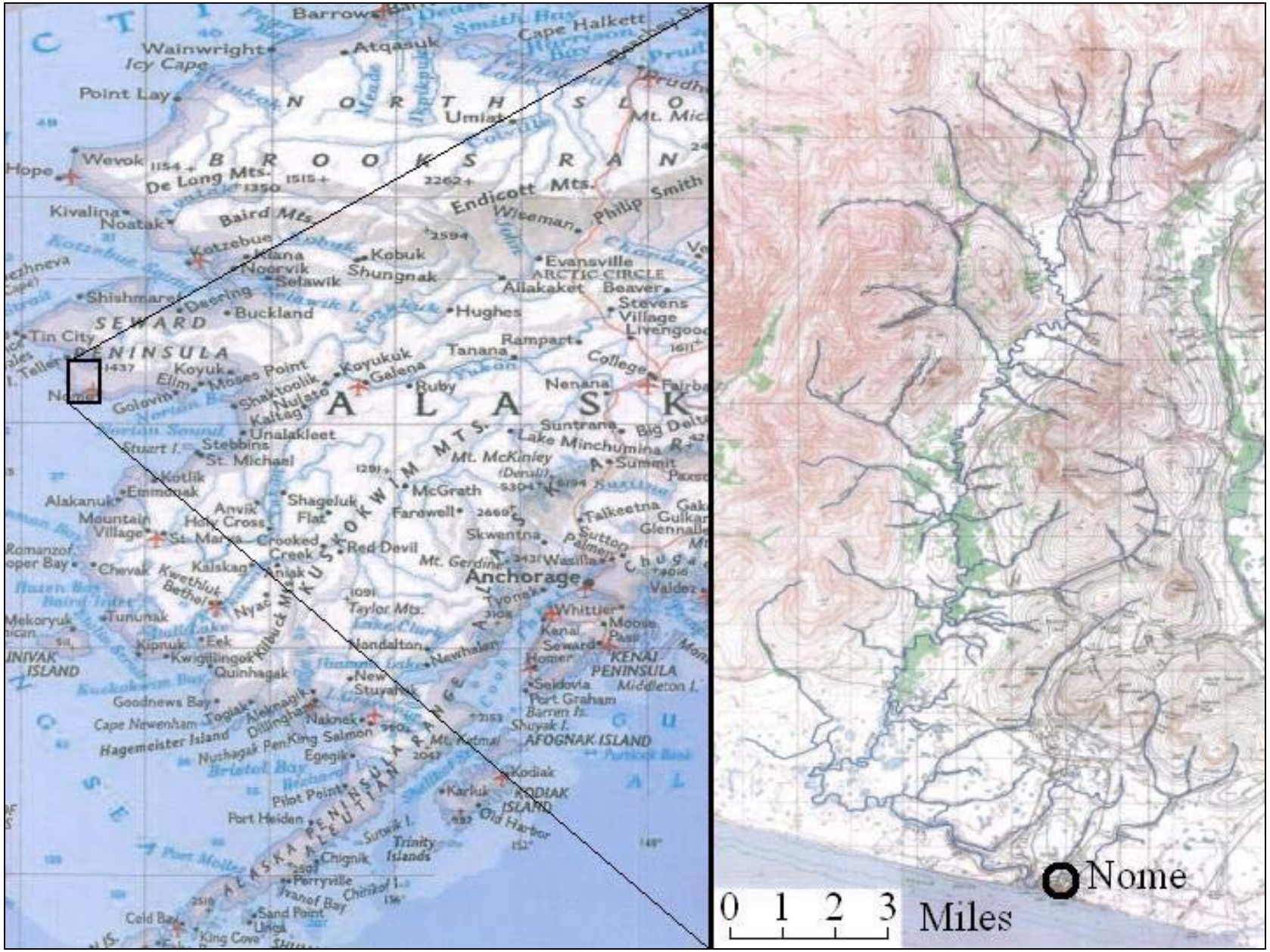

Figure 1. Map showing the location of the Snake River in Norton Sound, Alaska

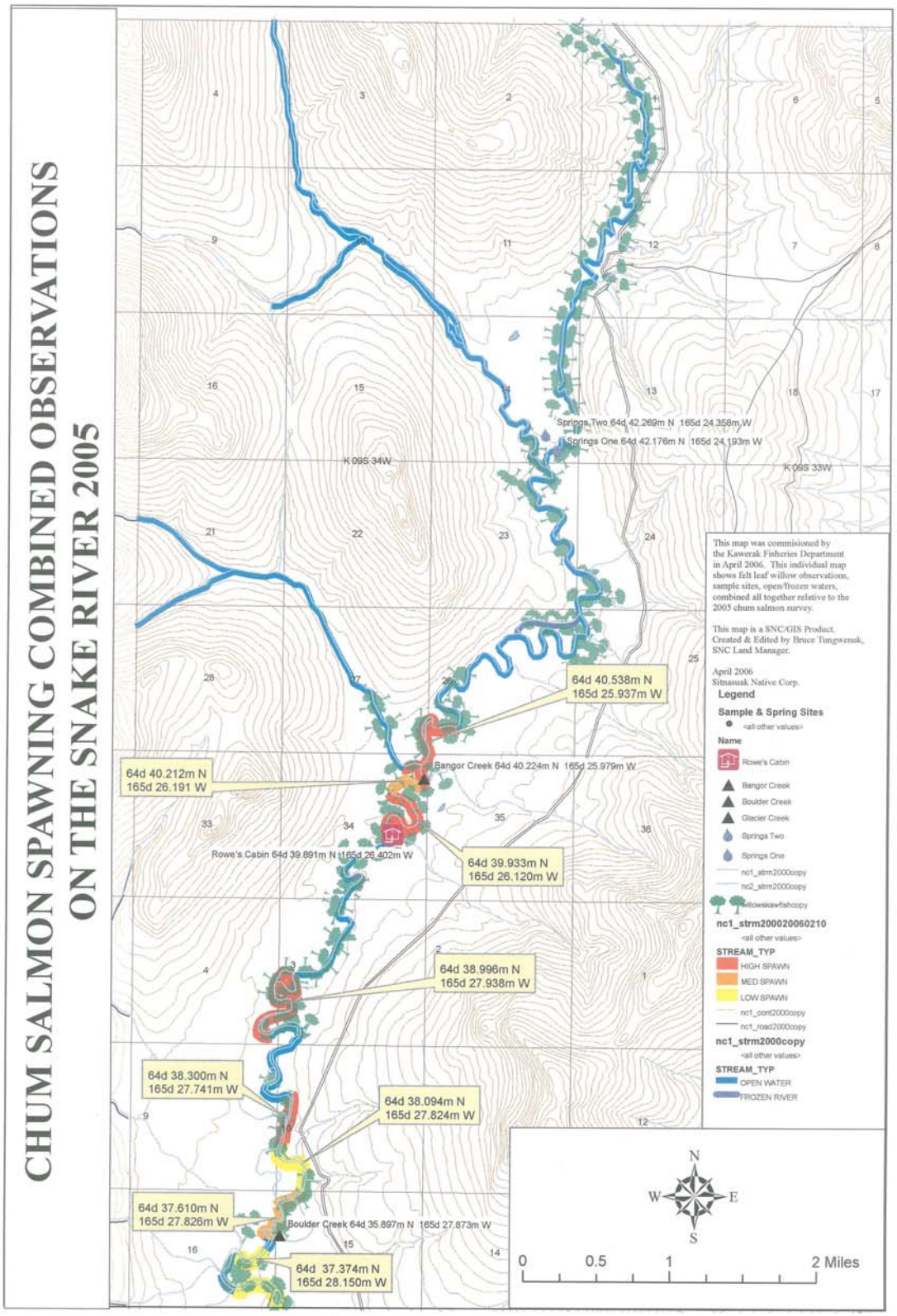

Figure 9. Chum salmon spawning sites, areas of felt leaf willow, and areas of open water and frozen water on the upper Snake River, 2005.

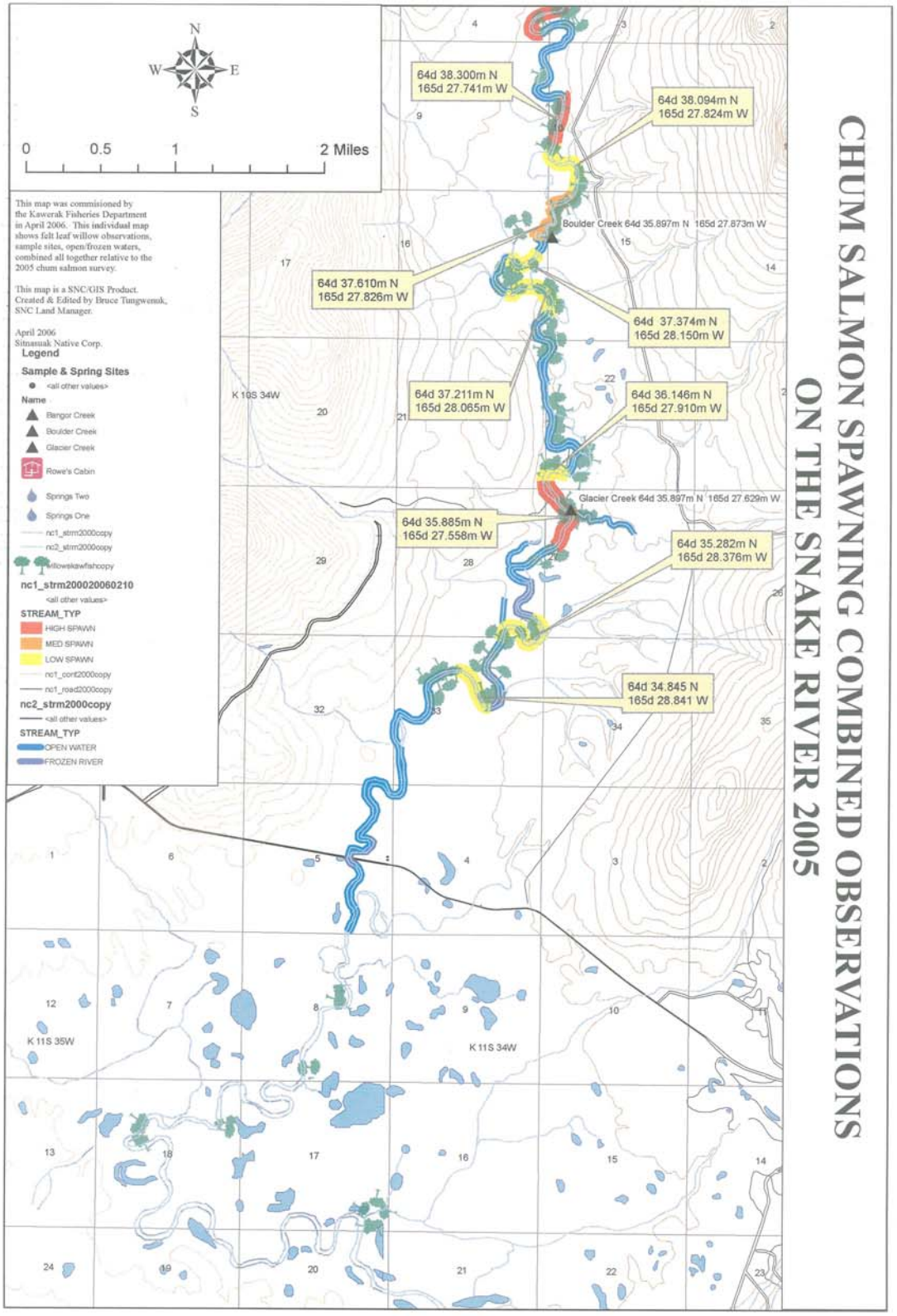

Figure 10. Chum salmon spawning sites, areas of felt leaf willow, and areas of open water and frozen water on the lower Snake River, 2005.

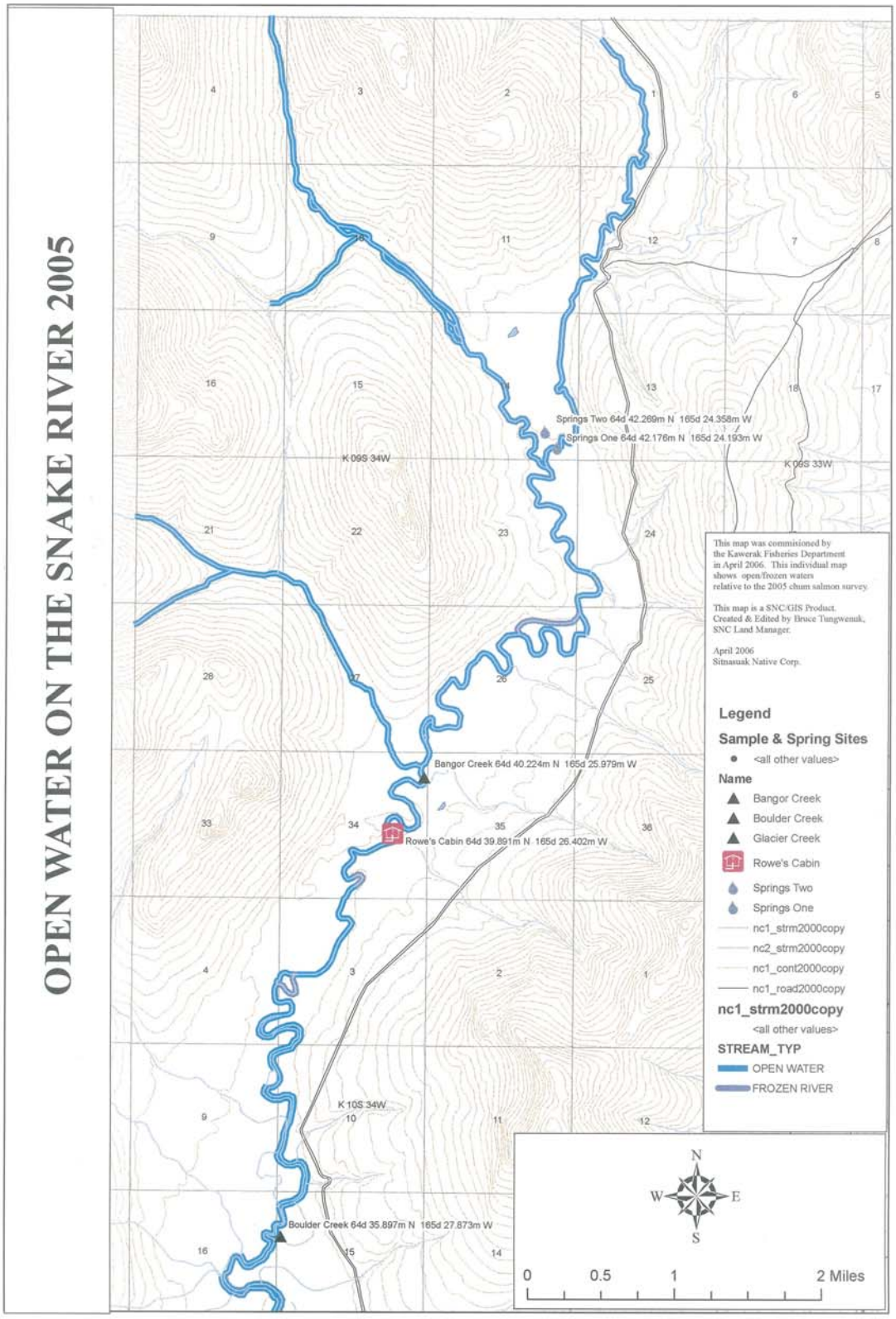

Figure 11. Areas of open water (in blue) and frozen water (purple) on the upper Snake River, 2005.

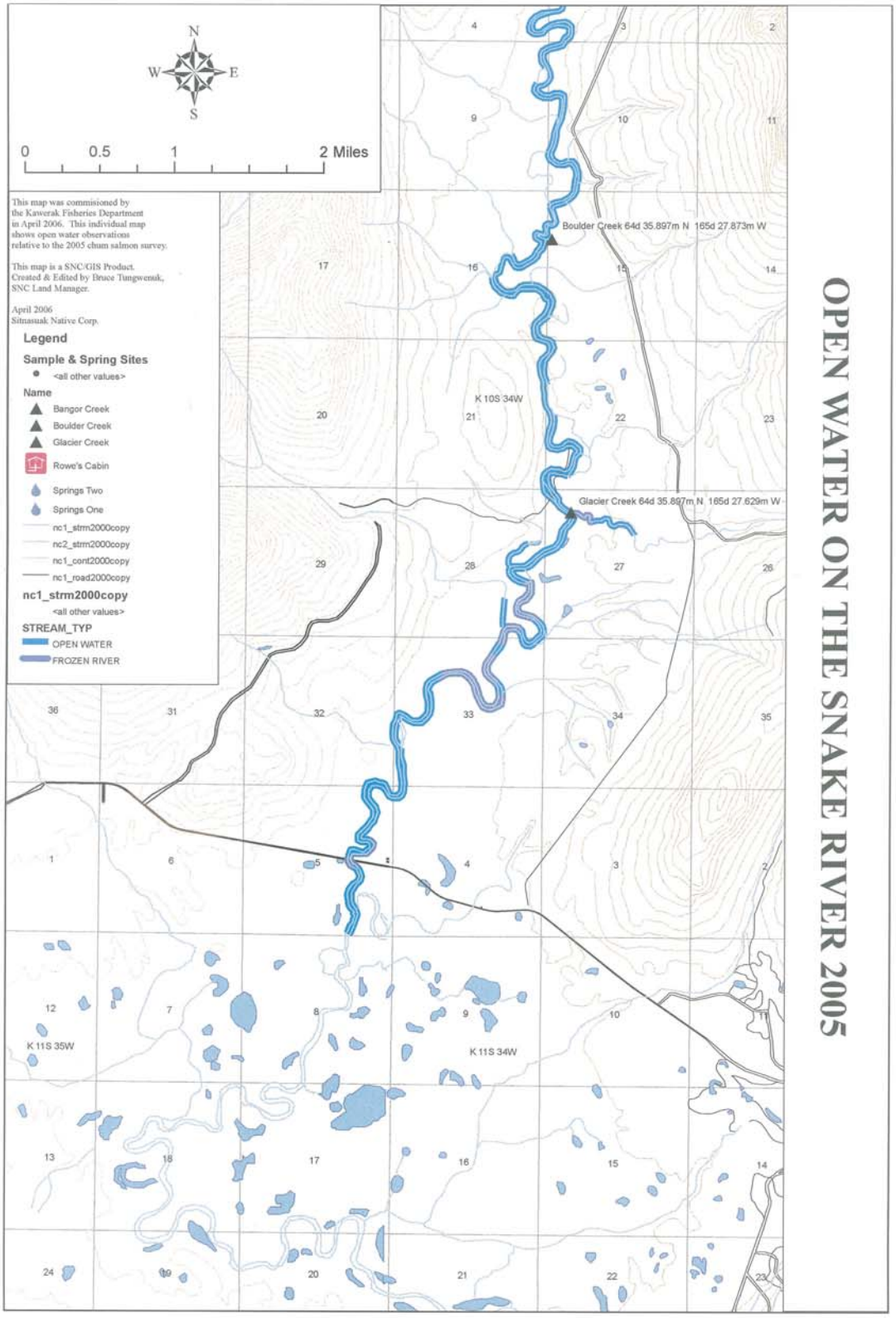

Figure 12. Areas of open water (in blue) and frozen water (purple) on the lower Snake River, 2005.

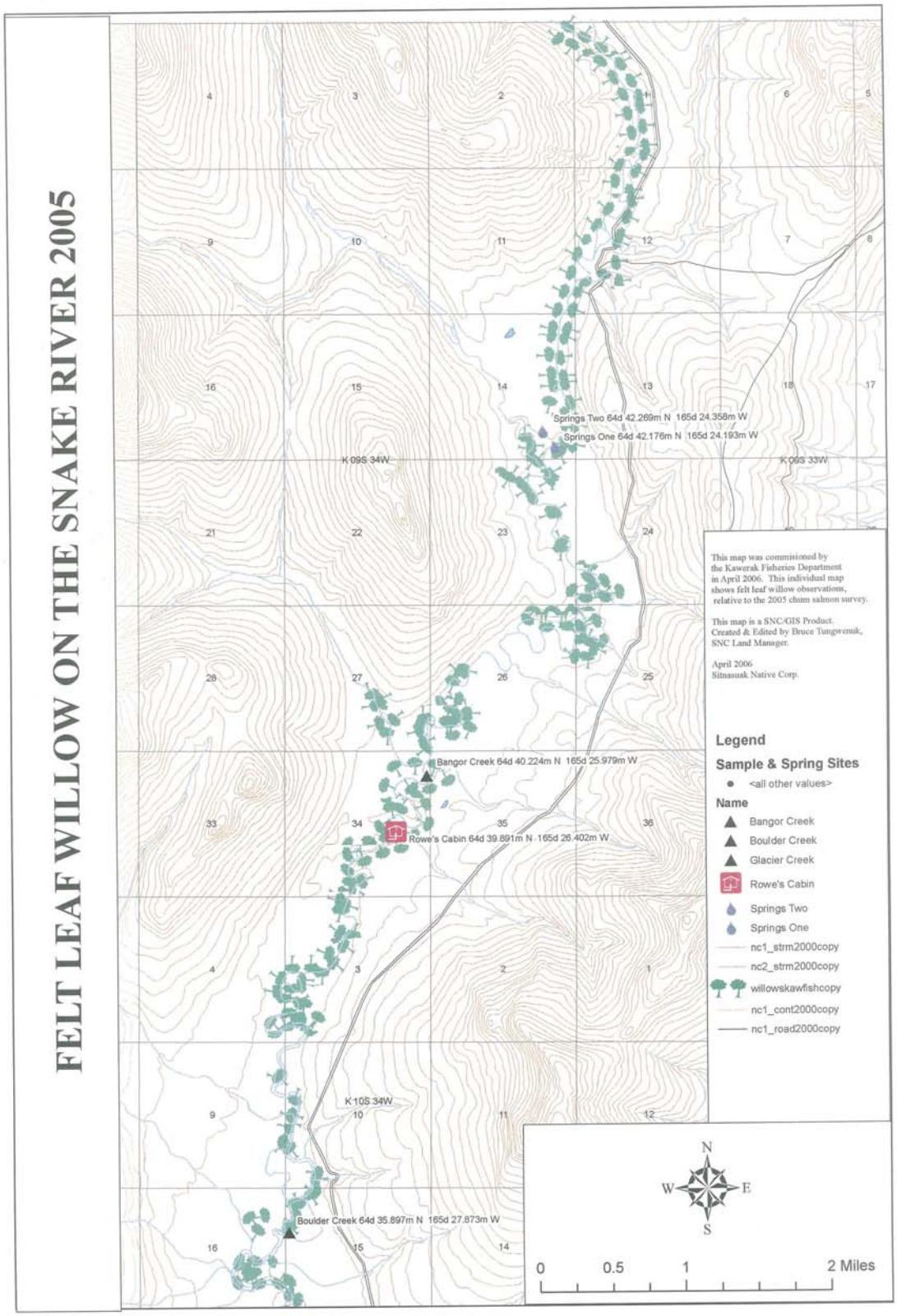

Figure 13. Areas of felt leaf willow (marked by the tree symbol) on the upper Snake River, 2005.

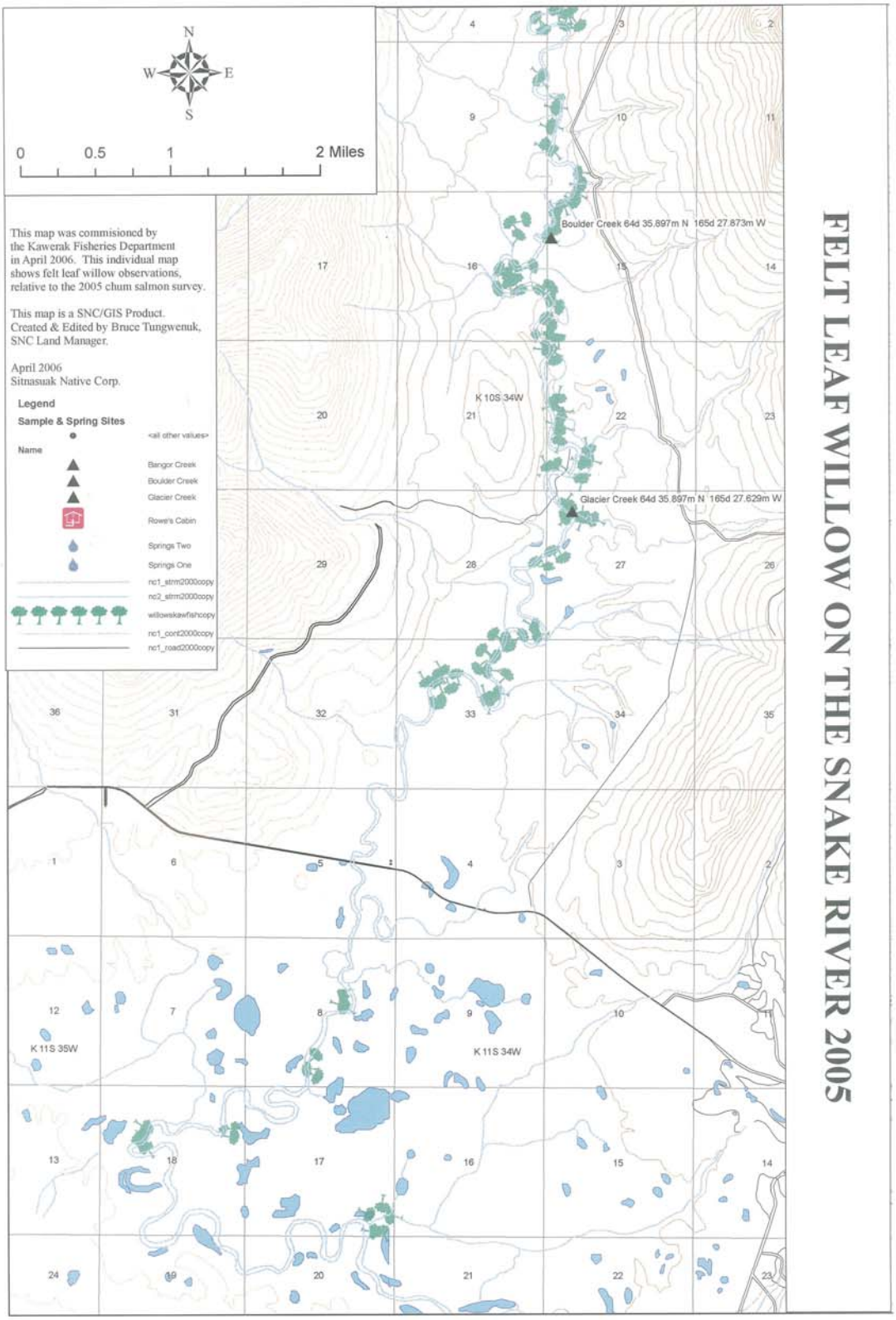

Figure 14. Areas of felt leaf willow (marked by the tree symbol) on the lower Snake River, 2005.

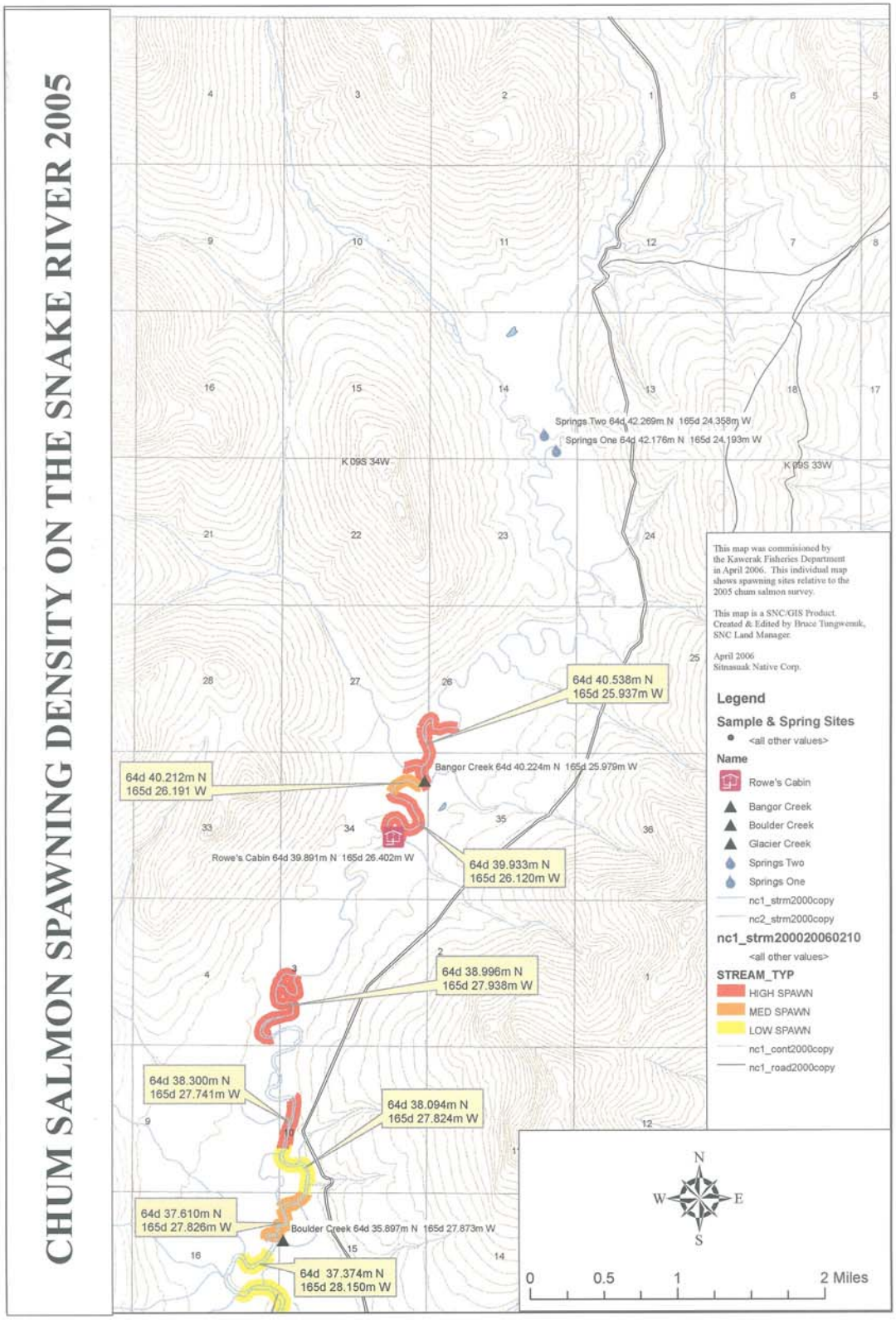

Figure 15. Chum salmon spawning sites categorized by relative density of spawners (high, medium or low) on the Upper Snake River, 2005.

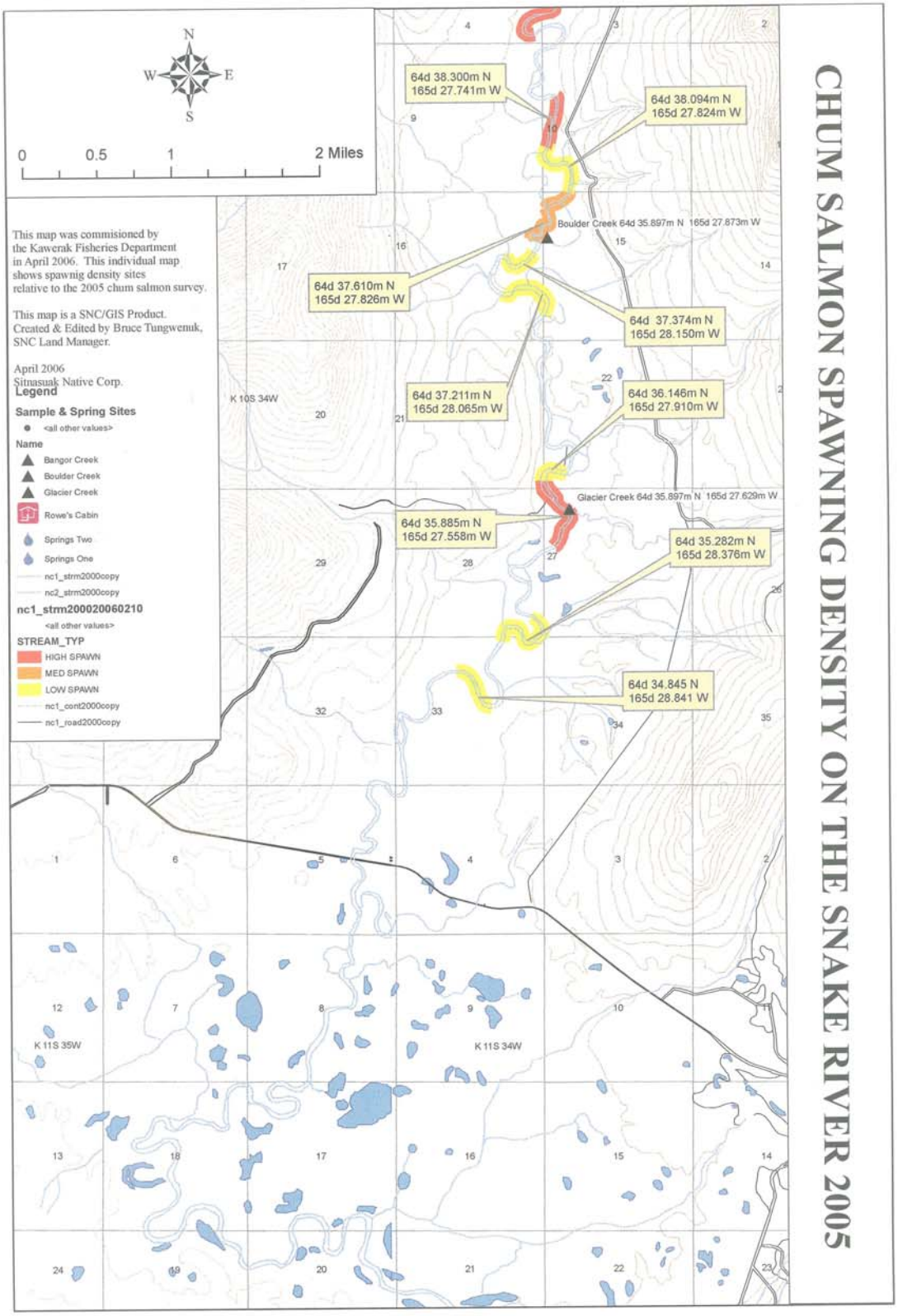

Figure 16. Chum salmon spawning sites categorized by relative density of spawners (high, medium or low) on the lower Snake River, 2005.

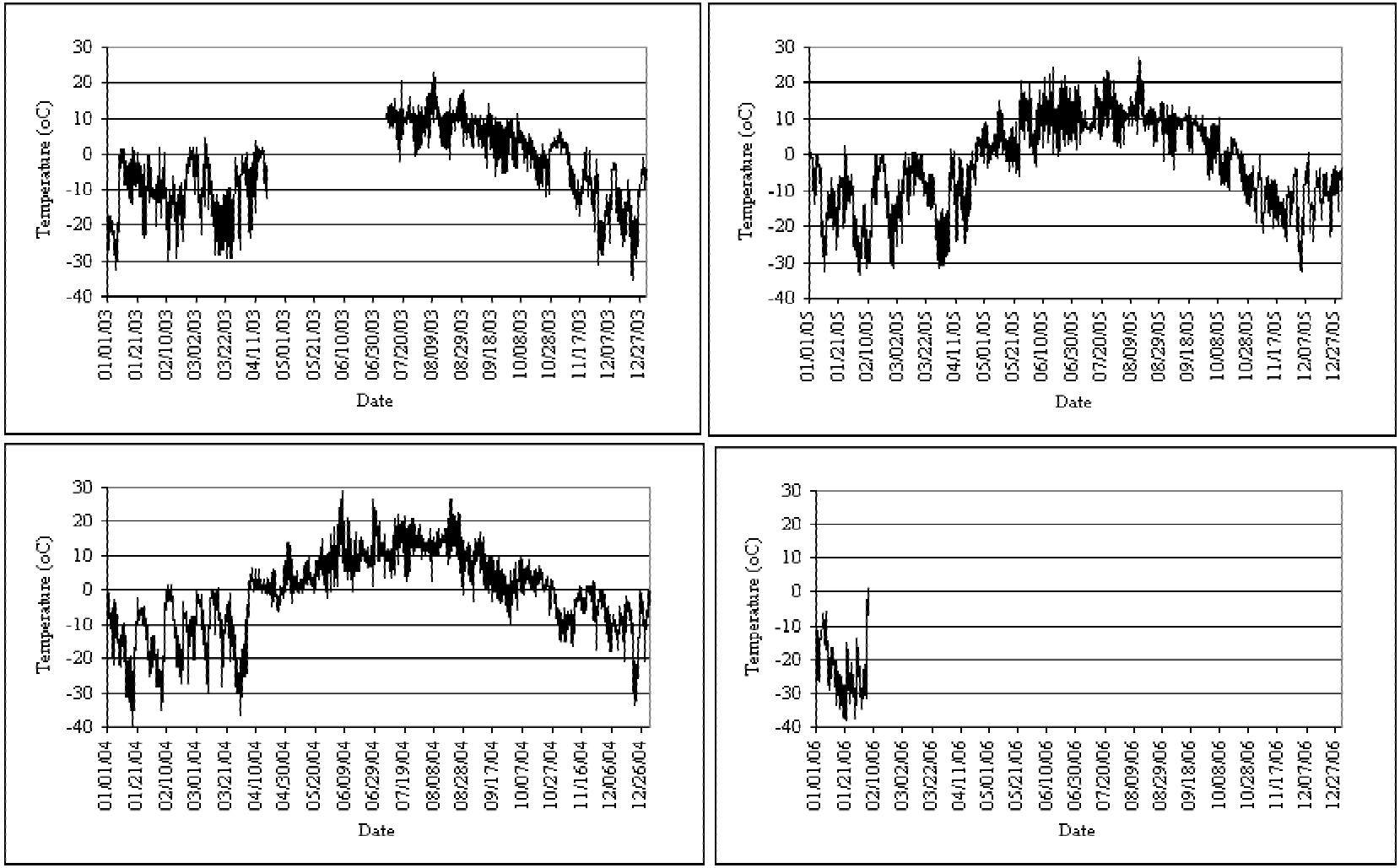

Figure 17. Snake River air temperature recorded at the enumeration camp (2003-2006). Data from Kroeker and Dunmall (2006).

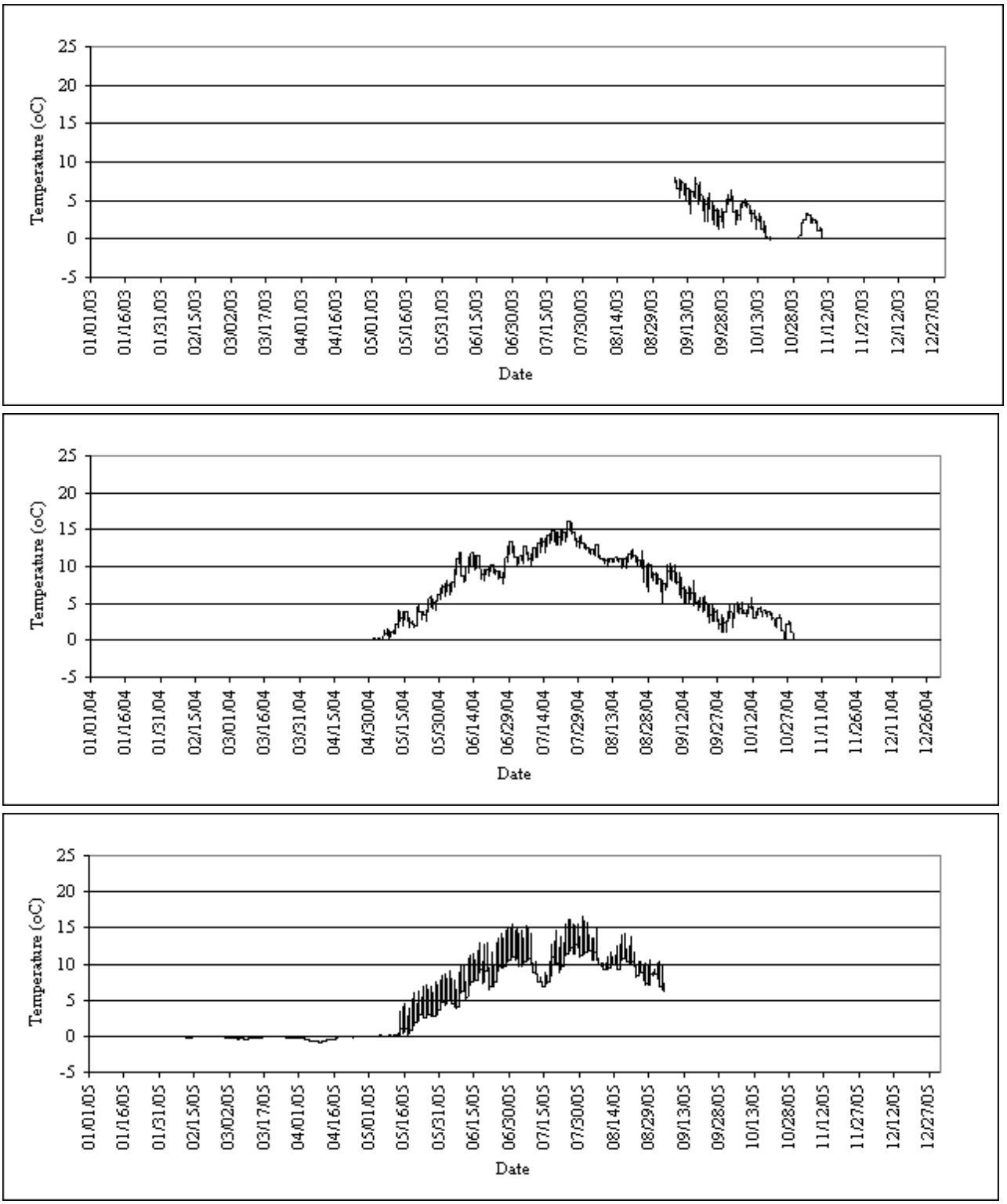

Figure 18. Snake River instream water temperature recorded at the enumeration camp (2003-2005). Data from Kroeker and Dunmall (2006).

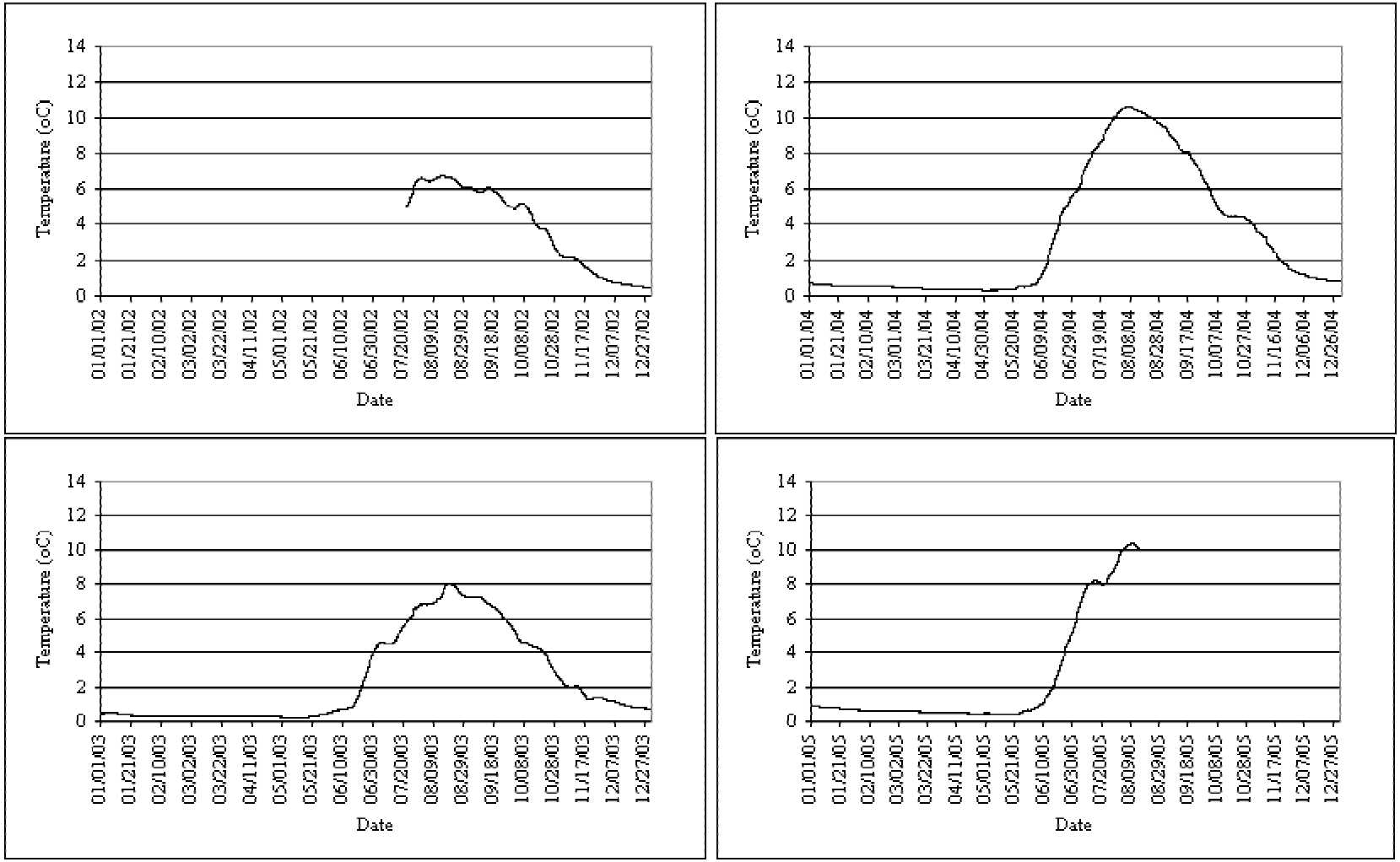

Figure 26. Hyporheic temperature collected at the Glacier Creek site, Snake River, in 2002 (A), 2003 (B), 2004 (C), and 2005 (D). (Data from Kroeker and Dunmall 2006).

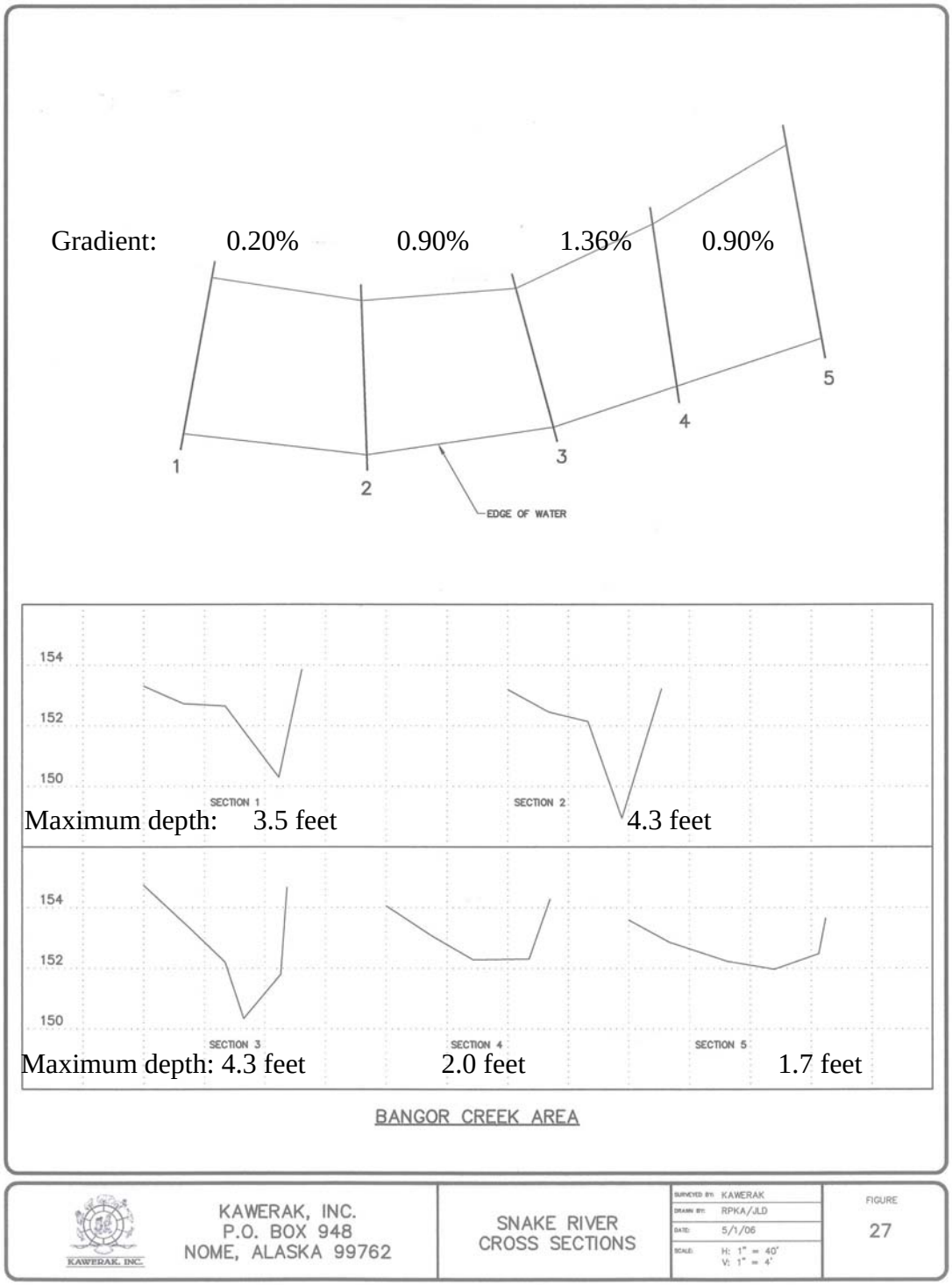

Figure 27. Cross sectional profiles of the Snake River mainstem riverbed at the Bangor Creek site. The water flows from Transect (Section) 5 to Transect 1.

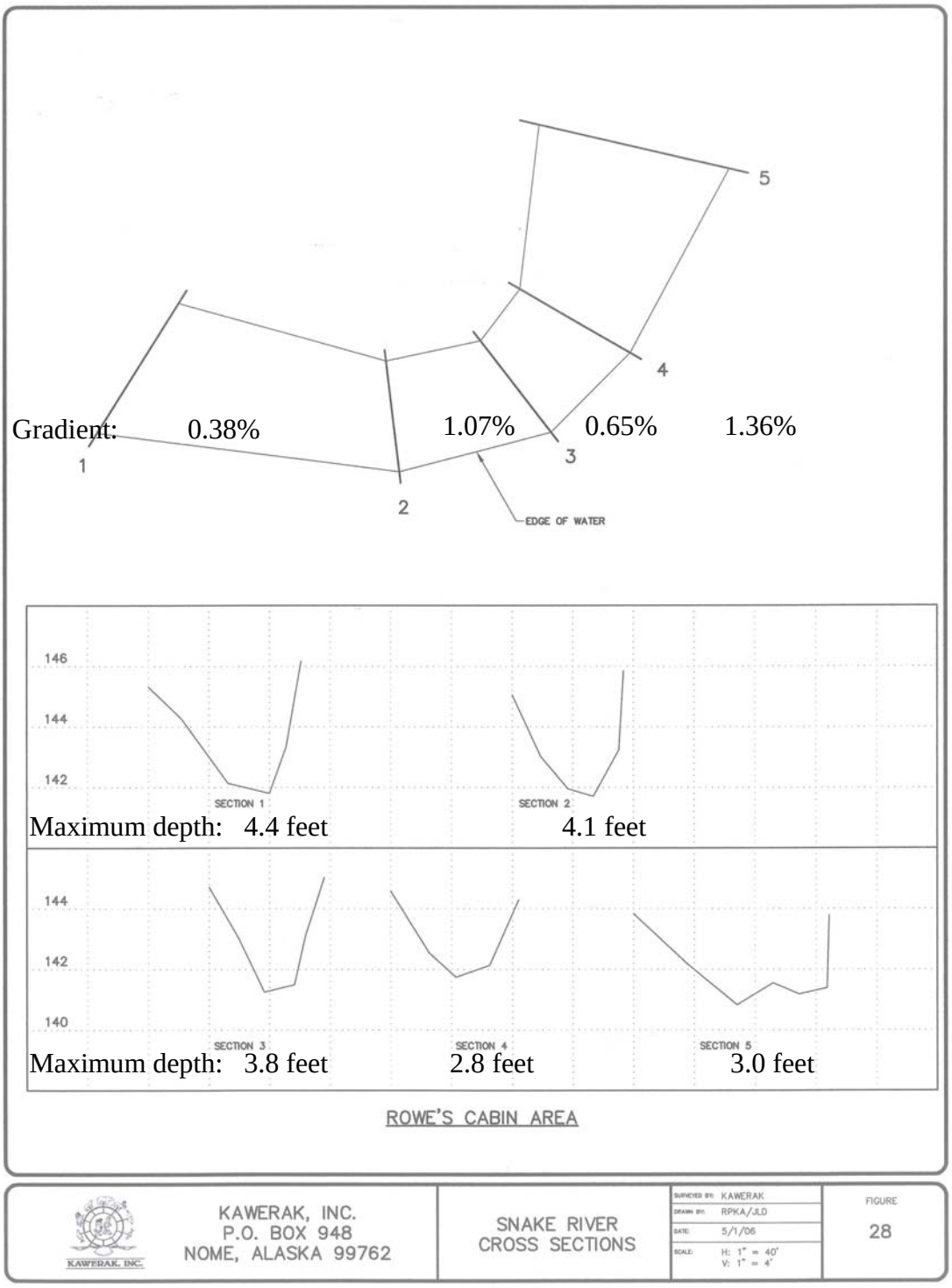

Figure 28. Cross sectional profiles of the Snake River mainstem riverbed at the Rowe's cabin site. The water flows from Transect (Section) 5 to Transect 1.