INVESTIGATION OF SEEPS AND HYDROLOGIC EXCHANGE

BETWEEN

SURFACE WATERS AND THE HYPORHEIC ZONE

FOR SELECTED SECTIONS

OF STREAMS 2002 AND 2004

DRAFT REV. 5

February 02, 2010

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1. INTRODUCTION

Hydrologic exchange between stream surface waters and the hyporheic zone, the portion of the groundwater interface in streams where a mixture of surface water and groundwater are found, is an important factor influencing stream ecological processes. In particular hydrologic exchange influences nutrient cycling, benthic algae productivity, benthic macroinvertebrate distribution and life history patterns (Stanford and Simons 1992; Boulton 1993; Stanford and Ward 1993; Valett et al. 1993; Brunke and Gonser 1997, Boulton et. al. 1998) not to mention the importance for fish spawning (Bjornn and Reiser 1991). Upwelling waters from the hyporheic zone deliver nutrients to the stream channel influencing rates of algal production and benthic community composition (Stanford and Ward 1993). Salmonids in some systems preferentially select spawning sites in areas with high groundwater-–surface water exchange (Baxter and Hauer 2000). These areas of hydrologic exchange may increase egg survival by providing a continual water flow for exchange of nutrients, dissolved oxygen and flushing flows for waste byproducts.

Hydrologic exchange between surface water and shallow groundwater in the hyporheic zone typically exhibits spatial heterogeneity corresponding to landform patterns. At the landscape scale, topography (stream gradient), valley constrictions and geologic uplifts exert a strong influence on areas of hydrologic exchange. Areas of lower stream gradient directly downstream of high gradient sections (including the mainstem and tributary streams) tend to be upwelling zones. Likewise areas of impermeable bedrock downstream of alluvial deposits of gravel and cobble tend to be areas of increased groundwater upwelling. Within confined valley segments areas of increased hydrologic exchange tend to occur at the upstream end (downwelling) and the downstream end of the constriction (upwelling).

The 2007 surface water and hyporheic zone investigation on stream 2003 (Appendix A) documented hydrologic exchange at three geographic scales; landscape, reach and habitat. Reach and landscape scale investigations were undertaken to delineate broader spatial patterns in hydrologic exchange associated with landforms. The landscape scale investigations in 2007 documented spatial grouping of temperature gradients adjacent to steeper hill slopes suggesting hydrologic exchange processes driven by topographic features. In the habitat scale investigation, most adult coho selected downwelling zones for spawning with moderate hydraulic conductivity. The direction of hydrologic exchange, upwelling verses downwelling, was bidirectional driven by slope in the channel bedform, substrate composition, and slope of adjacent uplands.

The 2009 landscape and reach scale study design is very similar to the work done in 2007. The 2009 study objectives on streams 2002 and 2004 included;

1. Characterization of the landscape scale spatial dynamics of the surface water and hyporheic zone interface in streams 2002 and 2004 adjacent to and downstream of the mine boundary by examining water surface temperatures and valley topography;

2. Characterization of the influence of hill slope topography, beaver ponds and wetlands on surface water and hyporheic zone exchange;

3. Assessment of hydrologic exchange in stream reaches adjacent to potential discharge locations on stream 2002;

4. Measurement of the vertical hydraulic gradients within the surface water and hyporheic zone in stream 2002 to characterize the direction of vertical flow at the reach scale, and,

5. Locate and map springs and seeps along the valley sidewalls within the study area.

2. METHODS

The piezometer study was designed to document springs and seeps and areas of hydrologic exchange between surface water and the hyporheic zone in streams 2002 and 2004. In this report, the hyporheic zone refers to the porous interstitial zone up to sixty centimeters (cm) below the channel bed. Field investigations were divided between landscape and reach scale efforts to document the spatial heterogeneity of vertical hydraulic gradients between the surface water and hyporheic zone and document associated landform features influencing these gradients. On stream 2004, field work was limited to landscape scale investigation using water temperature as a surrogate indicator for positive hydrologic exchange. Similar landscape scale field work was conducted on stream 2002. Reach scale investigations on stream 2002 utilized piezometers driven into the hyporheic zone to quantify vertical hydraulic gradients. The field methods were similar to those used on stream 2003 during the 2007 field season and are reviewed below.

2.1 LANDSCAPE SCALE

At the landscape scale, potential areas of exchange between the surface water and hyporheic zone on streams 2002 and 2004 were initially characterized using U.S. Geologic Survey topographic 7.5' quadrangle maps (1:24,000 scale) and aerial photos. Geomorphic variables and surface water features potentially influencing surface water—groundwater exchange were identified. These variables include bounded and unbounded alluvial valley segments, confined valley segments, valley bottom width, stream gradient slope, and proximity to stream confluences and wetland complexes. Baxter and Hauer (2000) characterized bounded alluvial valley segments as "unconfined stream sections at least 500 meters in length and greater than 50 meters in valley bottom width with a downstream geomorphic nickpoint." In streams 2002 and 2004, nickpoints were limited to changes in channel slope and valley width constrictions. In addition, large wetland complexes were identified as features potentially influencing hydrologic exchange.

Portions of streams 2002 and 2004 adjacent to the mine site were traversed longitudinally in August 2009 to measure water temperatures. Field crews walked in an upstream direction measuring stream temperatures. Temperature can be a positive indicator of hydrologic upwelling zones since groundwater is typically several degrees cooler than adjacent surface water temperatures during the summer season (Silliman and Booth 1993). Researchers recorded stream temperatures at the substrate boundary using a Hanna Instruments 93510 thermistor with a 765W temperature probe with an accuracy of ±0.2°C. Stream temperatures were recorded approximately every 50 meters or at features of interest. Features of interest included tributary confluences, side channels, spring seeps, stream habitats, beaver ponds, adjacent wetlands, abrupt changes in upland topography and mainstem surface water temperature changes. Surface water temperature measurement locations were recorded using a Trimble Pathfinder ProXH with sub-30 centimeter post processing accuracy. In addition, all spring seeps were located with a GPS.

To account for diel temperature fluctuations in stream surface water, temperature data was normalized by subtracting a downstream water temperature from an adjacent upstream location

(typically 50 meters or less). This transformation of temperature data eliminated the influence of diel temperature fluctuations on surface water temperatures. Water temperatures in side-channels, spring seeps and tributaries were expressed as the difference between the measured water feature and the adjacent ambient water temperature.

2.2 REACH SCALE

Reach scale investigations were conducted on three reaches located longitudinally within a single contiguous valley segment in the upper half of stream 2002 adjacent to the proposed mine boundary (Figure 2.2-1). Reach lengths ranged from 1200 to 2600 meters. Reaches were located at potential sites for surface water discharge augmentation or locations of specific interest based on the landscape scale field results. Reach 1 overlaps a potential site for surface water augmentation. Reach 2 was located downstream of a second potential site for surface water augmentation. Steeper hill slopes on the west side of stream 2002 intersect with a ridge from the east causing a valley constriction. Reach 3 was located adjacent to a steep ridge constricting the valley width from the west.

2.2.1 Measuring Vertical Hydrologic Exchange

Piezometers in the reach scale investigations were spaced at 10 to 50 meter increments longitudinally. Hydrologic exchange between the surface water and hyporheic zone was quantified by measuring the vertical hydraulic gradient (VHG). VHG was calculated using the following equation:

$$VHG = (hs - hp)/dl$$

Where hs (cm) is the elevation of the stream surface;

hp (cm) is the water surface elevation in the piezometer; and

dl (cm) is the distance from the streambed surface to the depth of the first perforation in the piezometer.

The numerator (hs-hp) represents the difference in hydraulic head between the water surface in the piezometer and the level of the stream surface (the hydraulic head differential). Accordingly, VHG is a unitless measure that is positive under upwelling conditions and negative under downwelling conditions.

Water surface elevation in the piezometer, hp, was measured using a length of tygon tubing stretched from the top of the piezometer to the water surface elevation in the tube. Water surface elevation in the piezometer was determined by blowing air into the tygon tubing until bubbling was heard indicating contact with the water surface. Stream water surface elevation was measured from the top of the piezometer using a tape measure. The depth of the perforations, dl, was determined by calculating the difference between the distance from the streambed surface to a pre-established mark on the piezometer above the stream water surface and a known distance between the first perforation and the pre-established mark.

2.2.2 Piezometer Design and Installation

The piezometer was modeled after a design described by Baxter et al. (2003). The piezometers were constructed from chlorinated polyvinyl chloride (CPVC) pipe 165.1 cm in length with an outside diameter of 1.59 cm and an inside diameter of 1.11 cm. The bottom 15 cm of the piezometer was perforated with 30 evenly spaced holes 0.238 cm in diameter. The bottom end of the CPVC was plugged with a cork. Freeze and Cherry (1979) determined that when the perforated length of the piezometer is more than eight times its radius (Lp/R > 8), equations to estimate hydraulic conductivity by standard methods become relatively straightforward.

Piezometers were installed 30 to 60 cm into the stream substrate using a piezometer driving rod housed in a metal casing. When the desired depth was achieved the piezometer driving rod was removed from the outer casing and replaced with the piezometer. The outer casing was then removed and the piezometer remained in place for 24 hours to equilibrate prior to recording water elevations and hydraulic conductivity.

2.3 OTHER INFORMATION

In addition to the piezometer data listed above, substrate, habitat type, stream character, distance from tow-of-slope, and other pertinent information, including presence of seeps, was recorded. Substrate was described using the Wolman substrate classification (Wolman 1954), habitat type was described as pool, run or riffle, and stream character was described as meander or straight. Distance from tow-of-slope was measured using a Trimble True Pulse 360B laser range-finder and was measured in feet. Seep water quality samples were collected after the Oasis portion of the field program.

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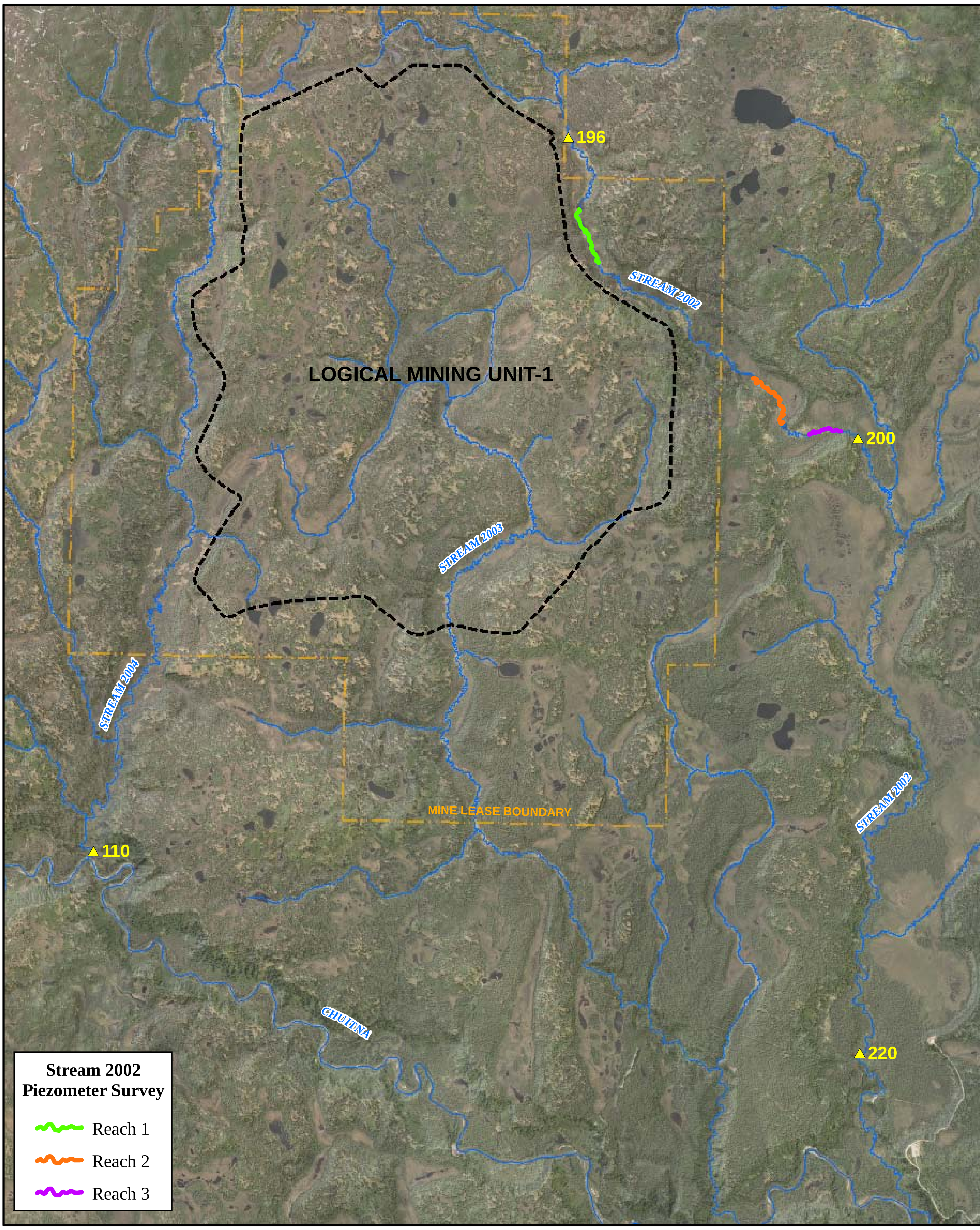

FIGURE 2.2-1
PIEZOMETER REACH LOCATIONS ON
STREAM 2002, AUGUST 2009.

0 750 1,500 3,000 4,500 6,000 Feet

0 250 500 1,000 1,500 Meters

N

1:42,000 1 inch = 3,500 feet

Projection: NAD83 AK State Plane Zone 4 (feet)

CHUITNA COAL PROJECT

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Legend

- Fixed Water Stations
- Project Area Stream
- Logical Mining Unit-1 Boundary
- Lease Boundary

Data Sources:
Stream Piezometer Data, Oasis, 2009.
Mine Infrastructure, Mine Engineers, 2006.
Aerial Orthophotography, Mine Engineers, 2005.

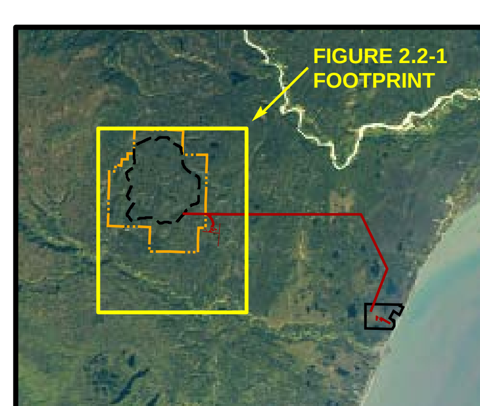

FIGURE LOCATION MAP

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3. RESULTS

The results are divided into the landscape scale temperature mapping in portions of stream 2002 and 2004 as well as investigations of hydrologic exchange between the surface water and hyporheic zone on three reaches on stream 2002. As mentioned previously, the Stream 2003 work conducted in 2007 is included in Appendix A. The results of seep water quality samples collected from all three streams in September 2009 is included in Appendix B.

3.1 LANDSCAPE SCALE INVESTIGATION

Surface water temperatures were measured on streams 2002 and 2004 from August 26 through August 30, 2009. Field staff traversed streams 2002 and 2004 longitudinally in an upstream direction measuring surface water features in the main channel, side channels, tributaries, springs, seeps and beaver ponds (Photos 3.1-1 through 3.1-5).

Photo 3.1-1: Side channel feature

Photo 3.1-2: Tributary features

Photo 3.1-3: Beaver pond feature

Photo 3.1-4: Seep feature

Photo 3.1-5: Mainstem stream channel

3.1.1 Stream 2002

A total of 370 surface water temperatures were measured along a 7873 meter length of stream 2002 over a two-day period, August 28-29, 2009. For comparative purposes, hourly surface water temperature was also obtained from three fixed stations, C220, C200 and C196. The fixed station data displayed strong diel fluctuations for the week of August 25-30, 2009 (Figure 3.1-1). The diel fluctuations were more pronounced at stations C196 and C200 located further upstream in the watershed and both are within the portion of the study included in the landscape scale study area. Station C220 was located further downstream. The increased discharge and adjacent wetlands at fixed station C220 likely buffered diel temperature fluctuations.

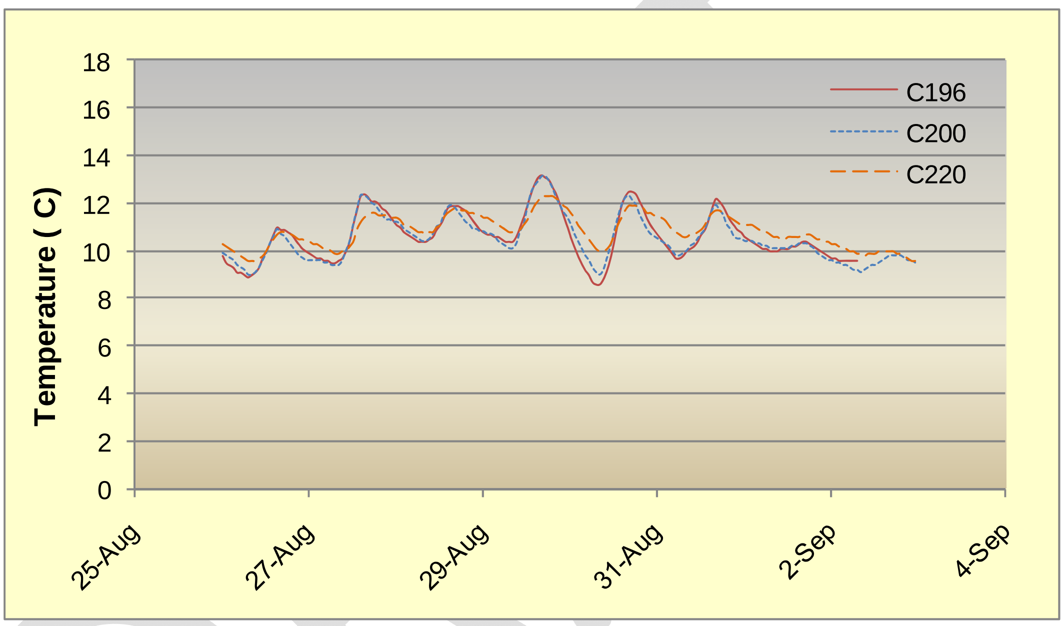

Figure 3.1-1: Hourly temperature data at fixed stations on stream 2002 August 2009

Longitudinal surface water temperatures were categorized by the respective water feature type where the measurement was taken; main channel, side channel, tributary, or spring seep. Temperature differences were observed between the respective water features as well as corresponding daytime water temperatures recorded at the fixed station locations (Figure 3.1-2). Side channels exhibited the highest temperatures recorded in stream 2002, 16.7 °C. Side channels also had the broadest temperature range; 9.6 °C between minimum and maximum. The temperature range in tributaries was 8.0 °C, similar to that observed in side channels. Side channels and tributaries were at times difficult to distinguish in the field due to the combination of tall grasses and shrubs obscuring a view of the source input as well as the meandering character of the stream alternating with wetlands and beaver ponds. In addition, several tributaries joined the mainstem via side channel oxbows. As a result, classifying a source input as a side channel versus a tributary was subjective in some cases (Photo 3.1-5). Mainstem temperatures ranged from a minimum of 7.8 °C to a maximum of 13.6 °C. The median mainstem temperature was 10.6 °C. The median temperature at seeps was 8.5 °C, 2.1 degrees cooler than the mainstem. Surface water temperatures at seeps ranged from a minimum of 4.7

to a maximum of 11.4 °C. Field staff observed rapid warming of seep water temperatures with increasing distance from the source due to solar radiation. In some cases, water temperatures originating from seeps with substantially cooler temperatures increased in the short distance between the source and mainstem to the point where the temperatures were on par with the mainstem or substantially warmer due to the small discharge volume. As a result, seep water temperature measurements varied substantially in the field dependent on the lateral proximity to the mainstem channel.

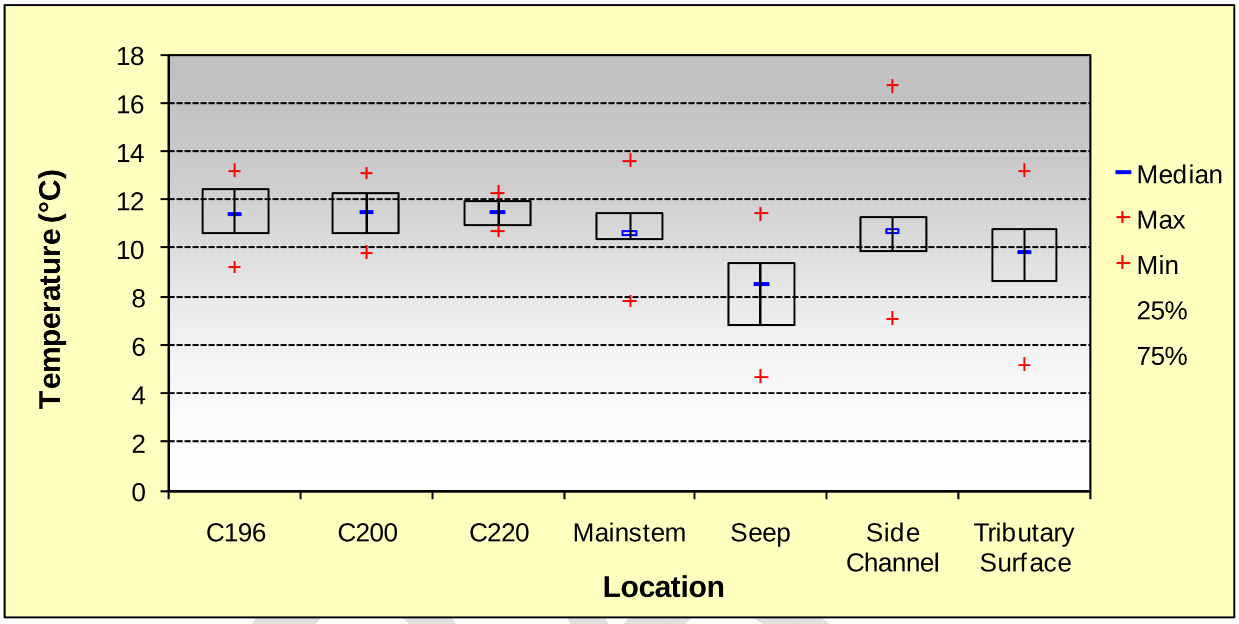

Figure 3.1-2: Box-Whisker plot of water temperatures on stream 2002 August 28-29, 2009

The longitudinal surface water temperatures were normalized to eliminate the diel temperature fluctuations observed at fixed station thermographs. Normalizing temperatures enabled spatial comparisons of water temperature without the temporal influence associated with solar radiation. Normalized water temperature data was overlayed on a map of stream 2002 to better understand longitudinal stream temperature patterns, in particular, the relationship between topographic features and coldwater upwellings at spring and seep locations (Figures 3.1-3 and 3.1-4). Water temperatures were grouped in 1 °C increments. Cooler water temperatures were found in sections of stream 2002 where the valley width was narrow, constricted by steeper hill slopes. This was evident in the upper end of stream 2002 as well as several locations where ridges and steep hill slopes protruded into the valley longitudinal axis. In these locations, springs and seeps were observed more frequently (Photo 3.1-6 and 3.1-7). The small volume of these springs and seeps did little to alter the water temperature in the adjacent mainstem. In sections of stream 2002 where the valley floor was wider, springs and seeps emerged at the toe of the adjacent hill slope. The flow pathway for these springs and seeps was typically along abandoned side channels eventually connecting into the mainstem (Photo 3.1-8 and 3.1-9). Water temperature in the side channels was typically considerably warmer relative to the spring source due to the low water velocities and solar heating along the low gradient channels. In some cases, these side channels were considerable warmer than the mainstem. Beaver ponds also tended to have warmer surface water temperatures than the mainstem due to solar

radiation on the surface waters. Vertical temperature gradients were not measured in the beaver ponds.

Photo 3.1-6: Spring creating side channel feature

Photo 3.1-7: Seeps along cut bank

Photo 3.1-8: Side channel draining spring to adjacent mainstem

Photo 3.1-9: Low volume side channel fed by spring

3.1.2 Stream 2004

On stream 2004, a total of 302 surface water temperatures were measured along a 7961 meter length over a two-day period, August 26-27, 2009. Using a helicopter field staff skipped over a section of the stream inundated by a large beaver dam complex. Water depth prevented the researchers from traversing this section. Hourly surface water temperatures were obtained from the C110 fixed station located downstream of the study area on Stream 2004 for comparative purposes. Diel temperature fluctuations similar to those observed in stream 2002 were observed in stream 2004 (Figure 3.1-5). Corresponding daytime surface water temperatures at C110 ranged from a minimum of 9.3 °C to a maximum of 12.3 °C (Figure 3.1-6). In comparison, the mainstem temperatures measured by staff traversing the length of the stream ranged from 8.1 to 13.1 °C with a median of 10.2 °C. Side channel temperatures ranged from 8.6 to 14.9 °C

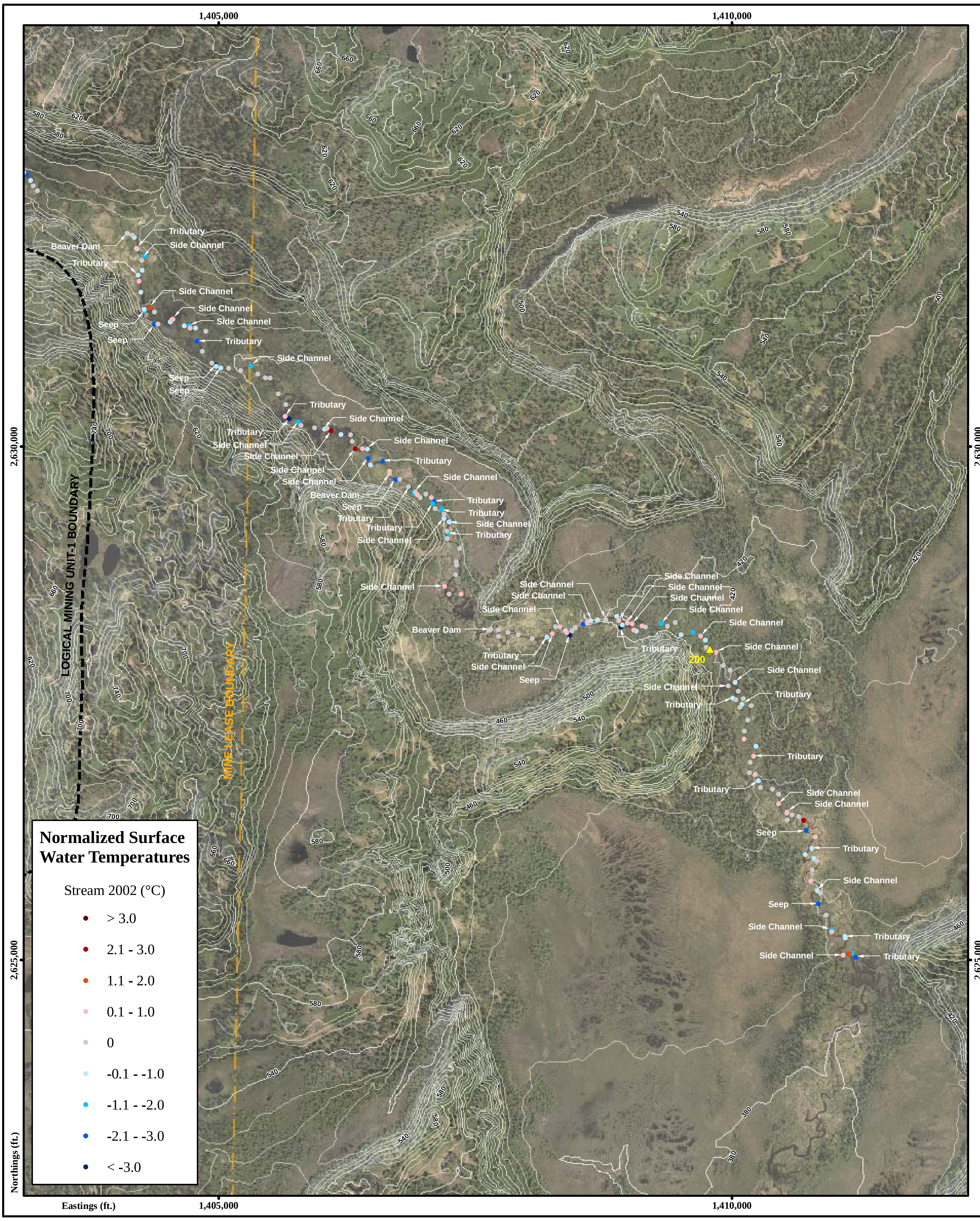

FIGURE 3.1-3

NORMALIZED SURFACE WATER TEMPERATURE ON THE LOWER PORTIONS OF STREAM 2002; AUGUST 28-29, 2009.

0 250 500 1,000 1,500 Feet

0 75 150 300 450 Meters

1:12,000 1 inch = 1,000 feet

Contour Interval: 10 ft. (AMSL)

Projection: NAD83 AK State Plane Zone 4 (feet)

Legend

Fixed Water Station & ID

Logical Mining Unit-1 Boundary

Lease Boundary

Data Sources:

Stream Temperature Data, Oasis, 2009.
Mine Infrastructure, Mine Engineers, 2006.
Contours, Mine Engineers, 2006.
Aerial Orthophotography, Mine Engineers, 2005.

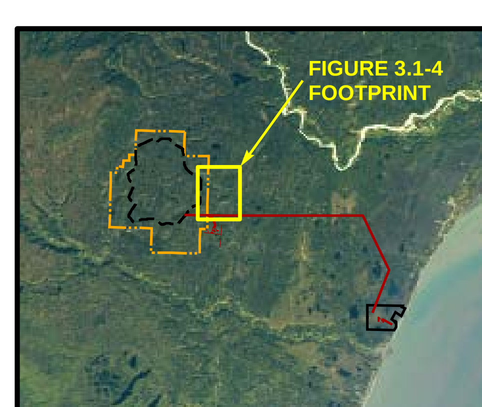

FIGURE LOCATION MAP

CHUITNA COAL PROJECT

PACRIM COAL

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Anchorage, AK 99501 USA
Phone: (907) 276-6868

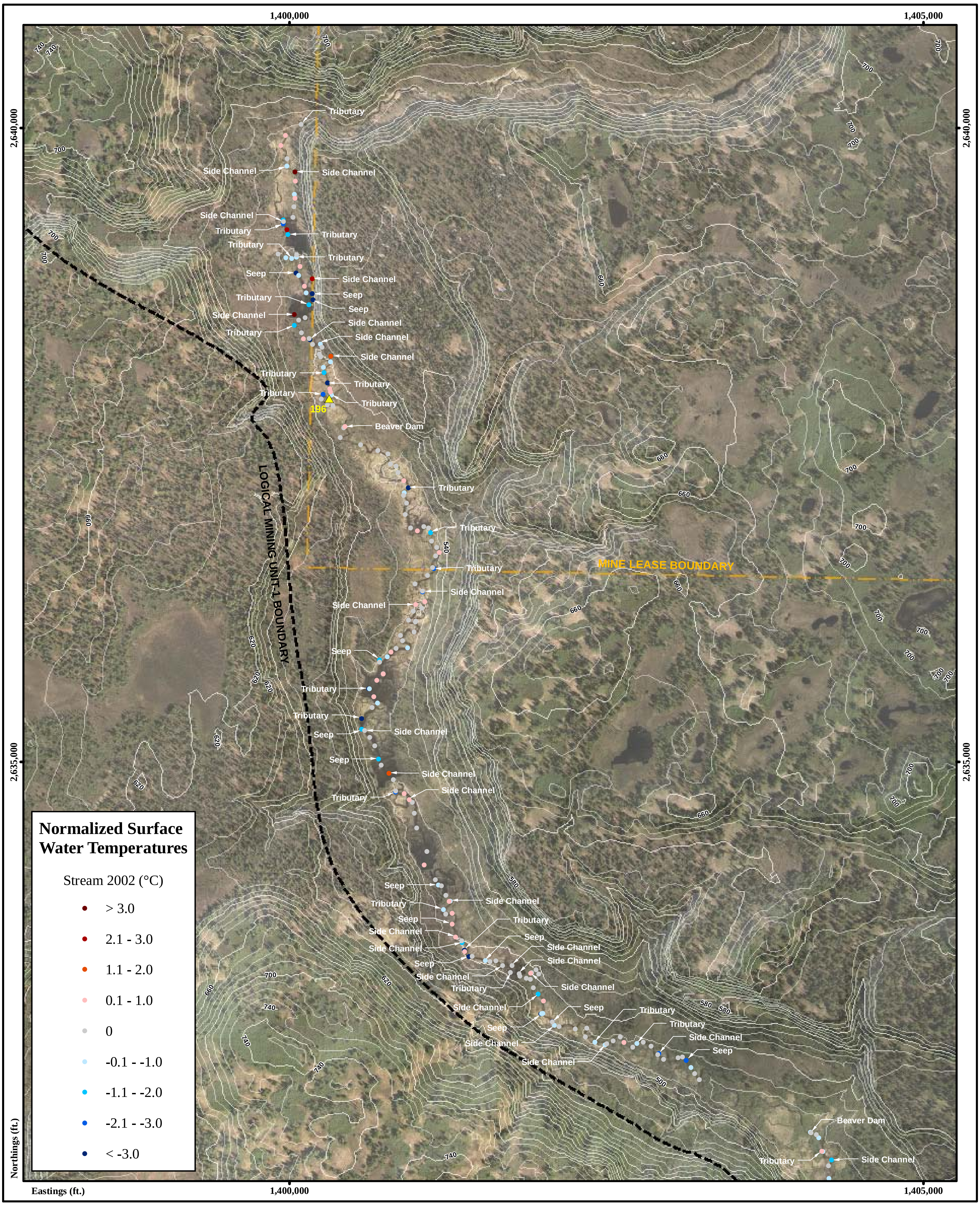

FIGURE 3.1-4
NORMALIZED SURFACE WATER TEMPERATURE ON THE UPPER PORTIONS OF STREAM 2002; AUGUST 28-29, 2009.

0 250 500 1,000 1,500 Feet
0 75 150 300 450 Meters

1:9,600 **1 inch = 800 feet**
Contour Interval: 10 ft. (AMSL)
Projection: NAD83 AK State Plane Zone 4 (feet)

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Phone: (907) 276-6868

Legend

- Fixed Water Station & ID
- Logical Mining Unit-1 Boundary
- Lease Boundary

Data Sources:
Stream Temperature Data, Oasis, 2009.
Mine Infrastructure, Mine Engineers, 2006.
Contours, Mine Engineers, 2006.
Aerial Orthophotography, Mine Engineers, 2005.

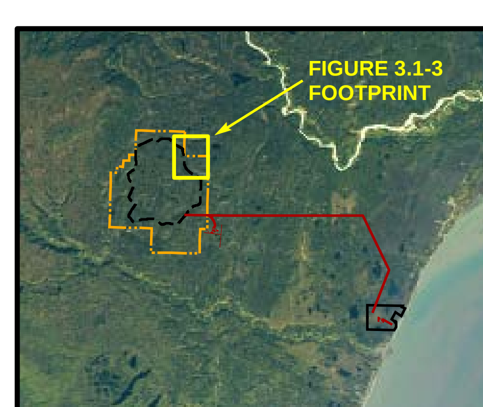

FIGURE LOCATION MAP

with a median of 10.1 °C. The maximum side channel temperature was substantially higher than temperatures observed elsewhere in stream 2004. In contrast, seeps ranged from 4.1 to 10.0 °C with a median of 8.2 °C. The median temperature at seeps was 2 degrees lower than the mainstem. The minimum temperature recorded at seeps (4.1 °C) was substantially lower than those observed in tributaries (7.7 °C), side channels (8.6 °C) or the mainstem (8.1 °C).

On stream 2004, springs and seeps tended to be concentrated in localized areas adjacent to steeper hill slopes to the west (Figure 3.1-7 and 3.1-8). The highest concentration of springs was found midway along the area traversed on stream 2004. Springs in this area were 4 or more degrees cooler than the adjacent mainstem. Springs were less frequent in the upper third of the area traversed on stream 2004.

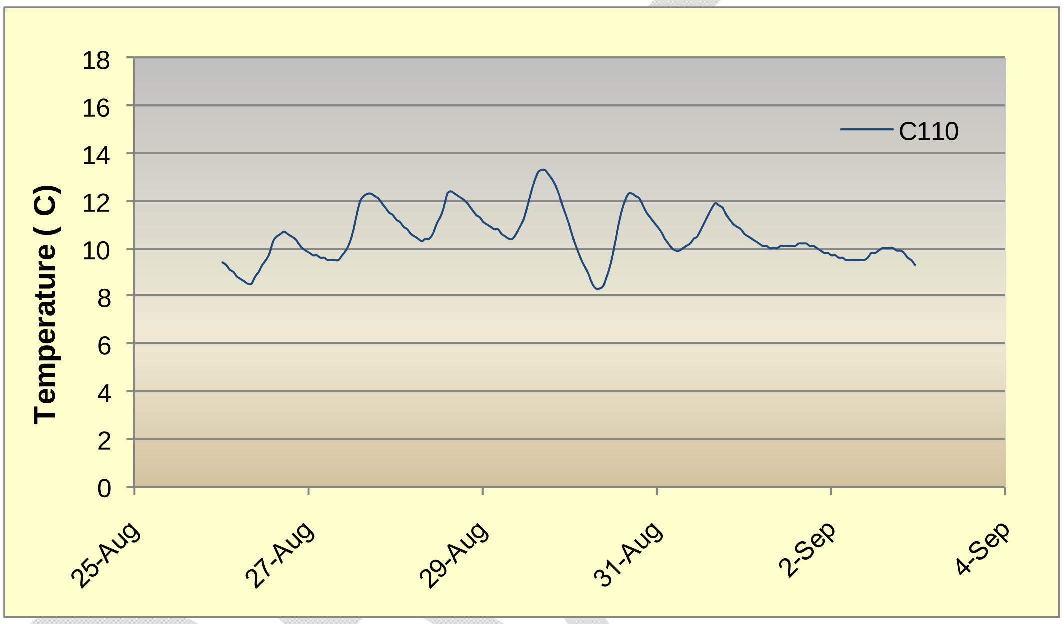

Figure 3.1-5: Hourly temperature data at fixed station C110 on stream 2004 August 2009

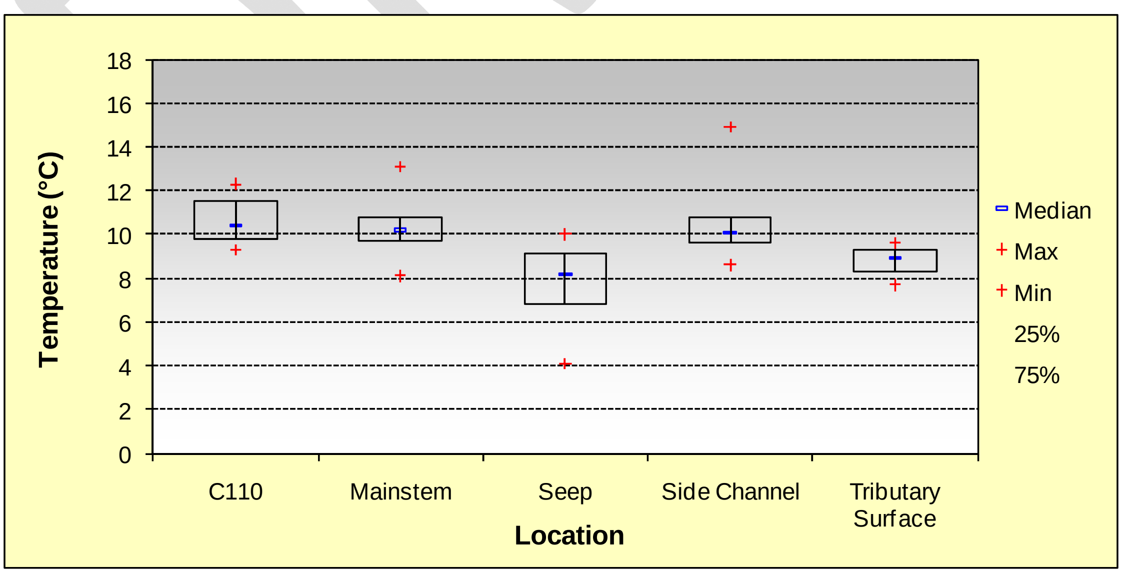

Figure 3.1-6: Box-Whisker plot of water temperatures on stream 2004 August 26-27, 2009

3.1.3 Springs and Seeps

Springs and seeps were identified in the field based on substantially cooler water temperatures relative to the mainstem channel. Dense vegetation as well as solar radiation on side channels and mixing with surface waters may have caused field staff to miss springs and seeps while traversing the reach. Consequently, this was not a comprehensive mapping of springs and seeps in portions of stream 2002 and 2004.

There were a total of 21 springs and seeps identified along a 7,873 meter section of stream 2002 on August 28-29, 2009 (Figure 3.1-9). Springs and seeps were distributed throughout the length of the area traversed. Springs appear to be more prevalent in the reaches with a narrower valley width. Furthermore, springs and seeps were more common on the west-southwest bank of stream 2002 as opposed to the east-northeast bank. The topography on the west-southwest side of stream 2002 was steeper than the east-northeast side. Two springs were located at the start of the section traversed adjacent to an extensive wetland complex to the northeast. Hydraulic pressure from that wetland complex could be influencing these 2 springs.

On stream 2004, a total of 30 springs and seeps were identified along a 7,961 meter section of stream 2004 on August 26-27, 2009 (Figure 3.1-10). Springs and seeps were more localized on stream 2004 compared to stream 2002. Springs were more prevalent in areas with narrow valley widths, steeper hill slopes and intruding ridges.

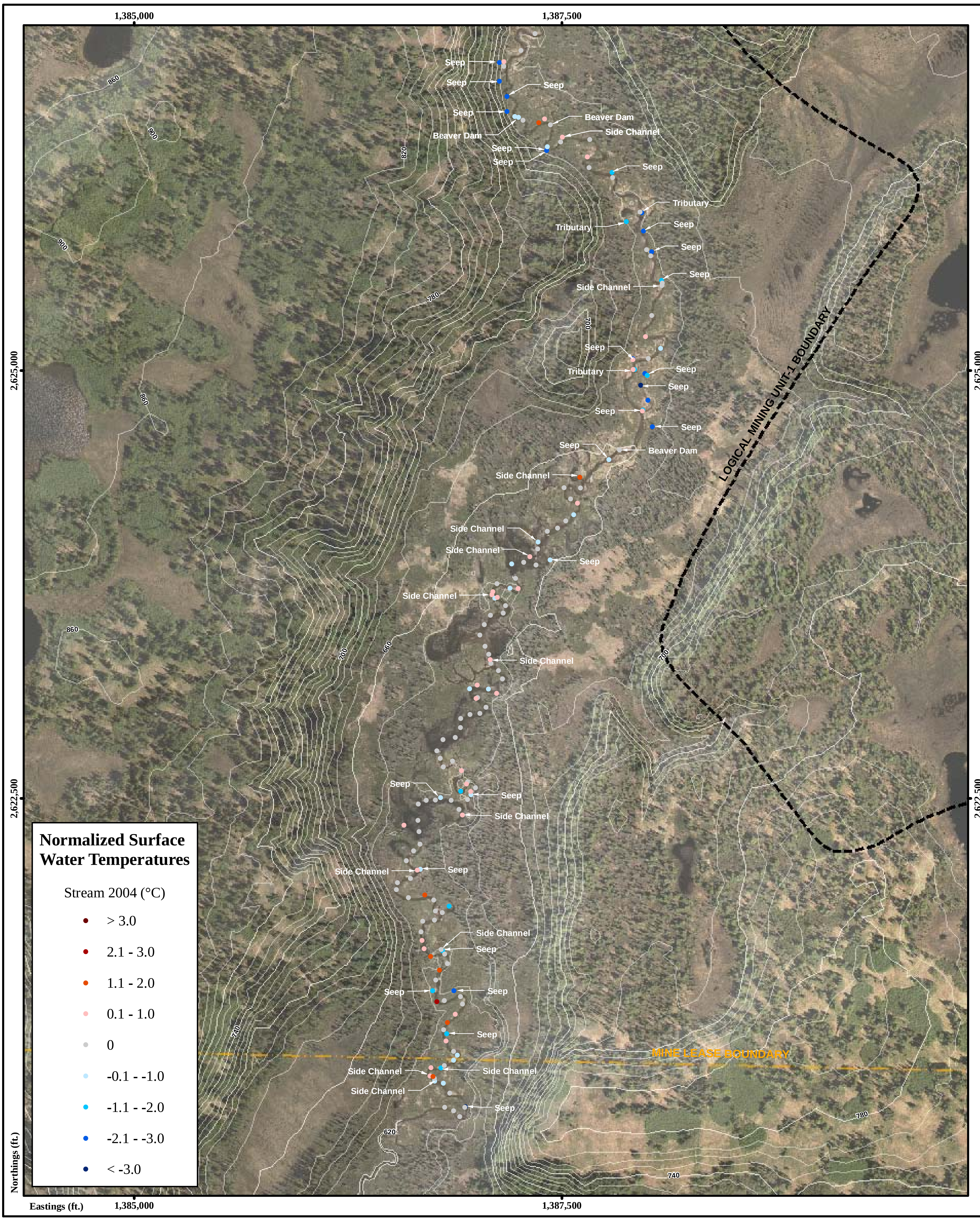

FIGURE 3.1-7
NORMALIZED SURFACE WATER TEMPERATURE ON THE LOWER PORTIONS OF STREAM 2004; AUGUST 26-27, 2009.

0 300 600 1,200 Feet
0 60 120 240 360 Meters

N

1:7,200 1 inch = 600 feet
Contour Interval: 10 ft. (AMSL)
Projection: NAD83 AK State Plane Zone 4 (feet)

Legend
Logical Mining Unit-1 Boundary
Lease Boundary

Data Sources:
Stream Temperature Data, Oasis, 2009.
Mine Infrastructure, Mine Engineers, 2006.
Contours, Mine Engineers, 2006.
Aerial Orthophotography, Mine Engineers, 2005.

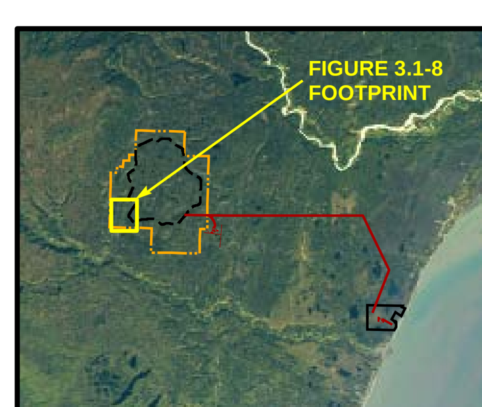

FIGURE LOCATION MAP

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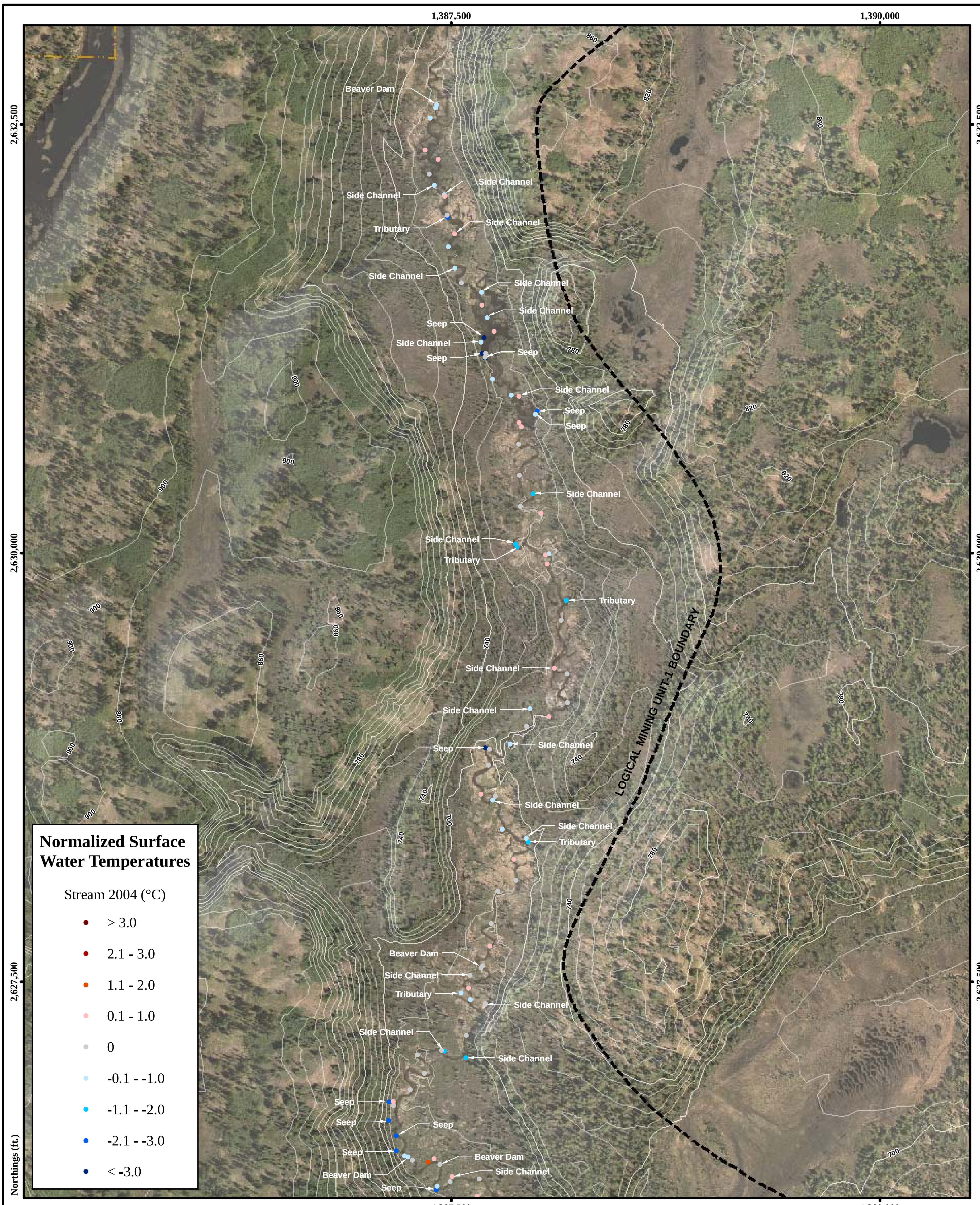

FIGURE 3.1-8

NORMALIZED SURFACE WATER TEMPERATURE ON THE UPPER PORTIONS OF STREAM 2004; AUGUST 26-27, 2009.

0 300 600 1,200 Feet

0 60 120 240 360 Meters

1:7,200 1 inch = 600 feet

Contour Interval: 10 ft. (AMSL)

Projection: NAD83 AK State Plane Zone 4 (feet)

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Legend

Logical Mining Unit-1 Boundary

Lease Boundary

Data Sources:
Stream Temperature Data, Oasis, 2009.
Mine Infrastructure, Mine Engineers, 2006.
Contours, Mine Engineers, 2006.
Aerial Orthophotography, Mine Engineers, 2005.

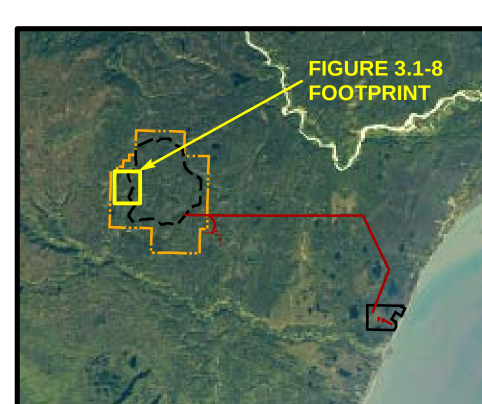

FIGURE LOCATION MAP

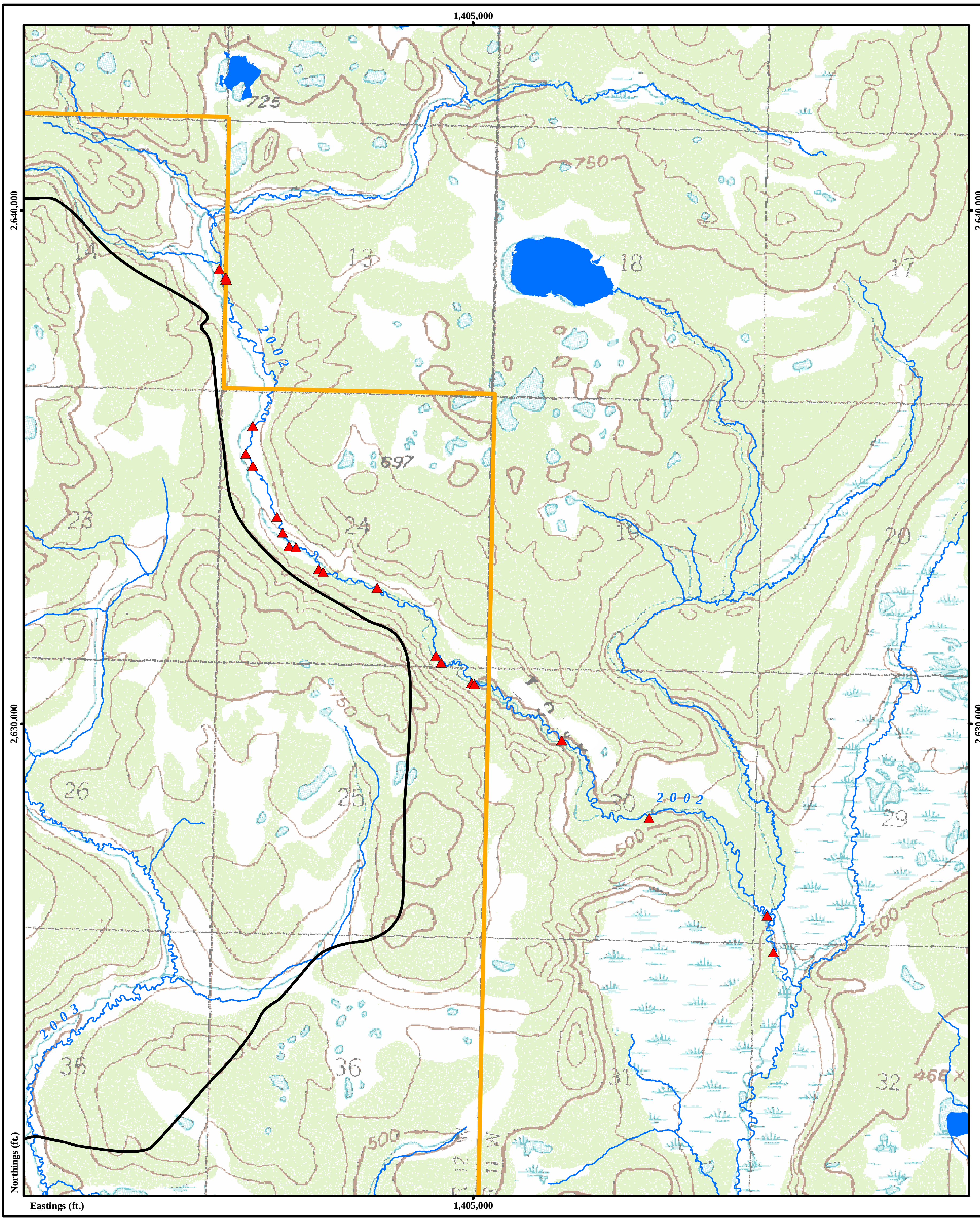

FIGURE 3.1-9: SEEPS PRESENT IN STREAM 2002, 2009 OBSERVATIONS

0 500 1,000 2,000 Feet

0 300 600 Meters

N

1:24,000 1 inch = 2,000 feet

Projection: NAD83 AK State Plane Zone 4 (feet)

Legend

- Seeps Observed, August 2009
- Project Area Stream
- Project Area Lake
- Logical Mining Unit-1 Boundary
- Lease Boundary

Data Sources:
Seep Data, Oasis, August, 2009.
Mine Infrastructure, Mine Engineers, 2006.
Hydrology, Oasis, 2007
USGS Topographic Quadrangle, 1:63360,
Tyonek Sheets A2, A5, & A7, 1958.

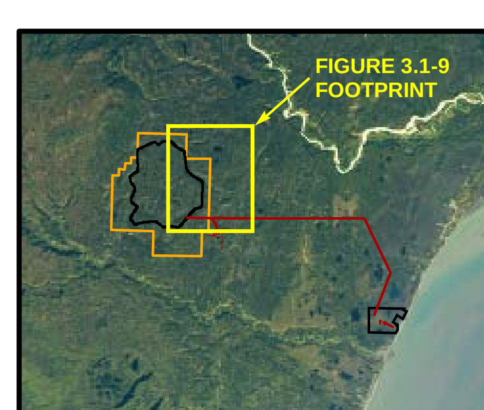

FIGURE LOCATION MAP

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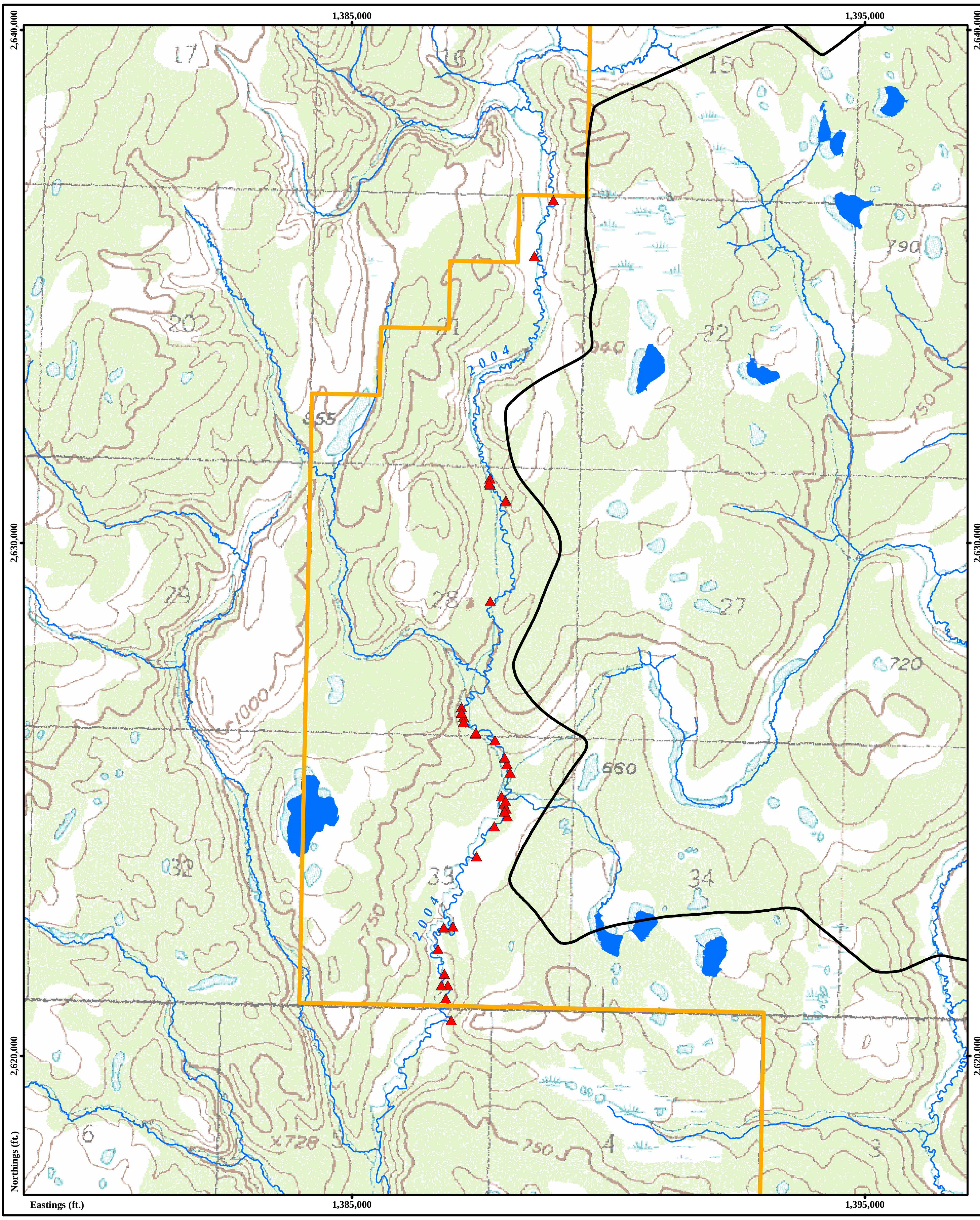

FIGURE 3.1-10: SEEPS PRESENT IN STREAM 2004, 2009 OBSERVATIONS

0 500 1,000 2,000 Feet

0 300 600 Meters

1:24,000 1 inch = 2,000 feet

Projection: NAD83 AK State Plane Zone 4 (feet)

Legend

- Seeps Observed, August 2009
- Project Area Stream
- Project Area Lake
- Proposed Road & Conveyor
- Proposed Facilities
- Logical Mining Unit-1 Boundary
- Lease Boundary

Data Sources:
Seep Data, Oasis, August, 2009.
Mine Infrastructure, Mine Engineers, 2006.
Hydrology, Oasis, 2007
USGS Topographic Quadrangle, 1:63360,
Tyonek Sheets A2, A5, & A7, 1958.

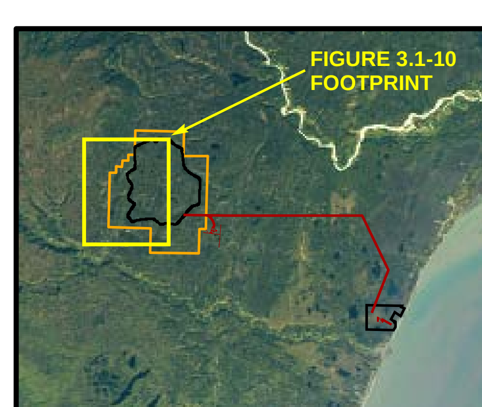

FIGURE LOCATION MAP

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3.2 REACH SCALE INVESTIGATION

Reaches 2002-R1, 2002-R2 and 2002-R3 were located longitudinally within a single contiguous bound valley segment in the upper half of stream 2002 adjacent the proposed mine limit boundary. This valley segment comprising all three reaches was classified as a Rosgen C type channel (OASIS 2007). Reach 2002-R1 overlapped a potential site for surface water augmentation. Reach 2002-R2 was located downstream of a second potential site for surface water augmentation. Reach 2002-R2 was located in an area with steeper hill slopes adjacent to the west side of stream 2002. Field staff observed numerous coldwater seeps and weeping cutbanks on both the left and right banks in this section during the landscape scale temperature mapping exercise. At this location, researchers anticipated subsurface flow pathways in the hyporheic zone would be forced to the surface by the steeper topography on the west coupled with the ridge protruding from the east at the bottom of the reach constricting the valley width.

A total of 120 piezometers were installed in stream 2002 in the three study reaches in late August and early September 2009. Fifty piezometers each were installed in reaches 1 and 2 in increments of 10 to 50 meters spanning 2268 and 2591 meters respectively. In reach 3, 20 piezometers were installed spanning a total distance of 1204 meters. Piezometers were primarily placed in glide habitats just below pool tail-outs. This habitat type corresponds with coho spawning habitat preferences observed in Stream 2003 during the 2007 study year (no spawning fish were observed during the 2009 study). Piezometers were located predominantly in glide habitats in all reaches although a number of pools and riffles were selected in each reach for VHG comparisons across habitat types. In some locations, piezometers were installed in shorter increments in areas with tight meander bends against adjacent hill slopes to detect changes in VHG associated with the landforms. The dominant substrate in all three reaches was sand and gravel.

3.2.1 Discharge

Discharge was measured immediately upstream and downstream of each piezometer reach to quantify water gain or loss in each reach. Reach 2002-R1 exhibited a slight decrease in discharge between the upper and lower cross sections; 3.3 to 2.8 cfs respectively (Figure 3.2-1), indicating a slight loss of surface water into the shallow groundwater zone. In reach 2002-R2, the upper and lower cross sections were nearly identical; 5.5 and 5.7 cfs respectively. In reach 2002-R3, the upper and lower cross sections were also nearly identical, 18.9 cfs and 18.7 cfs respectively. Discharge measures at the respective cross sections for the given sampling date were comparable to daily averages measured at the nearest fixed station on stream 2002, stations 200 and 220. The increase in discharge at reach 3 was largely the result of a moderate precipitation event that started on the evening of September 1st. Discharge measurements at two fixed stations on stream 2002, stations 200 and 220, recorded a measurable increase in discharge between September 1st and 2nd. This doubling of discharge during a moderate precipitation event underscores the flashy nature of streams 2002, 2003 and 2004 observed in previous years.

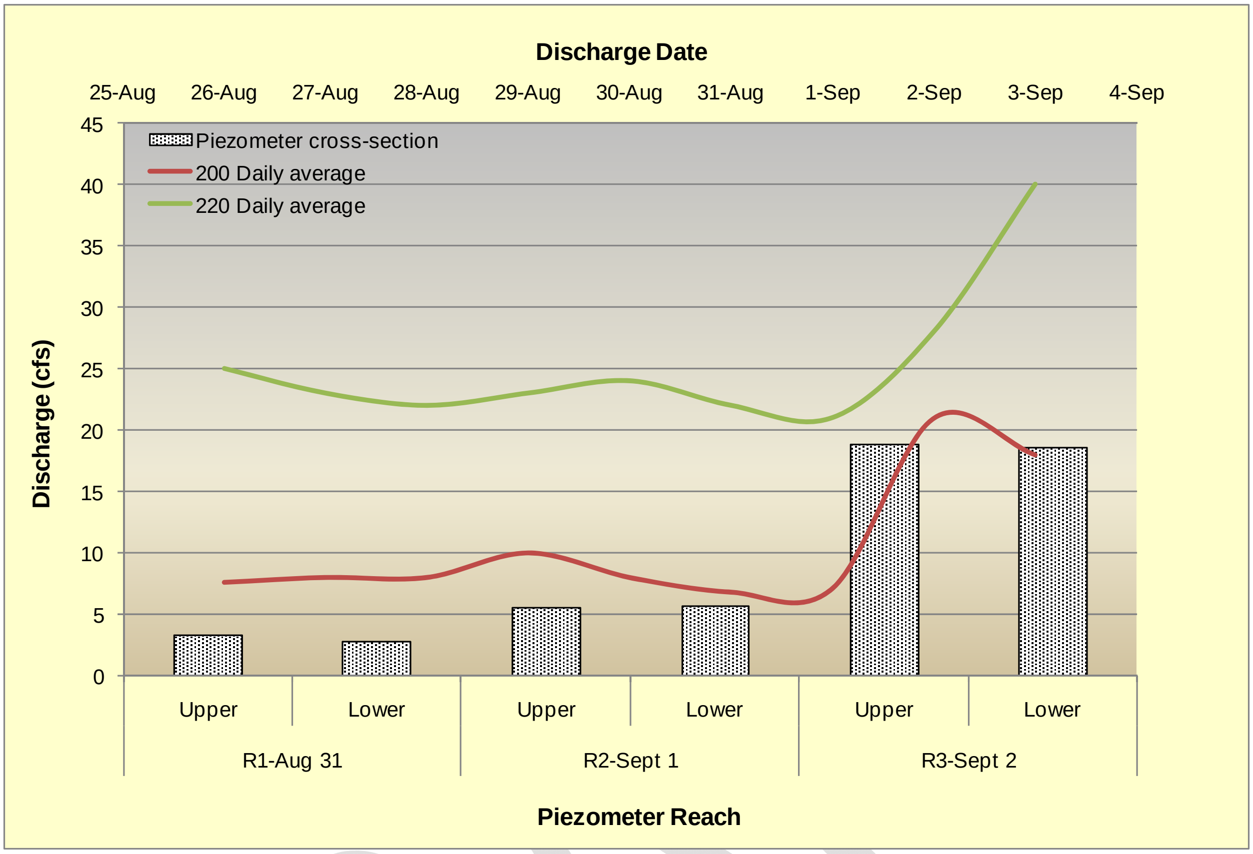

Figure 3.2-1: Discharge at reach cross-sections and fixed stations on stream 2002

3.2.2 Vertical Hydraulic Gradient

The piezometers in reaches 2002-R1, R2 and R3 exhibited distinct differences in VHG. Piezometers in reach 1 predominantly exhibited a downward hydraulic gradient from the surface waters to the hyporheic zone (Figure 3.2-2). Thirty piezometers had a negative VHG (downwelling) compared to 13 with positive values in reach 1 (Figure 3.2-3). The strongest upwelling zone was 0.3 at piezometer P-049. This piezometer was located in glide habitat on a meander bend 1.5 meters from the adjacent hill slope. Piezometer P-018 had the strongest downwelling in reach 1, -0.45. This piezometer was located in glide habitat in a straight section of reach 1 approximately equidistant on the valley floor from the adjacent hill slopes, 23 meters distant.

There appeared to be no correlation between VHG and channel sinuosity or habitat type. Of the 30 downwelling piezometers, 16 were located at meanders in the stream and 14 were located in places without bends. Piezometers were placed primarily in glide habitat with the exception of 4 located in pool habitat, 3 of which exhibited slight downwelling compared to 1 piezometer reflecting a positive VHG.

Reach 2 appears to be predominantly an area of upwelling. Thirty-two of the 50 piezometers had a positive VHG, upwelling, compared to 17 with a negative VHG indicative of downwelling. Piezometer P-081 had the highest positive VHG, 0.22. Piezometer P-094 had the lowest negative VHG, -0.22.

Longitudinally, the upwelling and downwelling in reach 2 appeared to be spatially distributed in clusters of upwelling alternating with clusters of downwelling. This mosaic pattern of upwelling and downwelling suggests an interaction between the intruding adjacent hill slopes and positive VHG values (Figure 3.2-4). Piezometers P-056 through P-065 were all upwelling with the exception of P-062. These piezometers were located directly upstream of a steep hill slope to the west constricting the valley width. P-064 and P-065 had the second highest VHG values in reach 2, 0.21 respectively. Piezometers P-079 through P-091 exhibited positive VHG values with the exception of P-090. These piezometers correspond to a section of reach 2 constricted by a ridge downstream extending from the east coupled with a broad valley bottom directly east of this section consisting largely of wetlands sloped toward stream 2002. From a landscape perspective, these landforms appear to result in positive VHG values for the 11 of 12 piezometers located in this section of reach 2.

Twenty piezometers were deployed in reach 3. Ten of the piezometers had negative VHG values. These were generally located in the upper 2/3 of the reach. Eight of the piezometers had positive VHG values. Five of these areas of upwelling piezometers were located in the lower 1/3 of the reach where stream 2002 runs up against a steep ridge from the west suggesting an interaction between the landform and VHG (Figure 3.2-5).

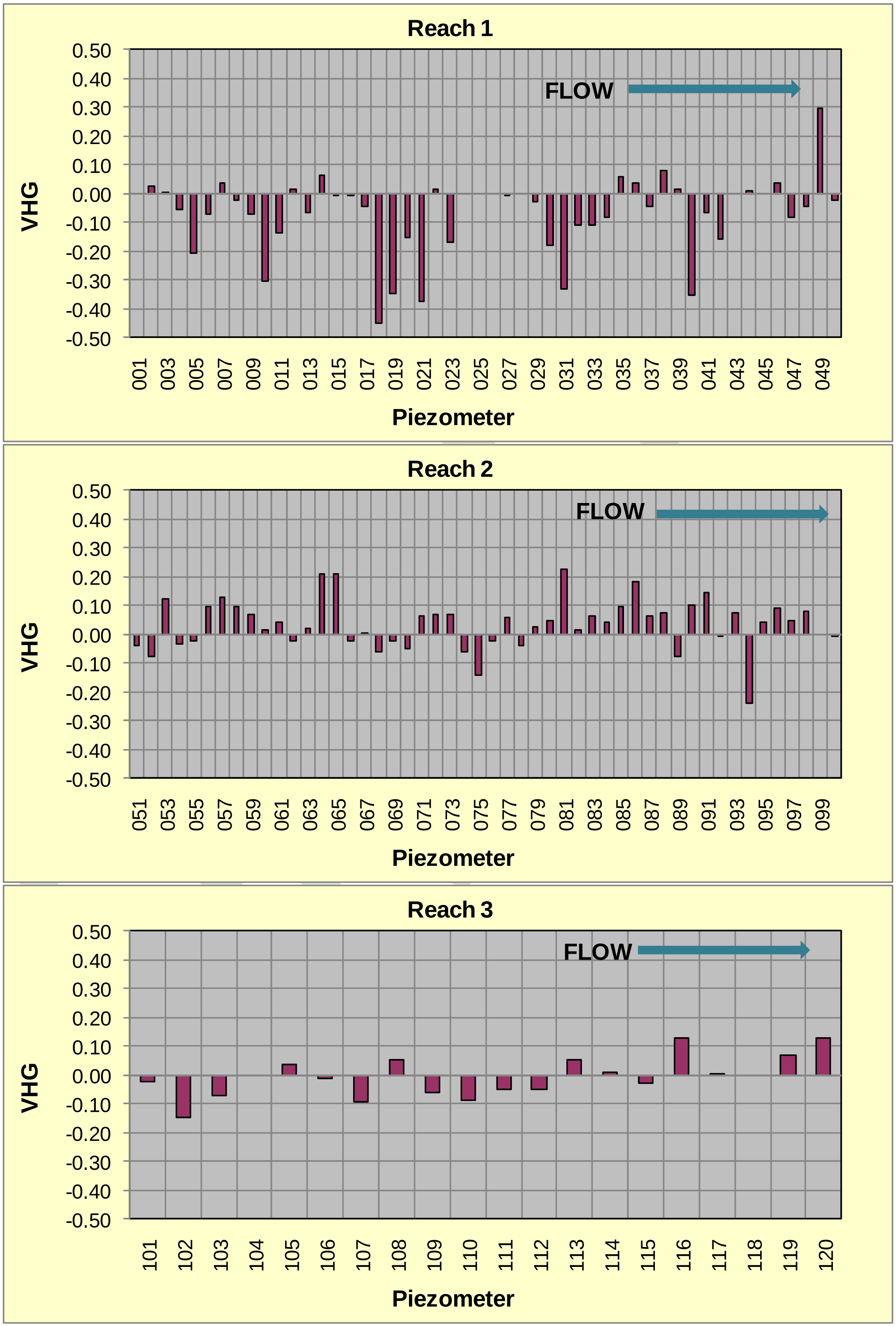

Figure 3.2-2: VHG measured for 3 reaches on Stream 2002, September 2009.

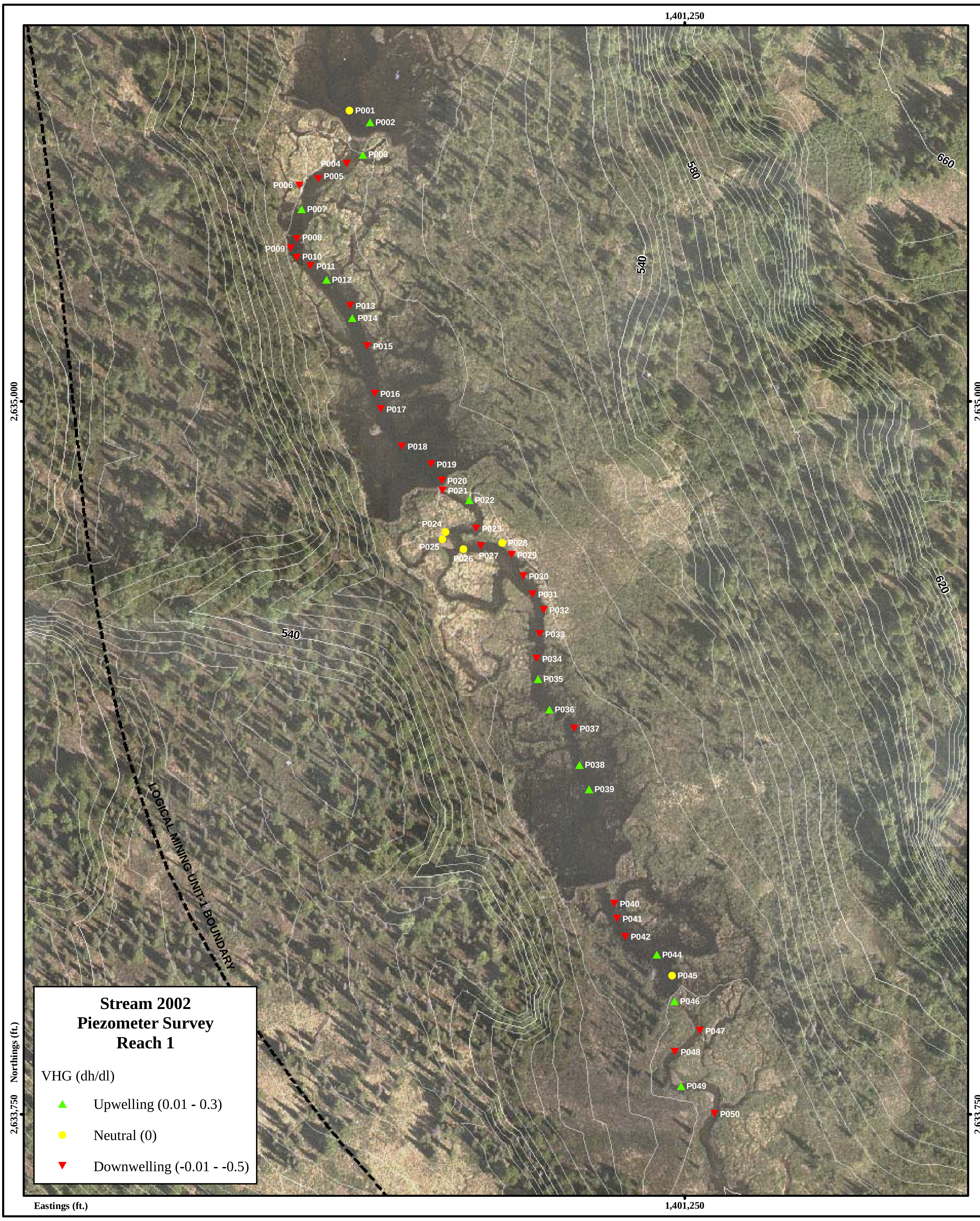

FIGURE 3.2-3
REACH 1 VHG ON STREAM 2002.

N

0 45 90 180 270 360 Feet

0 15 30 60 90 Meters

1:2,160 1 inch = 180 feet
Contour Interval: 5 ft. (AMSL)
Projection: NAD83 AK State Plane Zone 4 (feet)

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Legend

Logical Mining Unit-1 Boundary
Lease Boundary

Data Sources:
Stream Piezometer Data, Oasis, 2009.
Mine Infrastructure, Mine Engineers, 2006.
Aerial Orthophotography, Mine Engineers, 2005.

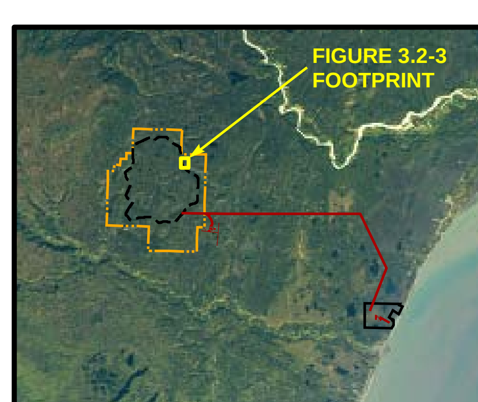

FIGURE LOCATION MAP

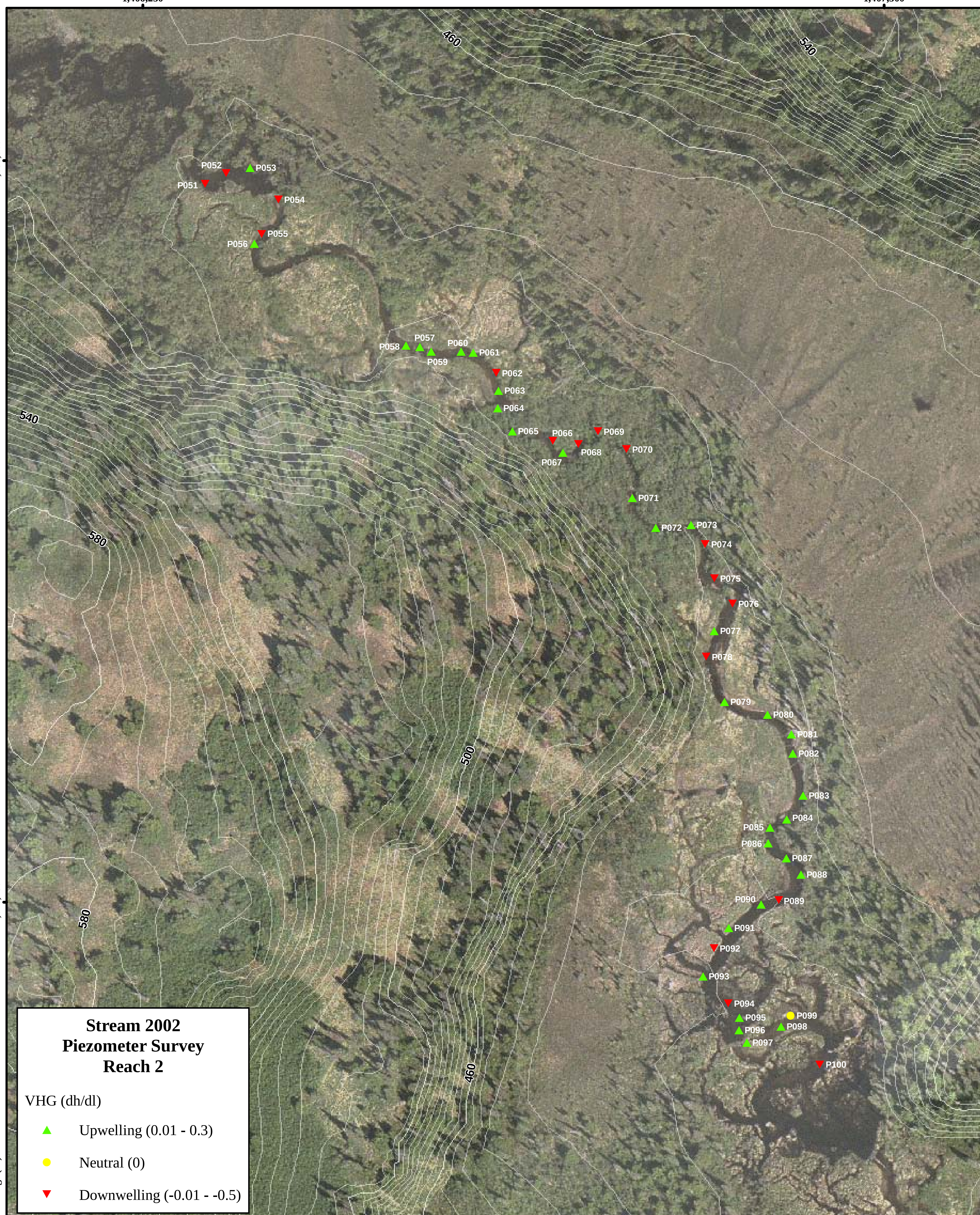

FIGURE 3.2-4

REACH 2 VHG ON STREAM 2002.

0 45 90 180 270 360 Feet

0 15 30 60 90 Meters

N

1:2,160 1 inch = 180 feet

Contour Interval: 5 ft. (AMSL)

Projection: NAD83 AK State Plane Zone 4 (feet)

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Logical Mining Unit-1 Boundary

Lease Boundary

Data Sources:

Stream Piezometer Data, Oasis, 2009.
Mine Infrastructure, Mine Engineers, 2006.
Aerial Orthophotography, Mine Engineers, 2005.

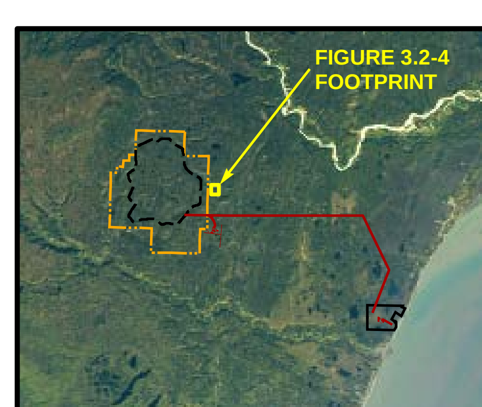

FIGURE LOCATION MAP

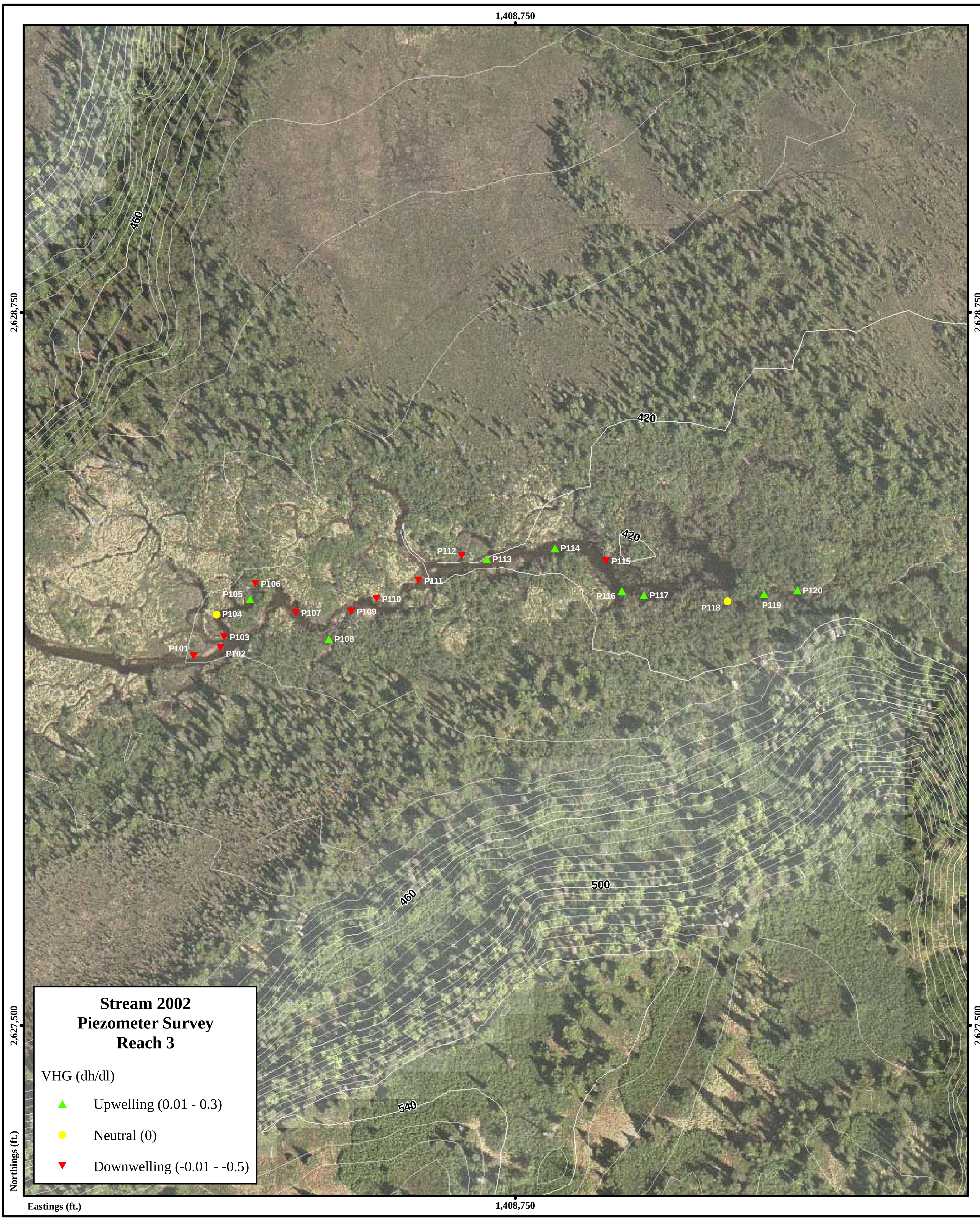

FIGURE 3.2-5
REACH 3 VHG ON STREAM 2002.

0 45 90 180 270 360 Feet

0 15 30 60 90 Meters

1:2,160 1 inch = 180 feet
Contour Interval: 5 ft. (AMSL)
Projection: NAD83 AK State Plane Zone 4 (feet)

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Legend

Logical Mining Unit-1 Boundary

Lease Boundary

Data Sources:
Stream Piezometer Data, Oasis, 2009.
Mine Infrastructure, Mine Engineers, 2006.
Aerial Orthophotography, Mine Engineers, 2005.

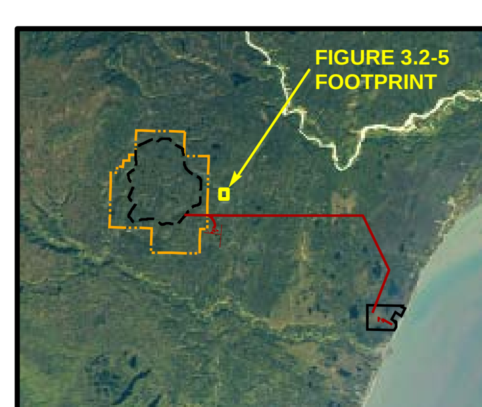

FIGURE LOCATION MAP

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4. DISCUSSION

The 2009 piezometer study documented hydrologic exchange between surface waters and the hyporheic zone at both the landscape and reach scales on sections of streams 2002 and 2004. Landscape scale investigations of stream temperature and spring seeps were carried out to map temperature gradients in the surface waters in each stream. Piezometers were installed in three reaches of stream 2002 to measure vertical hydraulic gradients between surface waters and the hyporheic zone. Reaches were selected, in part, to overlap potential locations for surface water discharge augmentation as well as assess the influence of landforms on hydrologic exchange.

Landform patterns strongly influence hydrologic exchange between surface water and shallow groundwater in the hyporheic zone. Streams 2002 and 2004 lack the pronounced geologic features such as valley constrictions and impermeable bedrock nick points other researchers have noted as drivers of hydrologic exchange (Stanford and Ward 1993; Baxter and Hauer 2000) . Nonetheless, surface water temperatures mapped in streams 2002 and 2004 exhibited spatial heterogeneity corresponding to changes in adjacent topography, suggesting hydrologic exchange processes driven by land form features. Areas of colder water, a surrogate measure for hydrologic exchange, were observed in localized areas of both streams. Water temperatures in stream 2004 exhibited more pronounced gradient and spatial heterogeneity compared to stream 2002 suggesting greater hydrologic exchange between surface water and shallow groundwater. The areas with more pronounced temperature gradients were typically associated with changes in topographic landform patterns on the western boundary of stream 2004. On stream 2002, temperature gradients were also associated with changes in topography adjacent to the valley floor but were less defined compared with stream 2004. Differences in stream gradients, valley width and adjacent wetland areas may further contribute to the spatial patterns in temperature gradients found in streams 2002 and 2004.

Overall, the landscape assessment on streams 2002 and 2004 did not find areas in the mainstem surface waters deviating strongly above or below ambient water temperatures. The small volume of individual spring inputs observed at land form features did not cause localized decreases in mainstem stream temperatures.

Side channel habitats were frequently observed on streams 2002 and 2004. In many cases, the source water for the side channels was a low volume spring seep. Water temperatures typically exhibited strong gradients between the spring source and the confluence with the mainstem channel during the summer sampling effort. The combination of the flat channel bed combined with the slow velocities and small volume caused substantial temperature increases during the day. The warmer temperatures in the side channel habitats provide an excellent environment for microbial and algal productivity, which, in turn, provides abundant food resources for juvenile salmonids.

Piezometers were installed on stream 2002 to delineate reach scale spatial patterns in vertical hydrologic exchange associated with land forms. Hydrologic exchange was observed in all three reaches studied on stream 2002. The direction of exchange, upwelling verses downwelling, was bidirectional. Hydrologic exchange appeared to correspond to changes in

adjacent topographic land forms and proximity of wetland features. Piezometers located directly upstream of valley constrictions typically had a positive VHG (upwelling). Overall, hydrologic exchange on stream 2002 appeared to correlate strongly with topography and changes in valley width at the landscape and reach scales. Nonetheless, considerable spatial heterogeneity was observed likely driven by localized flow paths associated with adjacent wetlands, paleochannels and channel bedform.

Reach 2002-R1 was located a small distance downstream from a steeper headwater area where three tributaries join to form the mainstem of stream 2002. This reach was fairly uniform in shape and width from top to bottom lacking pronounced changes in land form features or valley width throughout its length. Piezometers in reach 2002-R1 were predominantly downwelling. Discharge comparisons showed a slight decrease in surface water volume (0.5 cfs) between the upper and lower end of the reach further indicating downwelling in this reach. Overall, this reach would be considered a downwelling segment.

The influence of land forms on hydrologic exchange was most pronounced in reaches 2002-R2 and R3. Both reaches contained sections with steeper topography and longitudinal changes in valley width. Piezometers directly upstream and adjacent to valley constrictions and steeper land feature tended to have a positive VHG. In addition, a large wetland complex in close proximity to the bottom of reach 2002-R2 appeared to correlate with positive VHG values in piezometers.

The results obtained from the landscape scale temperature mapping and reach scale piezometer investigation serve as a guidance tool for selecting potential sites for surface water augmentation in stream 2002. Ideally, augmentation of surface discharge should occur in reaches least likely to disrupt hydrologic exchange, particularly reaches dominated by upwelling. Reaches that are predominantly upwelling should be avoided to minimize thermal impacts. Surface water augmentation in reaches dominated by hydrologic upwelling can artificially warm surface waters as well as disrupt stream ecological processes associated with upwelling zones, in particular, potential decreases in spawning success.

In 2007, researchers observed coho redds on stream 2003 at the microhabitat scale in areas of downwelling and moderate hydraulic conductivity. However, when viewed from the larger reach and landscape scale perspectives, the highest concentrations of spawning coho were observed in reaches that were predominantly upwelling zones. Baxter and Hauer (2000) observed a similar pattern for bull trout spawning: A higher number of bull trout spawning in upwelling reaches whereas the actual redds were in localized downwelling zones.

Altering hydrologic exchange and temperatures in upwelling reaches used by coho may decrease spawning success. Ideally, surface water augmentation would be located in reaches that are predominantly downwelling or lack VHG and do not have a high concentration of coho spawning. To avoid thermal loading, augmented water could be delivered offsite to stream 2002 and routed via an engineered channel. Off channel augmentation of surface water would allow water temperatures to equilibrate with ambient temperatures in stream 2002 prior to mixing.

Reach 2002-R1 was predominantly downwelling. Accordingly, this reach would be a suitable location for augmenting surface water discharge in stream 2002. A small wetland was observed adjacent to the western boundary in close proximity to the top of reach 2002-R1. The wetland could serve as an off channel discharge point for surface water augmentation and routed to stream 2002 via an engineered channel. Channel length, shape and gradient could be designed to ensure temperature equilibration as well as eliminate bank erosion and sediment delivery associated with increased discharge in the small channel currently draining the wetland.

In contrast to reach 2002-R1, reach 2002-R2 contained considerable areas of upwelling. Augmenting surface water discharge in this reach might interfere with hydrologic exchange flow paths and coho spawning success. Reach 2002-R3 contained nearly an equal number of upwelling and downwelling zones. The larger substrate sizes observed in 2002-R3 relative to the other two reaches might limit coho spawning. Nonetheless, additional surface water discharge in 2002-R3 might displace other stream ecological processes associated with upwelling zones. Identification of reaches with similar land features to those observed in reach 2002-R1 might yield additional sites for surface water augmentation.

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APPENDIX A

2007 PIEZOMETER STUDY

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2007 PIEZOMETER STUDY

The 2007 piezometer study was designed to document areas of hydrologic exchange between surface water and shallow groundwater in stream 2003. Field investigations were divided between landscape, reach and habitat unit scale efforts to document the spatial heterogeneity of vertical hydraulic gradients between the surface water—groundwater interface and document associated landform features influencing these gradients.

1.1. Landscape Scale Investigation

Researchers traversed stream 2003 longitudinally over a three-day period in July 2007 recording stream temperatures. Stream temperature can serve as a surrogate for mapping potential areas of hydrologic upwelling within a landscape perspective of the watershed (Silliman and Booth 1993). Stream surface water temperatures were transformed by subtracting a downstream water temperature from an adjacent upstream location (typically 50 meters or less). This transformation of temperature data eliminated the influence of diel temperature fluctuations on surface water temperatures. Water temperatures in side channels, spring seeps and tributaries were expressed as the difference between the measured water feature and the adjacent ambient water temperature.

Stream water temperatures exhibited spatial variations longitudinally within stream 2003 (Figure 3.8-1). Points with various degrees of blue shading were indicative of water temperatures cooler than adjacent ambient water temperatures. Conversely, surface water temperatures greater than adjacent ambient water temperatures were color coded from orange to red. The coolest water temperatures tended to occur at small spring seeps adjacent to the stream channel. The frequency of spring seeps was typically greater in reaches where the slope of the adjacent upland became steeper. Spring seeps also occurred in greater frequency in reaches adjacent to wetland complexes.

The headwaters of stream 2003 contained a high concentration of spring seeps that cumulatively resulted in substantially lower stream temperatures relative to downstream locations. The high frequency of spring seeps might be the result of the perched wetland bog due west. The wetland bog sloped eastward toward the channel. The channel itself was sandwiched against a steep upland slope on the opposite bank. Spring seeps were frequently observed along both banks longitudinally throughout this section of the river. In 2006, field researchers observed numerous coho spawning in this area while setting minnow traps. This reach was not included as part of the spawning survey effort in 2006 due to weather conditions precluding flights to the field during that scheduled field effort. Coho salmon may have selected this reach for spawning in part because surface water temperatures were strongly modified by groundwater inputs. Hydrologic exchange was also likely a factor for coho salmon spawning selection.

The lower mainstem of stream 2003 has a steeper gradient evident by the coarser substrate relative to upstream reaches. This section is more confined by canyon walls. In 2006, this reach was classified as a Rosgen B type channel (OASIS 2007). In this reach areas of cooler water relative to ambient stream temperatures were uncommon with the former limited to side

channels and tributaries only. The lack of thermal stratification longitudinally suggests very little hydrologic upwelling in this reach. The confined nature of the valley segment coupled with the steeper gradient likely limits hydrologic exchange (both upwelling and downwelling) between surface and sub-surface waters (Boulton 1993; Baxter and Hauer 2000).

Solar radiation on ponded water upstream of beaver dams substantially increased ambient surface water temperatures particularly in the early afternoon period when maximum air temperatures reached 23.5 ºC on July 19th, 2007. Surface water temperatures were typically several degrees cooler a short distance downstream from beaver dams. At a number of reaches directly downstream from beaver dams field researchers recorded substantially cooler water entering through spring seeps and abandoned side channels. Beaver dams could potentially be causing convective flow of stream water into the substrate and upwelling further downstream in the form of spring seeps or weeping into abandoned side channels. Coincidentally, beaver dams were typically observed at the terminus of bounded alluvial valley segments in stream 2003, locations predicted to be zones of hydrologic upwelling (Baxter and Hauer 2000). From an ecological perspective beaver dam site selection in areas of hydrologic upwelling might be preferable particularly in northern climates where winter temperatures could potentially freeze shallow ponds solid unless sufficient groundwater inputs ameliorate the sub-freezing air temperatures. The field effort in July 2007 lacked sufficient technical equipment to map watertemperatures in beaver ponds to verify the potential influence of groundwater upwelling within the beaver dam complex. From a fisheries perspective, beaver ponds provide important overwintering habitat for juvenile salmonids. Knowledge of beaver dam site selection will be an important component of the stream reclamation design and re-establishment of the fisheries community in the reclaimed stream channel.

Overall, visible landscape features were not sufficiently pronounced on stream 2003 to be used as predictors of hydrologic exchange longitudinally. The predominantly glacial alluvium lacked distinct surface nickpoints in the geologic stratigraphy to force hydrologic pressure upward at longitudinal breaks. Furthermore, the extensive areas covered by wetland complexes had a localized influence on hydrologic head. As a result, landscape scale features were not readily evident in stream 2003 that would serve as predictors of hydrologic exchange. Nonetheless, spatial heterogeneity was observed in water temperatures in stream 2003 suggesting areas of localized hydrologic exchange. The increased frequency of cooler spring seeps adjacent to steeper hillslope areas suggests hydrologic exchange in stream 2003 was influenced more by lateral topographic gradients than longitudinal geomorphic features.

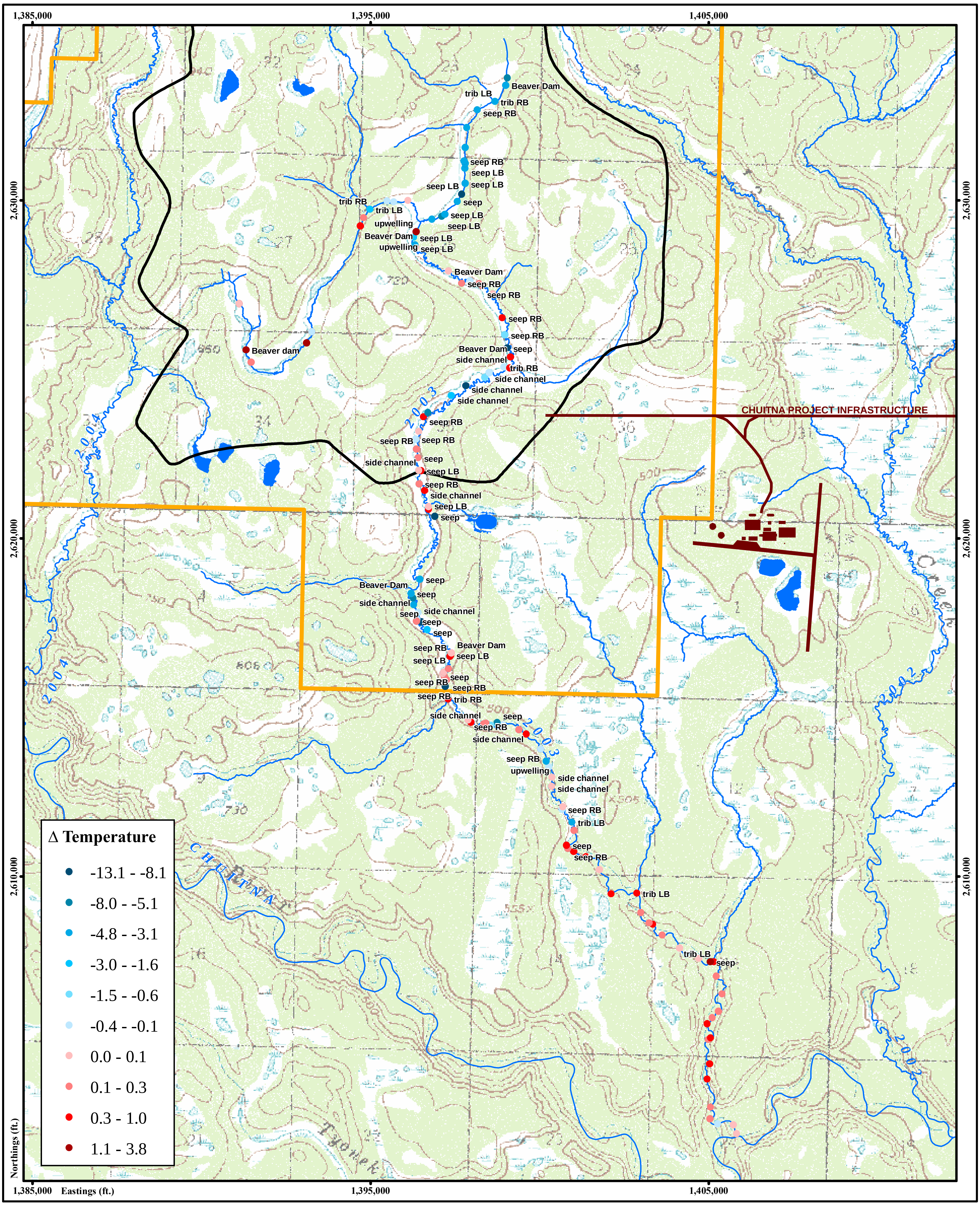

FIGURE 3.8-1.
DIFFERENCE BETWEEN AMBIENT SURFACE WATER AND ADJACENT TEMPERATURES ON STREAM 2003, JULY 17-19, 2007.

0 0.25 0.5 1 Miles
0 0.5 1 1.5 Kilometers
N
1:36,000 1 inch equals 3,000 feet
Projection: NAD83 AK State Plane Zone 4 (feet)

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Legend
- Project Area Stream
- Project Area Lake
- Proposed Road & Conveyor
- Proposed Facilities
- Lease Mining Unit-1 Boundary
- Lease Boundary

Data Sources:
Stream Temperature Data, Oasis, 2007.
Mine Infrastructure, Mine Engineers, 2006.
Hydrology, Oasis, 2007
USGS Topographic Quadrangle, 1:63360,
Tyonek Sheets A2, A5, & A7, 1958.

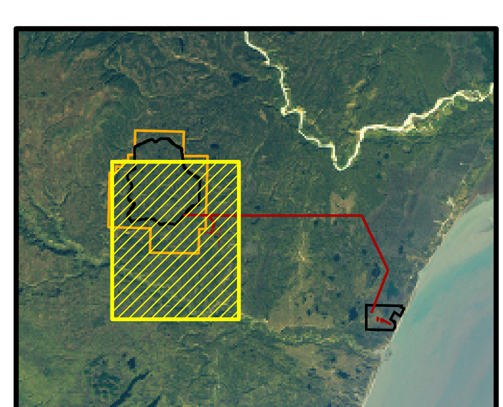

FIGURE LOCATION MAP

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1.2. Reach Scale Investigations

Reach scale analysis of hydrologic exchange occurred in three sections of stream 2003 over a period of three-days, July 20-22, 2007. A total of sixty-two piezometers were placed in the three study reaches. VHG and water temperature was measured in each piezometer tube. Unfortunately, the electronic meter used in the field for measuring water level height gave false readings. The false readings were detected only after analysis of the data. The electronic meter was replaced with an alternative method for measuring water height during the September piezometer investigations at the habitat scale but the July VHG data remained erroneous and, therefore, was not included in this analysis. As a substitute, the July water temperature data from each piezometer tube was used for detecting broad scale patterns in hydrologic upwelling in respective reaches.

Reach 2003-PR1 was located at the confluence with the Chuitna. This area was selected for reach scale piezometer study because it represented an unbounded alluvial valley segment, the only such reach in stream 2003. Field researchers anticipated that the majority of piezometers in this unbounded valley segment downstream of a high gradient confined reach would have a negative VHG indicative of surface water downwelling (Baxter and Hauer 2000). The difference between piezometer and surface water temperatures in reach 2003-PR1 was positive at four out of five piezometers indicating that subsurface water temperatures were strongly influenced by surface waters (Figure 3.8-2). Temperature differences between piezometers and adjacent surface water at reach 2003-PR1 ranged from 0.0 to 0.6 ºC.

Reach 2003-PR2 was located inside the proposed mine boundary close to the downstream end of the most extensive bound alluvial valley segment identified in stream 2003. Ideally, piezometers would have been located precisely at the downstream end of the bound alluvial valley segment, however, a series of beaver ponds at that location prevented placement of piezometers there. Field researchers anticipated strong positive VHG readings in this location similar to those observed by Baxter and Hauer (2000) at the downstream end of bound alluvial valleys. Nine of the ten piezometer temperatures were cooler than the adjacent surface water. Temperature differences between piezometers and adjacent surface waters ranged from -5.0 to 0.5 ºC. The average temperature difference for the ten piezometers was -2.8 ºC. The one positive reading occurred in a habitat transition area measured between a pool and a glide.

Reach 2003-PR3 was located inside the proposed mine boundary in the upper third of the same bound alluvial valley segment as reach 2003-PR2. This reach was selected for its upstream longitudinal position in the bound alluvial valley segment coupled with the high density of coho salmon spawning recorded for this reach during the 2006 spawning surveys. Piezometer temperatures were cooler than the adjacent surface water for all but one of the forty-seven piezometers. Temperature differences between piezometers and adjacent surface waters ranged from -7.9 to 0.0 ºC. The average temperature difference for the forty-seven piezometers was -3.9 ºC. The one location that showed no temperature difference between the surface water and piezometer occurred in the tail-out of the plunge pool immediately downstream of a beaver dam. Water temperatures in the piezometers in reach 2003-PR3 appeared to be strongly influenced by groundwater. This could indicate a reach with neutral or positive VHG.

1.3. Habitat Scale Investigations

Habitat scale investigation of hydrologic exchange occurred in two reaches in stream 2003 over a period of six-days, September 19-24, 2007. A total of ninety-seven piezometers were placed in the two study reaches, 2003-PH2 (47 piezometers) and 2003-PH3 (50 piezometers). Piezometers were installed in reach 2003-PH3 during a bankfull discharge event. Turbidity was high and no spawning fish were observed in the study reach. Within twenty-four hours discharge decreased dramatically, water clarity improved and adult coho salmon migrated into the reach to begin spawning adjacent to a number of piezometers. VHG and K_h were recorded when discharge returned to baseflow conditions. Piezometers were installed in reach 2003-PH2 several days later under baseflow discharge conditions. Adult coho salmon were observed spawning in the reach. Piezometers were positioned adjacent to redds and in habitat units without redds.

Reach 2003-PH2 was, for the most part a downwelling reach indicated by a predominance of negative VHG values measured at the piezometers (Figure 3.8-3).

VHG ranged from -0.15 to 0.08 with an average of -0.03. Only ten of the forty-seven piezometers installed in reach 2003-PH2 had a positive VHG. Four of these piezometers were grouped together at the bottom of the reach in a riffle habitat. The slope of the channel bedform in reach 2003-PH2 was fairly uniform throughout much of the reach (Figure 3.8-4). Negative VHG was documented in areas with convex and concave bedforms. Areas with positive VHG were observed in concave bedforms.

Hydraulic conductivity (K_h) in reach 2003-PH2 was for the most part greatest in the center of the channel rather than the margins (Figure 3.8-5). This spatial patterning might be a reflection of substrate sorting of the bedload during high discharge events. During periods of bedload movement smaller sized substrate material would be more likely to settle along channel margins whereas the thalwag would be composed of coarser grained materials. K_h values in reach 2003-PH2 reflect these lateral differences in interstitial porosity. K_h values ranged from a minimum of 9.7×10^{-4} cm/sec to a maximum of 5.9×10^{-2} cm/sec with an average of 3.1×10^{-2} cm/sec.

Seven coho salmon redds were observed in reach 2003-PH2. Four of the redds were located in zones with a negative VHG ranging from -.250 to -0.001. Two additional redds were located equidistant between piezometers with a negative VHG and a positive VHG. Four redds were located adjacent to piezometers with K_h ranging from 0.03 to 0.05 cm/sec, some of the highest K_h values recorded in the reach. A seventh redd was constructed by a coho salmon upstream of the piezometers after installation and therefore, the VHG was not known. The redd was located on the concave surface of a pool tail-out.

In reach 2003-PH3, VHG was more complex spatially than reach 2003-PH2 (Figure 3.8-6). VHG also had a wider range both positive and negative compared to reach 2003-PH2 but the average VHG was similar. VHG in reach 2003-PH3 ranged from -0.72 at piezometer number one to 0.56 at piezometer number two and averaged -0.05 overall for reach 2003-PH2. VHG did not adhere to predictable longitudinal spatial patterns analogous with channel bedform topography. Upwelling and downwelling zones were observed in both concave and convex bedforms (Figure 3.8-7).

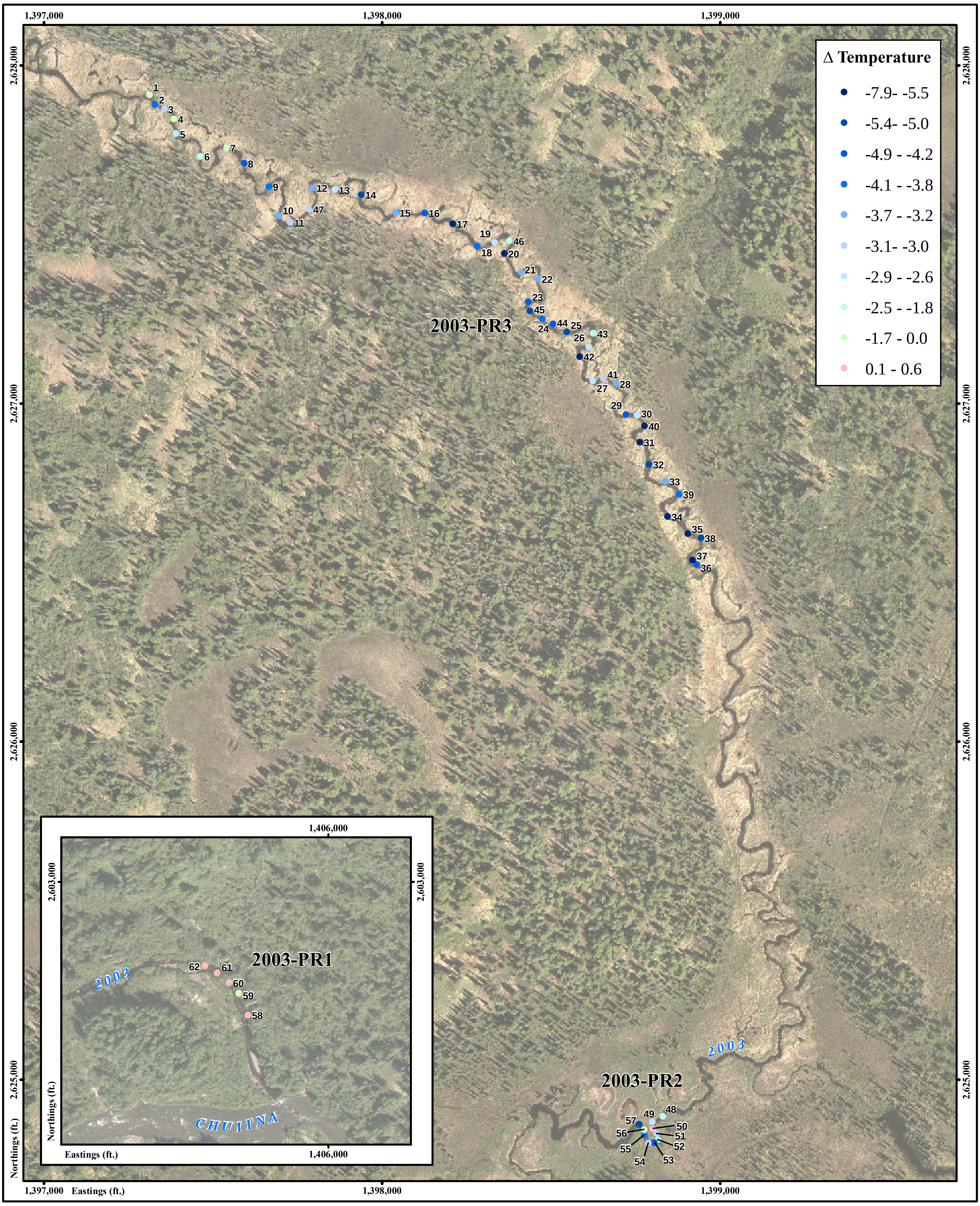

FIGURE 3.8-2.
TEMPERATURE DIFFERENCE BETWEEN PIEZOMETERS AND ADJACENT WATER TEMPERATURES IN REACHES 2003-PR1, 2003-PR2, AND 2003-PR3, JULY 20-22, 2007.

0 100 200 400 600 Feet
0 50 100 150 Meters
1:3,600 1 inch equals 300 feet
Projection: NAD83 AK State Plane Zone 4 (feet)

CHUITNA COAL PROJECT

PACRIM COAL

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Phone: (907) 276-6868

Legend
- Project Area Stream
- Proposed Road & Conveyor
- Proposed Facilities
- Lease Unit Boundary-1
- Lease Boundary

Data Sources:
Stream Temperature Data, Oasis, 2007.
Mine Infrastructure, Mine Engineers, 2006.
Hydrology, Oasis, 2007
Aerial Orthophotography, Mine Engineers, 2005.

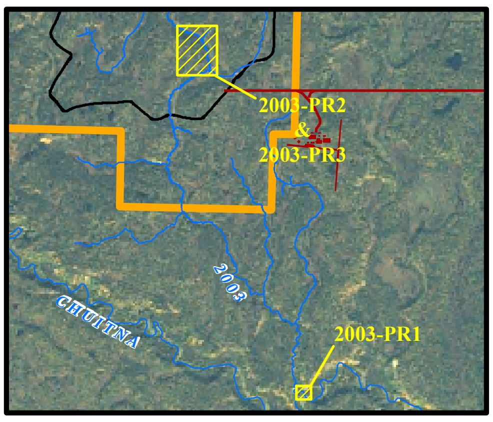

FIGURE LOCATION MAP

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White (1993), among others, conceptualized a longitudinal flow path between surface and subsurface waters at the pool-riffle-pool sequence whereby downwelling occurs at the concave pool tail-out (transition to glide) and upwelling occurs at the convex bedform characterized by riffle habitat. Irregularities in channel shape, slope, substrate porosity and lateral influence on hydraulic head from adjacent uplands may account for the non-conformity with conceptual models.

K_h also exhibited a high degree of spatial complexity longitudinally in reach 2003-PH3 (Figure 3.8-8). K_h ranged in value from a minimum of 2.4 x 10^{-7} cm/sec to a maximum of 5.9 x 10^{-2} cm/sec with an average of 2.4 x 10^{-2} cm/sec. The minimum K_h at site 2003-PH3 was three orders of magnitude lower than the minimum K_h in reach 2003-PH2. Irregularities in channel substrate material and slope likely account for the spatial complexity in K_h in reach 2003-PH3.

Adult coho salmon were actively spawning after installation of the piezometers in reach 2003-PH3. Twelve redds were observed in reach 2003-PH3 between piezometer No. 1 and No. 50. Additional redds were observed upstream and downstream of the piezometers. Nine of the twelve redds were located in areas with a negative VHG between -0.001 and -0.250 indicating hydrologic downwelling. A tenth redd was located in the middle of four piezometers; piezometers Nos. 2 and 3 upstream and Nos. 9 and 10 downstream. Piezometer Nos. 2 and 3 had positive VHG values while piezometer Nos. 9 and 10 had negative VHG values. Redds eleven and twelve were located directly upstream of a cluster of piezometers (Nos. 19, 20 and 21). VHG values were not measured at this location but presumed to be negative given the VHG values of the piezometers directly downstream and the bedform topography.

The 2007 piezometer investigation on stream 2003 documented the presence of hydrologic exchange between surface water and the interstitial sub-surface water. Habitat scale investigations demonstrated that there is nearly continuous exchange between surface and sub-surface water in the Rosgen C channel study reaches composed largely of gravel and sand substrate material. The direction of exchange, upwelling verses downwelling, was bidirectional driven by slope in the channel bedform, substrate composition, and slope of adjacent uplands. Most adult coho salmon selected downwelling zones for spawning with moderate hydraulic conductivity. Reach and watershed scale investigations were undertaken to delineate broader spatial patterns in hydrologic exchange. Preliminary work at these larger scales documented spatial grouping of temperature gradients suggesting hydrologic exchange processes driven by landscape scale features. Hydrologic exchange has been shown to be an important factor influencing stream ecological processes in particular nutrient cycling, benthic algae productivity and benthic macroinvertebrate distribution (Boulton 1993; Stanford and Ward 1993; Brunke and Gonser 1997, Boulton et al. 1998) not to mention the importance for fish spawning (Bjornn and Reiser 1991).

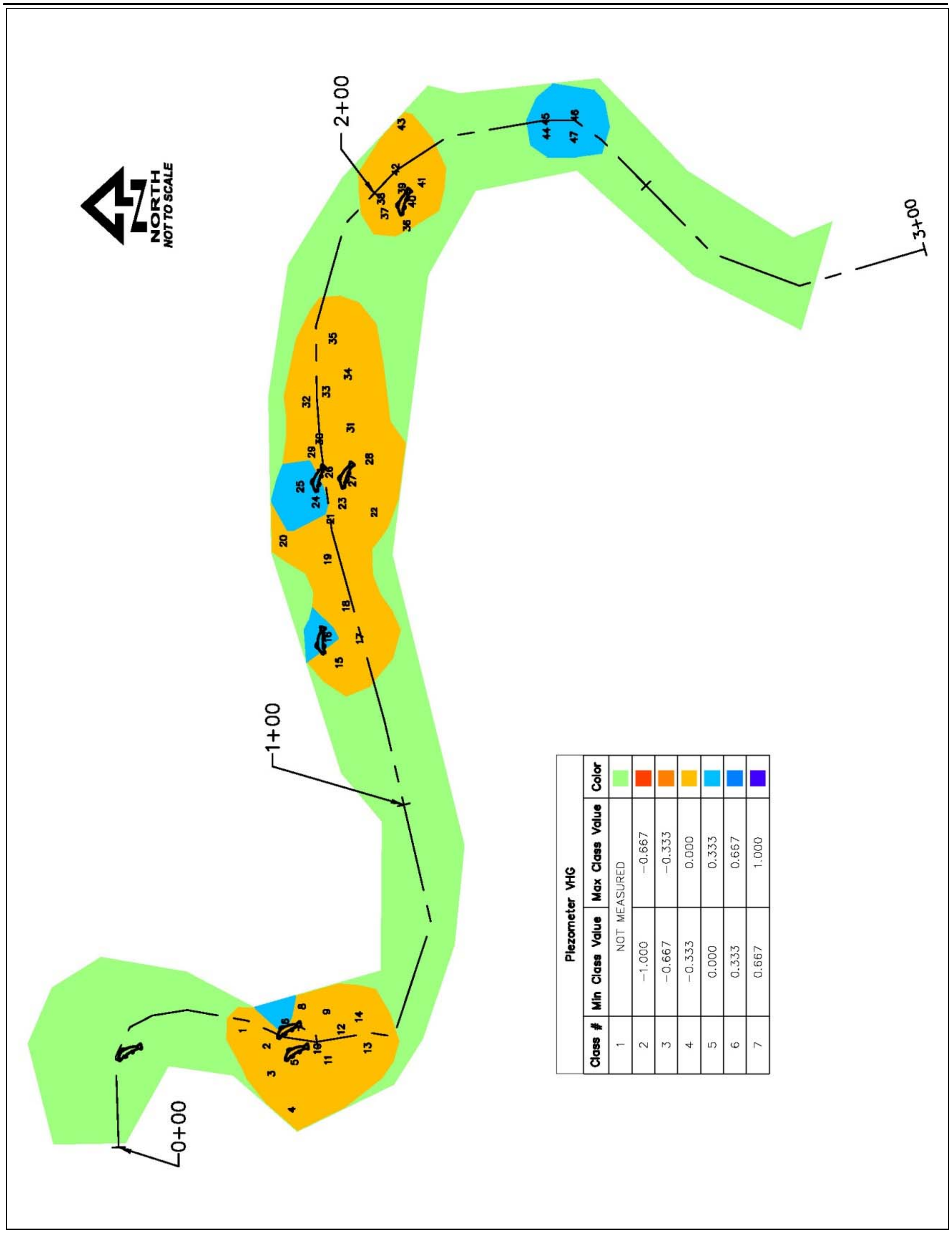

Figure 3.8-3. VHG measured at 47 piezometers installed in reach 2003-PH2, September 22-24, 2007.

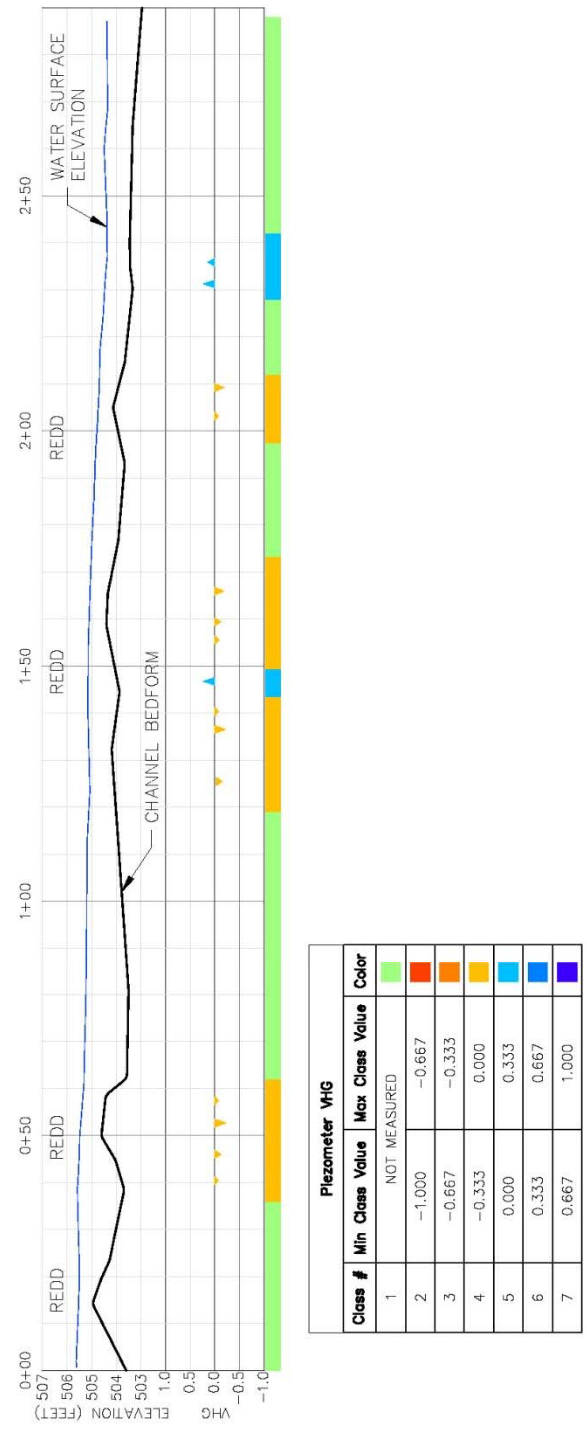

Figure 3.8-4. Longitudinal profile of VHG in reach 2003- PH2, September 22-24, 2007.

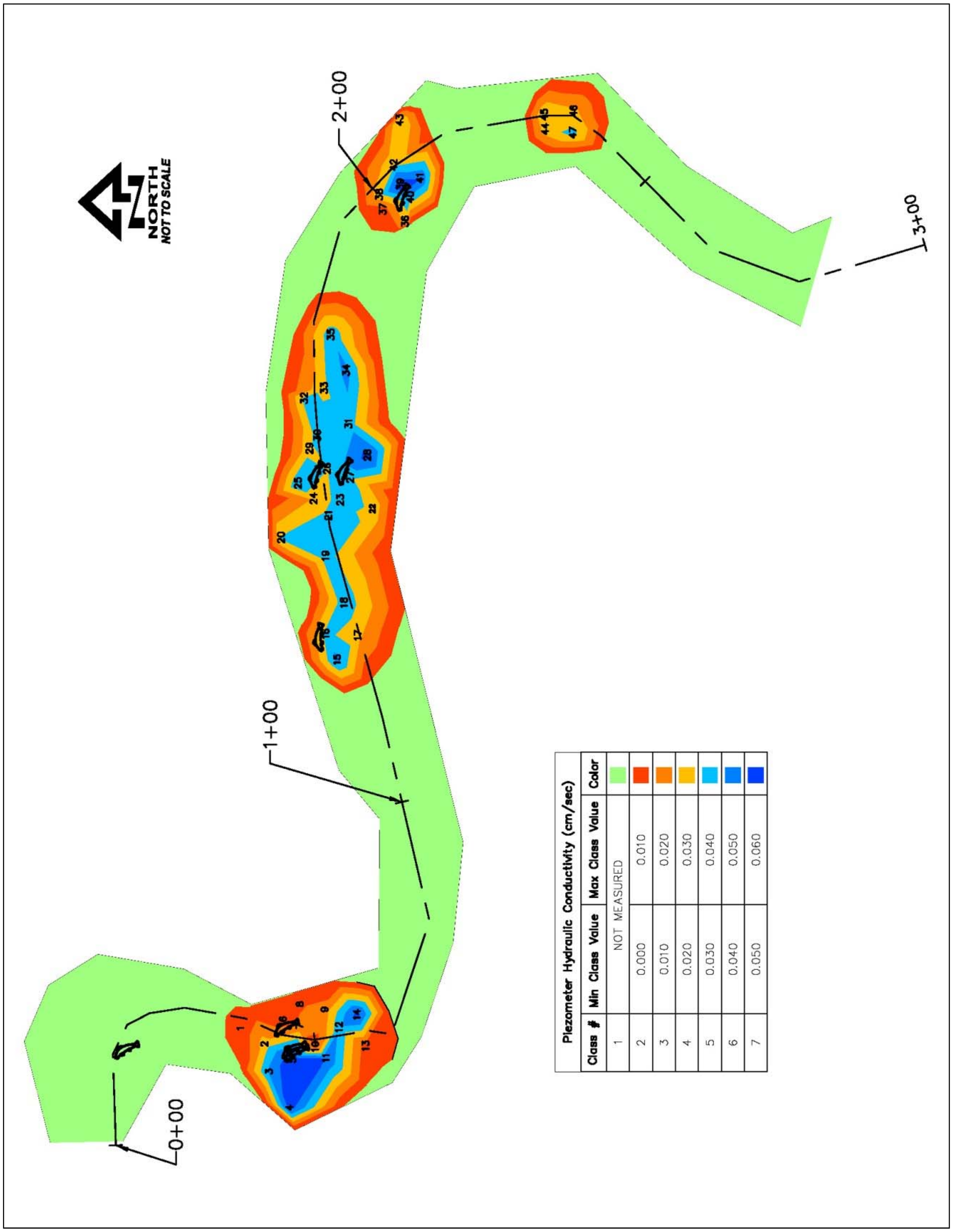

Figure 3.8-5. K_h measured at 47 piezometers in reach 2003- PH2, September 22-24, 2007.

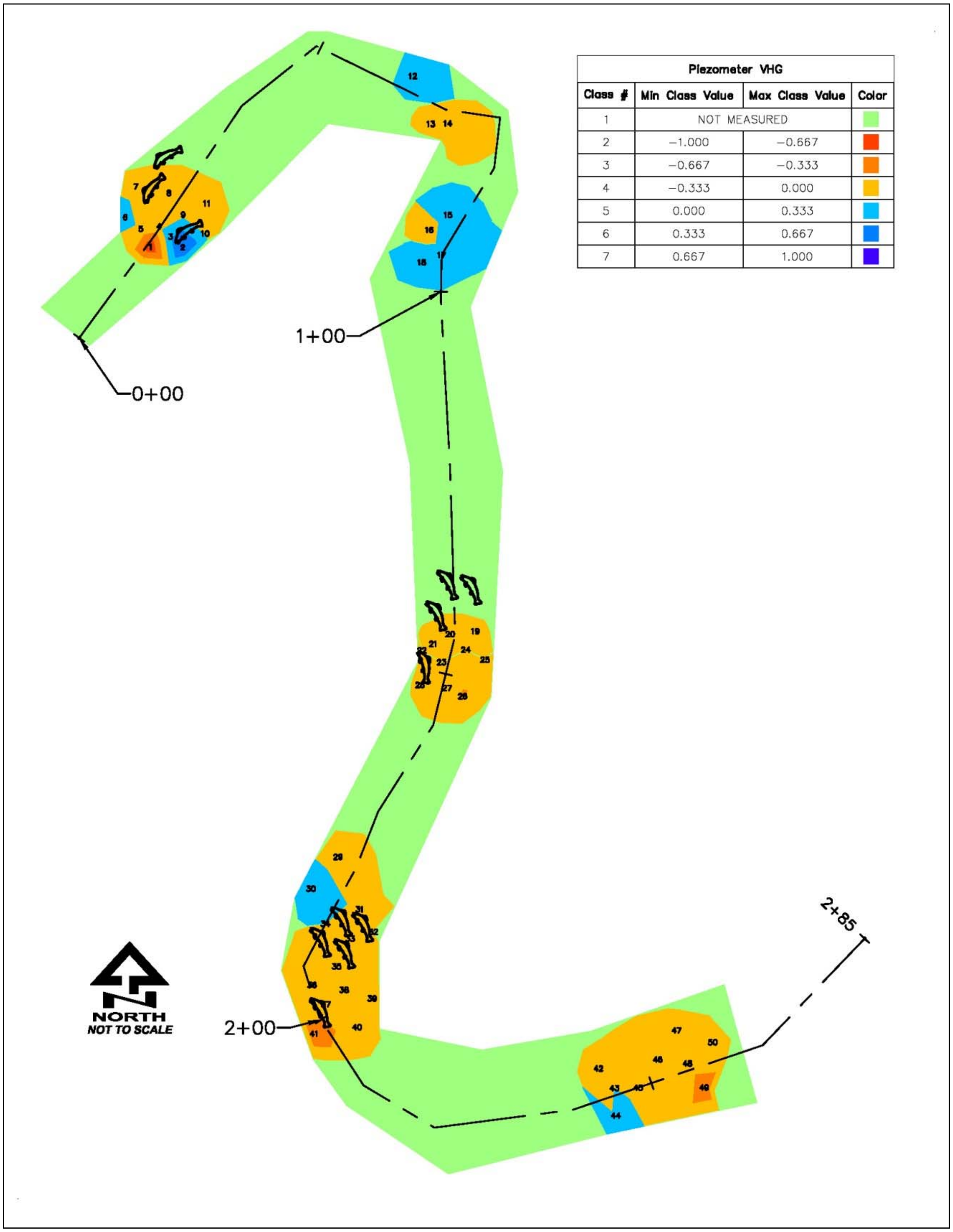

Figure 3.8-6. VHG measured at 50 piezometers installed in reach 2003-PH3, September 19-22, 2007.

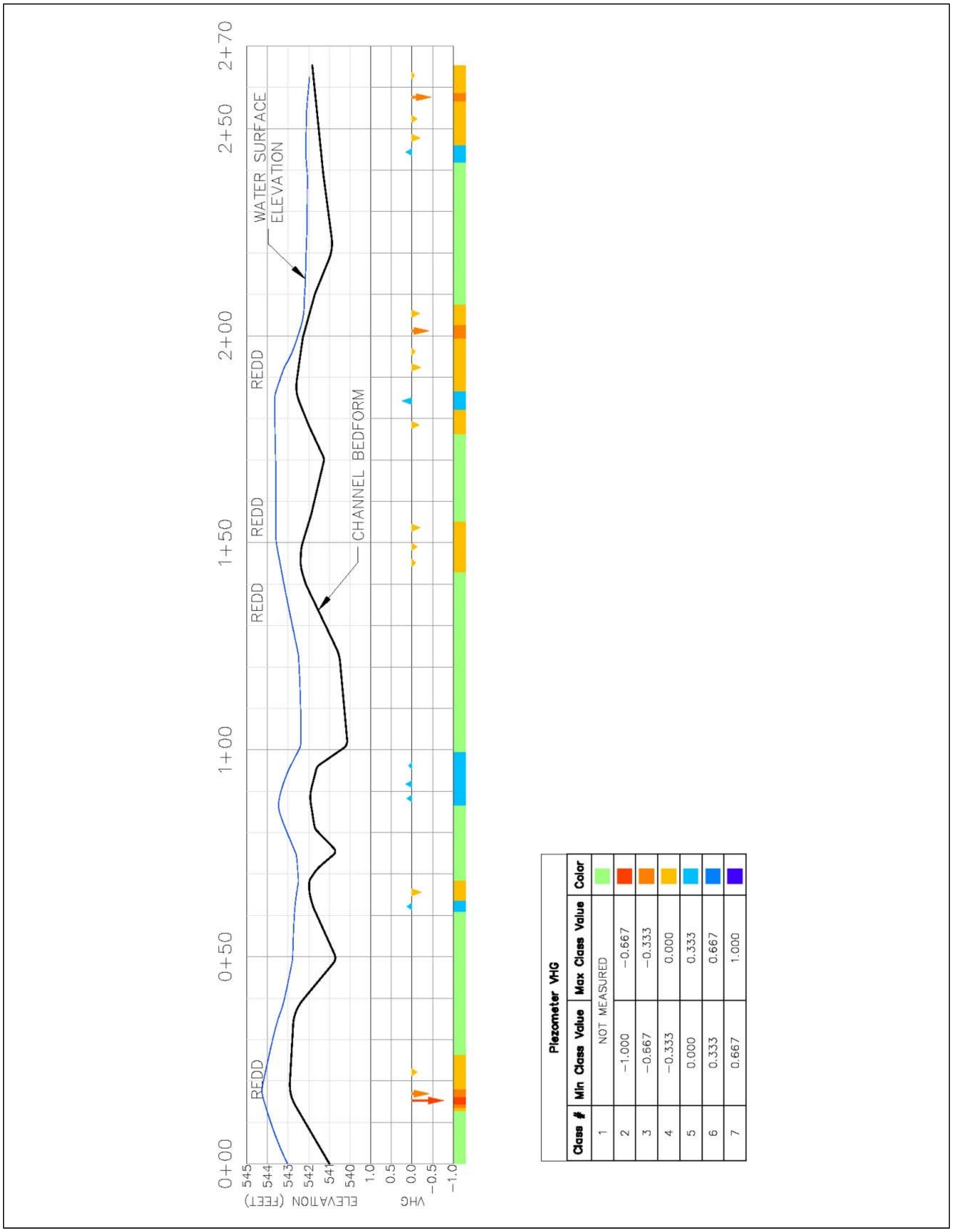

Figure 3.8-7. Longitudinal profile of VHG in reach 2003-PH3, September 19-22, 2007.

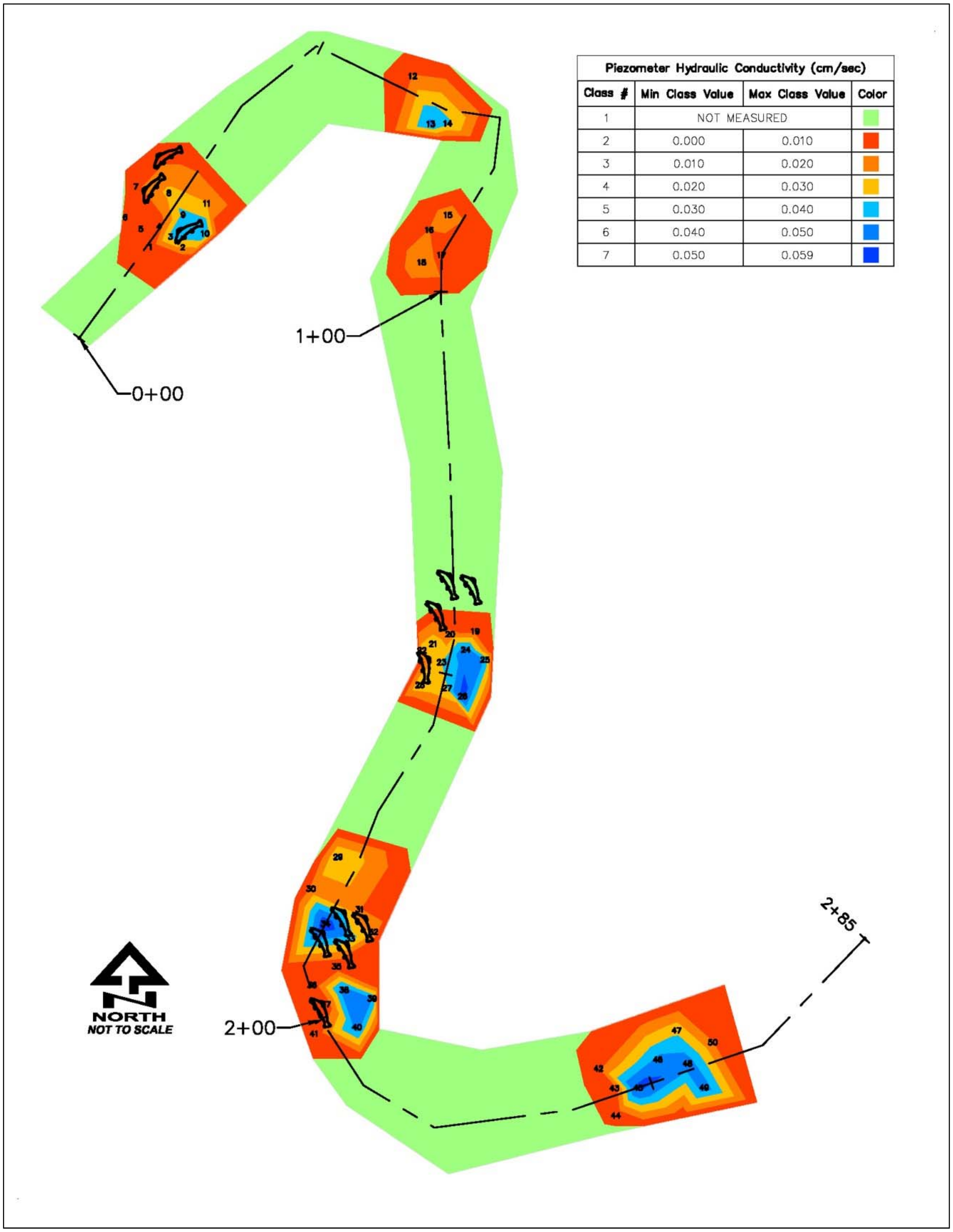

Figure 3.8-8. K_h measured at 50 piezometers in reach 2003-PH3, September 19-22, 2007.

APPENDIX B

CHUITNA COAL PROJECT
SEEP WATER QUALITY SUMMARY REPORT

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Chuitna Coal Project Springs Water Quality Summary Report

Methods

Five representative springs were selected from springs and seeps located during temperature profile reach surveys conducted by Oasis earlier in August of 2009. The springs were selected to represent both broad aerial distribution as well as cover the range of size of springs. The selected sites are shown below on Table 1.

On September 28th and 29th, 2009, field work was conducted to collect water quality samples from the springs and sent to a lab for analysis. Each spring was located from the air with GPS coordinates and a map in order to collect a grab sample for water quality analysis. Two springs in Stream 2002 and 2004 were sampled and one in Stream 2003. Only springs located on the proposed mine side of each stream were sampled, in order to obtain water quality data from the aquifer from within the mine boundary area. Photographs were taken from the air and on the ground for each spring sampled.

Table 1. Spring, relative flow and location sampled for water quality within the Chuit River watershed

Spring	Relative size and flow	Discharge to Stream	Location from stream	Comments
S76	moderate	2002	west bank	
S27	heavy	2002	west bank	several inlets into main spring channel
S36	low	2003	west bank	seep like
S68	moderate	2004	east bank	
S200	low	2004	east bank	seep like

Grab samples and one duplicate were collected at the spring discharge point into the stream. Samples were analyzed for general water quality and total and dissolved metals (Table 2). The dissolved metal samples were filtered in the field with a peristaltic pump and 0.45 micron filter within 15 minutes of the collection time as per EPA sampling protocols. All samples were transferred into labeled sterile sample bottles with preservative. The low level mercury analysis was sampled separately for dissolved and total. Samples were preserved and shipped on ice in coolers to Inter-Mountain Laboratories in Sheridan, Wyoming for analysis.

Table 2. Water quality parameters

Parameters	Detection Limit	Units	Method
General Parameters			
pH	0.1	s.u.	EPA 150.1
Specific Conductance	5	µmhos/cm^3	SM2510B
Total Dissolved Solids	10	mg/L	SM2540
Total Suspended Solids	5	mg/L	SM2540
Total Alkalinity as CaCO3	5	mg/L	SM2320B
Hardness, Calcium/Magnesium CaCO3	10	mg/L	SM 2340B
Nitrogen Ammonia, N	0.1	mg/L	EPA 350.1
Nitrogen Nitrate, N	0.1	mg/L	EPA 300.0
Nitrogen Nitrite, N	0.1	mg/L	EPA 300.0
Phosphorus, Orthophosphate as P	0.1	mg/L	EPA 300.0
Color	5	C.U.	SM 2120B
Cyanide	0.01	mg/L	SM4500 CN1
Total Organic carbon	1	mg/L	SM 5310B
Turbidity	0.1	NTU	SM 2130
Anions			
Bicarbonate as HCO3	5	mg/L	SM 2320 B
Carbonate as CO3	5	mg/L	SM 2320 B
Chloride	1	mg/L	EPA 300.0
Fluoride	0.1	mg/L	SM 4500FC
Nitrate+Nitrite as N	0.1	mg/L	EPA 300.0
Sulfate	1	mg/L	EPA 300.0
Cations			
Calcium	1	mg/L	EPA 200.7
Magnesium	1	mg/L	EPA 200.7
Potassium	1	mg/L	EPA 200.7
Sodium	1	mg/L	EPA 200.7
Dissolved Metals			
Aluminum	0.02	mg/L	EPA 200.7
Antimony	0.003	mg/L	EPA 200.8
Arsenic	0.005	mg/L	EPA 200.8
Barium	0.1	mg/L	EPA 200.8
Beryllium	0.002	mg/L	EPA 200.7
Boron	0.03	mg/L	EPA 200.7
Cadmium	0.00009	mg/L	EPA 200.8
Chromium	0.01	mg/L	EPA 200.7
Cobalt	0.01	mg/L	EPA 200.8
Copper	0.001	mg/L	EPA 200.8
Iron	0.02	mg/L	EPA 200.7
Lead	0.0003	mg/L	EPA 200.8
Lithium	0.01	mg/L	EPA 200.7
Manganese	0.01	mg/L	EPA 200.7
Mercury	0.000001	mg/L	EPA 1631
Molybdenum	0.01	mg/L	EPA 200.8
Nickel	0.01	mg/L	EPA 200.7
Selenium	0.003	mg/L	EPA 200.8
Silicon	0.1	mg/L	EPA 200.7
Silver	0.0002	mg/L	EPA 200.8
Strontium	0.01	mg/L	EPA 200.8
Thallium	0.001	mg/L	EPA 200.8
Titanium	0.01	mg/L	EPA 200.8
Vanadium	0.01	mg/L	EPA 200.8
Zinc	0.005	mg/L	EPA 200.7

Parameters	Detection Limit	Units	Method
Total Recoverable Metals			
Aluminum	0.02	mg/L	EPA 200.7
Antimony	0.003	mg/L	EPA 200.8
Arsenic	0.005	mg/L	EPA 200.8
Barium	0.1	mg/L	EPA 200.8
Beryllium	0.002	mg/L	EPA 200.7
Boron	0.03	mg/L	EPA 200.7
Cadmium	0.00009	mg/L	EPA 200.8
Chromium	0.01	mg/L	EPA 200.7
Cobalt	0.01	mg/L	EPA 200.8
Copper	0.001	mg/L	EPA 200.8
Iron	0.02	mg/L	EPA 200.7
Lead	0.0003	mg/L	EPA 200.8
Manganese	0.01	mg/L	EPA 200.7
Mercury	0.000001	mg/L	EPA 1631
Molybdenum	0.01	mg/L	EPA 200.8
Nickel	0.01	mg/L	EPA 200.7
Selenium	0.003	mg/L	EPA 200.8
Silicon	0.1	mg/L	EPA 200.7
Silver	0.0002	mg/L	EPA 200.8
Strontium	0.01	mg/L	EPA 200.8
Thallium	0.001	mg/L	EPA 200.8
Titanium	0.01	mg/L	EPA 200.8
Vanadium	0.01	mg/L	EPA 200.8
Zinc	0.005	mg/L	EPA 200.7

Results

Springs sampled had a neutral pH and low conductivity that ranged between 26 and 83 µmhos/cm (Table 3). Concentrations of total dissolved solids were low with an average of 50 mg/L. Hardness, color and total organic carbon was also low for all springs sampled.

Table 3. General Parameter readings for five springs in the Chuit River Watershed

Spring	pH	Conductivity (µmhos/cm)	TDS (mg/L)	TSS (mg/L)	Hardness (mg/L)	Color (C.U.)	TOC (mg/L)
S76	7.4	42	40	ND	10	ND	1
S27	7.4	57	50	ND	20	ND	1
S36	7.4	49	50	13	10	ND	2
S68	6.8	26	40	ND	ND	10	7
S200	7.5	83	70	ND	30	11	4

ND - not detected at the reporting limit

Major Ion Concentrations

Major ions detected from analysis of the five springs sampled include calcium, magnesium and sodium as cations and bicarbonate, chloride, nitrate + nitrite and sodium are the major anions (Table 4). All other major ions were not detected at the reporting limits. Concentrations of calcium and sodium were

consistently detected in every spring. Bicarbonate (HCO_3) was the dominant anion in the springs which ranged from 7 to 46 mg/L, and Chloride was the next most abundant anion detected.

Table 4. Major Ion concentrations (mg/L) detected in five springs sampled in the Chuit River watershed

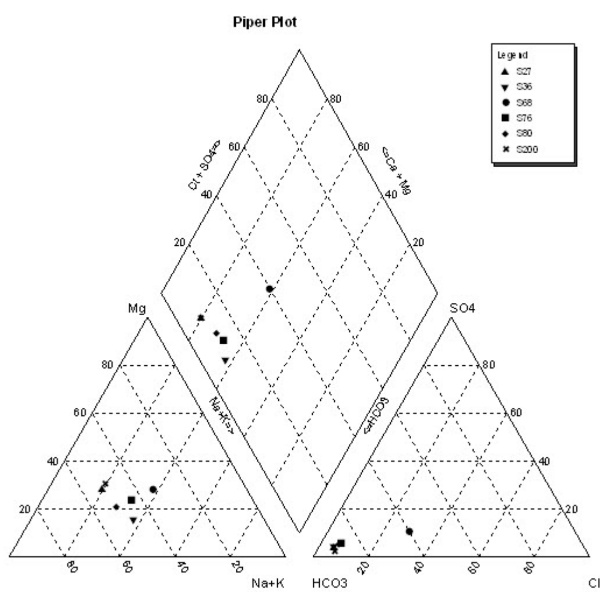
Spring	Calcium	Magnesium	Sodium	Bicarbonate	Chloride	Nitrate+ Nitrite	Sulfate
S76	3	1	2	20	ND	ND	ND
S27	6	2	2	28	ND	0.6	1
S36	5	ND	4	28	1	ND	1
S68	2	ND	2	7	2	ND	ND
S200	8	3	3	46	2	ND	ND

ND - not detected at the reporting limit

Bicarbonate, Chloride, Nitrate+Nitrite and Sulfate - anions

These characteristics are very similar to the stream water chemistry, which is a calcium bicarbonate type (RTi, 2009). Figure 1 below is a piper plot showing the general water chemistry based on the anion-cation analysis. The grouping of the results is consistent with the sample plots for the surface water and groundwater samples collected to date.

Figure 1 Piper Plot of Spring and Seep Samples



Total and Dissolved Metals

Twenty five metals were analyzed for total and dissolved concentrations (Table 2). Metals detected above the detection limit are included in Table 6 below. Silicon and Strontium were consistently detected above the detection limits in each spring sampled. Iron and Manganese were detected in most springs in the total and dissolved form, however; aluminum was detected primarily in the total form only (Figure 2). Copper and Titanium were detected only once in spring 76 in the total form, and Mercury was detected only in Spring 68 at the detection limit.

Table 6. Dissolved and Total recoverable metals concentrations (mg/L) detected in Five springs in the Chuit River watershed

	Aluminum	Copper	Iron	Manganese	Mercury	Silicon	Strontium	Titanium
Spring	D/T	D/T	D/T	D/T	D/T	D/T	D/T	D/T
S76	ND/0.08	ND/0.002	ND/0.29	ND/0.01	ND/ND	7.4/7.8	0.05/0.05	ND/0.03
S27	ND/0.03	ND/ND	ND/0.15	ND/ND	ND/ND	8.3/8.5	0.07/0.07	ND/ND
S36	ND/0.19	ND/ND	0.06/0.49	0.01/0.02	ND/ND	7.5/7.8	0.05/0.05	ND/ND
S68	0.11/0.23	ND/ND	0.30/0.61	0.02/0.03	0.000001/0.000001	5.8/5.9	0.02/0.02	ND/ND
S200	ND/0.13	ND/ND	0.17/1.56	0.03/0.06	ND/ND	8.6/9.0	0.06/0.06	ND/ND

D - dissolved

T - total

ND - not detected at the reporting limit

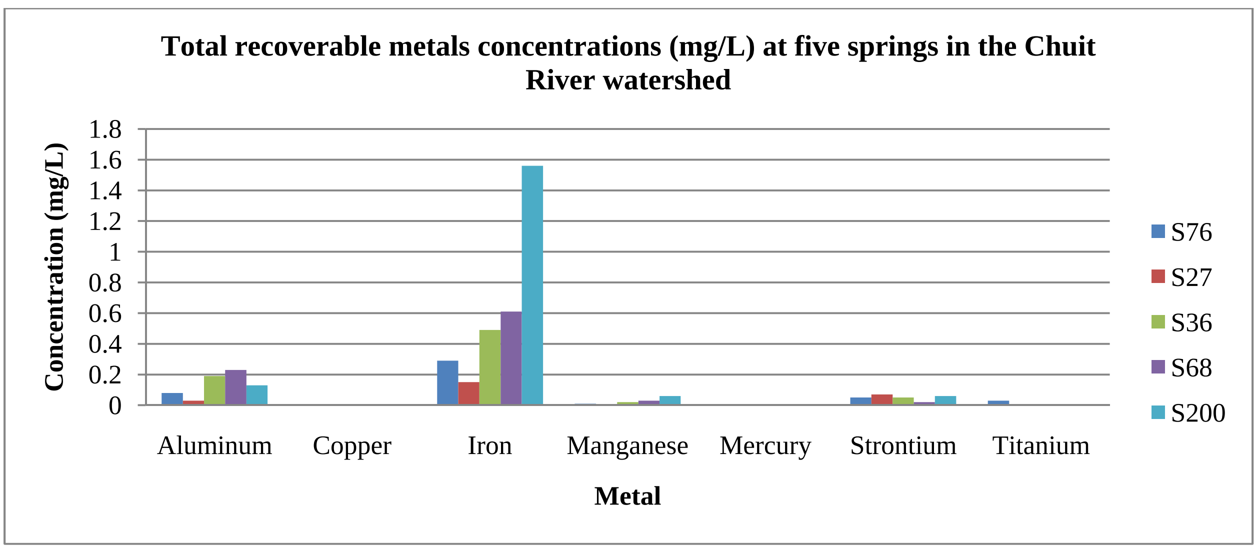


Figure 2. Total recoverable metals concentrations in five springs sampled

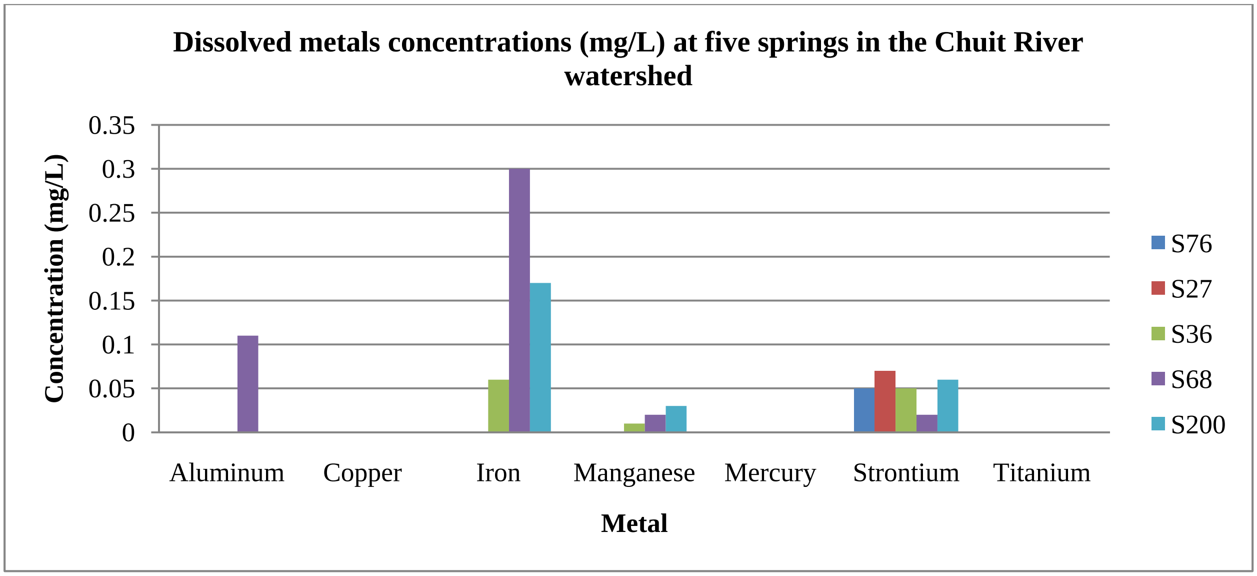


Figure 3. Dissolved metals concentrations in five springs sampled

The majority of the metals present in the five springs sampled were also found in the stream water quality results for the Chuit River watershed (RTi, 2009). The exceptions are boron, silver, nickel and zinc were detected in the streams but not in the springs; and silicon and strontium has not been detected in the streams, but was found in the springs (Table 6). Silicon was detected at high concentrations in comparison to all other metals sampled (Figure 4). These results may be indicative of solubility of silica in the rock formation (Hem, 1985). The water quality in the springs is also very similar to the lake water quality collected within the mine boundary, in that they both have consistently higher concentrations of silicon and strontium and moderate concentrations of iron with minimal or no detects of copper and mercury. However, the springs have lower concentrations of Aluminum when compared to the stream and lake water quality analysis.

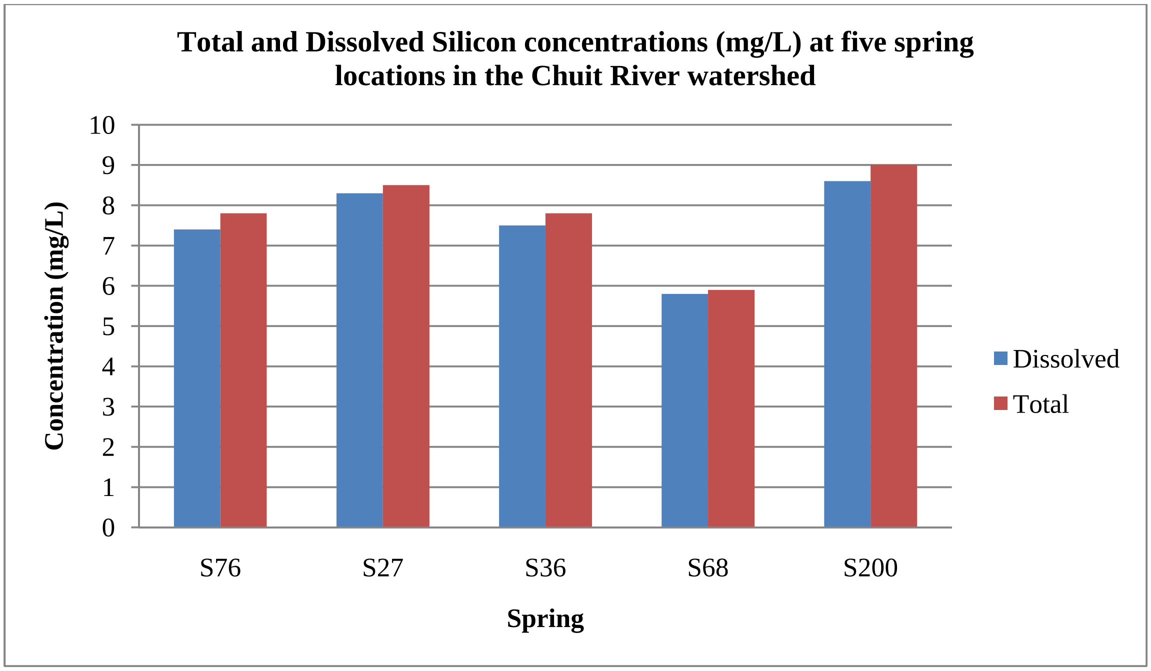


Figure 4. Silicon concentrations (mg/L) at five springs sampled

References

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