

Instream Habitat Analysis of Crooked Creek, 2014 Update

Donlin Gold Project



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1.0 INTRODUCTION

Donlin Gold LLC1 (Donlin Gold) is proposing the development of an open pit, hardrock gold mine located 277 miles (446 km) west of Anchorage, 145 miles (233 km) northeast of Bethel, and 10 miles (16 km) north of the village of Crooked Creek. For detailed information on this Project, refer to the Project Description (SRK, 2012) and Environmental Evaluation Document (ARCADIS, 2013). Among the potential environmental impacts from the proposed Project are direct and indirect effects of stream flow reductions along Crooked Creek. Such reductions in stream flow are anticipated to affect fish habitat during both summer and winter low-flow conditions. This study provides insight into the abundance, composition, and distribution of existing stream habitats along Crooked Creek that could be affected by the Project.

The document is a revision of the 2009 Instream Habitat Analysis (Ottetail 2012). The purpose of this revision is to present anticipated habitat loss as a result of the proposed project based on current water balance predictions.

1.1 Potential Effects of the Proposed Project

1.1.1 Stream Channel Habitat

During mining operations, surface runoff from rainfall, snowmelt, and groundwater seepage in many parts of the Project will be diverted and captured (stored). Once captured and stored, this water will be entrained in the tailings, lost in the milling processes, consumed in the power plant operations, or lost to the atmosphere through evaporation. Regardless of its final use or consumption, these diverted and stored waters will reduce the runoff that would normally reach surface waters in the study area (BGC 2014).

Crooked Creek, located near the ultimate pit (Figure 1), would be affected by pit depressurization activities and other diversions that cause flow reductions (BGC 2014). Crooked Creek at the American Creek confluence has an average annual pre-Project flow of 78.8 cfs (average flow). Flow reductions are predicted to be greatest during the winter months (December to March) and reach a maximum reduction of 33 percent during February and March in Year 20 of Project operations, under dry conditions (10-year low flow) (BGC 2014; Table 1). The reduction in flow on an average year would be greatest in January at 24 percent with an average yearly reduction of 17 percent (BGC 2014). Changes in the flow of Crooked Creek could have adverse effects on aquatic habitat by lowering water levels, and possibly excluding areas currently used for salmon spawning and rearing (Becker and Neitzel 1985, Farag et al. 2010, McMichael et al. 2005).

Studies have shown that some salmon (such as chum salmon) prefer to spawn in areas of upwelling and warmer water, while others (such as Chinook salmon) prefer areas of downwelling and areas of high dissolved oxygen (Geist et al. 2002). In streams where the majority of hyporheic water is from groundwater sources, the areas of upwelling may differ in temperature from the temperature of water in the stream channel. However, in many stream reaches, hyporheic water is derived from the stream water itself, and is not below ground long enough to be affected by ground temperatures. In these cases, hyporheic water temperatures may not differ significantly from the stream channel water (Geist et al. 2002).

Threats to salmon spawning areas as an effect of mine activities include dewatering, changes in the amount of groundwater available, decrease in dissolved oxygen concentration, changes in nutrient and heavy metal concentrations, and changes in water temperature (Becker and Neitzel 1985, Geist et al. 2002). OtterTail Environmental, Inc. (OtterTail) has conducted an aquatic resources biomonitoring program within the Crooked Creek drainage since 2004 to document pre-Project baseline conditions and to assist with Project design and mitigation planning. This program includes baseline data collection and monitoring of metals in fish, fish populations, and aquatic macroinvertebrates (OtterTail 2011). An additional component was developed in 2009 to characterize stream habitat along Crooked Creek.

1.1.2 Off-Channel Habitat

In unconfined natural alluvial river systems such as Crooked Creek, side channel habitat is constantly created and abandoned as the river migrates laterally and changes course. Naturally formed off channel habitat is usually associated with former stream channels abandoned through natural process, or the landward side of gravel bars formed during high flow events within the active channel area. Off channel habitats generally evolve over time from being an active channel to a backwater, then often to an isolated oxbow intermittently connected to the main flow during floods, and finally to a wet depression on the floodplain. This evolution might occur over decades. As long as the stream is creating new side channels, all successional stages of side channel development will occur within the stream corridor, providing a niche for all successive plant and animal communities (Roni et al. 2002, Saldi-Caromile et al. 2004).

Off channel habitats often derive a major portion of their water from either groundwater or seepage from the adjacent stream or river. The role of surface water in side channel habitats varies depending on mainstem and groundwater hydrology, channel topography, and physical features.

The presence of off channel habitat, especially a series of these habitats in various stages of succession, increases the diversity of aquatic habitat available within a stream corridor. Also, during flood events, side channels frequently offer aquatic species refuge from adverse mainstem conditions. Juvenile coho are known to actively and preferentially migrate from mainstem rearing locations to off channel habitats in both fall and spring for protection from freshet activity and low summer flow stranding (Saldi-Caromile et al. 2004). Utilization of these habitats results in higher survival rates. Though residence times vary, they migrate back to the mainstems generally in the spring. Side channel habitats have been constructed and studied by Swales and Levings (1989), and Cederholm and Peterson (1989) to determine behavioral and physiological responses of coho salmon in these habitats.

Although ponds are not generally associated with coho salmon habitat, beaver ponds and riverine ponds have been identified as productive coho habitat in Alaska and in Washington in recent years (Bryant 1988, Peterson 1982a). Many of the abandoned oxbows in the Crooked Creek drainage are connected to the mainstem at some point during high flow events, and beaver activity is prevalent throughout the drainage (OtterTail 2011). Off channel wetlands and ponds have been found to provide critical habitats for juvenile salmonids (Peterson 1982b; Cederholm and Scarlett 1981), and a variety of wildlife species (Zarnowitz and Raedeke 1984). When these areas are more regularly and

permanently available, as in larger stream basins, they can provide additional benefits such as high quality protected spawning habitat especially for coho and chum salmon that actively seek these areas when inundated with sufficient flow. They are also recognized for their value as summer and winter rearing habitat for coho salmon.

Additional investigations in Canada by Tschaplinski and Hartman (1983) and Brown and McMahon (1987) also confirmed these habitat preferences by juvenile coho and the value of off channel in increasing production. Nickelson et al. (1992) concluded that off channel habitat development has the highest potential for increasing wild coho salmon production in Oregon coastal streams. High quality off channel habitats have not only been found to improve juvenile freshwater survival, but lead to faster growth rates and larger size, thus increasing marine survival (Bilton et al. 1982).

It has been well documented that off channel habitats serve very important functions for fish during the winter months. As water temperatures decrease below 9 °C (48 °F), coho salmon fry become less active and seek deep (approximately 45 cm, or 18 inch), slow (15 cm/sec) water in or very near (1 m (3ft)) dense cover of roots, logs, and flooded brush (Hartman 1965, Bustard and Narver 1975a). Several studies indicate that the amount of suitable winter habitat may be a major factor limiting coho production (Chapman 1966, Mason 1976, Chapman and Knudsen 1980). Swimming ability of coho salmon is decreased as the water temperature drops; therefore, winter cover is critical for protection from predation, freezing, and, especially, displacement by winter freshets (Bustard and Narver 1975b, Mason 1976, Hartman et al. 1982). Chapman and Knudsen (1980) found a very low winter biomass of coho salmon in channelized and grazed sections of streams in Washington, which they attributed to the reduced pool volumes and amount of instream and bank cover present in those areas (McMahon 1983).

In South Central Alaska (Region II), rivers and streams are typically covered with ice and have the potential to develop ice on the streambed for significant periods of the year. These conditions reduce the habitat suitability of certain portions of these systems for overwintering juvenile and resident fish species (Cunjak 1996). Though these icing conditions prevail in primary channels, side channels and sloughs, they still provide suitable habitat for overwintering fishes due to upwelling groundwater, low flow velocities, and suitable cover in the form of living and dead large woody debris and standing riparian vegetation.

A study by Bustard (1986) demonstrated that juvenile steelhead, coho salmon, and Chinook salmon have increased winter survival in side channel and side slough habitats that are characterized by relatively warm water due to upwelling groundwater. Swales et al. (1986) also found that juvenile coho salmon preferred off channel habitats influenced by warmer water temperatures due to upwelling groundwater and characterized by low flow velocities.

Additionally, a review by Cunjack (1996) discusses a large body of literature focusing on winter habitat relationships for juvenile and adult life stages of fish. This review discusses the use of side channel (off channel) habitats by overwintering fish and the importance of upwelling groundwater in these habitats. Due to energetic constraints associated with reduced metabolic activity, fish seek aquatic habitats characterized by relatively warm water that is flowing slowly. Due to upwelling groundwater, these habitats are key to

survival in winter when deep pools in main channels develop frazil ice¹ and become unsuitable to occupy. Crooked Creek may experience these types of conditions in winter. Cunjack (1996) also discussed the importance of habitat complexity for overwintering fishes due to species-specific habitat requirements or preferences, the importance of beaver ponds and large woody debris to overwintering salmonids, and the negative impacts associated with water withdrawal during winter months. Reductions in stream flow can lead to increases in ice formation, dewatering of off channel habitats, the stranding of fish, and the exclusion of fish from important channel margin habitat that is utilized for feeding and cover.

For the purposes of the habitat study at Crooked Creek, connectivity was defined as a physical “wet” connection between the off channel habitat and the main channel. This dynamic natural pathway provides for the movement of energy and/or materials such as organisms from one habitat type to another and creates a physical linkage between habitats through a natural corridor. Materials may be abiotic (such as water, sediment and nutrients) or biotic (such as organisms, species or groups of species). Movement of particulate and dissolved nutrients and carbon among habitats on the floodplain represents an important aspect of river ecosystem function. Water quality of isolated and semi-isolated backwaters is controlled largely by the frequency and duration of flooding (Knowlton and Jones 1997, Richardson et al. 2004, Strauss et al. 2004).

1.2 Goals and Objectives

As stated previously, mining operations are predicted to decrease annual stream flow conditions in Crooked Creek near the mine facilities (Table 1) by approximately 17 percent by year 20 of operations, under average conditions. Predicted stream flows show the greatest reduction during the winter months (i.e., January – March), where baseflow (i.e., groundwater outflow) is the dominant source of water to Crooked Creek (BGC 2014; Table 1). Decreases in base flow may have effects on the amount of off channel habitat available during low summer, and more importantly, low winter flow conditions.

The primary goal of this habitat mapping study was two-fold, to assess current base flow habitat conditions and to quantify the amount of off-channel habitat currently available in Crooked Creek at base flow conditions. Specific objectives included:

- 1) To map and characterize the Crooked Creek drainage (habitat mapping);
- 2) To identify adult salmon spawning locations within the Crooked Creek mainstem (redds survey), and assess the potential relationship between the location and density of redds and sediment composition and areas of ground water upwelling;
- 3) To conduct a detailed Rosgen channel classification survey (AREMP protocol) at the Crooked Creek reach predicted to experience the greatest reductions in baseflow, and where previous fish data had been collected;
- 4) To assess connectivity of off-channel habitat areas under low-flow conditions that could function as fish rearing habitat; and

¹ Frazil ice forms in flowing or turbulent water that has become supercooled by heat transfer to overlying air.

- 5) To assess habitat suitability for rearing juvenile salmon.

1.3 Study Area

The habitat mapping study area encompassed the mainstem of Crooked Creek; a tributary that flows into the Kuskokwim River near the village of Crooked Creek (Figure 1). The Crooked Creek mainstem begins at the confluence of Flat and Donlin Creeks and flows approximately 17.4 linear miles (28 km) or 33 river miles (53.1 river km) to the Kuskokwim River (approximately at river mile 259 / 416.7 rkm) (Whitmore et al. 2008). All aspects of this study were conducted within mainstem Crooked Creek. The proposed Donlin Creek mine is located near the upper mainstem section of Crooked Creek (Figure 1).The Kuskokwim River is the second largest river drainage in Alaska, draining an area approximately 50,193 mi² (130,000 km²), 11 percent of the total area of Alaska (Brown 1983). The Crooked Creek drainage includes major upstream tributaries such as Flat Creek and Donlin Creek, as well as a number of tributaries entering lower sections of the mainstem (Figure 1). A detailed Map Book of the Crooked Creek drainage including all areas mapped for this study can be found in Appendix A.

2.0 METHODS

2.1 Habitat Reach Selection Methods

Within the study area, Crooked Creek was divided into five habitat reaches, based on potential flow-related impacts from the Project. These reaches were established to allow for summarizing habitat data by areas of differing levels of predicted flow impacts. A description of these reaches follows:

- **HAB5** is the uppermost reach, and includes the mainstem of Crooked Creek from the confluence of Donlin Creek and Flat Creek, downstream to American Creek. This reach serves as a reference reach, located upstream of most flow related impacts.
- **HAB4** encompasses the mainstem of Crooked Creek from American Creek downstream to Anaconda Creek. According to the Project water balance, this reach is expected to see the greatest flow reductions of any reach (BGC 2014).
- **HAB3** covers the mainstem of Crooked Creek from Anaconda Creek to Crevice Creek. During the development of the 2009 study that this updated analysis is based on, the project water balance indicated this reach would have the greatest stream flow reductions as a result of the Project. Accordingly, a detailed survey reach was established within this reach. Since 2009, the water balance model has been updated and this reach no longer has the greatest expected flow reductions. However, stream flow reductions are still predicted for this reach.
- **HAB2** extends from Crevice Creek downstream to Getmuna Creek. Baseflow reductions are expected in this reach, but to a lesser extent than HAB4 and HAB3.
- **HAB1** covers the remaining portion of Crooked Creek, from Getmuna Creek to the mouth at the Kuskokwim River. This reach is expected to see minor stream flow reductions, as tributary contributions will dilute most of the flow impacts from upstream. This reach was included in the study, as aerial surveys have documented abundant adult salmon spawning in the reach (OtterTail 2011).

Within each of these reaches, individual habitats, salmon spawning habitat, and off channel connectivity, were assessed as described in the following sections.

2.2 Habitat Mapping Methods

USGS discharge data and multiple years of baseline data collection at the Crooked Creek drainage by OtterTail were used to define baseflow conditions. Accordingly, stream habitat was mapped along Crooked Creek from the confluence of Donlin and Flat Creek to its confluence with the Kuskokwim River (33 river miles / 53.1 km) from August 14, 2009 to September 15, 2009. Medium-scale habitats that form by the interactions of hydrological and geomorphologic processes (e.g., pools, runs, riffles) were mapped. This mesohabitat approach was intended to provide sufficient detail to assess existing habitats and to provide a snapshot of current base flow habitat conditions that could be used to address water resources planning at a large (stream-wide) spatial scale (Jacobson 2008; Tickner

et al. 2000). This approach also allowed for the rapid collection habitat data over long river distances.

Habitats were identified and mapped while wading the stream channel. The identification of habitat types followed the set of criteria used in Parasiewicz (2001) and Bovee et al. (2007) (Appendix B). The habitat types identified were delineated in the field as a geo-referenced polygon, or habitat mapping unit (HMU) on hand-held Trimble Yuma (Yuma) running ArcPad® software. High resolution aerial orthophotography captured in of the Crooked Creek drainage was used as a background for the map. The orthophotography was taken prior to the establishment of the USGS gage, so it was unclear what the exact stage height was at the time the aerial photograph was taken. It is clear that the orthophotography was taken at a stage higher than base flow; therefore mapped wetted areas of the HMUs collected during the survey were generally narrower than those displayed on the aerial photo.

Additional information such as embeddedness, substrate, habitat features (attributes), depth, and water velocity were collected at seven random locations within each habitat type identified. These and additional site characteristics were also recorded in the Yuma at the time of mapping. Embeddedness was determined within each sample location by a technician twisting his/her feet on the substrate three times (Parasiewicz 2001; Appendix C). Substrate was determined by recording the dominant substrate type within a square meter of each random sample location (Appendix D). Depth and average water column velocity measurements were collected at a minimum of seven locations within each habitat type using either a dipping bar (for depths < 1m) or an Acoustic Doppler Current Profiler-ADCP (for depths > 1m) that has an effective depth range of 0.4-40 m.

Additionally, attributes of each habitat that could potentially be used by fish were recorded. These attributes including features such as large boulders, overhanging vegetation, submerged vegetation, canopy shading, undercut banks, woody debris, and shallow margins. Definitions of these attributes can be found in Appendix E.

Water velocities were collected for each HMU mapped. For this study, the dipping bar was used in riffles and shallow water areas where the ADCP could not accurately capture velocity (<0.4 m). The techniques of the EPA Standard Operating Procedure for Dipping Bar Stream Flow Velocity Measurements (EPA 2002) were used. A SonTek™ RiverSurveyor® M9 ADCP was mounted on a Hydroboard and coupled with a with a GPS unit (YSI/Xylem Inc., San Diego, CA). It should be noted that the ADCP was originally designed for use in determining stream discharge along a stream cross section, but in this study it was also used for rapid determination of depth and column velocity in order to associate these measurements with specific habitat types identified along longitudinal transects.

ADCP was also used to measure discharge at one representative habitat type each day of the survey, at cross-sections near the mouth of major tributaries, and the mainstem of Crooked Creek below the confluence of these tributaries. This was done to determine the discharge of each tributary to the Crooked Creek mainstem. At each cross-section, a meter tape was set up perpendicular to flow across the wetted width of the stream (Figure 2). The shallow margins were determined by measuring the point closest to each bank that was >0.3m). This depth was chosen to assure the ADCP would capture all

measurements within the ADCP's operational range (i.e., 0.4-40 m). These shallow margins were set as endpoints for the ADCP discharge analysis using RiverSurveyor® Live software. RiverSurveyor® Live estimates the discharge of the shallow margins using width and depth information at the start and end points of the transect, and adds these data to discharge of the rest of the transect. After setting up the shallow margin calculations, the ADCP was slowly pulled across the transect perpendicular to the flow of water. This was done four times, alternating starting sides for each pass to reduce sampling error and get an average discharge at each transect.

The ADCP longitudinal transects performed to estimate velocity within a variety of habitat types along the length of the river were conducted simultaneously with the mapping of stream habitat. Depth and velocity data was continuously recorded by the ADCP while the Hydroboard was floated behind a raft in a zig-zag pattern. The end of each longitudinal transects corresponded with the downstream-end of a particular habitat type. Backwater habitat and abandoned channel areas were also surveyed using the ADCP. Data collection was started at one edge of the backwater, and the Hydroboard was maneuvered through the length of the backwater in a zig-zag pattern. This allowed a profile of the bathymetry of the channel. If the backwater was connected to the mainstem, ADCP data collection started in the mainstem, and the Hydroboard was floated across the shallowest point separating the backwater from the mainstem. Velocities were not analyzed in off-channel habitats and were assumed to be near zero.

All habitat data collected including habitat types, attributes, substrate, embeddedness, depth, and velocity were imported into ArcMap 9.3 GIS software. This data was then transferred into Microsoft Access® database. Similarly, ADCP data files were exported from SonTek™ Riversurveyor Live® software to Microsoft Excel®. These files were consolidated and exported to a Microsoft Access® database. Individual ADCP longitudinal profile and cross sectional measurements were subjected to a variety of filters designed to eliminate inaccurate or biased measurements (Appendix F).

Mean water velocities for individual habitat types were calculated by averaging all ADCP measurements from both longitudinal and cross sectional transects, that fell within the digitized boundary of each habitat type.

2.3 Salmon Spawning Habitat Survey Methods

Parallel to the habitat mapping survey, the redds survey was conducted on the mainstem of Crooked Creek, starting at the confluence of Flat and Donlin Creeks and proceeding downstream to its confluence with the Kuskokwim River. Chum and Chinook salmon spawning were suspected to be complete during the time of the survey. This time frame was developed based on previous aerial salmon survey data collected from 2004 to 2009, as well as salmon escapement data collected at the Crooked Creek Weir in 2008 and 2009 (OtterTail 2011).

Redds were identified by two fisheries biologists, either from a boat or on foot. Newly formed redds appear lighter in color than the undisturbed surrounding gravels and may remain discernible for a period of days to weeks, depending on stream flow and periphyton accumulation (Gallager et al. 2007). A redd was counted if it had a defined pit and downstream tail spill. The location of redds encountered was recorded using a GPS. Redds were also assigned a general location within the wetted channel relative to the left

wetted edge (facing upstream). Locations were set within 0 to 25 percent, 25 to 75 percent, and 75 to 100 percent of the wetted width from the left bank. Ground survey redd counts were compared to aerial survey counts conducted in July and September, 2009 to verify count accuracy. Detailed aerial survey locations and results can be found in OtterTail (2011). Aerial reach boundaries for the mainstem of Crooked Creek can be found in Appendix A. No effort was made to associate redds with fish species.

Further, given that a potential reduction in stream flow associated with the proposed Project could lead to increased settlement of fine substrate, the percent pool tail surface fines (i.e., particles less than 2 mm diameter) were measured in the tails of pools as described by AREMP (2009). The accumulation of fine sediment within salmonid redds is generally considered to be one of the main factors contributing to a reduction in embryo survival (Sear et al. 2008). The infiltration of fine sediment (typically considered to be sediments < 4mm) and consequent reductions in surface water exchange and oxygen delivery is widely acknowledged as a critical factor in determining the survival of salmonid embryos (Geist and Dauble 1998, Lorenz and Eiler 1989, Malcolm et al. 2008). Fine sediments deposited in the riverbed block interstitial pore spaces and inhibit the passage of water through the hyporheic zone.

Fine substrate measurements were collected as described by AREMP (2009) every 5th pool tail and at each pool tail with redds encountered along the mainstem of Crooked Creek. A 14-inch (35.56 cm) square Klamath grid with seven equally-spaced horizontal and vertical twine partitions was used to measure percent fines in pool tails. The grid has 50 intersections, 49 of which are formed by twine intersections and the fiftieth by the top left corner of the grid frame. The number of intersections resting atop >2mm diameter substrate was visually estimated along the intermediate axis at each of the three grid placements. The 2mm threshold was selected because fine gravels (2–6 mm) have been shown to have negative effects on the emergence success of salmonids (Beschta and Jackson 1979, Kondolf 2000, McHenry et al. 1994). Two millimeter pieces of colored electrical tape were placed on each side of the grid frame to aid in visual size determination. Three grid measurements were taken in each pool tail at 25, 50, and 75 percent of the distance across the wetted width from left bank (facing upstream). Measurements were taken approximately at 10 percent of the pool length upstream of the pool-tail crest or one meter upstream of the crest, whichever was less (AREMP 2009). Depth measurements were taken at the center of each Klamath fines grid measurement with a meter stick. An approximation of the percent surface fines in each grid was calculated by dividing the sum of intersections with fine sediment by the total number of intersections (50). The three measurements were averaged to calculate an approximation of the mean percent surface fines per pool tail.

Temperature measurements were also collected at all sampled pool tails and spawning locations to attempt to document potential zones of hydrologic upwelling. Temperature can be a positive indicator of hydrologic upwelling zones since groundwater is typically several degrees cooler than adjacent surface water during the summer season (Silliman and Booth 1993). This may not always be the case if groundwater residency is short or as ambient air temperatures drop and surface waters become cooler than groundwater. Measurements were collected with a Hanna Instruments® HI 93510N thermistor equipped with a pre-calibrated HI 762BL stainless steel probe. Meter resolution was 0.1°C; 0.1°F (-58.0 to 230.0°F). Meter accuracy was ±0.4°C; ±0.8°F. Temperature measurements were

collected just below the surface, at 50 percent of the water column depth, and approximately six inches into the stream bottom. All measurements were allowed at least 30 seconds to stabilize. To account for temporal and special temperature fluctuations in stream surface water, the ambient water temperature (column) was subtracted from the substrate temperature measurements, thus normalizing the data. Potential zones of hydrologic upwelling were expressed numerically as negative values. As noted, this may not always hold true, particularly when ambient air temperatures drop below that of the substrate water.

The relationship between the abundance of redds and average pool-tail depth, substrate and column water temperature, and abundance of fine sediments was examined using multiple regression techniques using JMP® Statistical software.

2.4 Detailed Stream Channel Classification Survey

A detailed reach habitat survey was conducted at the biomonitoring site CR1 located just downstream of Anaconda Creek (Figure 1). The survey methods used were adapted from the Aquatic and Riparian Effectiveness Monitoring Program (AREMP 2009). The survey was conducted along a 1,574 ft (480 m) reach starting a pool tail. A total of 11 major transects (A-K) perpendicular to the channel were spaced 131 ft (40 m) measured with a meter tape along the thalweg. Two additional transects (L and M) were added to the upstream end of the survey to encompass the entire CR1 biomonitoring site. Minor transects were spaced halfway between all major transects (A2, B2,...L2). Measurements were collected at 13 major transects and 12 minor transects along the reach.

All channel measurements were collected using a Lasertech® Impulse laser range finder mounted on a tripod and used in conjunction with a Lasertech® Mapstar digital compass. The entire survey was linked to a static pair GPS survey conducted with 2 Magellan® Promark3 GPS systems mounted on tripods and equipped with external antennas. The following variables were measured:

Sinuosity - defined as the deviation of the path of the river from its shorted possible path (a straight line). This was calculated as the length of the reach along the thalweg, divided by the straight-line distance between the thalweg points at the start and end of the reach. Distance was measured using a laser range finder.

Reach gradient - the slope of the river channel along the reach. This was calculated by taking the difference in elevation between the wetted edges of transects A and M (at the bottom and top of the reach), and dividing this difference by the reach length (1,574 ft / 480 m). Measurements were collected with a laser range finder.

Bankfull width - represents the width of the channel at its highest flow, determined using changes in vegetation, topography, or sediments changes. Measurements were collected with a laser range finder at the 13 major transects and used to calculate the average bankfull width.

Pool-habitat information - included the location of the tail crest, pool head and maximum depth of each pool, was also captured with a laser rangefinder. A habitat unit was considered a pool if it met the following criteria:

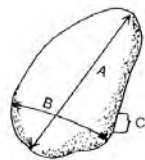
- Concave profile laterally and longitudinally
- A pool head and tail crest were observed
- The wetted-channel width occupied 90 percent of the wetted width at any location within the length of the unit
- The unit length was greater than its width
- The maximum depth was at least 50 percent greater than the pool-tail depth
- Thalweg passes through the unit (No Side Pools).

It is important to note that this definition of a pool differs from that used for the stream-wide habitat mapping survey.

Residual pool depth - calculated as the elevation difference between the thalweg depth at the pool-tail crest and the maximum pool depth. Residual pool depth was calculated using measurements collected with laser survey equipment.

Percent fines - particles less than 2 mm diameter were measured in the tails of pools following the same AREMP (2009) methods previously described under *Section 2.3*.

Substrate data - collected using procedures adapted from those described by Wolman (1954), Rosgen (1996), Bain et al., (1985), Platts et al., (1983), and Plafkin et al., (1989).



A = LONGEST AXIS (LENGTH)
B = INTERMEDIATE AXIS (WIDTH)
C = SHORTEST AXIS (THICKNESS)

Substrate particles for the D16, D35, D50, D84, and D95 calculations were measured using a modification of the substrate protocol described by AREMP (2009). Five substrate particles were randomly selected from all 25 transects at 10%, 30%, 50%, 70% and 90% of the distance across the bankfull channel. Each particle was measured along its intermediate axis (B in diagram) with a meter stick.

Large woody debris - The large-wood protocol was adapted from AREMP (2009). Pieces of wood found within the main channel and any side channels were counted if they had a minimum length of 9.8 ft (3 m), were at least 0.66 ft (0.2m) in diameter at one third of the distance from the large end, and either hung over or touched below the bankfull elevation of the channel. The length and diameter of the first 10 pieces encountered in the reach and every 5th piece thereafter was measured using a measuring tape so that subsequent estimates could be corrected. Length and diameter were visually estimated for all remaining pieces. In addition, codes were recorded that described: 1) the location of the wood relative to the channel; 2) whether the piece was natural or artificial (e.g., part of a man-made structure); 3) whether the piece had a cut end; 4) whether the piece was single, part of an accumulation of 2-4 pieces touching or part of a jam of 5 or more pieces; and 5) the percent of each piece of wood that would be submerged at bankfull flows (AREMP 2009).

2.5 Off-Channel Habitat Assessment Methods

The concept of bankfull stage was utilized for determining off-channel connectivity. The term “bankfull” was originally used to describe the elevation on the bank where flooding begins. In many stream systems, the bankfull stage is associated with the flow that just fills the channel to the top of its banks and at a point where the water begins to overflow onto a flood plain. Bankfull discharge is associated with a momentary maximum flow which, on the average, has a recurrence interval of 1.5 years as determined using flood frequency analysis (Dunne and Leopold 1978). Stream dimensions, patterns, and bed features associated with the longitudinal river profile are generally described as a function of channel width measured at bankfull stage.

Since streams are self-formed and self-maintained, it is important to relate measurable features one can identify in the field to a relatively frequent, corresponding bankfull discharge (Rosgen 1996). For those stream types that exhibit a well-developed floodplain, such as the “C”, “D”, “DA”, and “E” types – the bankfull stage is easily and reliably identified as the elevation of the floodplain (Rosgen 1996). Crooked Creek exhibits a “C4” type channel, and thus displays identifiable bankfull features. Bankfull elevation was further verified by field observations of a bankfull flow event in early May, 2009. From this observation, bankfull discharge was determined to be approximately 2,460 cfs (69.6 m³/s) at the USGS gage station (Figure 3).

Off channel habitats were only assessed if the habitat showed evidence of connectivity at or below a bankfull stage flow event. This results in an analysis of only those habitats that are frequently connected. There are several visual or physical indicators of the bankfull stage that enable field determination of this important parameter for areas where extensive stream flow records are not available. The bankfull stage indicators vary in their importance and discriminating power for different stream types (Rosgen 1996). The indicators used for this study for the determination of bankfull elevation were adapted from Rosgen (1996) and are listed below:

- The elevation associated with the top of the *highest* depositional features (e.g. point bars, central bars within the active channel). These depositional features are especially good indicators for channels in the presence of terraces or adjacent colluvial slopes.
- A change in vegetation (especially the lower limit of perennial species). The lowest elevation of birch, alder, and dogwood can be reliably useful, whereas willows are often found below the bankfull elevation.
- Slope or topographic breaks along the bank.
- A change in the particle size of bank material, such as the boundary between coarse cobble or gravel with fine-grained sand or silt.

Main Channel Cross Sections

Cross section measurements were collected to identify the elevation changes in the main channel water surface elevation necessary to connect the off channel habitats. This technique was chosen because changes in water height associated with changes in

discharge are directly related to channel shape. For example, a bankfull flow event in a channel with a relatively narrow bankfull width may result in larger increase in water surface elevation as compared to the same flow event in a channel with a relatively wide bankfull width. Cross sectional measurements were conducted on the main channel adjacent to the connection point for each off channel habitat. The specific location of main channel cross sections relative to the off channel habitat varied according to channel conditions, but was generally ± 49 ft (± 15 m) from the connection point. To obtain more accurate discharge and velocity measurements, the following areas were avoided: areas with obvious obstructions, such as root wads or logs; areas with heavy back eddy conditions.

Measurements taken at each main channel cross section included bankfull width, bankfull height, wetted width, and water depth at the thalweg. Bankfull indicators were assessed and agreed upon by several staff members with experience in identifying these indicators prior to measurements. Bankfull indicators upstream and downstream were also examined to aid in the final bankfull elevation determination. Bankfull height was measured as the vertical distance (m) from the base flow water surface to the bankfull height based on indicators described in Figure 4. Bankfull width was measured perpendicular to the channel as the distance between banks at the bankfull elevation. A monument of painted rebar was placed at the bankfull elevation nearest to the off channel habitat, to allow for future surveys and to link the off-channel cross section bankfull elevation to that of the main channel.

Wetted width was measured as the distance between the wetted edges, as measured in-line with the bankfull measurement. If small depositional bars or islands were encountered, they were included in the wetted width. Depth at thalweg was measured as the vertical distance from the stream substrate at the thalweg to the water's surface (Figure 4).

From Flat Creek downstream to Crevice Creek, channel cross sections and connectivity parameters of off channel habitats were measured with a survey-grade Lasertech® laser range finder and prism, and recorded onto a Trimble Nomad® field data recorder running Tripod Data Systems® Survey Pro software. Laser surveys were linked to a static pair GPS survey for geo-referencing. For the remaining sections of Crooked Creek downstream of Crevice Creek, channel measurements were conducted using survey tapes and height rods and geo-referenced with a single GPS measurement.

Additionally, where conditions allowed, detailed cross-sectional profiles for the wetted portions of the main channel were collected using a SonTek™ RiverSurveyor® M9 Acoustic Doppler Current Profiler (ADCP). ADCP collected depth, velocity, and cross sectional area measurements. See *Section 2.2* for ADCP operations protocol. These measurements, paired with future measurements and laser cross sections will allow for the development of stage-discharge relationships for each cross section. The cross sectional areas for the wetted portions of the main channels were used for the connectivity analysis described below.

Off Channel Habitat Cross Sections and Connection Elevations

Additionally, cross sections were conducted within the off channel habitat at the shallowest point, or the point at which the habitat would first become disconnected as stream flow decreased (connection point). The same measurements taken on mainstem cross

sections were recorded for off channel habitat cross sections (Figure 4). If the connection point was dry, wetted widths were not collected. A connection elevation was determined by measuring the vertical distance from the shallowest point at which water would connect from the mainstem to the bankfull height determined for the main channel (monument rebar). Subtracting this value from the main channel bankfull height results in the change in mainstem surface water elevation necessary to connect the off channel habitat to the mainstem (Figure 4). It is important to note that the bankfull elevation changes at each cross section, based on channel width. In large off channel habitats, supplementary cross sections were collected within the habitat to characterize wetted widths, bankfull widths, and thalweg depths. Supplementary cross section measurements were collected within representative sections of the off channel habitat, or where channel characteristics changed dramatically. These cross sections were used as guidelines for desktop GIS digitations of estimated surface areas for flows above baseflow conditions.

Estimating Changes in Off Channel Habitat Connectivity at Various Flows

The relationship between the water surface elevation at baseflow and bankfull elevations, coupled with the mainstem cross sectional profile allow for extrapolation of main channel cross sectional area at different water surface elevations. From main channel cross sections, water surface elevations corresponding to base flow, 25, 50, 75, and 100 percent of bankfull, were calculated using field measurements (Figure 4). The elevations above base flow were acquired by simply dividing the distance between base flow and bankfull into four sections (Figure 4). These sections were used to generalize the status of off channel habitat connectivity at these flow conditions, without having a defined stage-discharge relationship established at each location.

Using the connection elevation for off channel habitats, connectivity was assessed at each of these pre-determined elevations. In the example shown in Figure 4, the off channel habitat would be disconnected at a main channel elevation of 25%, and connected at 50%, 75%, and bankfull. Using GIS, off channel habitats were mapped as being connected or disconnected at these pre-determined elevations (Figure 4).

An additional analysis was done to assess connectivity during active mining using the calculated reduced flow numbers at average and low flow conditions during the peak mining activities at year 20. An additional analysis was done to assess connectivity during active mining using the calculated reduced flow numbers at average and low flow conditions during the peak mining activities at year 20. To perform this analysis connection depths for each off channel habitat were calculated as the depth of water at the connection point at mapping discharge (The zero contour in the bathymetric contour map described in section 2.7). For each scenario the projected drop in stage height for each reach was determined by subtracting the stage height for the reach at projected flow levels (BGC data 2014) from the stage height at mapping discharge (4719 m³/hr). If the projected drop in stage height was greater than the connection depth then the habitat was no longer connected. All stage heights were calculated from the stage discharge curves developed for each reach described in Section 2.8 While off-channel habitat was able to be digitized at elevations above mapping discharge stage height, we did not have enough information to determine the area of off-channel habitats at flows lower than mapping discharge and so surface area was unable to be calculated

Several other assumptions were made in determining the connectivity status of off channel habitats. First, in Crooked Creek, as with most highly sinuous streams, channels are highly dynamic and may change dramatically from year to year, month to month or even week to week, particularly after flood events or ice jams. Off channel habitats connected at baseflow in 2009 may be disconnected in 2010. From the time of the aerial photography (2007) to the time of the 2009 survey, several new channels were established, creating new off channel habitat. The second assumption is that the course of the main channel does not change with increasing stage. The third is that abandoned channels will have a slope similar to the main channel (i.e., water would flow from the upstream end to the downstream end). The fourth is that changes in flow will not alter channel shape or connectivity elevations. For example, at a higher flow, sediment may be deposited at connection points, altering the connectivity elevation of a particular off channel habitat. Additionally, high flow events may scour outside bends, thereby increasing bankfull width, and subsequently altering bankfull heights. No attempt was made to predict changes in habitat type at different flow stages. For example, if an off channel habitat is predicted to connect at both ends, (i.e., side channel), it is still considered off channel habitat even though it may have substantial flow.

Estimating Changes in Off Channel Habitat Surface Area at Various Flows

Field digitations of the off channel habitat surface area at base flow conditions were performed on a Yuma loaded with aerial photography loaded in ArcPad®. Methods for mapping off channel habitat are the same as those used in the mesohabitat mapping, and are presented in *Section 2.2*.

Additional digitations of estimated off channel habitat surface area at various flow stages were conducted post-survey with desktop ArcMap® version 9.3 GIS software. Upstream and downstream connection elevations determined from field measurements were used to calculate a generalized slope for each habitat. Vegetation information from aerial photography as well as data from off channel habitat longitudinal profiles and supplementary cross sections collected within off channel habitats were used to guide digitations of estimated surface area for flows above base flow. The off channel habitat connectivity at baseflow and estimated connectivity at 50% of bankfull, and bankfull stages were digitized using features in ArcMap 9.3.

Longitudinal profiles of off channel habitats were collected utilizing two different methods: 1) laser survey elevations of the thalweg of the off channel habitat at 2-5m intervals; and 2) where conditions allowed, ADCP longitudinal profiles for the wetted portions of the off channel habitat. Longitudinal profiles allow for more detail predictions of the extent of off-channel habitat inundation at various river stages. They were also used as a guideline for estimating inundation surface areas for off channel habitats with desktop GIS digitations. Additionally, supplementary off channel habitat cross sections were collected in representative habitats to provide verification of bankfull elevations for surface area digitations.

Several other assumptions were made for calculating the surface area of off channel habitats at flows other than base flow. The first is that calculations for off channel surface area at flows greater than or less than baseflow are estimates and have only been verified with ground measurements in a few representative locations. The second assumption made is that the estimated surface area of off channel habitats would increase relative to

discharge, independent of connection status. For example, if an off channel habitat remains disconnected at a 50% bankfull stage, its surface area would still increase to a 50% bankfull stage due to changes in the elevation of the water table. There are many factors that affect the water table including upland vegetation, wetlands, and local geology. The third assumption made is that if an off channel habitat is connected at the downstream end and not at the upstream end at a particular flow, backfilling will occur from the bottom up.

Discharge Measurements at Off Channel Connection Points

Discharge was measured at the main channel cross sections associated with each off channel habitat connection point. These discharge measurements were not used in determining the connection status for off channel habitats, but rather were implemented as a basis for developing a stage discharge relationship at each connection point. With future discharge measurements at each of these locations, a stage discharge relationship can be developed to allow for more accurate and predictive estimates of off channel habitat connectivity to the main channel.

2.6 Habitat Suitability Methods

A habitat suitability model provides an objective quantifiable method of assessing the existing habitat conditions within Crooked Creek by measuring how well each habitat variable meets the habitat requirements of the species life stage (Raleigh et al. 1986).

OtterTail developed a generalized habitat suitability model for characterizing the relationship between habitat features, and their importance to fish. OtterTail focused its suitability criteria on salmon as a group, as these species are of primary concern to local residents as well as local, state, and national government agencies for the Crooked Creek system. The habitat of Crooked Creek may not be as important to adult salmon productivity, but does provide important rearing habitat for juveniles which may spend only a few weeks (pink and chum salmon juveniles) to as long as 3 years (Chinook and coho salmon juveniles) in freshwater prior to migrating to sea (Raleigh et al. 1986). In Alaska, freshwater residence of juvenile coho salmon has been shown to last as long as 2 to 4 years (Drucker 1972; Crone and Bond 1976).

In addition, juvenile summer and winter rearing habitat is a major factor to the survival and production of Chinook salmon (Raleigh et al. 1986). Therefore, the specific salmon life stage with the highest potential to be affected by predicted base flow reductions in Crooked Creek was determined to be juvenile salmon rearing.

This model was based on available literature and previous studies that documented the importance of specific habitat features to juvenile salmon rearing. OtterTail used the Alaska Department of Fish and Game (ADF&G) habitat suitability index models and instream flow suitability curves for Chinook and coho salmon as a starting point for developing suitability criteria (McMahon 1983; Raleigh et al. 1986). Below is a brief summary of some of additional studies used to develop the habitat suitability criteria for this model.

Juvenile coho salmon tend to remain in slow water habitats after emerging from the gravel, avoiding riffle areas with faster water (Morrow 1980). Newly emerged coho salmon fry

aggregate along stream margins, in shallow pools, backwaters, and eddies (Lister and Genoe 1970; Stein et al. 1972). Burger et al. (1983) found that recently emerged Chinook salmon juveniles (<50 mm long) in the main stem of the Kenai river tended to stay close to the banks and were often found in reaches where the river had flooded terrestrial areas. Most of these juveniles were found in zones of zero water velocity, and almost 80 percent were captured in areas where water velocity was less than 0.2 ft/sec (6.1 cm/sec). Larger juvenile coho salmon are typically captured in creek mouth basins, backwater pools, and man-made canals. Ninety percent of these fish were in habitat having no measureable water velocity. Coho salmon parr tend to be most abundant in large, deep pools (> 0.30 m), where they congregate near instream and bank (overhead) cover of logs, roots, debris, undercut banks, and overhanging vegetation (Ruggles 1966; Lister and Genoe 1970; Mason 1976, McMahon 1983).

Juvenile Chinook salmon use water depth (deep, low-velocity pools and bank eddies), surface turbulence, instream structures, and substrate (primarily 10 to 40 cm in size) as cover, with substrate being a major source of escape and winter cover (Hartman 1965; Everest 1969). Platts (1974) found greatest densities of juvenile Chinook associated with large, deep, low-velocity pools with abundant instream cover, overhanging banks and vegetation, and rubble substrate.

2.7 Habitat Analysis Methods

Each HMU mapped was scored on the habitat suitability for juvenile salmon rearing. Scoring was based on the presence and abundance of attributes, and the HMU type. Scores for these two components were then summed to generate an overall suitability score for each HMU.

Attribute scores for the presence and abundance of habitat attributes including boulders, overhanging vegetation, submerged vegetation, canopy shading, undercut banks, woody debris, and shallow margins were given scores between zero and three, depending on the abundance of the attribute (i.e. low, present, abundant; Appendix G) Refer to Appendix E for definitions of each attribute. Attributes estimated to cover less than 10 percent or less of the HMU surface area were classified as low, and given a score of zero for that attribute. Attributes estimated to cover between 10 and 50 percent of the HMU surface area were considered present. Attributes estimated to cover more than 50 percent of the HMU surface area were considered abundant (Appendix G). Based on available literature and OtterTail field observations from eight years of sampling juvenile salmon in Crooked Creek, values given to each attribute were weighted according to the attributes importance to juvenile salmon. Shallow margins and woody debris were given the strongest weightings (Appendix G).

Each HMU type was also given a score from one to eight, based on characteristics deemed favorable to juvenile salmon. These scores were based on available literature and weighted based on OtterTail field observations from eight years of sampling juvenile salmon in Crooked Creek. Pools, backwaters and abandoned channels received the strongest weightings.

A total score for each HMU was compiled by adding the scores for each attribute to the score for the HMU type. Total scores were then divided into four suitability classifications; poor, fair, good and excellent (Appendix G).

2.8 Flow Reduction Habitat Modeling Methods

To project potential aquatic habitat loss from estimated flow reductions in the main channel of Crooked Creek, a bathymetric map was generated from ADCP data points. The bathymetric contour map was generated with 5 cm river depth intervals in order to predict habitat surface area loss by utilizing regional stage-discharge curves (Appendix I). Additional site-specific stage-discharge curves were developed to calculate surface area-loss for the each of the following segments of Crooked Creek: downstream of Crevice Creek, Crevice Creek to Anaconda Creek, Anaconda Creek to Omega Gulch, and Omega Gulch to American Creek (Appendix I). In order to estimate the potential effect of predicted flow reductions on specific habitat types of Crooked Creek, projected stream depth decreases were used to estimate decreases in riffle, run, and pool habitat surface areas.

Contour Mapping Methods

ADCP points were imported into ArcGIS® 9.3 for construction of a derived bathymetric contour map for analysis and evaluation. A polygon shapefile of the wetted surface of the mainstem of Crooked Creek was constructed by merging all of the HMU polygons into a single polygon (*refer to section 2.2 for HMU methods*). This compiled polygon served as a starting surface area for developing the model, as this mapping took place at a summer baseflow conditions. Within the boundaries of this polygon, a median polyline was constructed, representing of thalweg of Crooked Creek. ADCP point depths were used to guide the development of this line. This polyline was buffered to a width of 4.9 ft (1.5 m) and converted to a polygon mask of thalweg location. Using ArcEdit®, the mask was then used to extract the ADCP and cross section depth data that was located within this buffer.

In areas lacking sufficient thalweg depth data, points were added using average HMU maximum depths from HMUs immediately upstream and downstream of the data gaps. The spatial location of the added thalweg points was guided by professional judgment based on known characteristics of the Crooked Creek channel. For example, lacking direct measurements, the thalweg location would be expected to be closer to the outside bank of a sharp stream bend than to the center of the channel in a pool segment. Maximum depths for each HMU habitat type were assigned where depth was not available based on averaged maximum depths from the same habitat types approximately 0.5 miles upstream and downstream of the reaches where data was not available. Additional thalweg depths were extrapolated from maximum depths of adjacent HMUs.

The extracted thalweg points were then Spline interpolated within the 4.9 ft (1.5 m) thalweg buffer, using ArcGIS® spatial analyst extension to derive an interpolated thalweg depth. Spline interpolation, also known as Thin-Plate Interpolation, is a statistical technique used to derive a two dimensional raster diagram representing (X,Y,Z) coordinates. Z representing the variable of measure, in our study Z=depth in meters. Spline interpolation is particularly useful in creating elevation and contour plotting as the Spline Function assumes a minimum curvature while creating a two-dimensional plane intersecting sampling points. The Spline function for raster calculation is as follows:

$$S(x, y) = T(x, y) + \sum_{j=1}^n \lambda_j R(x_j)$$

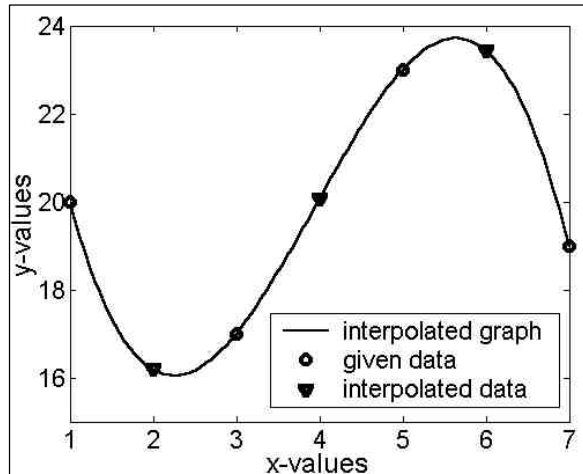
where:

$j = 1, 2, \dots, N$

N is the number of points.

λ_j are coefficients found by the solution of a system of linear equations.

r_j is the distance from the point (x,y) to the j th point.



(Math.colostate.edu)

Spline interpolation for contour interval building is useful in that it conditionally limits the curvature post known point onto raster surface thereby avoiding the Runge's phenomenon which observes interpolation behavior errors when approximating polynomials of higher degrees, indicating that higher degrees do not necessarily improve accuracy (EPA 2004).

The initial spline interpolation was used to create a derived raster of thalweg values. Using XPro Tools® extension, a point shapefile was created along the thalweg polyline at 6.6 ft (2.0 m) increments. The interpolated raster was then extracted into a point shapefile representing thalweg depths.

Additionally, a second point shapefile was created along the wetted edge of the compiled HMU polygon shapefile using XPro Tools® extension. Points were spaced at a 3.3 ft (1.0 m) interval. This shapefile represented the water's wetted edge, and each point was given a depth value of zero.

The derived values were then merged into a single point shapefile containing the complete ADCP dataset, cross sectional depth measurements, dipping bar depth measurements, interpolated thalweg depths, and wetted edge depths (zero depth) to create a base shapefile for bathymetric contour mapping. This final depth data set consisted of 347,214 points, of which 166,335 were measured river depth values, 161,493 were spatially located wetted edge points, and 19,386 were modeled thalweg depths. Using ArcGIS® 9.3 Spatial Analyst, the point shapefile was Spline Interpolated to create a bathymetric contour raster (FIGURE 14). The resulting interpolation was then cut with the combined HMU polygon. Contour intervals were then depicted onto the raster diagram in 1.97 in (5 cm) depth intervals. A polyline shapefile, consisting of aquatic habitat types, was then spatially joined to the contour interval shapefile. Contour intervals and aquatic habitat

types were then converted from polylines into polygons using ArcEdit® to calculate surface area.

Using ArcEdit® area calculation, the corresponding surface areas of each contour interval and aquatic habitat type were calculated. As subsequent depths were attained, the contour intervals were 'grouped' or summed to establish the estimated surface area lost for corresponding depth intervals. This enabled an estimated surface area loss to contour depth table to be generated for each Crooked Creek habitat reach and further divided into riffle, run, and pool habitat types.

2.9 Stage-Discharge Curve Creation Methods

Stage-discharge curves were needed to calculate the change in water surface elevation associated with predicted changes in stream flow. Existing curves were available for Crooked Creek at Crevice Creek (CCAC) and Donlin Creek below Ophir Creek (DCBO). Curves were needed for the areas in-between the existing curves including Crooked Creek below American Creek (CCBAM), Crooked Creek below Omega Gulch (CCBO), and Crooked Creek below Anaconda Creek (CCBA). These curves were generated using the following methods.

The first step in generating the curves was to adjust the existing curves to a real stream depth by establishing an off-set value. Gage heights were compared to depth measurements taken during manual stream flow measurements collected by Donlin Gold environmental staff. The offset value was calculated by taking the difference between the real maximum depth of the stream and the corresponding gage height. For DCBO, this value was +0.56 ft (0.17 m); for CCAC the offset value was +0.89 ft (0.27 m). New curves for DCBO and CCAC were plotted by adjusting the stage height by the offset value.

The second step was to generate a percent drainage area of the Crooked Creek watershed for each curve location needed. By subtracting out watershed areas downstream of each curve location, a percentage of the Crooked Creek watershed was obtained for each new curve location. These watershed percentages were then adjusted to be in terms of a percentage of the CCAC curve. This method assumed precipitation, groundwater influence, and overall discharge would be proportionate to watershed surface area.

The third step was to extrapolate 98 curves between the offset adjusted DCBO curve and the offset adjusted CCAC curve. This was accomplished by using a forecast function in Microsoft® Excel. The forecast function calculates a predicted value based upon two known values using least squares linear regressions. A forecasted value was created for each percentile rank between CCAC and DCBO measured values. Both discharge and adjusted stage height were projected for 98 values between CCAC and DCBO for relation to drainage area rank. The result is a set of 100 curves; with the DCBO curve CCAC being curve

The fourth step involved combining forecasted adjusted stage height values to forecasted discharge values, and creating an adjusted stage-discharge curve. Curves were selected and combined based upon the area percentile rank of drainage area between CCAC and DCBO. The drainage area percentile rank of each stream section was then used to select

the corresponding stage-discharge curve for each river section. This enabled stage-discharge curves to be generated for each stream segment between CCAC and DCBO.

In the fifth step, trend line functions were generated from the extrapolated stage-discharge curves using Microsoft Excel's power functions. Discharge values were then generated using stage heights from 0-2 meters in 0.01 meter increments. These values were then back referenced to estimated discharge depletions calculated from the BGC stream flow reduction report (BGC 2014). In order to determine maximum depletion possibilities, the project timeframe year-20 depletion percentages were used in association with predicted 10-year low flow discharges for summer and winter.

The final step was to apply predicted flow depletions to the extrapolated stage-discharge curves. This provided an estimated stage height for a given level of flow. The difference between the estimated stage height and the stage height at mapping discharge (the 0 contour in the bathymetric contour map) was used to calculate habitat surface area and volume for a given level of flow. Bathymetric contours were generated for 5 cm intervals and surface area and volume were calculated for each 5cm reduction in stage height. Stage heights intermediate between the 5cm contours were estimated by linear interpretation. For example if there was 2 acres of habitat with a stage reduction of 10 cm and 4 acres of habitat with a stage reduction of 15 cm then a projected stage reduction of 12.5 cm would result in 3 acres of habitat. (Table 10).

2.10 Assumptions and Limitations Flow Reduction Habitat Modeling

The low flow model described above was designed to address a need for a quantitative analysis of the effects of flow depletions on fish habitat. The model should not be interpreted to be a precise analysis, but rather was designed to inform interested parties of the potential effects. All results stated in *section 3.6* should be treated as estimates. Several assumptions were made during the low flow model development. Those assumptions and other limitations to the accuracy of this model are stated below:

- Hypothetical stage-discharge curves were used for predicting changes in water elevation.
- Assumed that in the Crooked Creek drainage, groundwater influence, precipitation, and other factors that influence stream discharge are constant from one watershed to the next.
- Assumed that the channel shape in winter is identical to the channel shape during open water periods.
- Used watershed area as a factor in selecting appropriate stage-discharge curves for areas lacking existing curves.
- Assumed that the CCAC curve would represent conditions downstream of Crevice Creek, even though the gage station is upstream of the Crevice Creek confluence.

3.0 RESULTS

All surveys were conducted along Crooked Creek during low flow conditions from August 14 to September 15, 2009. The average discharge during the study was 202 cfs (range 185-256 cfs) / 5.72 m³/s (5.24-7.24 m³/s) based on the USGS gage at Crooked Creek (Figure 3). The calculated low flow for this time of year is 260-273 cfs with average flow of 531-540 cfs at the confluence of Bell Creek and Crooked Creek, (BGC 2014) which is actually upstream of the USGS station.

3.1 Habitat Mapping Results

During the survey, a total of 840 habitat mapping units (HMU) were identified and mapped along the 33 mile (53.1 km) long Crooked Creek mainstem. A Map Book showing the habitats mapped is included in Appendix A. Run habitat made up the majority (61.4%) of the total wetted surface area in Crooked Creek during the survey period; this was the most abundant habitat with 325 of the 840 HMU types mapped as a run (Table 2). Substrates in run habitat were predominantly microlithal (2.0-6.3cm) or mesolithal (6.3-20cm) with little fine sediment present. A relatively small portion of run habitat contained abundant shallow margins or woody debris. All HMU boundaries were heads-up digitized in the field using GPS and orthophotography to verify where the technician was in relation to the HMU they were digitizing.

Riffle was the second most numerous habitat type mapped (206 of 840 mesohabitats), but made up only 12.2% of the total wetted surface area (Table 2). Many of the riffles encountered were much shorter than the other HMU types, typically transitioning quickly into a run or pool habitat during the survey period.

Of all riffles sampled in Crooked Creek, 30.2% contained abundant shallow margins with little flow. Although fish were not sampled as part of this study, abundant juvenile fish were often observed during the mapping survey in these riffle margin areas. Fish sampling in Crooked Creek has also documented numerous juvenile salmonids in these habitats. Biologically, these observations make sense since the shallow margins are adjacent to swift water where food production for fish is highest (Ruggles 1966).

Water velocities measured with the dipping bar in riffle habitat were consistent with ADCP measurements. ADCP measured mean riffle velocity was 0.16 fps (0.05 m/s) faster than the dipping bar mean (Table 2). The slight discrepancy between these mean velocities may be explained by the limitations of each sampling method. The dipping bar is capable of taking measurements in very shallow water, while the ADCP is limited to water with depths of greater than 1.3 ft (40 cm). These shallow water areas often have low velocities. Also, the dipping bar is limited to depths of less than 60cm while the ADCP is capable of collecting measurements in deeper water, and deeper sections of riffles often have the highest water velocities.

Pool habitat was rather limited accounting for 118 of the 840 HMUs identified and mapped and making up only 7.6% of the total Crooked Creek wetted surface area (Table 2). Much of what would also likely be considered run habitat at a higher flow, qualified as a pool during this survey based on the habitat type criteria used (Appendix A). Substrate in pools was dominated by sand and small cobble, and over 20% of all pools sampled contained abundant woody debris or shallow margins which are considered optimum habitat for

juvenile salmon rearing. Juvenile coho salmon stay almost entirely in pool habitat and avoid riffle areas (Morrow 1980) or areas with higher velocities.

Glide and fast run habitat were not very common within the Crooked Creek mainstem. The stream is very sinuous, with many meandering sections not suitable for glides or fast run criteria (Table 2; Appendix A). Fast runs were observed only in the lower sections of Crooked Creek where the stream becomes larger (Table 2; Appendix A).

The most dynamic habitat types mapped during this survey were backwaters, side arms, and abandoned channels (Table 2; Appendix A). Backwaters and abandoned channels were only mapped if evidence of connectivity to the main channel at a flow less than or equal to a bankfull event was observed (refer to Section 2.5 for definitions of bankfull). A total of 83 backwater HMUs were digitized accounting for 4.6 percent of the total wetted area of the Crooked Creek mainstem (Table 2). The majority of the backwater habitat appeared to be nearly disconnected from the mainstem at the sampled low flow. Many juvenile salmon were observed in these backwater areas during sampling, and it is well documented that rearing salmon prefer this type of slower water areas that provide cover (Narver 1978, McMahon 1983, Raleigh et al. 1986, Morrow 1980, ADF&G 1986).

Side arms were also rare and accounted for only 39 of 840 HMUs digitized and approximately 3 percent of the wetted area mapped (Table 2). Many of the side arms observed were surrounded by low elevation sediment bars adjacent to the main channel, suggesting that at slightly higher flows they would connect to the main channel. Not all sections of divided channel were classified as side arms because according to the criteria used, bisected channels are not considered side arms even though they may exhibit some of the same properties (Bovee et al. 2007). Most side arms observed during the survey could be considered fair to good salmon habitat because of their abundant shallow margins, woody debris, and canopy cover (Table 2).

Disconnected habitats (defined as abandoned channels) occurred wherever there was a depression of sufficient depth that water could be stored, but with no surface connection to the mainstem at the time of the survey. Abandoned channels accounted for six percent of the wetted surface area mapped although relatively large disconnects occurred at multiple locations throughout Crooked Creek. Abandoned channels are remnant channels cut off from Crooked Creek by reconfiguration of the stream channel, typically during flood events. The highly sinuous stream channel will often shift its course from season to season and remnant channels are evident throughout the floodplain (Figure 5; Appendix A). By definition, HMUs classified as abandoned channels must connect with the mainstem at or below bankfull conditions. However, some abandoned channel habitat persisted at lower flows (e.g., Figure 5- Example 3). Although only 48 of 840 HMUs were classified as abandoned channels, making up approximately six percent of the wetted area mapped (Table 2; Appendix A), they were considered excellent salmon habitat primarily due to the abundant fish cover that was observed (Table 2).

A total of 168 separate longitudinal profiles were compiled to result in a single longitudinal profile detailing depth and current velocity for the entire mainstem of Crooked Creek. ADCP data indicated that under low flow conditions, large areas of both pool and run habitat presented low water velocities near the stream margins. Mean water velocities for each habitat type fell within expected relative ranges (i.e., pools slower than runs, runs slower than riffles). Riffles showed the greatest variation in water velocity as shown in Figures 6 and 7. Variations in gradient and substrate roughness likely have a greater

influence on water velocity in riffle habitat due to the relatively shallower water column depth.

To assess the accuracy of the ADCP discharge measurements, discharge estimates based on ADCP cross sections at the USGS gage station were compared to the USGS discharge measurement. The two discharge estimates were fairly similar; ADCP cross sections conducted on August 14, 2009 resulted in an average discharge estimate of 254 cfs (7.18 m³/s) and the corresponding USGS discharge measurement was 273 cfs 7.73 m³/s). Discharge estimates for September 12, 2009, were 131 cfs (3.71 m³/s) and 188 cfs 5.32 m³/s) based on ADCP and USGS, respectively. According to SonTek™, it is likely that the substrate roughness present at the USGS gage station may have a larger influence on discharge measurements at the lower discharge observed in September. It should also be noted the USGS discharge rating curve is still undergoing development and adjustments, and fewer discharge measurements are available to anchor the lower range of the rating curve, therefore the USGS rating curve may be susceptible to greater error at these low flows.

3.2 Spawning Salmon Survey Results

Spawning redds were present in 48 percent of the habitats sampled. The survey of redds and pool tail fines shows that salmon spawning areas are more common in the lower reaches of Crooked Creek, especially near the confluence of Getmuna Creek (Figures 8; Appendix A). Redd density ranged from 1 to 59 redds in a single habitat unit. The number of redds documented by the ground survey of the Crooked Creek mainstem was similar to the number of redds counted in aerial surveys in 2009 (Table 4). It is important to note that habitats sampled during the spawning survey do not necessarily match up with mapped habitat types. This is because pool habitats, as defined for the pool tails and redds analysis, include some habitats that would be classified as riffle and run according to the criteria used for habitat mapping. Also, some very small riffles may be combined with larger habitats under the mesohabitat approach used in mapping Crooked Creek.

A summary of characteristics measured at redd and pool tails surveyed along Crooked Creek is included in Table 5. It was hypothesized that a higher density of redds would be present in areas of groundwater activity (hyporheic flow), which could be identified by cooler water temperatures at or near the substrate (Buffington and Tonina 2009, Geist et al. 2002). However, a relationship between red density and water temperature at the substrate ($r^2=0.01$; $F=0.5$; $n=40$) or in the water column ($r^2=0.01$; $F=0.6$; $n=40$) in Crooked Creek was not observed (Table 6). The difference between the water column and substrate temperature was also used as a potential indicator of hyporheic flow, but a relationship between this variable and redd density was not evident. Although this temperature gradient is often used as an indicator of hyporheic flow in a stream, it is not the only indicator of hyporheic flow. Lorenz and Eiler (1989) showed that the difference in water temperature between the substrate and the water column only indicated the presence of hyporheic activity if the ground temperature was sufficient to lower the temperature of the water, and also showed that fine sediments in redds indicated the presence of upwelling. Overall, a temperature gradient was not observed throughout the pool tails and redds sampled during this survey.

A significant correlation was not observed between redd density and the percentage of fine sediments at the pool tail ($r^2=0.042$; $F=0.22$; $n=40$), or between redd density and depth ($r^2=0.043$; $F=0.19$; $df=40$) (Table 6). However, consistent with studies indicating that

spawning chum salmon can tolerate water as shallow as 18 cm (Thompson 1972) and the minimum spawning depth for Chinook salmon is 30 cm (Geist and Dauble 2004), most redds in this study were found at depths of 30 cm or greater (Figure 9). Results from this redd survey were also consistent with findings from a previous study indicating that salmon egg survival decreases when fine sediment accumulation within the red reaches 13% (McHenry et al. 1994); the contribution of fine particles to stream substrate in all redds sampled during this survey ranged from 4.7 to 18 percent and fine particles accounted for less than 13 percent of the substrate composition at approximately 86 percent of these redds (Table 6; Figure 10). In addition, it appears that there are substantial differences in substrate temperature, percent of pool tail fines, and depth in pool tails with and without redds Figure 11.

Pools with a higher density of redds were found closer to the mouth of Crooked Creek; lower redd densities were found in the upstream habitat sections (Figure 8). The high density of redds in HAB1 may be explained to the reach's proximity to the Kuskokwim River, the larger size of habitats that can harbor a greater number of spawning salmon (Figure 8), and higher winter stream flow. The highest redd densities were observed near the confluence of Getmuna Creek, in the same area where previous aerial salmon surveys have documented the highest salmon densities along the Crooked Creek drainage (OtterTail 2011; Table 4).

3.3 Detailed Stream Survey Results

The detailed channel survey provided a snapshot of stream characteristics in one representative reach of the Crooked Creek mainstem, including detailed channel profiles, habitat composition, substrate, large woody debris, and entrenchment information. The survey indicated that the Crooked Creek mainstem is a meandering (sinuosity >1.5), low gradient, slightly entrenched stream (Figure 12; Table 7).

Discharge for this reach during the study period was relatively low for Crooked Creek (279 cfs or 7.9 m³/s). Large woody debris in this reach was scarce and substrate size was dominated by coarse gravel (D50=31.7 mm). Using the Rosgen classification system for natural rivers, the Crooked Creek mainstem can be rated as C4, which includes streams characterized by gravel substrates and pool-riffle sequences (Rosgen 1996).

It should be noted that fish population data has been collected since 2004 in the uppermost 300 ft (91.5 m) of the detailed survey reach. The electrofishing data from 2004-2009 indicated that in most years, juvenile salmon were relatively scarce in this reach. From 2004 to 2008, the abundance of coho and Chinook salmon ranged from 5 to 44 fish/300ft and 0 to 5 fish/300ft, respectively. However, juvenile coho salmon abundance increased to 832 fish/300 ft in 2009, suggesting that this reach provides salmon spawning or rearing habitat for juvenile coho salmon (OtterTail 2011). Substrate characteristics in the reach sampled are consistent with substrate size identified as preferred substrate for spawning salmon (Table 7). Kondolf (2000) have shown salmon prefer to spawn in gravels that are small enough to be moved by the fish itself (typically <128mm), yet not dominated by fine sediment (<2mm).

3.4 Off Channel Habitat Analysis Results

A total of 55 off channel habitats were identified along Crooked Creek from Flat Creek to the mouth at the Kuskokwim River. Note that this total does not reflect the same totals displayed in Table 2, as some small back waters designated during the mesohabitat

mapping were not considered off channel habitats, as they occurred within bankfull of the main channel. Examples of off-channel habitats identified are shown in Figure 13. During the baseflow, 15.3 acres (61,874 m²) of off channel surface area are connected to the mainstem channel. At bankfull, an estimated 68.0 acres (274,026 m²) of off channel habitat are connected to the mainstem. Although off channel habitats may only be available intermittently or seasonally, they can still provide critical refuge for juvenile coho and other salmonids (Saldi-Caromile et al. 2004).

Flat Creek to American Creek (HAB5)

At survey discharge conditions, a surface area of 0.66 acres (2,686 m²) identified as off channel habitat was connected to the main channel. This area amounts to approximately 89 percent of the total off channel habitat area from Flat Creek to American Creek (Table 8). This high percentage of habitat connected at baseflow can lead to a high frequency of connectivity, making these habitats available to fish throughout much of an average flow year. At 50% bankfull and bankfull stages, an estimated 1.22 and 2.11 acres (4,954 and 8,550 m²) of off channel habitat are connected, respectively.

Recent revisions to the water balance model show potentially substantial flow reductions within this reach (Table 1; BGC 2014). At mapped discharge and average year summer flows all nine off channel habitats have connectivity to the main channel and provide critical fish habitat. However, even at the greatest estimate flow reductions during peak 20-year operations (March) there are still 8 of 9 off channel habitats still connected to the main channel. (Table 8A).

American Creek to Anaconda Creek (HAB4)

Approximately 2.20 acres (8,907 m²) of off channel habitat surface area are connected to this section of Crooked Creek's main channel at mapped discharge conditions. Of all off channel habitat areas identified in this section, 83 percent was connected to the mainstem (Table 8). Similar to the Flat Creek to American Creek section the high percentage of off channel habitat area connected at mapped discharge is likely to result in a high frequency of connectivity to the main channel throughout much of an average flow year. This reach is predicted to have the greatest flow reductions associated with pit dewatering activities and surface flow alterations (Table 1).

Given the high degree of connectivity at mapped discharge, it is likely that most off channel habitat surface area maintains a connection with Crooked Creek mainstem if flow is reduced. At average discharge at the Year-20 discharge reduction there are still 9 of 12 (75%) still connected to the mainstem of Crooked Creek. At summer low flow and reduced flow conditions 7 of 12 (58%) of off channel habitats remain connected. Even during winter low flow reduced conditions 7 of 12 habitats remain connected to the main channel (Table 8A).

Anaconda Creek to Crevice Creek (HAB3)

All of the 1.75 acres (7,080 m²) of off channel habitat surface area along this stream section is connected to Crooked Creek at baseflow conditions (100%) (Table 8). This relatively shorter stream section was isolated due to possible proposed effects of mine operation on stream flow (Table 8). At mapping discharge there was only one off channel habitat connected out of a total of two (50%). However that area stay connected to the main channel even at winter (March, Year-20) low flow reduced conditions (Table 8A).

Crevice Creek to Getmuna Creek (HAB2)

Of the 12.38 acres (50,112 m²) identified during baseflow conditions as off-channel habitat along this stream section from Crevice Creek to Getmuna Creek, approximately 8.22 acres (33,283 m²) (66.4 percent) were connected to the mainstem (Table 8). The lower degree of connectivity at base flow suggests that a good portion of the habitat may become disconnected at lower flows, particularly during dry years. This scenario may increase the likelihood of isolating fish from the main channel under lower flow conditions.

At average discharge during summer (June) there are 7 of 17 (41%) of the off Channel habitats are connected Crooked Creek. However, at average summer flow at Year-20 discharge reduction there are only 3 of 17 (18%) connected to the mainstem of Crooked Creek. At winter low flow (January) at average undisturbed flow 1 of 17 (6%) are still connected. At average disturbed flow at the Year-20 flow it is reduced to none of 17. At the winter low flow (March, 10% percentile) undisturbed or disturbed discharge, none of the off channel habitats are connected to the mainstem of Crooked Creek. (Table 8A)

Getmuna Creek to the Mouth (HAB1)

At baseflow conditions, 2.45 acres (9,918 m²) (64.3%) of the 3.81 acres (15,428 m²) of off channel habitat identified in this section were connected to Crooked Creek. From Getmuna Creek downstream, effects of pit dewatering activities will likely be buffered by additional flow from tributaries (Tables 1 and 8).

At average discharge during summer (June) there are only 2 of 4 (50%) of the off Channel habitats are connected Crooked Creek. At average summer flow at Year-20 discharge reduction that number is reduced to one (25%) connected to the mainstem of Crooked Creek. At winter low flow (January) at average undisturbed, at the Year-20 disturbed flow, and at the winter low flow (March, 10% percentile) undisturbed or disturbed discharge, none of the off channel habitats are connected to the mainstem of Crooked Creek. (Table 8A)

With predicted effects of pit dewatering activities associated with the proposed Project, concern arose as to the effects on off channel connectivity. Mining operations are predicted to decrease stream baseflow conditions in Crooked Creek near the proposed mine area from a year round average of 15-21% by year-20 of mining operations (Figure 1; Table 1). Actual decrease ranged from 14% in the fall at Crevice creek to as high as 33% at American Creek in March of Year-20 of operations (Table 1). Predicted stream flows show the greatest reduction during the winter months (i.e., January – March), where baseflow (i.e., groundwater outflow) is the dominant source of water to Crooked Creek (BGC 2014). Overall, this study suggests that Crooked Creek currently has ample off channel habitat in a variety of successional stages, providing diverse habitat to a variety of aquatic organisms. A reduction in stream flow could affect the frequency of connectivity of these off channel habitats to the main channel. However, the effects of stream flow reductions would likely have the greatest effects during extremely low flow periods, and the degree of such effects on habitat conditions will vary across different sections of the Crooked Creek channel.

Winter conditions represent the area of greatest concern when discussing baseflow reductions. With little surface water flow to buffer mine reductions in baseflow, decreased flow could have substantial effects on off channel connectivity as well as decreasing the surface area of these habitats.

3.5 Habitat Suitability Results

A total of 840 HMUs were mapped during the survey. Results from the fish habitat suitability model found, at baseflow conditions, 7 percent of the entire 33 miles (53 km) of mainstem Crooked Creek habitat would be considered excellent juvenile salmon rearing habitat, 31 percent considered good, 51 percent fair, and 10 percent considered poor habitat. Breakdown of each HMU type are described below (Table 9).

Runs

Results showed that runs make up the majority (61.4 percent) of the total wetted surface area in Crooked Creek during baseflow conditions (Table 2). Runs are also the most abundant HMU type, with 325 of the 840 HMUs mapped as a run type (Table 2). A relatively small portion of runs contained abundant shallow margins or woody debris, and this was reflected in the juvenile salmon habitat suitability results. Only 0.2 percent of all runs mapped were shown to contain excellent juvenile salmon rearing habitat based on OtterTail's suitability model (Table 9). Good juvenile salmon habitat encompassed 33.4 percent of runs, while fair habitat was the most common in runs at 64.2 percent. Only 2.3 percent of runs contained poor juvenile salmon habitat.

Riffles

The second most abundant HMU type was riffle habitat (206 of 840 HMUs), but made up only 12.2 percent of the total wetted surface area (Table 2). At base flow conditions, many of the riffles encountered were much shorter than the other HMU types, typically transitioning quickly into a run or pool habitat. Juvenile salmon suitability was mostly poor (71.2 percent), with only 1.54 percent considered good habitat, 27.3 percent fair habitat, and no riffles considered excellent habitat (Table 9). This was expected, as juvenile coho salmon stay almost entirely in pools, avoiding riffle areas (Morrow 1980) or areas with higher velocities.

During sampling, riffles were observed to be more productive than the results of the habitat suitability display. Of all riffles sampled in Crooked Creek, 30.2 percent contained abundant shallow margins. These areas with little to no flow were often observed to contain juvenile fish during the ground survey, and OtterTail fish sampling in Crooked Creek has also shown that juvenile salmonids use these habitats. The shallow margins are also adjacent to swift water, where food production for fish is highest (Ruggles 1966; OtterTail 2011).

Pools

Pools accounted for 118 of the 840 HMUs in Crooked Creek and only 7.6 percent of the total wetted surface area (Table 2). Because of the conditions that existed during the survey, much of what would likely be a run at a higher flow qualified as a pool during this survey based on the HMU criteria (Appendix B). Over 20 percent of all pools sampled contained abundant woody debris or shallow margins and the suitability model found 4.9 percent of pools to contain excellent habitat, 70.2 percent contain good habitat, and 24.9 percent contain fair habitat (Table 9). No pools were shown to contain poor salmon habitat.

Glides and Fast Runs

Glides and fast runs were not very common within the Crooked Creek mainstem. The stream is very sinuous, with many meandering sections not suitable for glides or fast run

criteria (Appendix A). Fast runs were observed only in the lower sections of Crooked Creek where the stream becomes larger. Based on the model, glides and fast runs were dominated by fair salmon rearing habitat, at 87.4 percent and 73.5 percent respectively (Table 9).

Backwaters, Abandoned Channels, and Side Arms

The most dynamic HMU types mapped during this survey were backwaters, side arms, and abandoned channels. The variability in the areas of these three HMU types occurred, at least in part, because they have the potential to readily change from one HMU type to another depending on flow conditions. An area might be disconnected at a very low flow, become connected as a backwater at an intermediate flow, and connected from top and bottom (thereby becoming a sidearm) at higher flows. Backwaters and abandoned channels were only mapped if they showed evidence of connectivity to the main channel at a flow less than or equal to a bankfull event (*refer to Section 2.4 for definitions of bankfull*).

A total 83 backwaters were found during this survey (Tables 2, and 9), and they contained the second largest area of favorable juvenile salmon habitat in the drainage. Backwater habitats contained 4.27 acres (17,300 m²) of excellent juvenile salmonid habitat, and 6.00 acres (24,282 m²) of good habitat (Tables 2, and 9). No backwater HMUs were classified as poor salmon. The majority of the backwaters appeared to be nearly disconnected from the mainstem at the sampled low flow. OtterTail observed juvenile salmon using these backwater areas during sampling, and it is well documented that rearing salmon prefer these slower water areas that contain cover (Narver 1978, McMahon 1983, Raleigh 1986, Morrow 1980, ADF&G 1986).

Side arms were not very abundant, composing only 39 of 840 HMUs mapped (Table 2). Many of the side arms observed were surrounded by low elevation sediment bars adjacent to the main channel, suggesting that at slightly higher flows they would become part of the main channel. A complicating factor was that not all sections of divided channel, when observed, were classified as side arms. According to our definitions, bisected channels were not classified as side arms, even though they may have exhibited some of the same properties (Bovee et al. 2007).

Of the 39 side arms observed during the survey, none were considered to be excellent juvenile salmon rearing habitat. Fair salmon habitat dominated the sidearm habitats, with 60.9 percent considered fair (Table 9). Only 5.5 percent of sidearm habitat was considered poor for juvenile salmon, while 33.8 percent were considered good. However, many of the side arms observed contained abundant shallow margins, woody debris, and canopy shading.

Disconnected HMUs (defined as abandoned channels) occurred wherever there was a depression of sufficient depth that water could be stored, but with no surface connection to the mainstem at the time of the survey. Abandoned channels did not account for a significant proportion of total habitat area (6 percent), although relatively large disconnects occurred at multiple locations throughout Crooked Creek (Table 2; Appendix A). The abandoned channels are typically remnant channels cut off from Crooked Creek by reconfiguration of the stream channel, typically during flood events. The highly sinuous stream will often change from season to season, and remnant channels are evident throughout the floodplain (Appendix A). By definition, those HMUs considered to be

abandoned channels must be able to connect with the mainstem at or below bankfull conditions. The abandoned channel displayed in Figure 13 - Example 3 persisted at lower flows, but evidence of connectivity was present, and this section was modeled to be connected to the mainstem with an increase of only 50 percent of baseflow.

Abandoned channels contained the greatest area of suitable salmon habitat. Although only 48 of 840 HMUs were classified as abandoned channels, 11.53 acres (46,650 m²; 82.4 percent) of abandoned channel habitat was considered excellent for juvenile salmon (Table 9). No fair or poor habitat was documented in abandoned channels, and 3.8 mi² (9.9 km²) of the abandoned channels mapped were considered good juvenile salmon habitat. This is attributed, in large part, to the abundant fish cover that was observed in these habitats (Table 2).

3.6 Flow Reduction Habitat Modeling Results

Bathymetric mapping of the Crooked Creek mainstem between American Creek and Getmuna Creek resulted in 122.86 acres (49.74 ha) of aquatic habitat at mapping discharge, consisting of 26.69 acres (10.81 ha) of riffle habitat, 85.22 acres (34.50 ha) of run habitat, and 10.95 acres (4.43 ha) of pool habitat. Mapping Discharge was estimated using average discharges during the August 14 2009 to September 15, 2009 period the habitat mapping was recorded. Low flow conditions was based on the 10th percentile at 20-year operation level for June (Typically the lowest average flow for summer). Low flow conditions indicate a reduction in surface area to 93.24 acres (37.75 ha), consisting of 14.33 acres (5.8 ha) riffle habitat, 69.47 acres (28.12 ha) run habitat, and 9.44 acres (3.82 ha) pool habitat from an average summer flow condition (June). Summary data for low flow modeling can be found in Tables 10. The final stage-discharge curves used in this model can be found in Figure 14. An example of the final contour mapping can be found in Figure 15.

Bathymetric contour mapping for average winter undisturbed average (January) flow conditions indicated a total surface area of 89.18 acres (36.11 ha), consisting of 13.24 acres (5.36 ha) riffle habitat, 66.75 acres (27.03 ha) run habitat, and 9.19 acres (3.73 ha) pool habitat. Low flow conditions at 20-year indicate a reduction in total surface area to 76.28 acres (30.88 ha), consisting of 9.41 (3.81 ha) of riffle habitat, 58.43 acres (23.66 ha) of run habitat, and 8.43 acres (3.41 ha) of pool habitat (Table 10). Please note that average flow conditions were lowest in January, but low flow conditions (10th percentile) were lowest in March (Table 1, BGC 2014)

Crooked Creek Below American Creek (CCBAM)

Derived stage-discharge curves indicate that lowered flows to Crooked Creek from mining operations will reduce summer low flow (10th percentile, Table 1) conditions by an estimated maximum of 0.56 ft (0.17 m). Bathymetric surface areas indicate a 0.56 ft water stage reduction will result in an estimated reduction of 12 percent of riffle habitat, 5 percent of run habitat, and 3 percent of pool habitat. This indicates a total approximate aquatic habitat reduction of six percent during 20-year summer low flow conditions from water level reductions due to mining disturbances (Table 10).

Impacted winter low flow conditions indicate an estimated maximum water stage reduction of 0.92 ft (0.28) meters from base low flow conditions at Year-20 operations stage. Bathymetric surface areas indicate a 0.92 ft water stage reduction will result in an estimated reduction of 11 percent of riffle habitat, 4 percent of run habitat, and 3 percent

of pool habitat (Table 10). This correlates to a total approximate aquatic habitat reduction of four percent during low flow conditions from water level reductions due to mining disturbances at Year-20 of operations (Table 10).

Crooked Creek Below Omega Gulch (CCBO)

Derived stage-discharge curves indicate that lowered flows to Crooked Creek from mining operations will reduce summer low flow conditions by an estimated maximum of 0.58 ft (0.18 m). Bathymetric surface areas indicate a 0.58 ft water stage reduction, which will result in a reduction of seven percent of riffle habitat, four percent of run habitat, and three percent of pool habitat. This correlates to a total approximate aquatic habitat reduction of four percent during summer low flow conditions at the Year-20 water level reductions from mining disturbances (Table 10).

Impacted winter ten-year low flow conditions are estimated to reduce water levels by a maximum of 0.98 ft (0.30 m). Bathymetric surface areas indicate a 0.98 ft (0.30 m) water stage reduction will result in an estimated reduction of 13 percent of riffle habitat, 6 percent of run habitat, and 4 percent of pool habitat (Table 10). This indicates a total approximate aquatic habitat reduction of seven percent during winter low flow conditions at the Year-20 water level reductions from mining activities (Table 10).

Crooked Creek Below Anaconda Creek (CCBA)

Derived stage-discharge curves indicate that lowered flows to Crooked Creek from mining operations may reduce summer low flow conditions by an estimated maximum of 0.66 ft (0.20 m). Bathymetric surface areas indicate a 0.66 water stage reduction will result in a reduction of 13 percent of riffle habitat, 6 percent of run habitat, and 4 percent of pool habitat. This indicates a total approximate aquatic habitat reduction of seven percent during summer low flow conditions at Year-20 water level reductions from mining activities (Table 10).

Impacted winter low flow conditions are estimated to reduce water stage levels by an estimated maximum of 1.05 ft (0.32 m) from base low flow conditions. Bathymetric surface areas indicate a 1.05 ft water stage reduction will result in an estimated reduction of 21 percent of riffle habitat, 8 percent of run habitat, and 5 percent of pool habitat (Table 10). This indicates a total approximate aquatic habitat reduction of nine percent during low flow conditions at Year-20 water level reductions due to mining activities (Table 10).

Crooked Creek Below Crevice Creek (CCAC)

Derived stage-discharge curves indicate that lowered flows to Crooked Creek from mining operations will reduce summer ten-year low flow conditions by an estimated maximum of 0.69 ft (0.21 m). Bathymetric surface areas indicate a 0.69 ft water stage reduction will result in a reduction of 12 percent of riffle habitat, 6 percent of run habitat, and 5 percent of pool habitat. This indicates a total approximate aquatic habitat reduction of seven percent during summer low flow conditions at Year-20 water level reductions due to mining activities (Table 10).

Disturbed winter low flow conditions indicate an estimated water stage reduction maximum of 1.09 ft (0.33 m) from base ten-year low flow conditions. Bathymetric surface areas indicate a 1.09 ft water stage reduction will result in a reduction of ten percent of riffle habitat, five percent of run habitat, and four percent of pool habitat (Table 10). This

indicates a total approximate aquatic habitat reduction of six percent during ten-year winter low flow conditions at Year-20 water level reductions due to mining disturbances (Table 10).

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5.0 Tables

Table 1

Estimates of Percent Change in Flow to Crooked Creek per Month

Estimated Percent Change in Stream Flow in Crooked Creek														
		REACH>	HAB5/HAB4		HAB4		HAB3		HAB2		HAB1		HAB1	
		Location>	@ American Creek		Below Omega Gulch		Below Anaconda Creek		Below Crevice Creek		Below Getmuna Creek		Below Bell Creek	
Month	Project Timeframe	FLOW CONDITION >	10yr LF¹	AVG²	10yr LF¹	AVG²	10yr LF¹	AVG²	10yr LF¹	AVG²	10yr LF¹	AVG²	10yr LF¹	AVG²
Jan	Year 10		-25	-20	-18	-9	-22	-14	-20	-13	-10	-6	-8	-5
	Year 20		-32	-24	-25	-16	-29	-21	-27	-19	-14	-9	-11	-7
	Closure (Pit Lake at Capacity)		-10	-10	--	--	-11	-11	-10	-10	-5	-5	-4	-4
Feb	Year 10		-26	-20	-20	-14	-24	-18	-22	-17	-11	-8	-8	-6
	Year 20		-33	-23	-26	-18	-30	-22	-27	-20	-14	-9	-11	-7
	Closure (Pit Lake at Capacity)		-10	-11	--	--	-11	-11	-10	-9	-5	-4	-4	-3
Mar	Year 10		-28	-17	-22	-12	-26	-16	-23	-15	-11	-7	-9	-5
	Year 20		-33	-19	-25	-15	-29	-19	-27	-17	-12	-8	-9	-6
	Closure (Pit Lake at Capacity)		-10	-11	--	--	-11	-12	-10	-9	-5	-4	-4	-3
Apr	Year 10		-14	-13	-10	-9	-14	-13	-12	-12	-6	-6	-5	-4
	Year 20		-15	-14	-11	-11	-16	-15	-14	-14	-6	-7	-5	-5
	Closure (Pit Lake at Capacity)		15	2	--	--	7	-3	8	0	4	0	3	0
May	Year 10		-18	-14	-11	-8	-16	-12	-14	-11	-6	-5	-5	-4
	Year 20		-25	-15	-20	-11	-25	-16	-23	-14	-13	-7	-11	-5
	Closure (Pit Lake at Capacity)		38	10	--	--	24	3	24	5	11	2	9	2
Jun	Year 10		-25	-18	-16	-10	-20	-15	-18	-13	-10	-6	-8	-5
	Year 20		-29	-21	-22	-15	-26	-20	-24	-18	-12	-9	-10	-7
	Closure (Pit Lake at Capacity)		15	11	--	--	6	3	9	7	4	3	3	2
Jul	Year 10		-25	-18	-14	-11	-18	-15	-17	-14	-8	-7	-6	-5
	Year 20		-28	-21	-21	-15	-26	-19	-23	-17	-11	-8	-9	-6
	Closure (Pit Lake at Capacity)		-16	2	--	--	-16	-3	-11	0	-5	0	-4	0
Aug	Year 10		-19	-15	-11	-10	-15	-14	-14	-13	-7	-6	-5	-5
	Year 20		-21	-17	-15	-12	-19	-16	-17	-15	-8	-7	-6	-5
	Closure (Pit Lake at Capacity)		15	-6	--	--	-15	-9	11	-5	-5	-2	-4	-2
Sep	Year 10		-17	-14	-9	-9	-13	-13	-12	-12	-6	-6	-4	-4
	Year 20		-18	-15	-11	-10	-16	-15	-15	-14	-7	-6	-5	-5
	Closure (Pit Lake at Capacity)		8	-3	--	--	-10	-7	-7	-4	-3	2	-2	-1
Oct	Year 10		-17	-14	-8	-8	-13	-12	-12	-11	-5	-5	-4	-4
	Year 20		-15	-16	-8	-11	-13	-16	-11	-14	-3	-7	-1	-5
	Closure (Pit Lake at Capacity)		-12	-11	--	--	-13	-13	-11	-10	-5	-5	-4	-4
Nov	Year 10		-19	-15	-6	-6	-11	-11	-10	-10	-5	-5	-4	-4
	Year 20		-21	-17	-11	-10	-17	-16	-15	-14	-7	-7	-5	-5
	Closure (Pit Lake at Capacity)		-11	-10	--	--	-12	-11	-11	-10	-5	-5	-4	-4
Dec	Year 10		-22	-18	-7	-5	-12	-11	-11	-10	-5	-5	-4	-4
	Year 20		-25	-20	-14	-12	-19	-17	-18	-16	-7	-7	-5	-6
	Closure (Pit Lake at Capacity)		-11	-10	--	--	-11	-11	-10	-10	-5	-5	-4	-4
Average	Year 10		-19	-15	-13	-9	-15	-13	-11	-12	-7	-6	-5	-4
	Year 20		-21	-17	-15	-12	-20	-17	-18	-15	-8	-7	-6	-6
	Closure (Pit Lake at Capacity)		-3	-3	--	--	-6	-7	4	-3	-2	-2	-1	-4

Notes:

Data from BGC (July 11, 2014)

1)- 10yr LF = 10 - year low flow (10th percentile) 2)- AVG = average flow (50th percentile)

-- = Estimate not available

Table 2**Crooked Creek Habitat Mapping Summary (2009)**

		Habitat Type (HMU) ¹								
Parameter	Units or Dimentions	Riffle	Fast Run	Run	Glide	Pool	Side Arm	Back water	Abandoned Channel	Total
General Statistics										
# of HMU	#	206	5	325	16	118	39	83	48	840
Total Wetted Surface Area	m ²	112,729	3,793	568,638	43,433	70,587	27,375	42,553	56,587	925,696
% of Total Wetted Surface Area	%	12.18	0.41	61.43	4.69	7.63	2.96	4.60	6.11	100.00
Water Velocity										
Mean water velocity	m/s	0.61	0.81	0.42	0.46	0.29	0.28	0.26	0.26	
% Area Dominate Substrate ²										
Silt, loam, clay	(<0.063mm)	--	--	0.32	--	7.31	22.49	67.51	76.35	
Sand	(0.063-2mm)	--	--	11.36	--	39.82	10.71	7.94	0.71	
Gravel (medium to fine)	(2mm-2cm)	2.67	--	13.09	16.20	17.19	40.96	0.74	1.29	
Gravel (Coarse - egg size to small fist)	(2-6.3cm)	62.76	42.01	53.18	73.82	30.57	22.89	20.69	6.96	
Cobble (Medium - baseball to softball)	(6.3-20cm)	34.57	57.99	22.05	9.98	5.11	1.94	2.01	--	
Cobble (Coarse - blocks; head-sized cobble)	(20-40cm)	--	--	--	--	--	--	--	--	
Cobble (Large)	(>40cm)	--	--	--	--	--	--	--	--	
Bedrock	unlimited	--	--	--	--	--	--	--	--	
Organic - sludge	<FPOM	--	--	--	--	--	--	0.26	--	
Particulate organic matter	FPOM-CPOM ⁴	--	--	--	--	--	--	0.40	0.03	
Plants (Submerged mats; often w/ detritus)	unlimited	--	--	--	--	--	--	0.45	14.65	
Wood (trees, roots, dead branches, etc)	unlimited	--	--	--	--	--	1.01	--	--	
% Area of Abundant HMU Attributes ³										
Boulders	%	0.08	--	--	--	--	--	--	1.36	
Overhanging Vegetation	%	0.07	--	0.43	--	2.13	--	0.51	0.67	
Submerged Vegetation	%	0.65	--	0.40	--	1.08	0.49	13.82	81.77	
Canopy Shading	%	2.06	--	12.76	0.47	2.90	38.39	23.83	5.00	
Undercut Bank	%	19.68	--	28.56	80.26	10.17	8.37	2.40	0.93	
Woody Debris	%	1.54	--	11.08	--	22.28	36.43	22.55	7.58	
Shallow Margin	%	30.16	--	17.53	9.51	26.76	50.66	87.14	83.23	

Notes:

1)- Refer to Appendix B for definitions of HMU Types

2)- Refer to Appendix D for definitions of Substrate (Choriotops)

3)- Refer to Appendix E for definitions of HMU Attributes. Calculations are based on abundant classification (Attribute present in >50% of the HMU surface area)

4)- FPOM- 0.45um- 1mm; CPOM- 1mm- 10cm (4in)

Table 3

Water Velocity Measurements in Riffle Habitats Along Crooked Creek (2009)

Method	# of Measurments	Mean Water Velocity (m/s)	Minimum Water Velocity (m/s)	Max Water Velocity (m/s)	SD
Dipping Bar	855	0.563	0.251	1.491	0.23
ADCP	7365	0.614	0.000	2.375	0.39

Table 4

Number of Redds Observed Along Crooked Creek During Ground and Aerial Surveys (2009)

Reach¹	# Redds Observed	
	Aerial²	Ground³
CRR1	303	222
CRR2	291	249
CRR3	29	29
CRR4	6	19
CRR5	6	13

Notes

1)- Refer to Figure 1 for reach locations

2)- Aerial redds counts conducted July 19-22, 2009 and September 13-15, 2009

3)- Ground surveys conducted August 14-September 15, 2009

Table 5

Summary of Attributes Measured at Redds and Pool Tails Surveyed Along Crooked Creek (2009)

Habitat Reach	Type	Substrate temp (°C)	Change in temp (°C) ¹	Depth (mm)	% Fines	# Redds
HAB5	Redd	5.55	0.03	375.4	8.1	1.6
	Pool tail	4.94	-0.12	413.3	11.4	--
HAB4	Redd	6.01	-0.03	274.7	10.6	3.2
	Pool tail	6.44	0.08	306.8	11.8	--
HAB3	Redd	8.02	0.04	310.3	9.3	3.0
	Pool tail	7.79	0.07	294.3	10.8	--
HAB2	Redd	7.52	0.11	438.8	5.6	11.1
	Pool tail	7.79	0.07	294.3	10.8	--
HAB1	Redd	7.30	0.10	431.2	4.7	23.1
	Pool tail	6.90	0.00	445.0	10.3	--
TOTAL ²	Redd	6.99	0.07	395.5	6.7	11.8
	Pool tail	6.55	0.03	331.1	11.1	--

Notes

See Figure 1 for habitat section locations

Values are mean for habitats sampled within each section

1)- Difference between water column and substrate temperature

2)- Grand mean for all habitat sections

Table 6

Temperature, Depth, and Percent Fines at Redds Observed Along Crooked Creek (2009)

REDD ID	Habitat Reach	Column Temp °C	Surface Temp °C	Substrate Temp °C	Change in Temp °C (Column to Substrate)	Depth (mm)	% Fines	# Redds
REDD1	HAB5						7.33%	1
REDD11	HAB5	5.000	5.000	5.000	0.000	351	9.33%	3
REDD15	HAB5	5.767	5.800	5.633	0.133	407	6.67%	1
REDD16	HAB5						8.00%	3
REDD18	HAB5	7.100	7.100	7.100	0.000	358	7.33%	1
REDD20	HAB5	5.800	5.800	5.733	0.067	490	9.33%	1
REDD4	HAB5	5.200	5.200	5.200	0.000	338	5.33%	1
REDD7	HAB5	4.600	4.600	4.633	-0.033	308	11.33%	2
REDD25	HAB4	5.933	5.933	5.833	0.100	255	14.67%	1
REDD26	HAB4	6.100	6.100	6.067	0.033	427	4.00%	4
REDD28	HAB4	5.200	5.200	5.300	-0.100	312	6.67%	1
REDD29	HAB4	5.933	5.933	6.267	-0.333	248	13.33%	4
REDD32	HAB4	6.100	6.100	6.167	-0.067	232	18.00%	8
REDD34	HAB4	6.600	6.600	6.400	0.200	175	6.67%	1
REDD45	HAB3	7.100	7.100	7.067	0.033	255	14.00%	7
REDD49	HAB3	9.000	9.000	9.000	0.000	324	0.00%	1
REDD50	HAB3	8.100	8.100	8.000	0.100	352	14.00%	1
REDD54	HAB2	6.967	6.967	7.167	-0.200	347	10.67%	1
REDD55	HAB2	7.100	7.100	7.100	0.000	377	2.67%	8
REDD56	HAB2	8.033	8.067	7.833	0.200	365	10.00%	4
REDD60	HAB2	7.267	7.267	7.133	0.133	422	6.67%	7
REDD61	HAB2	7.600	7.600	7.367	0.233	545	8.67%	11
REDD68	HAB2	8.183	8.183	7.800	0.383	472	1.33%	20
REDD69	HAB2	8.700	8.700	8.367	0.333	487	2.67%	19
REDD70	HAB2	8.700	8.700	8.367	0.333	558	0.00%	3
REDD71	HAB2	6.733	6.750	6.867	-0.133	362	7.33%	6
REDD72	HAB2	7.000	6.933	7.033	-0.033	382	10.00%	48
REDD73	HAB2	7.200	7.200	7.167	0.033	403	6.00%	5
REDD75	HAB2	7.600	7.600	7.533	0.067	428	2.67%	8
REDD76	HAB2	8.033	8.033	8.000	0.033	558	4.67%	4
REDD77	HAB1	6.433	6.400	6.500	-0.067	430	5.33%	34
REDD78	HAB1	6.733	6.733	6.700	0.033	473	6.00%	13
REDD79	HAB1	6.900	6.900	6.800	0.100	437	1.33%	20
REDD80	HAB1	7.333	7.333	7.167	0.167	390	4.67%	14
REDD81	HAB1	8.100	8.100	7.900	0.200	375	5.33%	13
REDD82	HAB1	8.200	8.200	8.167	0.033	510	3.33%	28
REDD83	HAB1	8.300	8.300	8.067	0.233	388	13.33%	3
REDD85	HAB1	7.867	7.900	7.667	0.200	450	2.67%	1
REDD86	HAB1	8.183	8.200	7.733	0.450	478	2.00%	30
REDD87	HAB1	6.600	6.600	6.600	0.000	412	2.67%	45
REDD88	HAB1	8.267	8.267	8.033	0.233	553	2.67%	25
REDD89	HAB1	6.600	6.600	6.700	-0.100	417	10.00%	59
REDD90	HAB1	6.900	6.900	6.900	0.000	367	1.33%	6
REDD92	HAB1	7.200	7.200	7.200	0.000	262	3.33%	42
REDD93	HAB1	7.300	7.383	7.333	-0.033	527	6.00%	14

Table 7

Detailed Stream Reach Survey – Habitat Classification (2009)

Stream Classification Criteria¹	Units	Value	Average	Minimum	Maximum
Sinuosity	Ratio	2.6	--	--	--
Discharge	m ³ /sec	7.9	--	--	--
Gradient	Ratio	0.008	--	--	--
Large Woody Debris	Count	4	--	--	--
Entrenchment	Ratio	>2.2			
Width to Depth	Ratio	--	18.5	7.1	29.3
Wetted Width	m	--	12.3	8.4	18.6
Bankfull Width	m	--	17.6	14.7	23.1
Pool Tail Fines	%	--	24.1	6.0	72.0
Residual Pool Depth	m	--	0.8	0.6	1.1
Substrate Size ²	mm	--	33.6	10.6	56.4

Particle Size Indices¹

D ₁₆	mm	22.8	--	--	--
D ₃₅	mm	29.3	--	--	--
D ₅₀	mm	31.7	--	--	--
D ₈₄	mm	42.8	--	--	--
D ₉₅	mm	50.1	--	--	--

Rosgen Stream Classification Type¹

C4

Notes

1)- Refer to Rosgen (1996), and OtterTail (2009) for definitions of classification criteria

2)- Substrate length measured along b-axis (intermediate axis).

Table 8

Off Channel Habitat Connectivity and Estimated Surface Area for Various Flow Conditions for Mainstem Crooked Creek (2009)

Flow Conditions		Baseflow						25% Bankfull						50% Bankfull						75% Bankfull						Bankfull					
		Total Area		Units Connected	Area Connected		Connected	Total Area		Units Connected	Area Connected		Connected	Total Area		Units Connected	Area Connected		Connected	Total Area		Units Connected	Area Connected		Connected						
Reach		acres	m2	#	acres	m2	%	acres	m2	#	acres	m2	%	acres	m2	#	acres	m2	%	acres	m2	#	acres	m2	%	acres	m2	#	acres	m2	%
HAB5	Flat to American	0.74	3,015	10	0.66	2,686	89	0.98	3,984	12	0.91	3,686	93	1.22	4,954	13	1.22	4,954	100	1.67	6,752	13	1.67	6,752	100	2.11	8,550	13	2.11	8,550	100
HAB4	American to Anaconda	2.26	9,162	11	2.20	8,907	97	3.36	13,596	13	3.33	13,477	99	4.46	18,029	14	4.46	18,029	100	6.31	25,539	14	6.31	25,539	100	8.17	33,049	14	8.17	33,049	100
HAB3	Anaconda to Crevice	1.75	7,080	3	1.75	7,080	100	2.36	9,533	3	2.36	9,533	100	2.96	11,986	3	2.96	11,986	100	4.31	17,434	3	4.31	17,434	100	5.65	22,882	3	5.65	22,882	100
HAB2	Crevice to Getmuna	12.38	50,112	12	8.22	33,283	66	17.37	70,296	12	11.34	45,897	65	22.36	90,480	14	15.64	63,275	70	30.58	123,763	14	25.32	102,450	83	38.81	157,045	21	38.81	157,045	100
HAB1	Getmuna to Mouth	3.81	15,428	3	2.45	9,918	64	5.63	22,778	3	3.92	15,869	70	7.44	30,128	3	5.39	21,820	72	10.33	41,814	3	7.08	28,658	69	13.22	53,500	4	13.22	53,500	100
Total		20.95	84,797	39	15.29	61,874	73	29.70	120,187	43	21.86	88,463	74	38.44	155,577	47	29.67	120,065	77	53.20	215,302	47	44.68	180,833	84	67.96	275,026	55	67.96	275,026	100

Notes:

Table represents off channel habitats with connectivity at or below bankfull stage only

1)- **Total area** is the sum of the surface area of all off channel habitats within a given habitat reach, at a given flow condition. Total area for flow conditions other than base flow are estimates. Refer to text for methods used to determine total area. Note that the total area increases with each increasing flow condition.

2)- **# Units Connected** is the count of off channel habitat units that are connected at a given flow condition. Refer to text for methods used to determine connectivity.

3)- **Area Connected** is the sum of the surface area of all off channel habitats within a given habitat reach, at a given flow condition, that are connected to the main channel at that flow condition. Area Connected for flow conditions other than base flow are estimates. Refer to text for methods used to determine total area. Note that area connected does not always increase with each increasing flow condition. This is because the surface area was assumed to increase with the rising water table, independent of connectivity to the main channel.

4)- **Connected** is the percentage of the total surface area of off channel habitat that is connected to the main channel for a given habitat reach, at a given flow condition.

5)- **Flow conditions** - refer to text for methods used for delineating flow conditions.

Table 8A

Off Channel Habitat Connectivity at Various Flow Conditions for Mainstem Crooked Creek (2014)

Reach	Total Units	Mapping Discharge		June 50% Undisturbed		June 50% Disturbed		June 10% Undisturbed		June 10% Disturbed		January 50% Undisturbed		January 50% Disturbed		March 10% Undisturbed		March 10% Disturbed	
		# Connected	% Connected	# Connected	% Connected	# Connected	% Connected	# Connected	% Connected	# Connected	% Connected	# Connected	% Connected	# Connected	% Connected	# Connected	% Connected	# Connected	% Connected
1	4	2	50%	2	50%	1	25%	0	0%	0	0%	0	0%	0	0%	0	0%	0	0%
2	17	5	29%	7	41%	3	18%	2	12%	1	6%	1	6%	0	0%	0	0%	0	0%
3	2	1	50%	1	50%	1	50%	1	50%	1	50%	1	50%	1	50%	1	50%	1	50%
4DN	4	4	100%	4	100%	4	100%	3	75%	3	75%	3	75%	3	75%	3	75%	3	75%
4UP	8	6	75%	6	75%	5	63%	4	50%	4	50%	4	50%	4	50%	4	50%	4	50%
5	9	9	100%	9	100%	9	100%	8	89%	8	89%	8	89%	8	89%	8	89%	8	89%

Table 9

Juvenile Salmon Habitat Suitability for Base Flow Conditions Crook Creek (2009)

Suitability Classification ²	HMU Type ¹								
	<u>Riffle</u>	<u>Fast Run</u>	<u>Run</u>	<u>Glide</u>	<u>Pool</u>	<u>Side Arm</u>	<u>Backwater</u>	<u>Abandoned Channel</u>	<u>Total</u>
	Area HMU ³ (m ²) %	Area HMU ³ (m ²) %	Area HMU ³ (m ²) %	Area HMU ³ (m ²) %	Area HMU ³ (m ²) %	Area HMU ³ (m ²) %	Area HMU ³ (m ²) %	Area HMU ³ (m ²) %	Area HMU ³ (m ²) %
Excellent	-- --	-- --	1,074 0.2	-- --	3,483 4.9	-- --	17,300 40.7	46,650 82.4	68,508 7.4
Good	1,739 1.5	-- --	189,700 33.4	5,492 12.6	49,520 70.2	9,243 33.8	24,282 57.1	9,937 17.6	289,912 31.3
Fair	30,734 27.3	2,787 73.5	364,896 64.2	37,941 87.4	17,585 24.9	16,672 60.9	971 2.3	-- --	471,585 50.9
Poor	80,256 71.2	1,006 26.5	12,969 2.3	-- --	-- --	1,461 5.3	-- --	-- --	95,691 10.3
Total Area	112,729	3,793	568,638	43,433	70,587	27,375	42,553	56,587	925,696

Notes:

1)- Refer to Appendix B for definitions of HMU types

2)- See Appendix G for explanation of suitability classifications

3)- % HMU is the percent of the HMU type for each suitability classification

Table 10

Estimated Reductions in Aquatic Habitat Surface Area for Summer and Winter Average and Low Flow Conditions*

				Summer				Winter			
				Undisturbed Summer Mapped Discharge Average	Undisturbed Summer (June) Lowflow (10th percentile)	Disturbed Summer (June) Lowflow (10th percentile) 20-year operations	Percent Reduction of Habtat from low flow	Undisturbed Winter (Jan) Average	Undisturbed Winter (March) Lowflow (10th percentile)	Disturbed Winter (March) Lowflow (10th percentile) 20-year operations	Percent Reduction of Habtat from low flow
Crooked Creek Stream Section	Parameter	Habitat Type	# of Units								
Crooked Creek Below American Creek (CCBAM)	Stage (m)			1.49	1.10	0.93		1.00	0.70	0.57	
	Habitat Area (ac)	Riffles	29	2.70	1.61	1.42	12%	1.51	1.14	1.01	11%
		Runs	55	7.40	6.30	5.99	5%	6.12	5.58	5.36	4%
		Pools	32	3.32	2.94	2.84	3%	2.88	2.71	2.64	3%
		Total	116	13.42	10.85	10.25	6%	10.51	9.43	9.01	4%
	Habitat Area	Riffles	29	20%	15%	14%	--	14%	12%	11%	--
		Runs	55	55%	58%	58%	--	58%	59%	59%	--
		Pools	32	25%	27%	28%	--	27%	29%	29%	--
		Total	116	100%	100%	100%	--	100%	100%	100%	--
	Crooked Creek Below Omega (CCBO)	Stage (m ²)			1.45	1.02	0.88		0.91	0.58	0.49
Habitat Area (ac)		Riffles	22	2.01	1.15	1.07	7%	1.09	0.90	0.84	7%
		Runs	54	13.35	10.99	10.56	4%	10.65	9.70	9.43	3%
		Pools	19	2.82	2.50	2.43	3%	2.45	2.30	2.26	2%
		Total	95	18.18	14.64	14.06	4%	14.19	12.90	12.53	3%
Habitat Area		Riffles	22	11%	8%	8%	--	8%	7%	7%	--
		Runs	54	73%	75%	75%	--	75%	75%	75%	--
		Pools	19	16%	17%	17%	--	17%	18%	18%	--
		Total	95	100%	100%	100%	--	100%	100%	100%	--
Crooked Creek Below Anaconda Creek (CCBA)		Stage (m ²)			1.46	0.98	0.80		0.86	0.53	0.43
	Habitat Area (ac)	Riffles	14	3.25	1.06	0.92	13%	0.99	0.67	0.53	21%
		Runs	24	10.64	8.67	8.15	6%	8.43	7.34	6.78	8%
		Pools	3	0.58	0.49	0.47	4%	0.48	0.44	0.42	5%
		Total	41	14.47	10.22	9.54	7%	9.90	8.45	7.73	9%
	Habitat Area	Riffles	14	22%	10%	10%	--	10%	8%	7%	--
		Runs	24	74%	85%	85%	--	85%	87%	88%	--
		Pools	3	4%	5%	5%	--	5%	5%	5%	--
		Total	41	100%	100%	100%	--	100%	100%	100%	--
	Crooked Creek Below Crevice Creek (CCAC)	Stage (m ²)			1.52	1.00	0.83		0.88	0.53	0.43
Habitat Area (ac)		Riffles	64	18.73	10.51	9.30	12%	9.65	6.70	6.04	10%
		Runs	81	53.83	43.50	40.77	6%	41.55	35.81	34.02	5%
		Pools	13	4.22	3.51	3.32	5%	3.37	2.97	2.86	4%
		Total	158	76.78	57.52	53.39	7%	54.57	45.48	42.92	6%
Habitat Area		Riffles	64	24%	18%	17%	--	18%	15%	14%	--
		Runs	81	70%	76%	76%	--	76%	79%	79%	--
		Pools	13	5%	6%	6%	--	6%	7%	7%	--
		Total	158	100%	100%	100%	--	100%	100%	100%	--

-- Not Applicable

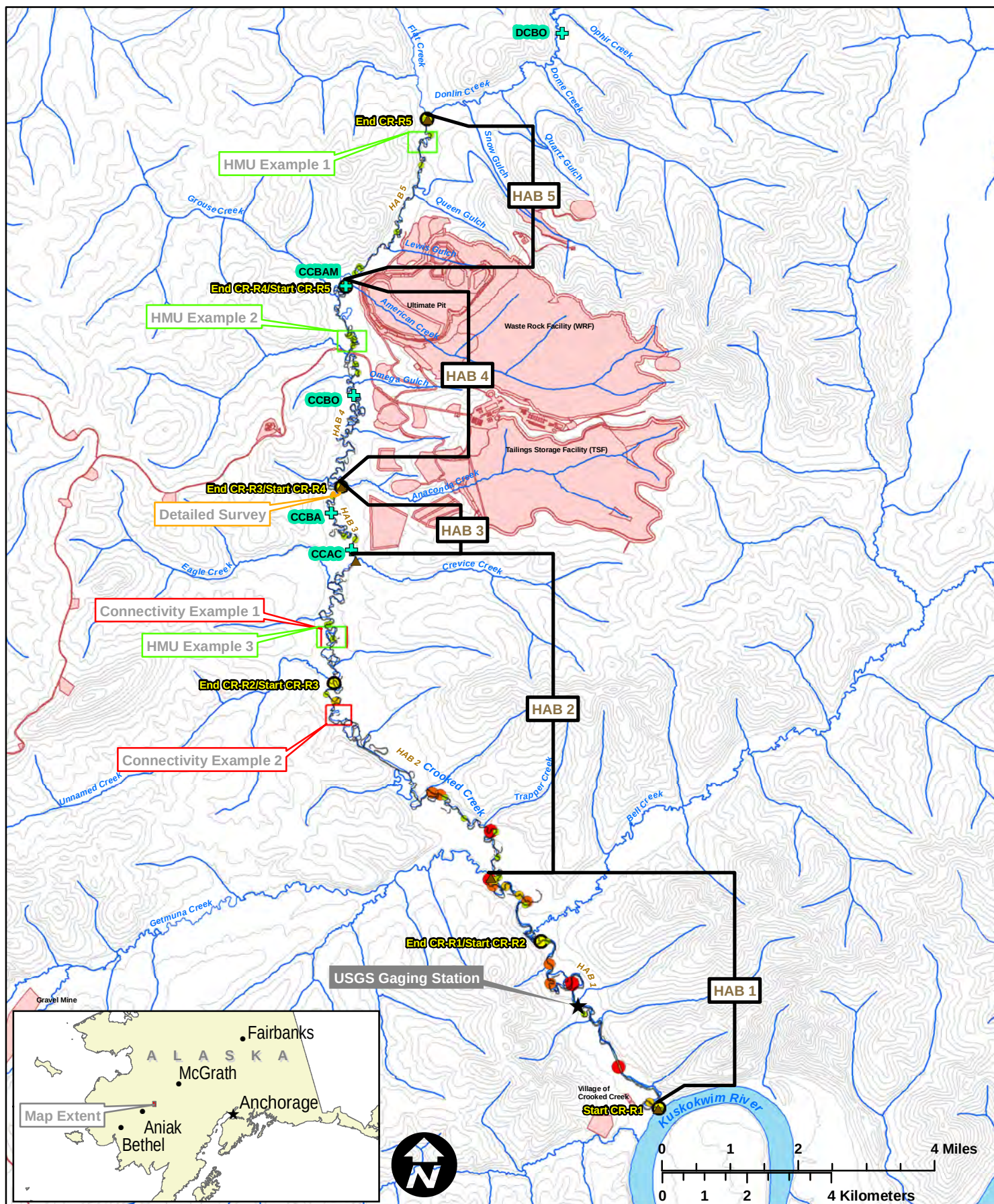
* Based on the BCG 2014 Memo Predicted Changes to Streamflow

Table 11

Aquatic Habitat Surface Area Calculations from Bathymetric Contour Mapping of Habitat Type by Stream Reach

CROOKED CREEK SAMPLING SECTION												
Contour Depth	Crooked Creek Below American Creek (CCBAM)			Crooked Creek Below Omega Gulch (CCBO)			Crooked Creek Below Anaconda Creek (CCBA)			Crooked Creek Below Crevice Creek (CCBC)		
	Riffle (m ²)	Run (m ²)	Pool (m ²)	Riffle (m ²)	Run (m ²)	Pool (m ²)	Riffle (m ²)	Run (m ²)	Pool (m ²)	Riffle (m ²)	Run (m ²)	Pool (m ²)
0 - 0.05 m	1233	2078	934	603	5631	744	751	3317	104	5781	18025	1312
0 - 0.1 m	1832	3141	1339	988	7779	1105	1234	5248	175	8589	28165	2074
0 - 0.15 m	2422	4141	1713	1356	9804	1443	1725	7077	243	11292	37926	2794
0 - 0.2 m	3069	5131	2083	1747	11775	1766	2274	8945	312	14318	47807	3506
0 - 0.25 m	3734	6139	2443	2169	13712	2082	2936	10936	384	17589	58024	4260
0 - 0.3 m	4204	7186	2801	2577	15660	2398	3604	13035	471	20462	68411	5045
0 - 0.35 m	4611	8323	3174	2984	17641	2724	4155	15216	546	23272	79155	5786
0 - 0.4 m	4924	9532	3545	3356	19723	3057	4704	17464	621	25482	90120	6515
0.4 m - max depth	2842	15567	9342	2894	35697	8937	777	21609	1694	7409	115052	10228
Total Surface Area:	7766	25098	12888	6250	55420	11994	5481	39073	2315	32890	205172	16742

6.0 Figures



Number of Salmon Redds

- 1-10 Redds
- 11-15 Redds
- 16-30 Redds
- 31-60 Redds



Infrastructure



Gage Stations



Habitat Reach Breaks



Crooked Creek Aerial Reach Breaks



Water Body



River or Stream



Contours (100ft)

Crooked Creek Habitat Analysis
Project Area Map

Figure 1

Figure 2

Acoustic Doppler Current Profiler (ADCP) Collecting Cross Section Profile and Velocity Measurements at Crooked Creek with ADCP Conceptual Photograph

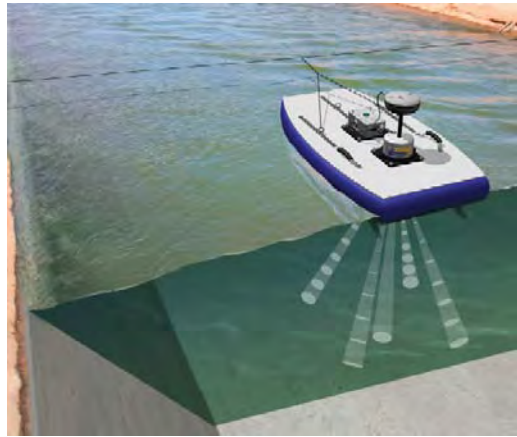
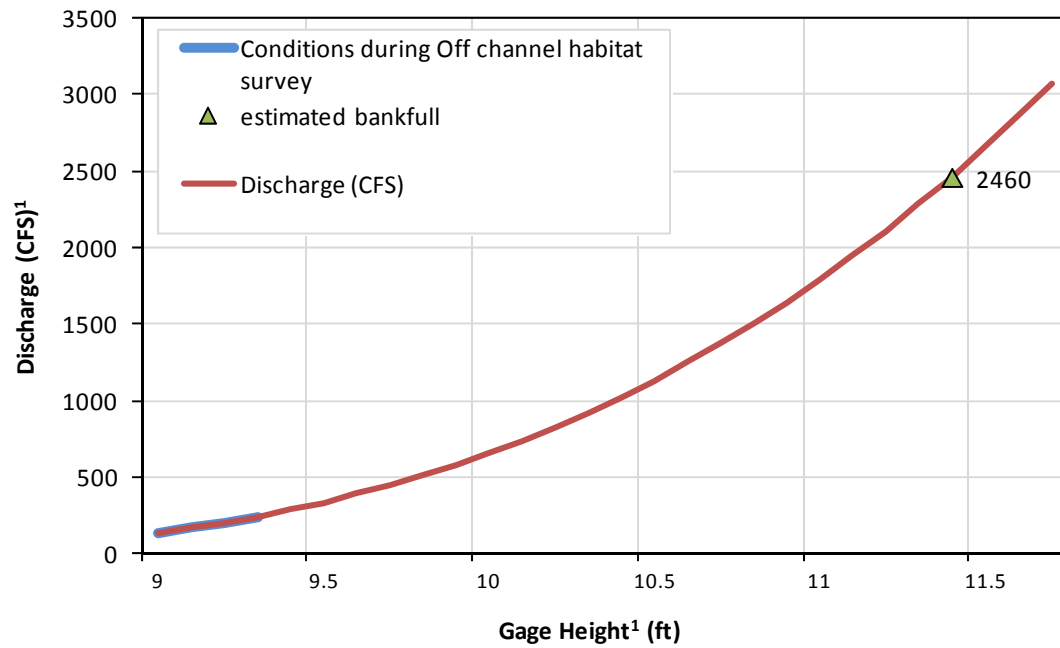


Figure 3

Stage Discharge Relationship for USGS Crooked Creek Gage Station 15304010



¹Discharge and gage height data source: USGS water data. Baseflow and bankfull estimates based on OtterTail field observations

Figure 4

Channel Cross Section Measurements Collected at Crooked Creek

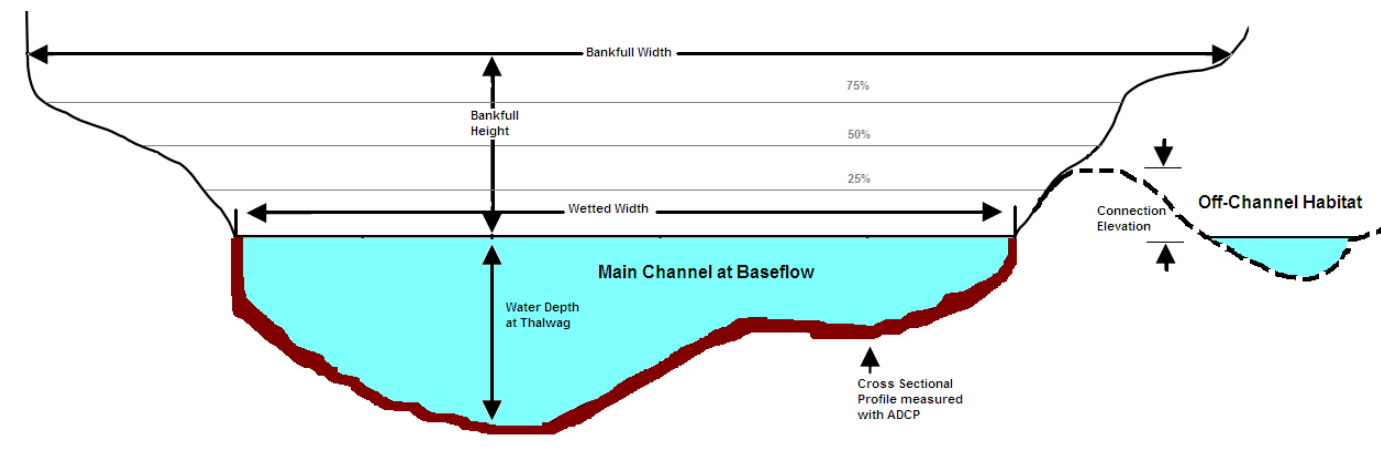


Figure 5
Crooked Creek Habitat Mapping Examples (2009)

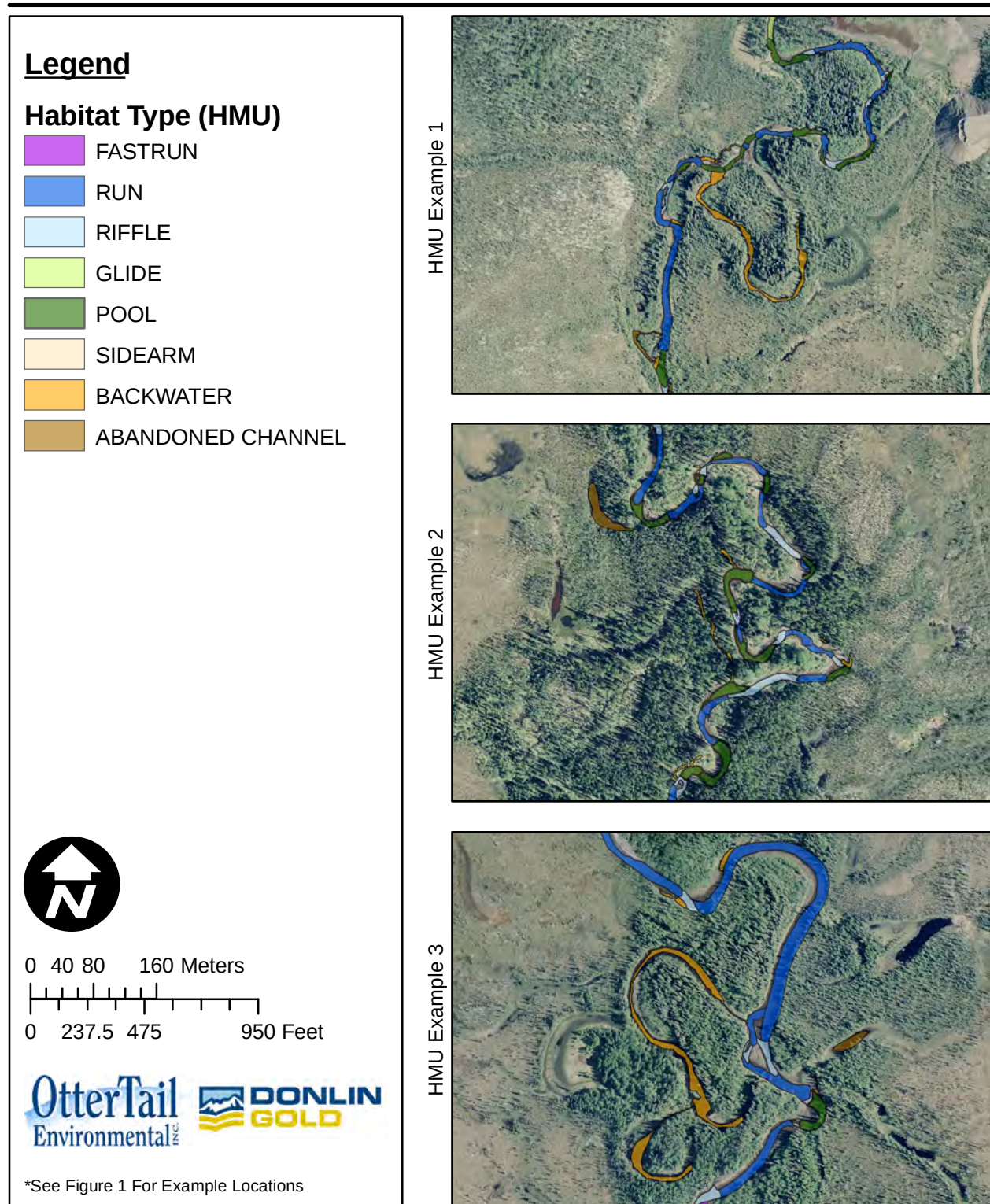


Figure 6
Water Velocity Distributions for Habitat Types Mapped along Crooked Creek (2009)

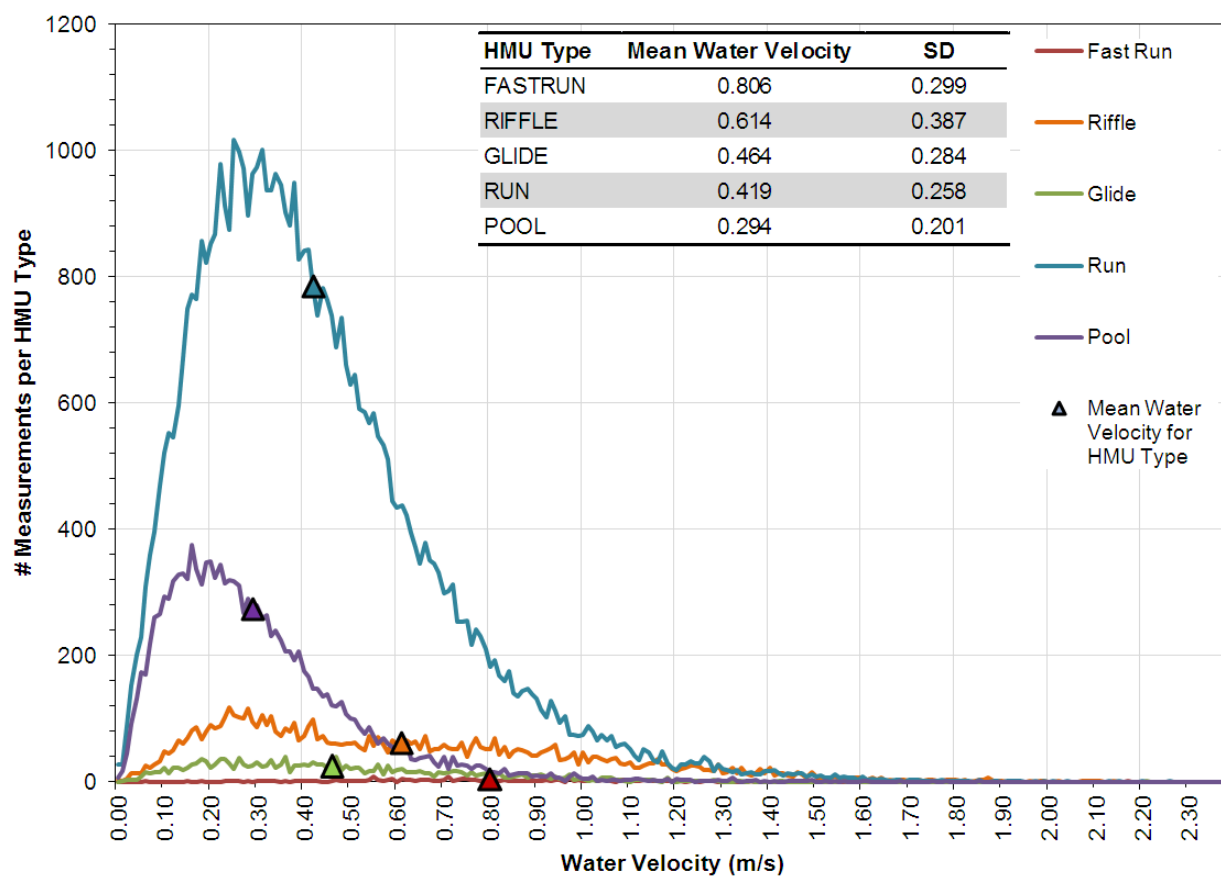
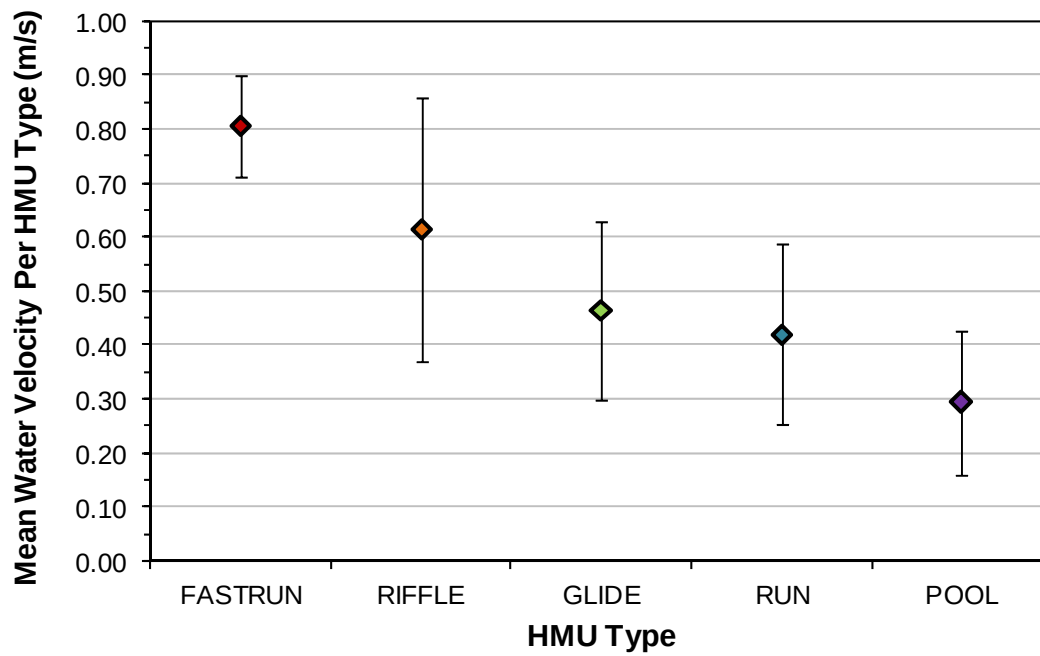


Figure 7

Mean Water Velocity for Habitat Types Mapped Along Crooked Creek
(2009)

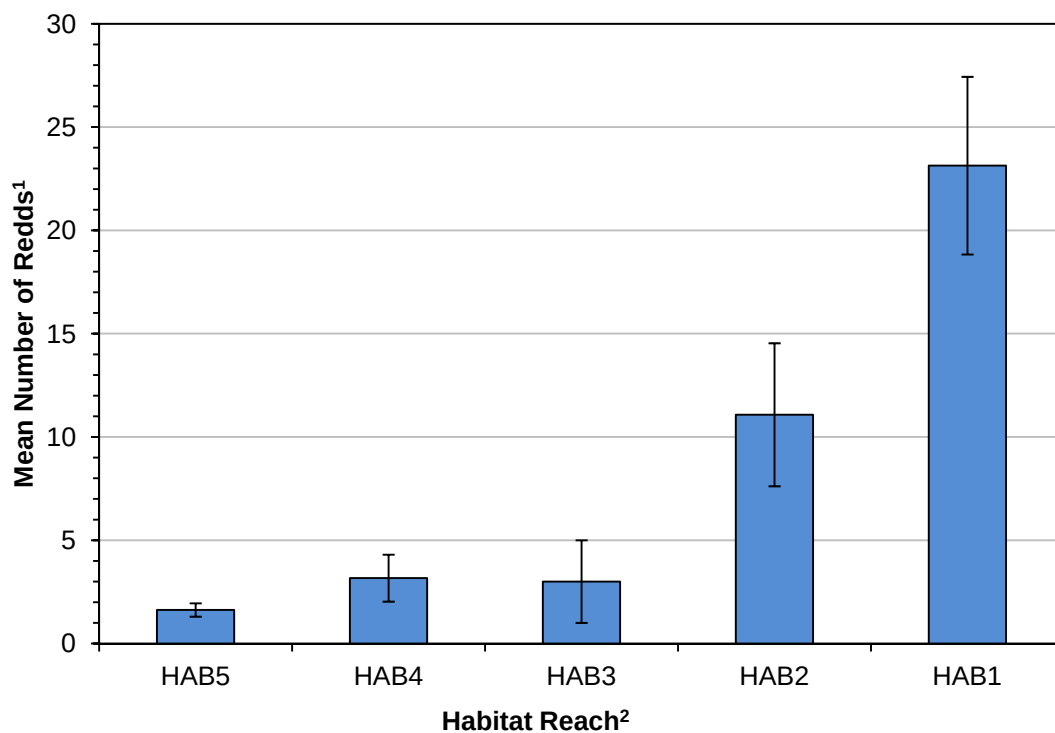


Notes:

Error bars represent one standard deviation. See text for definitions of HMU types

Figure 8

Mean Number of Redds per Habitat Section in the Crooked Creek Mainstem (2009)



Notes:

1)- Mean Number of Redds only includes HMUs where redds were present.

2)- HAB5 = Flat Creek/Donlin Creek confluence to American Creek; HAB4 = American Creek to Anaconda Creek; HAB3 = Anaconda Creek to Crevice Creek; HAB2 = Crevice Creek to Getmuna Creek; HAB1 = Getmuna Creek to the mouth of Crooked Creek at the Kuskokwim River.

Figure 9

Scatter-plot of Depth and Redd Density in Habitats Surveyed Along Crooked Creek

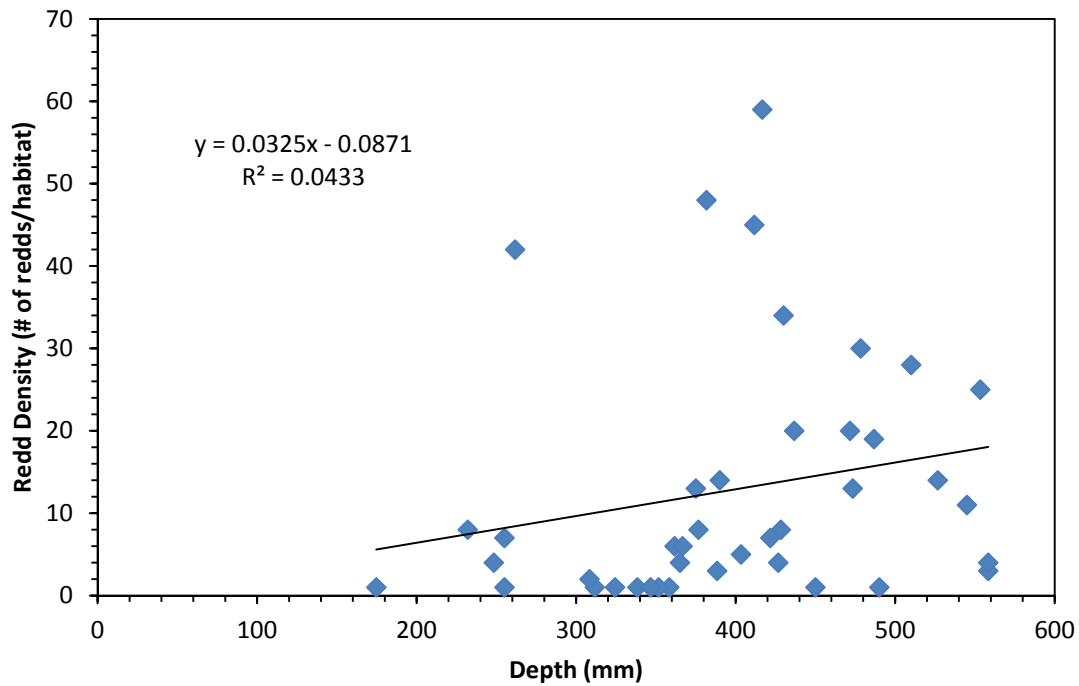


Figure 10

Scatter-plot of Percent Fine Sediment and Redd Density in Habitats Surveyed Along Crooked Creek

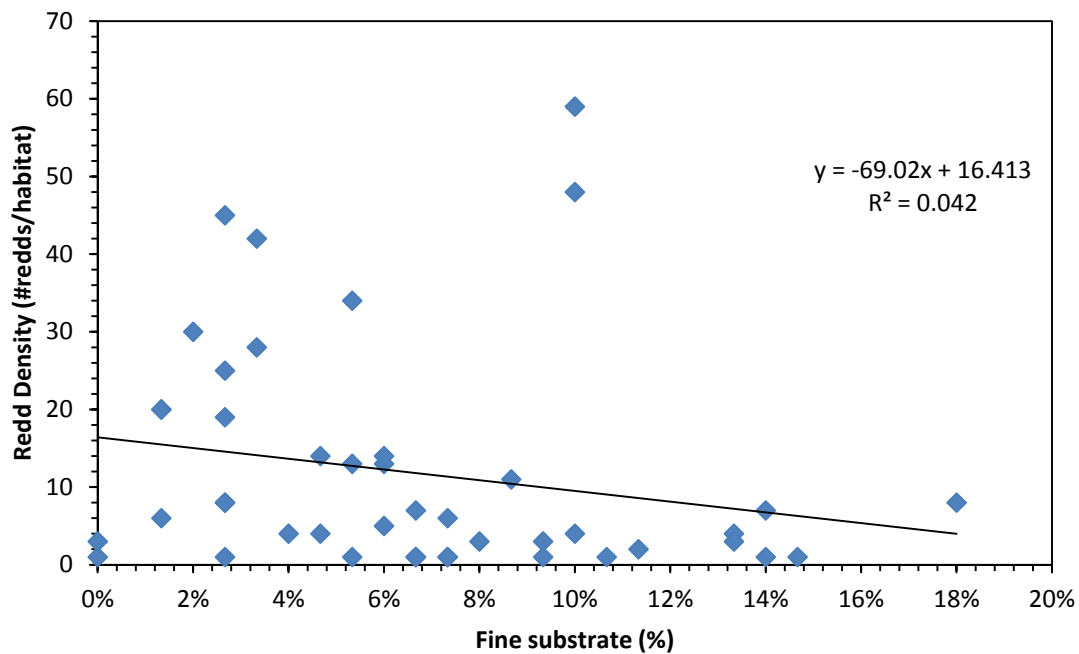


Figure 11

Substrate Temperature, Pool Tail Fines, and Depth in Pool Tails With and Without Redds Sampled Along Crooked Creek (2009)

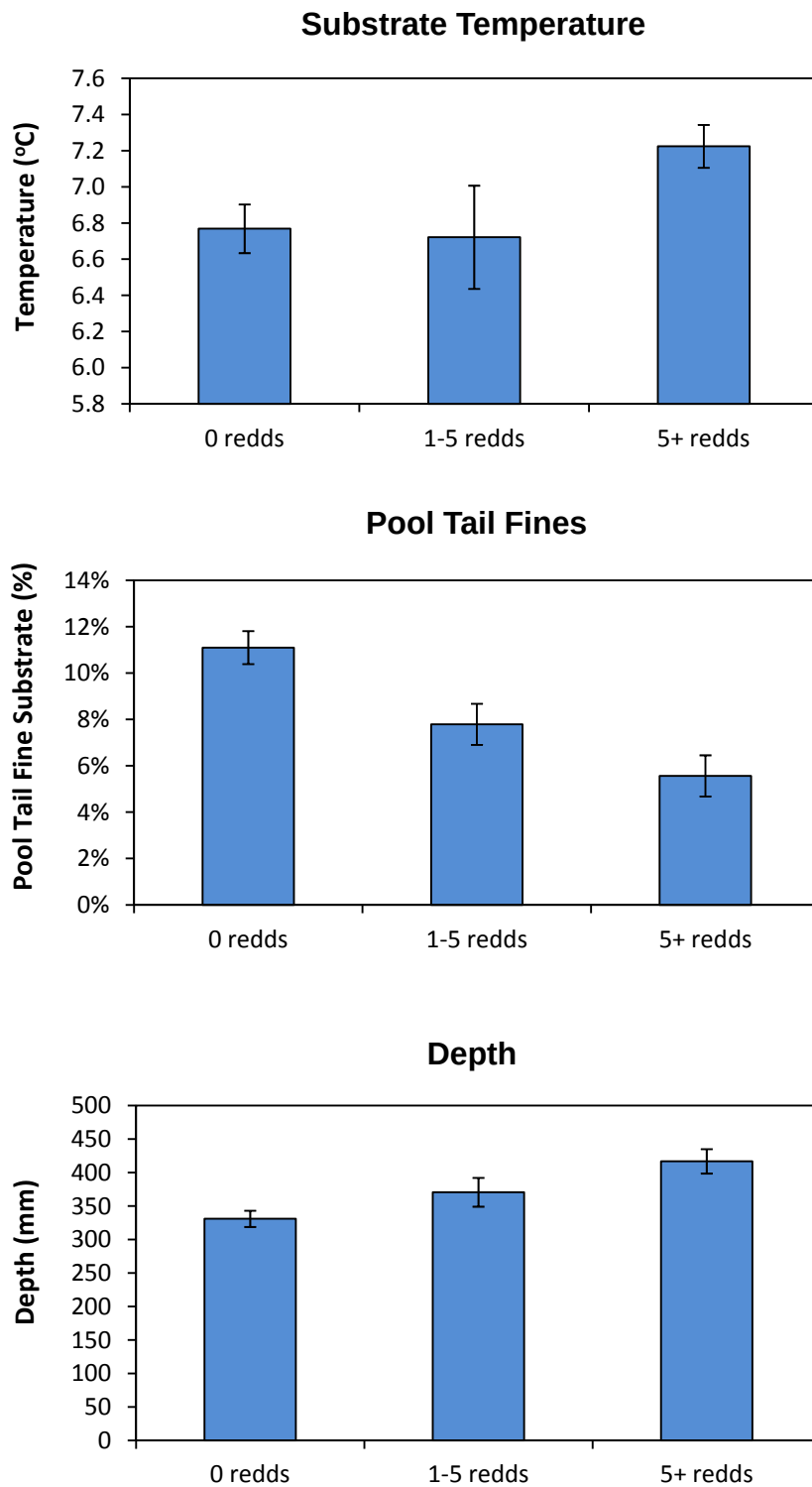


Figure 12
Crooked Creek Detailed Reach Survey – Channel Profile (2009)

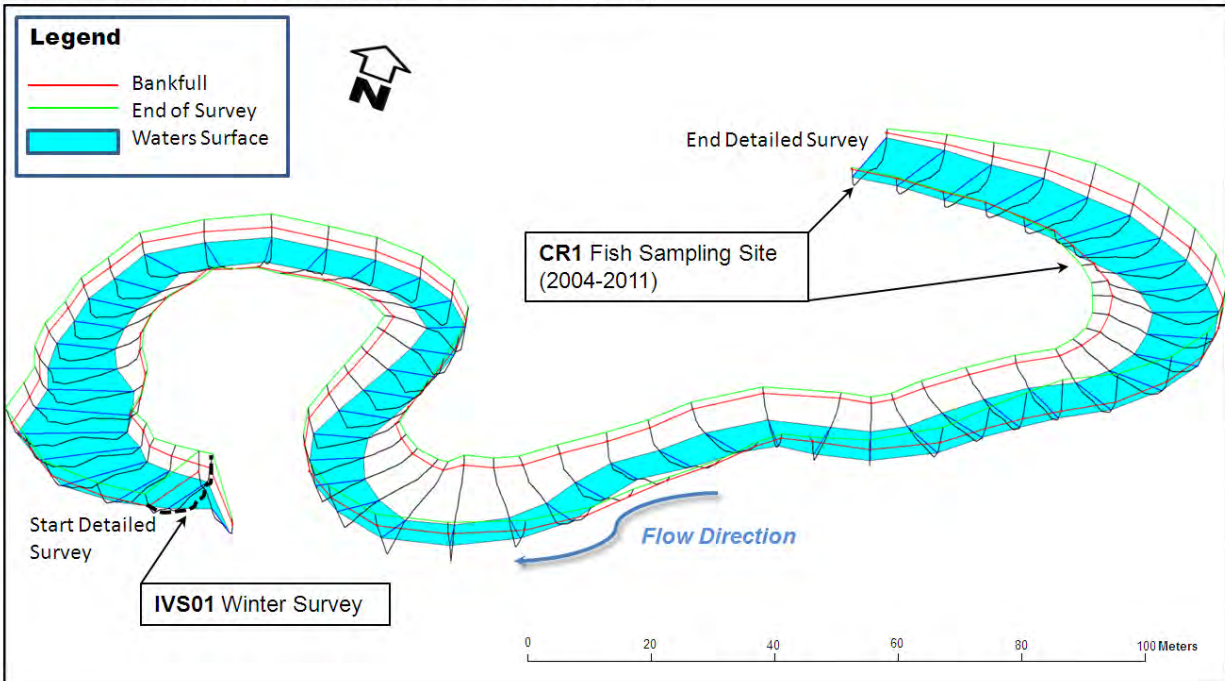
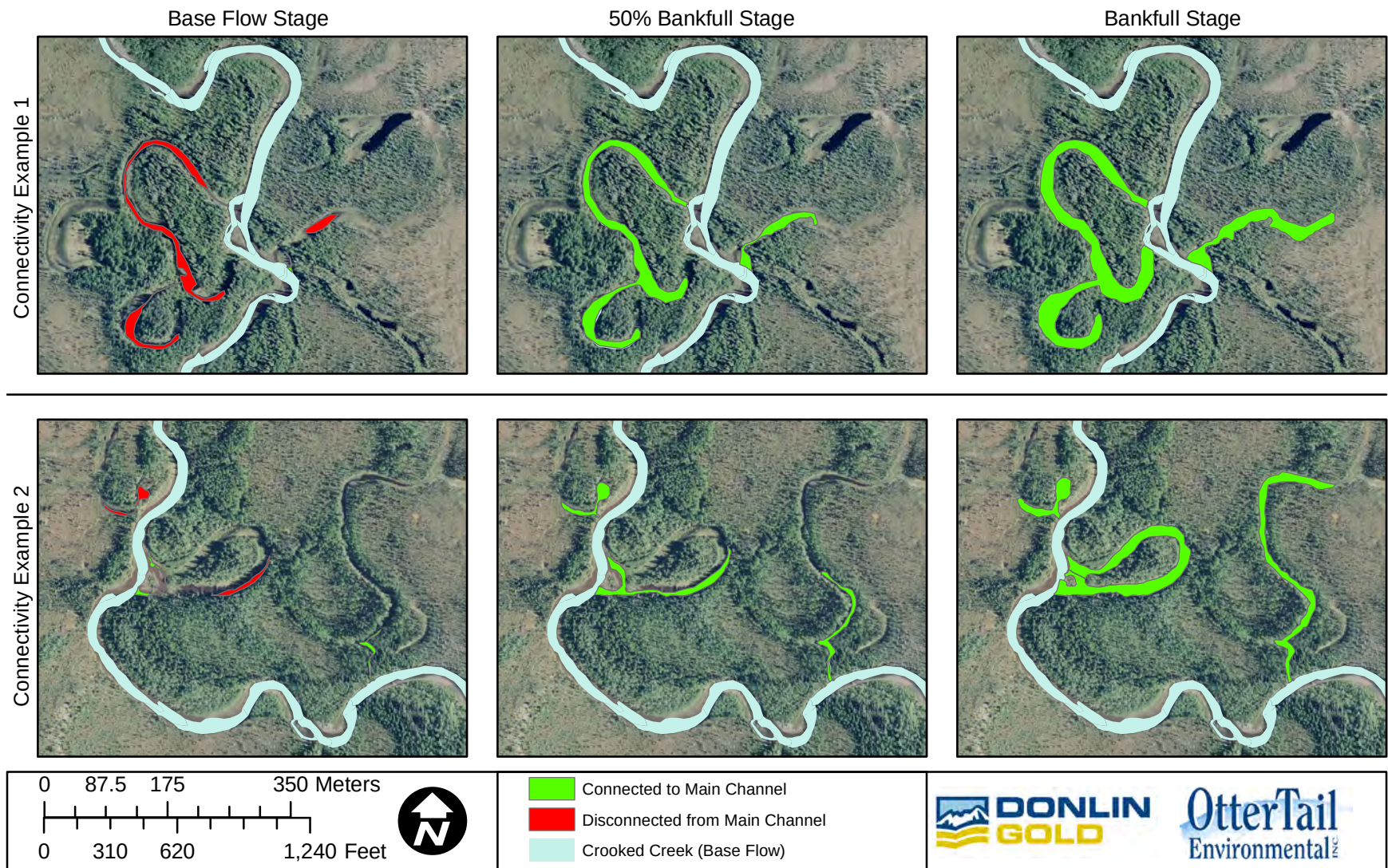


Figure 13
Crooked Creek Off Channel Connectivity Examples*



*see Figure 1 for Example Locations. Digitations for 50% Bankfull stage, and Bankfull stage display a hypothetical area based on limited cross sections located within off channel habitats

Figure 14
Stage-Discharge Curves used for Aquatic Habitat Reduction Modeling

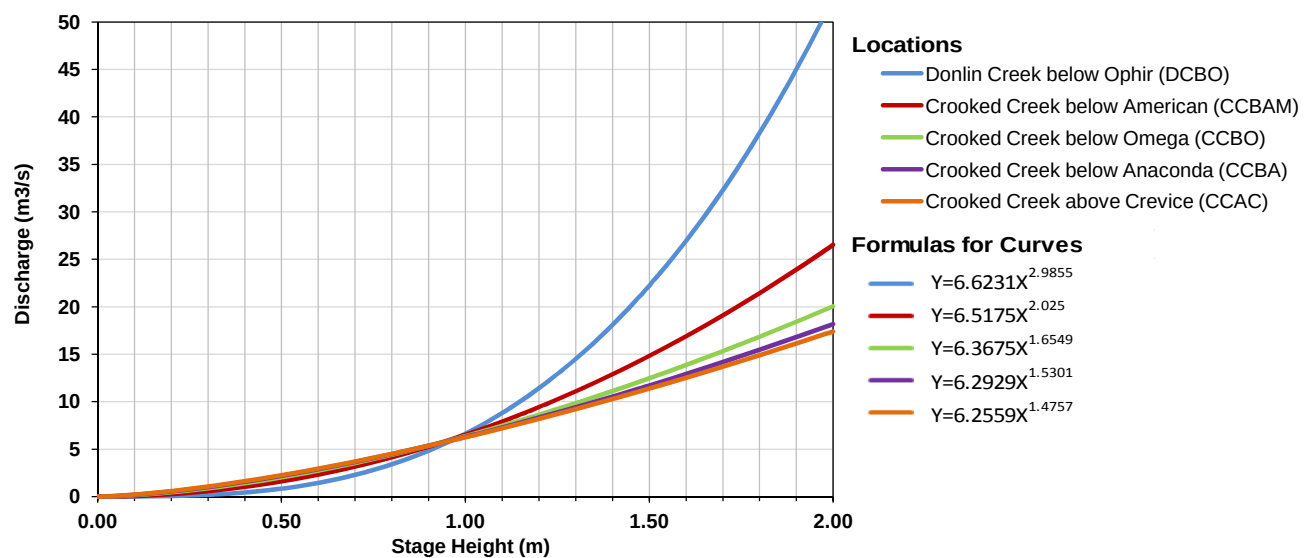
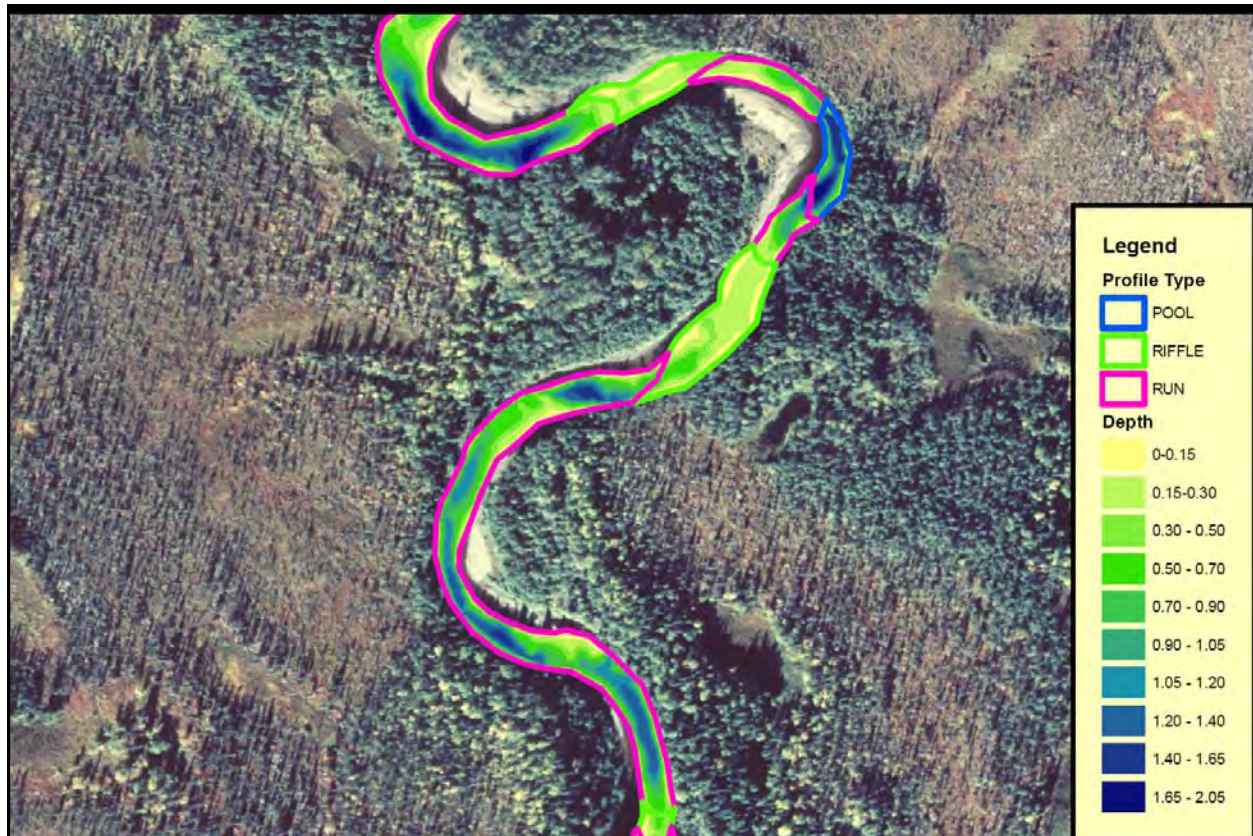


Figure 15

Bathymetric Contour Map of selected reach of Crooked Creek



1.0 Appendices

Appendix A - Crooked Creek Map Book

2009 Instream Habitat Analysis of Crooked Creek for the Donlin Gold Project

Appendix A

Crooked Creek Map Book

Prepared for:



Donlin Gold, LLC.
4720 Business Park Blvd. Suite G-25
Anchorage, Alaska 99503

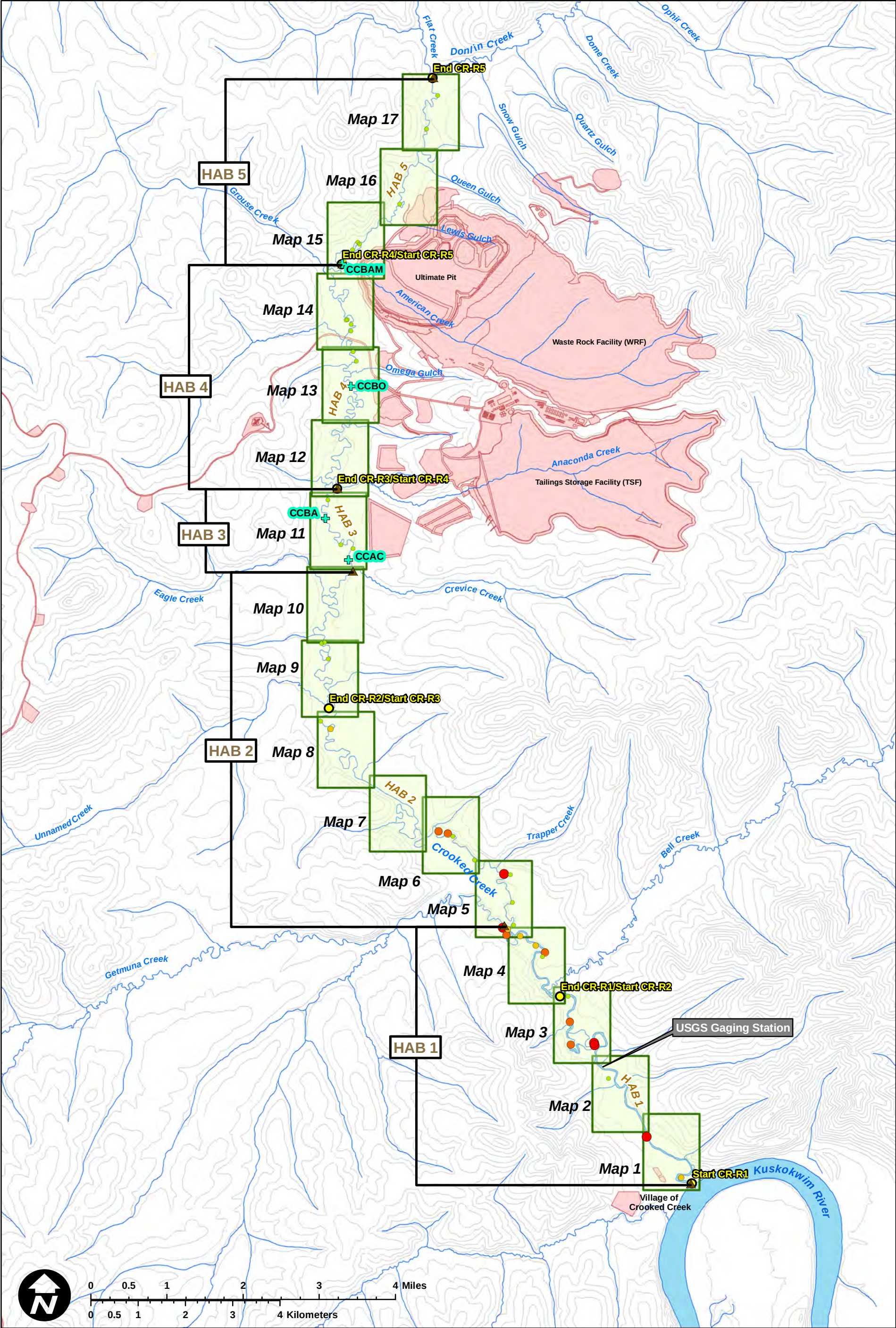


Prepared on December 31st 2012 by:

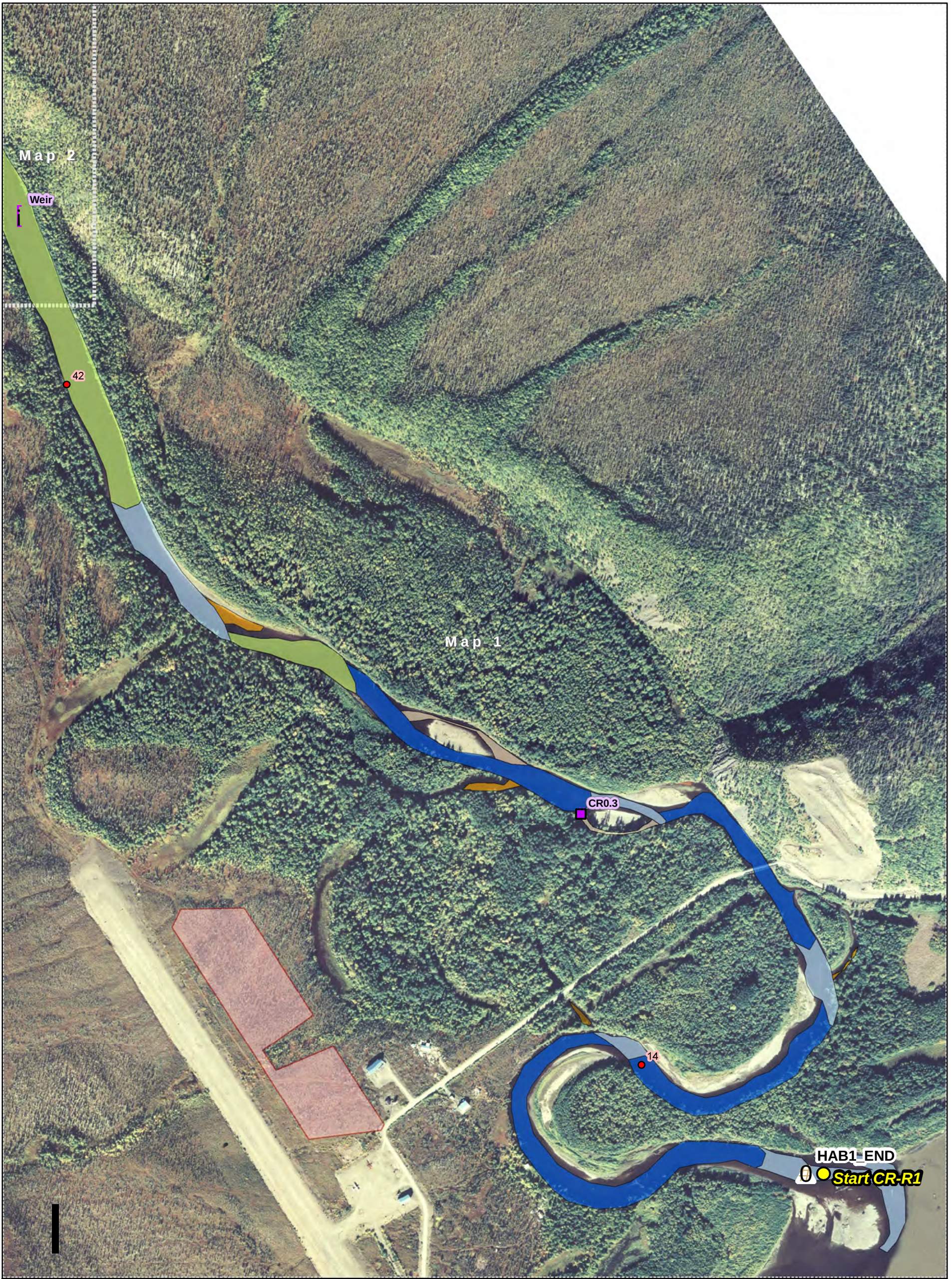


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Number of Salmon Redds 1-10 Redds 11-15 Redds 16-30 Redds 31-60 Redds	Infrastructure - Gage Station - Habitat Reach Breaks - Crooked Creek Aerial Reach Breaks	Water Body - River or Stream - Contours (100ft)	Crooked Creek Habitat Mapping 2009 - 2011	DONLIN GOLD OtterTail Environmental
Index Map				



Legend

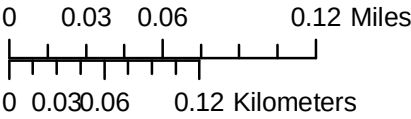
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|  | RUN |  | Infrastructure |
|  | RIFFLE |  | Donlin Gages- Habitat Report |
|  | GLIDE |  | Aerial Salmon Survey Reach Breaks |
|  | POOL |  | Habitat Reach Breaks |
|  | SIDEARM |  | Salmon Redds (# of Redds Observed) |
|  | BACKWATER |  | Winter Survey Location |
|  | ABANDONED CHANNEL |  | Biomonitoring Site |
| | |  | Fish Weir |

CROOKED CREEK HABITAT MAPPING 2009-2011

Proposed Donlin Gold Mine Area



Scale 1:4,696



Map 1 of 17



Legend

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BACKWATER

ABANDONED CHANNEL

Detailed_Survey

Infrastructure

Donlin Gages- Habitat Report

Aerial Salmon Survey Reach Breaks

Habitat Reach Breaks

Salmon Redds (# of Redds Observed)

Winter Survey Location

Biomonitoring Site

Fish Weir

CROOKED CREEK HABITAT MAPPING 2009-2011
Proposed Donlin Gold Mine Area



Scale 1:4,696

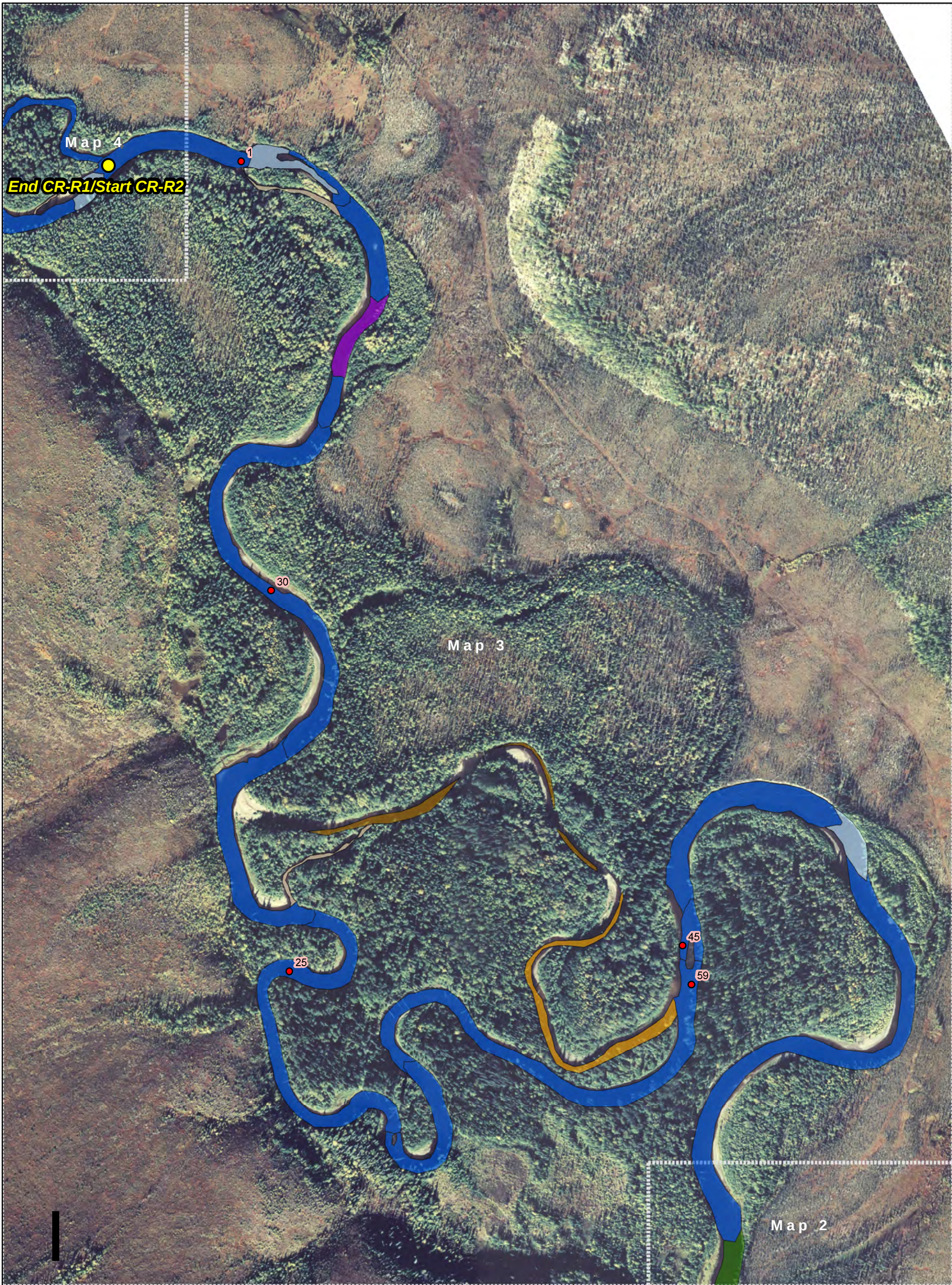
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Map 2 of 17

OtterTail Environmental, Inc. 02/09/2012



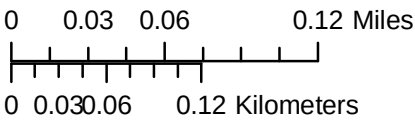
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| RUN | Infrastructure |
| RIFFLE | Donlin Gages- Habitat Report |
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| POOL | Habitat Reach Breaks |
| SIDEARM | Salmon Redds (# of Redds Observed) |
| BACKWATER | Winter Survey Location |
| ABANDONED CHANNEL | Biomonitoring Site |
| | Fish Weir |

CROOKED CREEK HABITAT MAPPING 2009-2011
Proposed Donlin Gold Mine Area



Scale 1:4,696



Map 3 of 17



Legend

FASTRUN

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POOL

SIDEARM

BACKWATER

ABANDONED CHANNEL

Detailed_Survey

Infrastructure

Donlin Gages- Habitat Report

Aerial Salmon Survey Reach Breaks

Habitat Reach Breaks

Salmon Redds (# of Redds Observed)

Winter Survey Location

Biomonitoring Site

Fish Weir

CROOKED CREEK HABITAT MAPPING 2009-2011

Proposed Donlin Gold Mine Area

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Scale 1:4,696

00.030.060.12 Miles

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Map 4 of 17

OtterTail Environmental, Inc. 02/09/2012



Legend

FASTRUN

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SIDEARM

BACKWATER

ABANDONED CHANNEL

Detailed_Survey

Infrastructure

Donlin Gages- Habitat Report

Aerial Salmon Survey Reach Breaks

Habitat Reach Breaks

Salmon Redds (# of Redds Observed)

Winter Survey Location

Biomonitoring Site

Fish Weir

CROOKED CREEK HABITAT MAPPING 2009-2011
Proposed Donlin Gold Mine Area



Scale 1:4,696

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00.030.060.12 Kilometers



Map 5 of 17

OtterTail Environmental, Inc. 02/09/2012



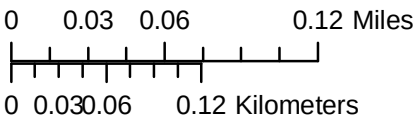
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| RUN | Infrastructure |
| RIFFLE | Donlin Gages- Habitat Report |
| GLIDE | Aerial Salmon Survey Reach Breaks |
| POOL | Habitat Reach Breaks |
| SIDEARM | Salmon Redds (# of Redds Observed) |
| BACKWATER | Winter Survey Location |
| ABANDONED CHANNEL | Biomonitoring Site |
| | Fish Weir |

CROOKED CREEK HABITAT MAPPING 2009-2011
Proposed Donlin Gold Mine Area



Scale 1:4,696



missing of 17

Map 8

Map 7

Legend

FASTRUN

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BACKWATER

ABANDONED CHANNEL

Detailed_Survey

Infrastructure

Donlin Gages- Habitat Report

Aerial Salmon Survey Reach Breaks

Habitat Reach Breaks

Salmon Redds (# of Redds Observed)

Winter Survey Location

Biomonitoring Site

Fish Weir

CROOKED CREEK HABITAT MAPPING 2009-2011

Proposed Donlin Gold Mine Area

DONLIN

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Scale 1:4,696

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Map 7 of 17

OtterTail Environmental, Inc. 02/09/2012



Legend

FASTRUN

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RIFFLE

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SIDEARM

BACKWATER

ABANDONED CHANNEL

Detailed_Survey

Infrastructure

Donlin Gages- Habitat Report

Aerial Salmon Survey Reach Breaks

Habitat Reach Breaks

Salmon Redds (# of Redds Observed)

Winter Survey Location

Biomonitoring Site

Fish Weir

CROOKED CREEK HABITAT MAPPING 2009-2011

Proposed Donlin Gold Mine Area

DONLIN

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Environmental

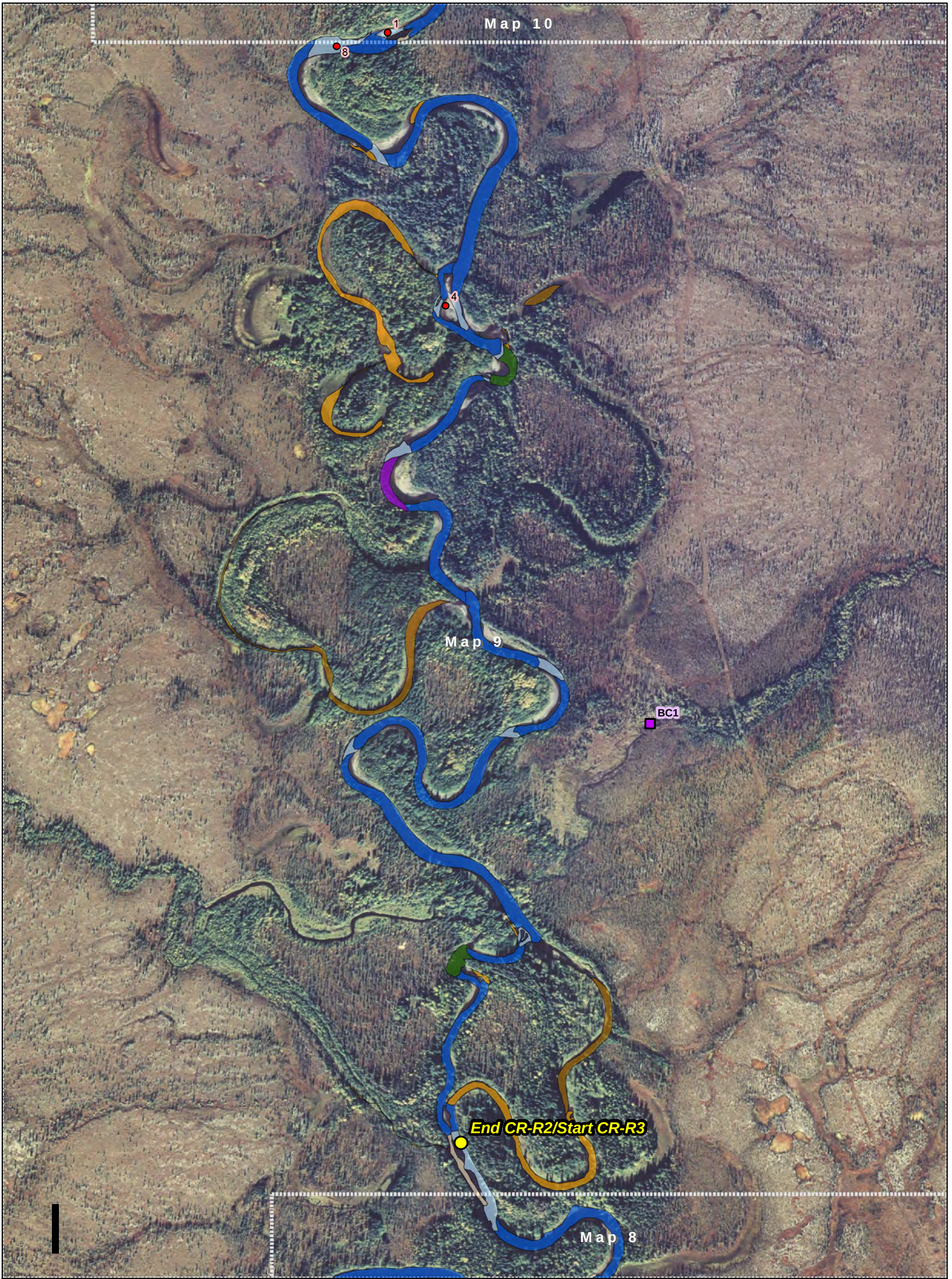
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Map 8 of 17

OtterTail Environmental, Inc. 02/09/2012



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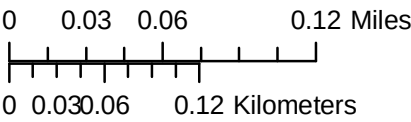
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| RUN | Infrastructure |
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| GLIDE | Aerial Salmon Survey Reach Breaks |
| POOL | Habitat Reach Breaks |
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| ABANDONED CHANNEL | Biomonitoring Site |
| | Fish Weir |

CROOKED CREEK HABITAT MAPPING 2009-2011

Proposed Donlin Gold Mine Area



Scale 1:4,696



Map 9 of 17



Legend

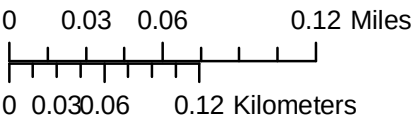
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|  POOL |  Habitat Reach Breaks |
|  SIDEARM |  Salmon Redds (# of Redds Observed) |
|  BACKWATER |  Winter Survey Location |
|  ABANDONED CHANNEL |  Biomonitoring Site |
| |  Fish Weir |

CROOKED CREEK HABITAT MAPPING 2009-2011

Proposed Donlin Gold Mine Area



Scale 1:4,696



Map 10 of 17



Legend

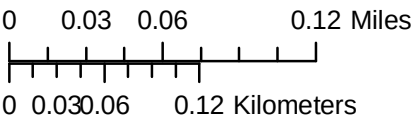
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|  POOL |  Habitat Reach Breaks |
|  SIDEARM |  Salmon Redds (# of Redds Observed) |
|  BACKWATER |  Winter Survey Location |
|  ABANDONED CHANNEL |  Biomonitoring Site |
| |  Fish Weir |

CROOKED CREEK HABITAT MAPPING 2009-2011

Proposed Donlin Gold Mine Area



Scale 1:4,696



Map 11 of 17



Legend

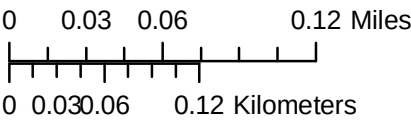
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|  POOL |  Habitat Reach Breaks |
|  SIDEARM |  Salmon Redds (# of Redds Observed) |
|  BACKWATER |  Winter Survey Location |
|  ABANDONED CHANNEL |  Biomonitoring Site |
| |  Fish Weir |

CROOKED CREEK HABITAT MAPPING 2009-2011

Proposed Donlin Gold Mine Area



Scale 1:4,696



Map 12 of 17



Legend

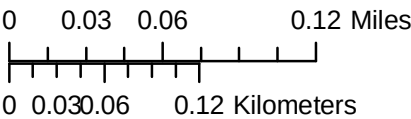
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|  RIFFLE |  Donlin Gages- Habitat Report |
|  GLIDE |  Aerial Salmon Survey Reach Breaks |
|  POOL |  Habitat Reach Breaks |
|  SIDEARM |  Salmon Redds (# of Redds Observed) |
|  BACKWATER |  Winter Survey Location |
|  ABANDONED CHANNEL |  Biomonitoring Site |
| |  Fish Weir |

CROOKED CREEK HABITAT MAPPING 2009-2011

Proposed Donlin Gold Mine Area



Scale 1:4,696



Map 13 of 17



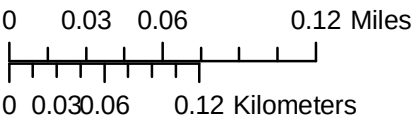
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| RUN | Infrastructure |
| RIFFLE | Donlin Gages- Habitat Report |
| GLIDE | Aerial Salmon Survey Reach Breaks |
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| BACKWATER | Winter Survey Location |
| ABANDONED CHANNEL | Biomonitoring Site |
| | Fish Weir |

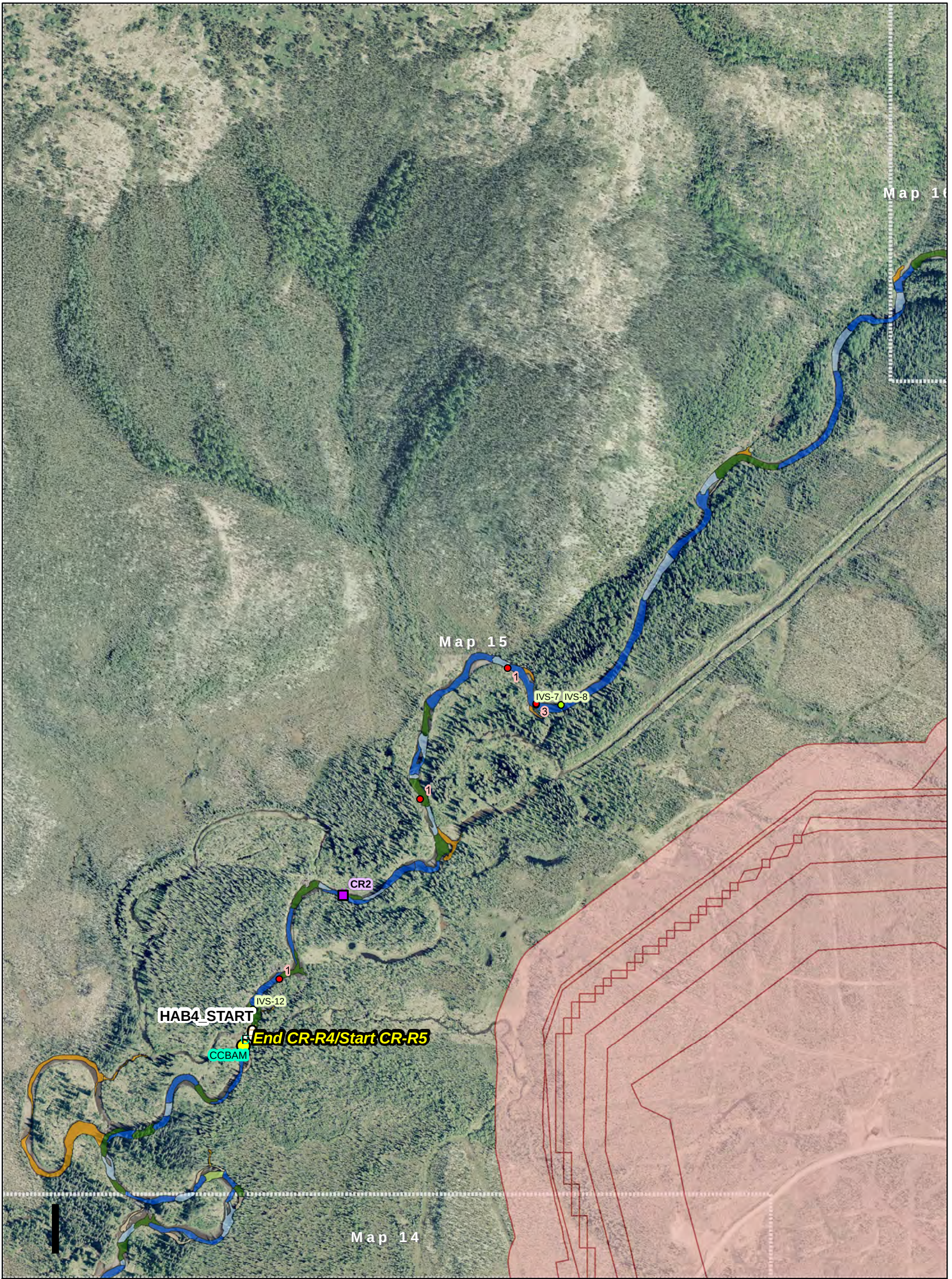
CROOKED CREEK HABITAT MAPPING 2009-2011
Proposed Donlin Gold Mine Area



Scale 1:4,696



Map 14 of 17



Legend

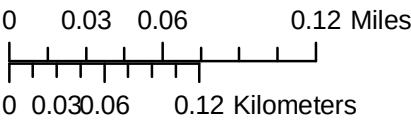
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| FASTRUN | Detailed_Survey |
| RUN | Infrastructure |
| RIFFLE | Donlin Gages- Habitat Report |
| GLIDE | Aerial Salmon Survey Reach Breaks |
| POOL | Habitat Reach Breaks |
| SIDEARM | Salmon Redds (# of Redds Observed) |
| BACKWATER | Winter Survey Location |
| ABANDONED CHANNEL | Biomonitoring Site |
| | Fish Weir |

CROOKED CREEK HABITAT MAPPING 2009-2011

Proposed Donlin Gold Mine Area



Scale 1:4,696



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Legend

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| FASTRUN | Detailed_Survey |
| RUN | Infrastructure |
| RIFFLE | Donlin Gages- Habitat Report |
| GLIDE | Aerial Salmon Survey Reach Breaks |
| POOL | Habitat Reach Breaks |
| SIDEARM | Salmon Redds (# of Redds Observed) |
| BACKWATER | Winter Survey Location |
| ABANDONED CHANNEL | Biomonitoring Site |
| | Fish Weir |

CROOKED CREEK HABITAT MAPPING 2009-2011
Proposed Donlin Gold Mine Area

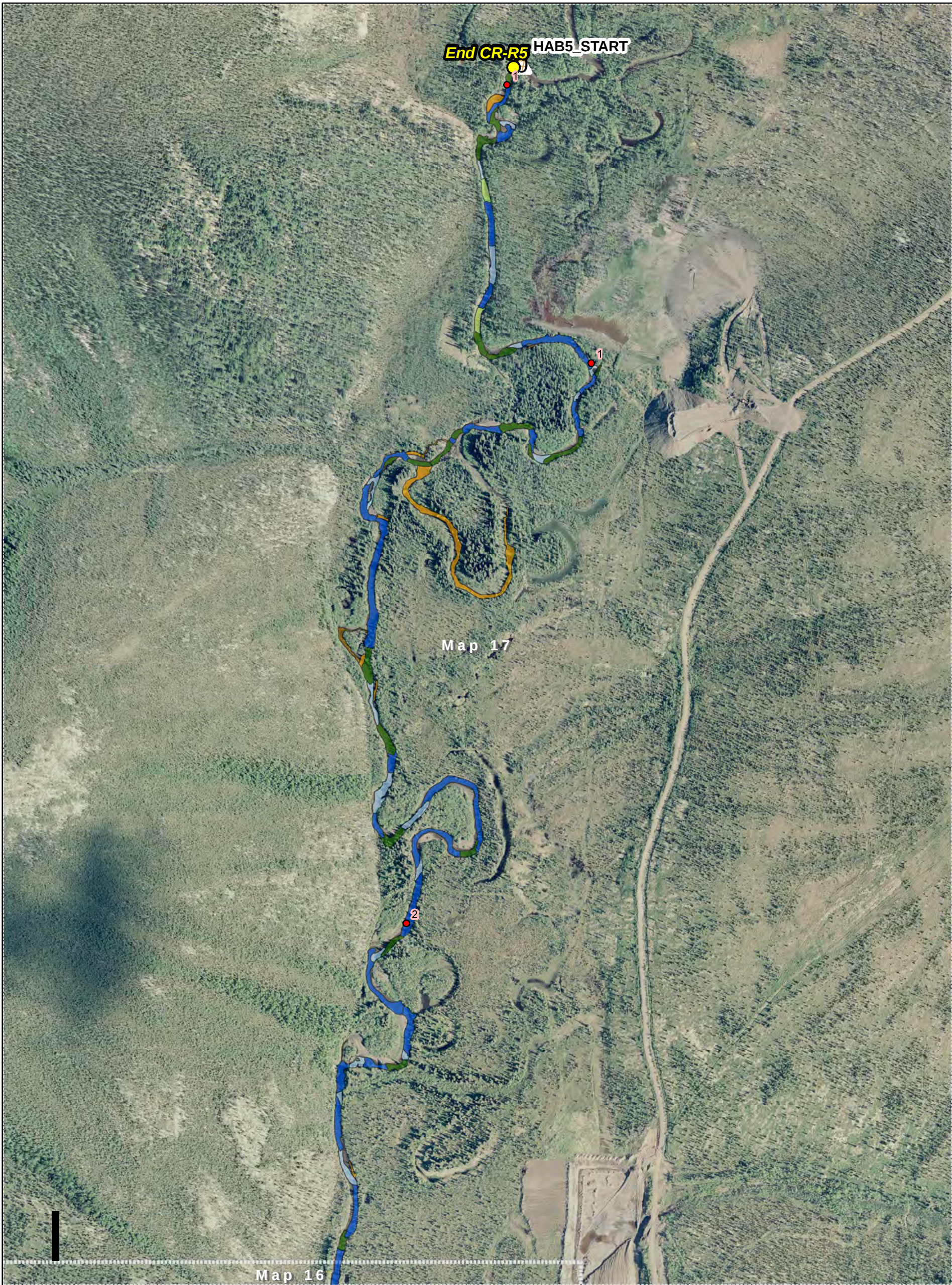


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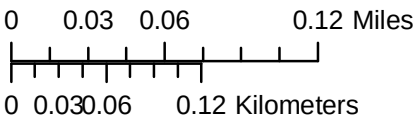
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| FASTRUN | Detailed_Survey |
| RUN | Infrastructure |
| RIFFLE | Donlin Gages- Habitat Report |
| GLIDE | Aerial Salmon Survey Reach Breaks |
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| ABANDONED CHANNEL | Biomonitoring Site |
| | Fish Weir |

CROOKED CREEK HABITAT MAPPING 2009-2011
Proposed Donlin Gold Mine Area



Scale 1:4,696



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Appendix B - Habitat Type (HMU) Definitions (2009)

Appendix B

Habitat Type (HMU) Definitions (2009)

HMU	Description
Cascade	Stepped rapids with very small pools behind boulders and small waterfalls.
Rapid	Higher gradient than a riffle, with faster current velocity, coarser choriotope, more surface turbulence, and convex streambed morphology.
Riffle	Shallow stream reach with moderate current velocity, some surface turbulence, high gradient, and convex streambed morphology.
Fast Run	Uniform fast-flowing stream channel.
Run	Deeper stream reach with moderate current velocity, but no surface turbulence. Laminar flow. Streambed is longitudinally flat and laterally concave.
Glide	Moderately shallow stream channel with laminar flow. Lacks pronounced turbulence, and exhibits flat streambed morphology.
Plunge Pool	Area where main flow passes over a complete channel obstruction and drops vertically to scour the streambed.
Pool	Deep water impounded by channel blockage or partial channel obstruction. Slow velocities with a concave streambed shape.
Side Arm	Channel around an island, smaller than half the width of the river, frequently at a different elevation than the main channel.
Backwater	Slack area along a channel margin caused by: 1) eddies behind obstructions, 2) development of sandbars during flood events, or 3) slack area through an abandonment of an older channel.
Abandoned Channel	Channel not connected at this survey (flow) but likely connected at higher flows; below bankfull.

Appendix C - Embeddedness Criteria used for Habitat Mapping

Appendix C

Embeddedness Criteria used for Habitat Mapping

Name	Definition
Loose	dislodges easily when stepped or kicked (<33%)
Embedded	river-bottom materials firmly placed, dislodges with effort (33%-66%)
Solid	plot is firm and compact (>66%)

Appendix D - Substrate Classifications used in Habitat Mapping on Crooked Creek (2009)

Appendix D

Substrate Classifications used in Habitat Mapping on Crooked Creek (2009)

Type	Name	Size Class	Description
Inorganic	Pelal	(<0.063mm)	Silt, loam, clay
	Psammal	(0.063-2mm)	Sand
	Akal	(2mm-2cm)	Gravel (medium to fine)
	Microlithal	(2-6.3cm)	Gravel (Coarse - egg size to small fist)
	Mesolithal	(6.3-20cm)	Cobble (Medium - baseball to softball)
	Macrolithal	(20-40cm)	Cobble (Coarse - blocks; head-sized cobble)
	Megalithal	(>40cm)	Cobble (Large)
	Gigalithal	unlimited	Bedrock
Organic	Sapropel	<FPOM	Organic - sludge
	Detritus	FPOM-CPOM*	Particulate organic matter
	Phytal	unlimited	Plants (Submerged mats; often w/ detritus)
	Xylal	unlimited	Wood (trees, roots, dead branches, etc)

Notes:

*FPOM (Fine Particulate Organic Matter): .45um- 1mm; CPOM (Coarse Particulate Organic Matter): 1mm- 10cm (4in)

Appendix E - Habitat Unit (HMU) Attributes

Appendix E

Habitat Unit (HMU) Attributes

Name	Definition
Boulders	Substrate >40cm
Overhanging Vegetation	Vegetation (<10 in off water surface)
Submerged Vegetation	Aquatic vegetation below water surface
Canopy Shading	Tree/canopy over waters edge
Undercut Bank	>90 degree bank to water profile
Woody Debris	Wood/debris within wetted channel
Shallow Margin	Little/no flow areas within HMU

Appendix F - Data Inclusion Criteria for Acoustic Doppler Current Profiler (ADCP) Measurements

Appendix F

Data Inclusion Criteria for Acoustic Doppler Current Profiler (ADCP) Measurements

Category	Criteria
Water Depth	Depth range of 0.3 - 5 meters (estimated 5 meter maximum)
Instrument Orientation	Hydroboard pitch between -10 and 10 degrees
	Hydroboard roll between -10 and 10 degrees
GPS parameters	Horizontal Dilution of Precision (HDOP) less than 21 (HDOP is a measurement describing the geometric strength of satellite configuration on GPS accuracy)
	GC-BC between -10 and 10. (GC-BC is an angular measurement comparing average GPS course across transect minus ADCP bottom-track course)
	D(BT)/D(GPS) ratio between 0.85 and 1.15 (Ratio of Bottom Track (BT) track distance to GPS track distance)

Appendix G - Criteria Used for Juvenile Salmon Habitat Suitability Model for Crooked Creek (2009)

Appendix G

Criteria Used for Juvenile Salmon Habitat Suitability Model for Crooked Creek (2009)

Attribute Weighting Table

Attribute	Abundance		
	Low	Present	Abundant
Boulders	0	0.225	0.75
Overhanging Vegetation	0	0.45	1.5
Submerged Vegetation	0	0.675	2.25
Canopy Shading	0	0.225	0.75
Undercut Bank	0	0.45	1.5
Woody Debris	0	0.9	3
Shallow Margin	0	0.9	3

HMU Type Weighting Table

HMU Type	Value
Riffle	1
Fast Run	2
Run	4
Glide	5
Pool	6
Side Arm	3
Backwater	7
Abandoned Channel	8

Suitability Classification

Rating	Greater Than	Less Than or Equal to
Excellent	12	17
Good	7	12
Fair	4	7
Poor	1	4