K4.24 FISH VALUES

This appendix provides additional technical information and discussion of the following topics related to potential impacts on fish and other aquatic species and wildlife, as described in Section 4.24, Fish Values:

- Selenium and impacts to aquatic species and wildlife
- Copper and impacts to aquatic species and wildlife
- Cadmium
- Mercury and impacts to aquatic species and wildlife
- Sulfate loading and mercury methylation
- Instream flow modeling

Section 4.18 and Appendix K4.18, Water and Sediment Quality, describe predicted concentrations of various components in surface water. For a detailed description of study methods and results of the project trace elements study, refer to Chapters 10 and 35 of the Environmental Baseline Data (EBD) reports (SLR et al. 2011a; SLR and Pentec Environmental/Hart Crowser 2011, respectively). All EBD tables referenced in this section are available in SLR et al. 2011a.

K4.24.1 Selenium

Selenium has a narrow range between essentiality and toxicity. As an essential nutrient, selenium is incorporated into functional and structural proteins; aquatic and terrestrial organisms require low levels of dietary selenium to sustain metabolic processes (Palace et al. 2004). Dietary requirements for fish range from 0.05 to 1.0 milligram per kilogram (mg/kg) of selenium on a dry-weight basis (Watanabe et al. 1997). The US Environmental Protection Agency (EPA) (2016) notes selenium deficiency may affect humans, sheep and cattle, deer, fish, aquatic invertebrates, and algae. Toxicity occurs in fish at an order of magnitude greater level than required to avoid deficiency (Palace et al. 2004).

Selenium is considered to be one of the most toxic but essential elements (Chapman et al. 2010). Chronic exposure to selenium can cause reproductive impairments (e.g., larval deformity or mortality), and also adversely affect growth and mortality in fish and aquatic invertebrates (e.g., larval deformity or mortality). The most well-documented toxic symptoms in fish are reproductive teratogenesis (formation of defects in developing embryos) and larval mortality. Egg-laying vertebrates appear to be the most sensitive taxa, with toxicity resulting from maternal transfer of selenium to eggs. Lethal and sublethal deformities can occur in developing fish exposed to selenium, affecting both hard and soft tissues (Lemly 1993b). Deformities in fish that affect feeding or respiration can be lethal shortly after hatching. Non-lethal deformities, such as distortions in the spine and fins, can reduce swimming ability and overall fitness. The EPA's (2016) recommended selenium water quality criteria represent the level below which aquatic impacts do not occur: these levels are 15.1, 8.1, and 11.3 mg/kg on dry weight in egg or ovary, whole body, and muscle, respectively.

The initial bioconcentration of selenium into primary producers from the dissolved phase is also the largest and potentially the most variable step in the trophic transfer of selenium (approximately 100 to 1,000,000-fold bioconcentration). At higher trophic levels, bioaccumulation occurs primarily through the dietary pathway (Presser and Ohlendorf 1987; Saiki and Lowe 1987; Luoma et al. 1992; Maher et al. 2010). Dissolved selenium does not contribute substantially to selenium bioaccumulation in higher trophic animals under environmentally relevant conditions (Lemly 1985; Ogle and Knight 1996).

Primary producers (trophic level 1 organisms such as periphyton, phytoplankton, and vascular macrophytes) assimilate dissolved selenium in their tissues. Next, aquatic primary consumers (trophic level 2 organisms such as zooplankton, insect larvae, larval fish, and bivalves) take up selenium from these primary producers and other particles. Predators (trophic level 3 and above such as fish and birds) then accumulate selenium progressively via the food web.

The type of waterbody (e.g., lentic [still] versus lotic [flowing]), and the type of food web influences selenium bioaccumulation in higher trophic organisms. Organisms in lakes, ponds, reservoirs, wetlands, or estuaries would tend to bioaccumulate more selenium than those living in waters with shorter residence times such as rivers and streams (Luoma and Rainbow 2005; Simmons and Wallschlägel 2005). In aquatic systems with similar dissolved selenium concentrations, fish that consume primarily freshwater mollusks would exhibit greater selenium bioaccumulation than fish that consume primarily insects or crustaceans, because mollusks tend to bioaccumulate more selenium than other trophic level 2 organisms (Luoma and Presser 2009; Stewart et al. 2004).

For birds, dietary selenium requirements appear to be between 0.05 and 0.5 mg/kg. Elevated dietary selenium in birds just before egg-laying can result in reproductive, teratogenic, and other toxic effects due to maternal transfer of selenium to eggs (Ohlendorf and Heinz 2011). However, selenium sensitivity among different bird species varies. Interpretive guidelines based on available data on selenium toxicity to birds indicate that selenium deficiency occurs generally below dietary concentrations of 0.30 mg/kg dry weight, and toxicity occurs generally above 5.0 mg/kg dry weight (Ohlendorf and Heinz 2011).

K4.24.1.1 Selenium Impacts to Aquatic Species and Wildlife

Fish and bird species are the species groups most sensitive to selenium toxicity due to maternal transfer in eggs. The primary exposure pathway of concern is aquatic bioaccumulation and subsequent food-chain biomagnification. Predicted project-related changes in selenium concentrations in various waterbodies during operations and post-closure activities are not sufficiently large to adversely impact sensitive fish and bird populations via aquatic or bioaccumulation pathways.

Predicted selenium concentrations in treated effluent discharges from water treatment plants (WTPs) range from 0.537 to 2.9 micrograms per liter (µg/L) during mine operations and various closures stages (see Table K4.18-13 through Table K4.18-16). Treatment prior to discharge would achieve the selenium discharge limit based on the Alaska Department of Environment Conservation (ADEC) aquatic life criteria of 5.0 µg/L. Downstream of the discharge location, concentrations of the selenium would be expected to rapidly decline due to dilution.

Changes in metals concentrations downstream of North Fork Koktuli (NFK), South Fork Koktuli (SFK), Upper Talarik Creek (UTC), and Frying Pan Lake were predicted based on a model that accounts for the effluent discharge from the WTPs, project-related dust deposition on the lake, and runoffs from surrounding terrestrial areas receiving project-related dust deposition (see Appendix K4.18). To be conservative, various assumptions are made in the model that bias the predicted concentrations to be higher than would be expected under realistic conditions. The conservative, high-end, long-term selenium concentrations in the rivers and lake are estimated to range from 0.32 to 1.4 µg/L. These predicted selenium concentrations are below ADEC's aquatic life criterion of 5.0 µg/L and the EPA's aquatic life criteria of 1.5 µg/L and 3.5 µg/L for lentic and lotic waters.

Predicted change in surface water quality from project-related dust deposition is presented in Table K4.18-18 and Table K4.18-19. Predicted selenium concentrations in various waterbodies range from 0.27 to 0.30 µg/L (see Table K4.18-18 and Table K4.18-19), which is the same as the baseline range (i.e., dust deposition would not result in appreciable change in the surface water selenium concentrations).

The EPA's aquatic life criteria of 1.5 µg/L and 3.5 µg/L for lentic and lotic waters, respectively, are derived based on bioaccumulation modeling, and are protective of adverse effects on sensitive aquatic species through bioaccumulation of selenium, particularly fish species, which are the most sensitive aquatic species. Therefore, aquatic impacts to invertebrates and fish species would not be expected to occur due to project-related changes in surface water selenium concentrations.

Similarly, at the high-end prediction of 0.32 to 1.4 µg/L in surface water (see Table K4.18-18 and Table K4.18-19), aquatic organisms and fish would not be likely to accumulate selenium above 5.0 mg/kg dry weight in their tissues, which is the general, literature-based toxicity threshold of dietary selenium for birds. Therefore, at the predicted surface water selenium concentrations, impacts on bird populations through the dietary exposure pathway would also not be expected.

K4.24.2 Copper

Copper is considered one of the most toxic elements for aquatic species; however, its toxicity varies based on environmental conditions and on species sensitivity.

Due to diverse influences of physicochemical factors on copper toxicity, the specific chemistry of the exposure water determines whether appreciable adverse effects occur. Other than copper concentration, factors that influence copper toxicity include pH, hardness, alkalinity, and organic carbon. ADEC's hardness-based aquatic life criteria for copper includes hardness-based adjustments using empirical regressions of toxic concentrations versus hardness. Because of general correlation between hardness and other factors (such as pH and alkalinity), the hardness adjustments address more bioavailability factors than hardness alone. However, these factors are not addressed separately for exposure conditions in which correlations between hardness and other factors may be different. Additionally, other physicochemical factors affecting metal toxicity, such as organic carbon, are not addressed by the hardness adjustment.

In 2007, the EPA updated the aquatic life criteria for copper based on the Biotic Ligand Model, which specifically accounts for the diverse interactions of various factors that influence copper bioavailability and toxicity. The Biotic Ligand Model approach is considered a better representation of the geochemical and biological interactions of copper than the hardness-based approach. However, in developing the Biotic Ligand Model-based aquatic life criteria, the EPA considered only the conventional toxicity related to survival, growth, and reproduction of aquatic species, and did not include other sublethal effects that may adversely impact their populations.

Copper has been known to impair olfaction, behavior, and other chemo/mechanosensory responses in aquatic organisms, including effects to the lateral line of fish (Hara et al. 1976; Linbo et al. 2006, 2009; Hansen et al. 1999a). The lateral line of fish is composed of neurons (hair cells) that enable schooling, predator avoidance, feeding, reproduction, and returning to natal streams (Hansen et al. 1999a, b; McIntyre et al. 2012). Copper avoidance behavior by rainbow trout and chinook salmon has been reported at concentrations ranging from 0.7 to 9.2 µg/L (Morris et al. 2019a). Neurophysiological studies on juvenile salmonids have reported inhibitory effects on sensory epithelium or olfactory bulb at 1.9 to 8 µg/L, ranging over 0.5- to 4-hour exposures (Morris et al. 2019a). Potential importance of such sublethal effects has led to concerns that both hardness-based and Biotic Ligand Model-based aquatic life criteria might not adequately protect fish and other aquatic organisms.

Meyer and Adams (2010), with a recent update (Meyer and DeForest 2018), evaluated the protectiveness of the hardness-based and Biotic Ligand Model-based aquatic life criteria for copper against impairment of behavior (e.g., ability to respond to olfactory alarm cues, predatory avoidance ability, and swimming performance) and chemo/mechanosensory responses (e.g., changes in electro-olfactogram, electroencephalogram, and histopathology of olfactory or lateral-line tissue). The updated meta-analysis of relevant studies indicated that the hardness-based chronic copper criteria were less protective than Biotic Ligand Model-based chronic copper criteria against impairment of behavior and chemo/mechanosensory responses. However, both hardness-based and Biotic Ligand Model-based chronic criteria were protective for the majority of the cases: 73.8 percent and 95.3 percent of the cases, respectively. Additionally, the ranges of water chemistry generally overlapped considerably for protective versus under-protective cases, and were not indicative of any systematic bias based on type of water chemistry.

Recent studies have investigated whether hardness-based and Biotic Ligand Model-based criteria are systematically less protective in low-hardness water of Bristol Bay headwaters (Morris et al. 2019a, b). Morris et al. (2019a) tested copper toxicity in low-hardness laboratory water (approximately 30 milligrams per liter [mg/L] as calcium carbonate [$CaCO_3$]), and reported that acute toxicity (median lethal toxicity or LC50) to rainbow trout occurred at 16 µg/L. In the same study, fathead minnows were exposed to laboratory and samples collected from NFK, SFK, and UTC; resulting LC50s were 29 and 79 µg/L, respectively. In the Morris et al. (2019b) study of copper toxicity toward olfactory impairment, rainbow trout was exposed to copper in a low hardness water (27 mg/L as $CaCO_3$); olfactory impairment inhibitory concentrations were reported to be 2.7 and 2.4 µg/L after 24- or 96-hour exposures, respectively. In 65 surface water samples collected from these rivers, reported copper concentrations ranged 0.18 to 2.92 µg/L (Morris et al. 2019a), which are lower than the acute toxicity values of 29 to 79 µg/L; however, at the higher range, are similar to inhibitory concentrations of 2.4 to 2.7 µg/L for olfactory impairment.

Compared to the inhibitory concentrations of 2.7 and 2.4 µg/L in the Morris et al. (2019b) study, the reported Biotic Ligand Model-based chronic criteria were 0.63 and 0.39 µg/L, and hardness-based chronic criteria were 3.9 and 2.9 µg/L, indicating that the hardness-based criteria are not protective of olfactory impairment in rainbow trout due to copper.

Overall, evaluations of copper toxicity on behavior and chemo/mechanosensory responses in fish indicate inhibitory concentrations as low as 0.7 µg/L (as dissolved copper) depending on species, life stage, exposure duration, and water chemistry. Furthermore, hardness-based criteria and Biotic Ligand Model-based criteria are generally protective against aquatic toxicity of copper, but they may not be protective for specific behavior and olfactory responses under specific conditions (such as low hardness).

K4.24.2.1 Copper Impacts to Aquatic Species and Wildlife

Fish and other aquatic species are the most sensitive to copper toxicity on behavior and olfactory responses. The primary exposure pathway of concern is the direct contact to bioavailable fraction of aqueous copper. As described in the following paragraphs, predicted project-related changes in copper concentrations in various waterbodies, during operations and post-closure activities, would not be sufficiently large to adversely impact the sensitive fish populations via behavioral and olfactory impairments.

Predicted copper concentrations in treated effluent discharges from WTPs would range from approximately 1.17*10^-4 to 0.23 µg/L during mine operations and in various closures stages (see Table K4.18-13 through Table K4.18-16). Treatment prior to discharge would achieve the copper discharge limit based on ADEC aquatic life criterion of 2.2 µg/L (see Table K3.18-1). Downstream of the discharge point, concentrations of the copper would be expected to rapidly decline due to dilution.

The discharge limit of 2.2 μg/L is based on hardness adjustment using the lowest of the 15th percentile from the treated water discharge locations (approximately 17 mg/L as $CaCO_3$). Baseline hardness in the mine site surface water ranges from 5.9 to 62.2 mg/L as $CaCO_3$ (see Table K.18-7 through Table K3.18-10). Hardness in effluent discharges is expected to be higher at 3.7 to 179 mg/L as $CaCO_3$ (see Table K4.18-13 through Table K4.18-16).

Changes in metals concentrations downstream of NFK, SFK, UTC, and Frying Pan Lake were predicted based on a model that accounts for the effluent discharge from the WTPs, project-related dust deposition on the lake, and runoffs from surrounding terrestrial areas receiving project-related dust deposition (see Appendix K4.18). To be conservative, various assumptions were made in the model that bias the predicted concentrations to be higher than would be expected under realistic conditions. The conservative, high-end, long-term copper concentrations in the rivers and the lake were estimated to range from less than 0.5 to 1.71 μg/L (see Table K.4.18-19). These concentrations are below the ADEC's aquatic life criterion of 2.2 μg/L, and the reported olfactory impairment threshold of 2.4 μg/L for fish in low hardness waters (Morris et al. 2019b).

Overall, site-related changes in copper concentrations in surface waterbodies would not be sufficient to cause adverse impacts to invertebrates and fish species, based on comparisons of predicted changes over baseline conditions and reported threshold concentrations of potential impacts.

K4.24.3 Cadmium

Cadmium can bioaccumulate in the tissues of aquatic life (EPA 2016). However, at criteria concentrations (i.e., at the ADEC water quality criterion), cadmium is unlikely to accumulate to levels that would result in adverse effects to aquatic invertebrates, fish, or wildlife from the ingestion of aquatic life that have accumulated cadmium in their tissues.

The biological integrity of aquatic systems is considered to be at greater risk than terrestrial systems from cadmium based on the greater sensitivity of aquatic organisms relative to birds and mammals. Freshwater biota is the most sensitive to cadmium; marine organisms are generally considered to be more resistant than freshwater organisms; and mammals and birds are considered to be comparatively resistant to cadmium. Based on this trend, criteria that are protective of aquatic life are also considered to be protective of mammalian and avian wildlife.

K4.24.4 Mercury

Methylmercury is the mercury species of greatest concern for wildlife health because it biomagnifies in food webs, reaching high concentrations in larger, predatory organisms. Consequently, exposure via ingestion of food items is the primary exposure route for methylmercury.

Toxicokinetics and biotransformation of methylmercury and inorganic mercury differ. Methylmercury is slower to depurate than other mercury species (Scheuhammer et al. 2007) and forms complexes that are transported through the body and across placental and blood-brain barriers (Basu et al. 2005). In contrast, inorganic mercury partitions evenly in blood between protein and plasma; is poorly transported across the blood-brain barrier; and is stored primarily in the kidney and liver. Exposure to methylmercury has been hypothesized to adversely affect a wide range of biological functions in upper trophic level organisms, including neurotoxicity, blood and serum chemistry, histology, growth and development, metabolism, behavior, vision, hearing, motor coordination, and reproduction (Eisler 1987; Colborn et al. 1993; Wolfe et al. 1998).

ADEC's water quality criterion of 0.012 µg/L for mercury is based on a human health criterion derived by EPA from a fish tissue concentration and conservative bioaccumulation factors. The EPA's current recommended ambient water quality criterion that is considered protective of the aquatic life, including invertebrates and fish, is 0.77 µg/L, and was updated in 1997. For the purposes of aquatic impacts evaluation, the more stringent criterion of 0.012 µg/L is used. Due to the bioaccummulative nature of methylmercury, several studies have attempted to establish critical tissue residue for the protection of fish. Current understanding supports a whole body tissue residue threshold of 0.21 mg/kg wet weight below which juvenile and adult fish are not impacted, and a threshold of 0.44 mg/kg above which adverse impacts may occur (Beckvar et al. 2005; Dillon et al. 2010). Adverse impacts may represent wide-ranging adverse effects discussed above.

For birds, reported threshold dietary doses range from 0.017 mg/kg body weight per day to 0.078 mg/kg body weight per day of methylmercury (Albers et al. 2007, 1976a; b; Gerrard and St. Louis 2001; Longcore et al. 2007; Custer et al. 2008).

The EPA's recommended fish tissue methylmercury criterion for the protection of human health is 0.3 mg/kg (EPA 2001). This criterion is protective of 90 percent of the general nationwide population, using a default fish consumption rate of 0.0175 kilogram of fish per day (kg fish/day). EPA encourages the states and tribes to develop methylmercury tissue criterion using local or regional data, if that would be appropriate for their target population. Human population at the highest risk due to methylmercury is the children of women who consume large amounts of fish and seafood during pregnancy due to its neurotoxicity. Based on current advice on fish consumption in Alaska, fish with tissue methylmercury concentrations less than 0.2 mg/kg is unrestricted for consumption by women who are or can become pregnant, nursing mothers, and children (Alaska Dept. of Public Health 2007, 2014).

Exposure to inorganic mercury occurs primarily via ingestion or direct contact. Inorganic mercury is primarily nephrotoxic in wildlife; but in some laboratory exposures, other effects have been observed, including enzyme inactivation and genotoxicity (Wolfe et al. 1998).

The dominant species of mercury transported by surface water in remote, unimpacted waterbodies are in dissolved form (Rohlfus et al. 2015), and generally associated with dissolved organic carbon (Nagorski et al. 2014; Stoken et al. 2016). Dissolved inorganic mercury can be converted to methylmercury by a diverse array of anaerobic microbial organisms through the process of methylation (Compeau and Bartha 1985; Fleming et al. 2006). Although methylmercury has been discharged directly to the environment in some cases (e.g., Minamata Bay, Japan) (Ekino et al. 2007), there are currently few direct anthropogenic sources of methylmercury to the environment (Boening 2000).

K4.24.4.1 Mercury Impacts to Aquatic Species and Wildlife

Fish and bird species are the most sensitive to methylmercury toxicity due to its ability to transfer through the blood-brain and placental barrier in organisms. The primary exposure pathway of concern is the aquatic bioaccumulation and subsequent food chain biomagnification.

Mercury concentration in the effluent from WTPs during operation and closure phases would be estimated to be 1.6*10^-5 µg/L or lower (see Table K.4.18-13 and Table K.4.18-16), which is orders of magnitude lower than the ADEC aquatic water quality criterion of 0.012 µg/L. Downstream of the discharge point, concentrations of mercury would be expected to represent baseline conditions.

Separate evaluation of predicted change in surface water quality from project-related dust deposition (see Table K4.18-18 and Table K4.18-19) was not estimated due to generally non-detect mercury concentrations in the baseline data. As discussed in Section 3.18, Water and Sediment Quality, based on the detection limits, approximately 95 percent of the baseline samples have mercury concentrations below 0.005 µg/L, and likely below 0.0015 µg/L, which is eight times less than the most stringent water quality criteria for mercury (0.012 µg/L). Dust deposition would not result in appreciable change in the sediment (see Table K4.18-17) or soil (see Table 4.14-1) mercury concentrations; predicted incremental change was 0.32 percent over baseline, resulting in essentially unchanged baseline levels that would be below all applicable threshold limits for adverse impacts. Based on these findings, the project-related mercury releases would not be expected to cause adverse impacts on the environment.

K4.24.4.2 Sulfate Loading and Mercury Methylation

The permitted discharge of treated water would be expected to cause increased sulfate loading to project area surface waterbodies. Therefore, concerns have been raised with respect to the potential for sulfate-induced mercury methylation in the project area surface waterbodies and subsequent potential impact on human health and the environment. However, sulfate-induced formation of methylmercury is a complex process that depends not only on the sulfate loading, but on various site-specific geochemical conditions. A qualitative assessment of the potential environmental impacts of project-related sulfate discharge is provided based on the site-specific conditions and the specific role of sulfur biogeochemistry in the formation of methylmercury in the environment.

Mercury Methylation

Inorganic mercury may be methylated by microorganisms in the environment to form methylmercury, an organic form that bioaccumulates at the base of the food web and biomagnifies up the food web, posing potential threat to wildlife and humans (e.g., via consumption of fish). Therefore, an understanding of the environmental factors that influence the formation of methylmercury from inorganic mercury is important to assess the potential impact of mercury on human health and the environment, as well as indirect potential economic consequences to sport and commercial fishing and subsistence consumers.

Net methylmercury production in the environment depends on the rate of methylation relative to the rate of demethylation of methylmercury. Methylmercury production in many freshwater and marine environments occurs primarily via the microbial sulfate reduction (MSR) process (Gilmour et al. 1992; Hsu-Kim et al. 2013; Driscoll et al. 2013), although microbial iron reduction and methanogenic processes are also known to produce methylmercury (Kerin et al. 2006; Yu et al. 2013). In the MSR, sulfate-reducing bacteria (SRB) produces methylmercury as a co-metabolic product. Demethylation occurs primarily via the photochemical reduction, which dominates demethylation in the photic zones of surface water; aerobic and anaerobic microbes have also been found to demethylate methylmercury to a lesser extent (Ullrich et al. 2001).

Two site-specific factors that determine the net mercury methylation in the environment include mercury bioavailability and microbial activity with respects to SRBs (Hsu-Kim et al. 2013). Mercury bioavailability refers to the amount of mercury that can potentially be methylated; bioavailability depends on the geochemical speciation or the form of mercury in a particular environment. Microbial activity refers to presence and activity of these microbes, which depend on various geochemical factors, including sulfur biogeochemistry.

Influence of Sulfate on Mercury Methylation

Sulfate loading can stimulate mercury methylation in aquatic and wetland areas; however, the relationship between sulfate loading and methylmercury production is complex. At lower concentrations, sulfate generally increases mercury methylation because of its role as an electron acceptor for SRB in the MSR process (Kampalath et al. 2013); however, at higher concentrations, the MSR process results in the formation sufficient sulfide, which can impact the mercury bioavailability and the amount of methylmercury produced (Paquette and Helz 1997). These dual effects of sulfate on mercury methylation is further influenced by various site-specific conditions (such as nitrate, organic carbon, pH, and mercury).

At low concentrations, additional sulfate can stimulate MSR and mercury methylation in anaerobic conditions (Jeremiason et al. 2006). At higher concentrations, further addition of sulfate increases inorganic sulfide, which appears to decrease the availability of inorganic mercury for methylation (Hsu-Kim et al. 2013; Johnson et al. 2016). Therefore, a range of sulfate and sulfide concentrations are expected to be optimal for mercury methylation, above which mercury methylation is inhibited (Hsu-Kim et al. 2013). The concentration-dependent stimulation and inhibition of methylmercury production by sulfate is recognized in the US Geological Survey (USGS) predictive model based on surface water sulfate concentrations as one of the readily available indicators of methylmercury levels (USGS 2019).

A broad range in sulfate concentration has been reported in association with maximum methylation efficiency because of the variable chemical reduction of sulfate to sulfide due to site-specific differences in the geochemical differences (Pollman et al. 2017). Orem et al. (2014) observed peak surface water methylmercury concentrations at sulfate concentrations of 2 mg/L and 10 to 15 mg/L at two different areas in the Everglades. In the freshwater wetland mesocosms, Myrbo et al. (2017) reported peak surface water methylation at sulfate concentrations of 59 and 93 mg/L.

Several studies have reported inhibitory effects of sulfide on mercury methylation, but mostly in wetlands. In South Florida, Orem et al. (2011) found that sulfide at greater than 1.0 mg/L (as sulfur) inhibited mercury methylation, but not at 0.05 to 0.15 mg/L (as sulfur). In a sulfate-enriched sub-boreal Minnesota wetland due to mining discharge, Bailey et al. (2017) found that sulfide above approximately 0.65 mg/L (as sulfur) inhibited mercury methylation, with some inhibitory effects within a wider range of 0.3 to 3.0 mg/L (as sulfur). In a freshwater wetland mesocosm (Myrbo et al. 2017), onset of inhibitory effects on mercury methylation occurred at sulfide concentrations between 0.3 and 0.7 mg/L (as sulfur).

Overall, because lower sulfate concentrations may limit MSR rates (Holmer and Storkholm 2001), the biogeochemical significance of MSR is often considered minimal in freshwater and low-salinity systems (Stagg et al. 2017). Therefore, increased sulfate loading to low-sulfate aquatic systems with organic sediment can result in increased mercury methylation via MSR (Paranjape and Hall 2017), but strong influence of site-specific conditions need consideration in determining the potential for increased methylmercury production. These conditions are discussed in the context of the project area and project-related impacts in the following section. The project area encompassed a large area (over 150 square miles), including and surrounding the deposit area.

Potential Impacts of Project-Related Sulfate Discharge

Methylmercury was detected in baseline fish tissue samples from the project area waterbodies. Therefore, mercury methylation is occurring in these waterbodies and/or the surrounding watershed, including surrounding wetlands. The following evaluations are provided in the context of whether project-related sulfate loading to the waterbodies would cause appreciable increase in the methylmercury production beyond the baseline. Owing to the uncertainties in the qualitative assessments discussed in this section, increased methylmercury production by project-related sulfate loading cannot be ruled out, particularly where conditions conducive to the MSR process and sulfate deficiency overlap. This conclusion is supported by an evaluation of the site-specific conditions and their impacts on two factors influencing mercury methylation: SRB activity, and mercury bioavailability.

Bigham et al. (2016) critically reviewed the literature on site-specific geochemical and physical parameters that may have different effects on microbial activity and mercury bioavailability. Those that are relevant for the current assessment include oxygen, temperature, selenium, iron, organic carbon, nitrate, and sulfur (discussed above). Because of their biogeochemical characteristics, abundance of wetlands in a watershed is another major factor associated with prevalence of methylmercury in waterbodies (Nagorski et al. 2014). These parameters are discussed in the following paragraphs to provide a general qualitative assessment of the project area conditions as a whole based on available data as indicators. Ideally, porewater data from sediment and wetland environments serve as the best indicators for mercury methylation potential; however, site-specific porewater data are not available. Therefore, available bulk sediment data are considered because they represent the next best indicators for mercury methylation potential. Additionally, surface water data are considered to provide an understanding of the general conditions of the aquatic systems, USGS (2019) identified surface water sulfate, total organic carbon (TOC), and pH as major parameters in their predictive model for surface water methylmercury concentrations.

SRBs are anaerobic microbes. Availability of oxygen and other more favorable electron acceptors, such as nitrate and iron, do not support the presence of SRB required for mercury methylation via MSR. Therefore, overall impacts of increased sulfate loading on methylmercury production depends on the extent of conditions conducive to methylmercury production that are also sulfate deficient. General conditions in the project area waterbodies with respect to their potential for producing methylmercury is provided below.

In shallow, more turbulent waterbodies, the water column may represent the conditions in the underlying surficial sediments, where mercury methylation is primarily expected to occur. Dissolved oxygen (DO) levels, oxidation-reduction potential (ORP), and nitrate/nitrite in the water column reflect the reducing/oxidizing (redox) conditions in these systems. In the surface waterbodies in the project area, DO concentrations range from 2.69 to 18.6 mg/L and median ORP ranged from 112 to 155 millivolts in project area rivers and lakes (see Table K3.18-7 through Table K3.18-10). Nitrate/nitrite was detected at frequencies of 77 to 93 percent, with concentrations ranging from 0.005 to 3.94 mg/L in the rivers and lakes (see Table K3.18-7 through Table K3.18-10). These water column data for the project area surface waterbodies reflect generally oxidizing conditions. Based on these data, sediment conditions may be oxidizing, particularly in shallow water and/or turbulent systems, such as in the headwaters. Presence of nitrate in these systems may also inhibit mercury methylation because the addition of nitrate has been successful as a remedial approach to limit methylmercury production in the Onondaga Lake (Todorova et al. 2009; Matthews et al. 2013). In deeper and more quiescent systems, which may occur along the water courses, the oxidizing conditions in the water column are not likely to reflect the sediment conditions, as shown by the acid volatile sulfide (AVS) and TOC in the sediment samples from the project area surface waterbodies.

AVS was measured in 34 sediment samples collected from June to September 2007 (SLR et al. 2011a; Chapter 10). Sample locations represent wide-ranging conditions, including streams, lakes, and ponds in the project area. AVS is typically evaluated in the context of metals bioavailability; if simultaneously extracted metals are lower than AVS (on a molar basis), it is surmised that the metals are in sulfide form with low solubilities, and therefore, have limited bioavailability. Presence of AVS is indicative of reducing conditions, and its absence may indicate oxidizing conditions. AVS was detected in 9 of 34 samples, or 26 percent of the samples, with a median concentration of 0.35 mg/kg (SLR et al. 2011, Table 10.2-2). The detection limits ranged from 0.4 to 6 mg/kg. Based on these detection limits and the inherent difficulties associated with the AVS method, the non-detect samples do not necessarily represent zero sulfides in specific samples; however, lower AVS detection frequencies indicate generally oxidizing conditions that are not conducive to mercury methylation via the MSR process. On the other hand, detection in 26 percent of the samples indicate that reducing conditions prevail in the watershed where mercury methylation would occur or are occurring. Based on these observations, although the majority of the aquatic areas are reflective of generally oxidizing conditions, areas of reducing conditions also occur in project area waterbodies.

TOC in sediments and surface water (in dissolved form, dissolved organic compound [DOC]) has major influence on metal speciation and bioavailability. Generally, TOC renders mercury less bioavailable for methylation. However, in mildly sulfidic waters, DOC may enhance mercury mobilization for microbes. In addition, TOC (as organic matter) may encourage microbial activity (i.e., higher methylation) by providing electron donor substrate. Sediment TOC was measured in the same 34 samples analyzed for AVS. The TOC ranged from 0.13 to 32.3 percent, with a median of 1.77 percent (SLR et al. 2011; Table 10.2-3). These TOC data indicate large variability in substrate conditions, with generally low TOC content. Locations with TOC in the higher range may indicate organic-rich and reducing conditions that are conducive to the MSR process. DOC in surface water from the project area rivers and streams range from 0.15 to 9.38 mg/L with median concentrations between 1.02 and 1.39 mg/L (see Table K3.18-7 through Table K3.18-9). Similar to sediment TOC, surface water DOC varies widely owing to the extent of the watershed, and indicates wide-ranging conditions in the rivers and streams, which may have varying influence on mobility and generation of methylmercury.

Other factors that may limit the impact of sulfate loading in stimulating methylmercury production include the temperature of the aquatic systems in the project area and presence of selenium and iron in sediments, as described below.

Mercury methylation in aquatic systems typically peaks during summer months, primarily reflecting temperature dependence of microbial activity, with optimal temperature range for growth of typically 27 to 30 degrees Celsius (ºC) (Sawicka et al. 2012). This means mercury methylation is inhibited compared to peak methylation, but not precluded at lower temperatures. The median temperature in the project area rivers and streams range from 1.27 to 2.96ºC, with a slightly warmer median of 9.62ºC in lakes; in the summer, maximum temperatures of 13.8 to 23.4ºC have been recorded in these rivers and lakes (see Table K3.18-7 through Table K3.18-10). Therefore, methylmercury production due to increased sulfate loading may be subdued compared to studies performed in warmer regions.

Presence of selenium is known to inhibit mercury methylation, primarily through limiting mercury bioavailability by forming insoluble mercury selenide species (Truong et al. 2013). Selenium was detected at higher frequency and concentrations than mercury in the project area sediments: selenium was detected in 68 percent of the samples (134 of 197 samples) at 0.018 to 13.1 mg/kg, whereas mercury was detected in 57 percent of the samples (113 of 197 samples) at 0.011 to 0.42 mg/kg (see Table K.18-19). Therefore, presence of selenium may inhibit mercury methylation stimulated by increased sulfate loading.

Iron can interact with sulfur species and may decrease methylmercury production in anaerobic environments of the project area waterbodies. This decrease may occur by shifting microbial assemblage from SRBs to iron-reducing microbes with less mercury methylation capacity (Lovley and Phillips 1986) and by altering mercury bioavailability via interaction with sulfur species (Mehrotra and Sedlak 2005). Ubiquity of iron in the environment is reflected in 100 percent detection in sediment samples from the project area waterbodies, with concentrations ranging from 2,670 to 83,400 mg/kg (see Table K3.18-19). Although these detections do not necessarily reflect its bioavailability and abundance in the sediment porewater, the impact that iron may have on limiting methylmercury production cannot be ruled out for project area waterbodies.

Above considerations indicate that the conditions in project area waterbodies vary widely. Although the conditions in the majority of areas do not appear to be conducive to the MSR process, conditions in significant portions of the areas do. In these areas that are conducive to the MSR process, increased sulfate loading would increase methylmercury production if those areas are sulfate deficient. Qualitative assessment of available data indicates widely varying sulfate concentrations in project area waterbodies. Sulfate was present in 97 percent of the sediment samples (174 of 197 samples), with concentrations ranging from 0.5 to 2,600 mg/kg; mean and median sulfate concentrations were 51.8 and 9.16 mg/kg, respectively (see Table K3.18-19). Similarly, sulfate was detected in almost all surface water samples, with 100 percent detection frequency; sulfate concentrations ranged 0.36 to 11.2 mg/L in the lakes, and 0.53 to 41.6 mg/L in the rivers (see Table K.18-7 through Table K3.18-10). Given the wide variability in sulfate concentrations in sediment and surface water, sulfate may be deficient, or the rate-limiting factor for MSR in some areas, but not in other areas. The project-related increase in sulfate loading is predicted to be 9.0 to 622 percent, depending on the streams and 119 percent overall (see Table K4.18-21). These increases occur through release of treated water during project operations and closure. The predicted concentrations in treated water are 125.5 mg/L at WTP #1 and 71.7 mg/L at WTP #2 during project operations (see Table K4.18-13), and ranges from 13 to 173 mg/L during closure (see Table K4.18-14 and Table K4.18-15). These concentrations are lower than the most stringent surface water quality criteria for the project of 250 mg/L (see Table K3.18-1) and are expected to be 5 to 10 times lower at discharge points due to stream dilutions (see Appendix K4.18, Water and Sediment Quality). Therefore, project-related sulfate loading may stimulate and/or enhance methylmercury production in sulfate-deficient areas, particularly in immediate downstream areas of the discharge points prior to flow-related dilutions occurring.

Concentrations of total mercury in effluent discharges are expected to be 1.6*10^-5 µg/L or lower during mine operation (see Table K4.18-13),which is orders of magnitude below the ADEC water quality criterion of 0.012 µg/L). Dilution in the receiving waterbodies would further reduce mercury concentrations downstream of discharge points. At these low concentrations and anticipated geochemical interactions with various sorptive phases, project-related mercury loading is not expected to contribute significantly to the sulfate-induced net methylmercury production.

Finally, abundance of wetlands connected to an aquatic system is known to be one of the most important factors in determining methylmercury concentrations in surface waterbodies (Nagorski et al. 2014; USGS 2019). Detailed discussions of wetlands in the project area are provided in Section 3.22 and Section 4.22, Wetlands and Other Waters/Special Aquatic Sites. Although these specific wetlands were not targeted for sampling, these areas are represented by the data discussed in the above paragraphs, which include various types of waterbodies with shallow areas of vegetation. Potential impacts would be expected to be restricted to wetlands with a hydrologic connection to the NFK, SFK, or UTC tributaries. Geographic information system (GIS) proximity analysis indicates 37 miles of streams contiguous with wetlands would potentially be affected by change in waterflow and WTP effluent along the NFK, SFK, and reach F of the UTC. As indicated previously, sulfate loading in these wetlands would be least diluted in the upper reaches immediately downstream of the discharge locations. Based on average annual streamflow, the discharge volume would be diluted approximately six times as it enters the NFK at the discharge point, and nine times by stream Reach NFK-A.

Conditions in the project area watershed vary widely, with some areas more conducive to methylmercury production than others. Observations of mercury in baseline fish tissue samples demonstrate that methylmercury is being produced, and is available in the project area watershed. In those areas, including sediments and wetlands, that are conducive to the MSR process and are also deficient in sulfate, project-related sulfate loading would stimulate and/or enhance methylmercury production. The degree to which this stimulation or enhancement occurs is likely to be lower than that observed in warmer areas. Nonetheless, overall impacts of project-related sulfate loading on mercury methylation and subsequent methylmercury-related concerns cannot be ruled out.

K4.24.5 Other Major Ions

Prediction of project-related mass loading indicates total environmental load would increase for major ions, including calcium, chloride, fluoride, magnesium, sodium, sulfate, and nitrate/nitrite (see Table 4.18-21). However, concentrations of these constituents, individually or as total dissolved solids, in treated water would meet the most stringent surface water quality criteria for the project (see Table K3.18-1). Treated water in various WTPs during operation and closure phases are predicted to have concentrations below the stringent water quality criteria, as shown in Table K4.18-13 through Table K4.18-16. Therefore, release of these ions is not likely to have adverse impacts on the environment via direct toxicity or indirectly through alteration of aquatic chemistry.

K4.24.6 Development and Application of the Instream Flow Fish Habitat Modeling

The following section describes criteria applied to define baseline conditions and evaluate the potential effects from flow alterations on fish and fish habitat.

K4.24.6.1 Instream Flow Methodology

The standard approach to instream flow analysis since 1980 has been the Instream Flow Incremental Methodology (IFIM). The IFIM is a structured habitat evaluation process initially developed by the Instream Flow Group of the US Fish and Wildlife Service (USFWS) in the late 1970s to allow evaluation of alternative flow regimes for water development projects (Bovee and Milhous 1978; Bovee et al. 1998). IFIM and PHABSIM are often used interchangeably, but while IFIM is a general problem solving approach, PHABSIM is a specific one-dimensional (1D) hydraulic model designed to calculate an index of microhabitat availability over a range of stream flows.

The model has been primarily criticized because habitat variables are limited to depth, velocity, and a “channel index” (substrate and/or cover component), as defined by the Habitat Suitability Criteria (HSC). A common complaint is the parsimonious nature of PHABSIM and associated HSC; namely, that it does not account for other factors that can affect fish populations. Water temperature, photoperiod, invertebrate drift, presence of predators, and density of competitors are some other variables known to influence position choice of salmonids (Hughes and Dill 1990; Riehle and Griffith 1993; Nislow et al. 1998; Allen 2000); however, because most of these variables are not directly influenced by streamflow, as is depth and velocity, a much more complex physical and biological model would be required to account for these factors. Although such models are becoming more frequent in use; in many cases, they remain experimental, with limited validation. Stalnaker et al. (1995) noted that “in nearly all of the studies conducted on habitat partitioning among stream-dwelling animals, these variables (depth, velocity, and channel index) were consistently found to be important determinants of species distribution and abundance.”

IFIM and PHABSIM are the most widely used tools for instream flow assessment in North America and are commonly used by resource agencies for evaluating water management alternatives, making water allocation decisions, and setting flow recommendations (IFC 2009).

The project applied the USFWS IFIM and its associated Physical Habitat Simulation Model (PHABSIM) to assess habitat and flow data, quantify fish habitat, and develop instream flow recommendations to mitigate the potential impacts from project development on aquatic resources. The instream flow modeling was conducted within the broad framework of the IFM, with several primary components, including habitat mapping, hydraulic modeling, biological modeling, and time-series analysis. The PHABSIM hydraulic model was applied to describe the relationship between streamflow and a suite of habitat parameters (e.g., depths, velocities, substrate), which is then used to estimate the suitability of habitat via a biological model (HSC). HSC describes the relative suitability of depth, velocity, and substrate for each target species and life-stage. The habitat mapping component used a combination of instream and aerial mapping that quantified the amount of physical habitat according to mesohabitat type, which was expanded to represent unsampled habitat area through the HABSYN program.

The HABSYN analysis is fully described in PLP 2018-RFI 048, which is included as an attachment to this appendix. PLP 2019-RFI 147, which provides a summary of current use of PHABSIM and associated modeling components for assessing instream flow in the US, including a description of how it was applied to the project for assessing potential changes to habitats, is also included as an attachment to this appendix.

K4.24.6.2 Derivation of Daily Flows

Daily streamflows for use in the aquatic habitat evaluation were computed based on 10 years of measured streamflow in the vicinity of the mine. The measured streamflows between January 1, 2005 and December 31, 2014 were used to represent the pre-mine streamflow conditions. The End of Mine (EOM) without treated water streamflows were estimated based on the 10 years of streamflow measurements, and a ratio of the monthly streamflow at EOM without treated water and monthly streamflow during pre-mine conditions. The EOM with treated water streamflows were estimated based on the 10 years of streamflow measurements, and a ratio of the monthly streamflow at EOM with treated water and monthly streamflow during pre-mine conditions. A daily streamflow was computed for each day of the 10-year measured streamflow record based on the EOM condition (PLP 2020 RFI-161). The following formulas were used to compute the EOM streamflows.

Daily streamflow at EOM without treated water:

$$Q_{D,E}, = Q_{D,PM} * (Q_{ME}/Q_{MPM})$$

Where:

$Q_{D,E}$ = Daily streamflow at EOM without treated water

$Q_{D,PM}$ = Daily streamflow during pre-mine condition

$Q_{M,E}$ = Monthly streamflow at EOM without treated water

$Q_{M,PM}$ = Monthly streamflow during pre-mine condition

Daily streamflow at EOM with treated water:

$$Q_{D,E,T} = Q_{D,E} + (Q_{M,E,T} - Q_{M,E})$$

Where:

$Q_{D,E,T}$ = Daily streamflow at EOM with treated water

$Q_{D,E}$ = Daily streamflow at EOM without treated water

$Q_{M,E,T}$ = Monthly streamflow at EOM with treated water

$Q_{M,E}$ = Monthly streamflow at EOM without treated water

A similar method was used to compute post-closure streamflows with and without treated water.

Wet, average, and dry years were considered for aquatic habitat evaluation; wet, average, and dry years were determined for each target species and life-stage based on the corresponding periodicity. For example, Chinook salmon spawn in July and August. The average flow during the July-August period was determined for each year from 2005 through 2014. The wettest and driest year in the 10-year record were used to represent wet-year and dry-year conditions, while the year best resembling the average condition during the 10-year record was used to represent the average-year condition (PLP 2020 RFI-161). Similarly, Coho salmon juvenile outmigration occurs in April through June; therefore, wet, average, and dry conditions were determined for the April-through-June period. A similar procedure was followed for the other target species and life-stages based on the corresponding months of the year for each periodicity (R2 2020).

The measured streamflow record (January 1, 2005 through December 31, 2014) was used to select the wet, average, and dry years associated with each target species and life-stages at the same four locations used for the monthly analysis (i.e., Stream Gage NK100A, Stream Gage SK100B, Stream Gage UT100B,and IFIM Transect 04MSK-RF2) (R2 2020).

K4.24.6.3 Instream Flow Modeling Results

The following figures and tables provide results of the instream flow modeling for various life stages of Pacific salmon and resident salmonids during pre-mine, operations, and closure phases under wet, average, and dry water years.

The instream flow modeling produced estimates of the area (in acres) of suitable habitat for each species and life stage by mainstem stream reach of the Koktuli River (KR), NFK, SFK, and UTC, as well as for one principal tributary to each of the three subbasins. The estimated amounts of suitable habitat, as well as the percent change from pre-project to either mine operations or mine closure, are listed in Table K4.24-1 for spawning by anadromous and resident salmonids; in Table K4.24-2 for juvenile rearing by anadromous and resident salmonids; and in Table K4.24-3 for adult rearing by resident salmonids. These tables show the magnitude of both increases and decreases in suitable habitat under each project phase and water year scenario. Table K4.24-1, Table K4.24-2, and Table K4.24-3 show decreases in suitable habitat that exceed 2 percent in red bold font; all other changes are either less than 2 percent or represent predicted increases in suitable habitat. It can be seen that most of the decreases exceeding 2 percent would be expected to occur in Tributaries NFK 1.190 and SFK 1.190. Also note that with few exceptions, suitable habitat in UTC would not be expected to change more than 2 percent. Section 4.24, Fish Values, summarizes the overall results presented in Table K4.24-1, Table K4.24-2, and Table K4.24-3, and the example figures shown below.

Figure K4.24-1 illustrates the frequency distribution of percentage changes in suitable spawning habitat for all Pacific salmon combined under an average water year. This figure illustrates that most predicted changes in the amount of suitable habitat would be expected to be less than

2 percent from pre-mine conditions, and that most changes would be expected to be positive (i.e., suitable habitat would increase during operations and closure). Similar results are seen for juvenile rearing of Pacific salmon and for spawning, juvenile rearing, and adult rearing by resident salmonid species (Table K4.24-2 and Table K4.24-3). All three tables contain equivalent estimates for the remaining water years (dry and wet), and for the remaining species and life stages that were modeled.

Figure K4.24-2 uses data in Table K4.24-1 to illustrate the relationship between stream reach and changes in suitable spawning habitat for Chinook salmon under different project scenarios and during an average water year. Note that suitable habitat increases in the downstream direction, and those reaches showing larger changes in habitat (e.g., tributaries, NFK-D, SFK-C) also show that relatively little suitable habitat exists even under pre-mine conditions. Similar results are seen under wet- and dry-year scenarios for juvenile rearing of salmon species, and for spawning, juvenile rearing, and adult rearing by resident salmonid species (Table K4.24-2 and Table K4.24-3).

To better visualize the relationship between stream reach and predicted changes in suitable habitat for each species and life stage, the estimated changes in suitable habitat by stream reach during an average water year scenario are depicted in maps using a color-coding system (see Table K4.24-1, Table K4.24-2, and Table K4.24-3 for values representing wet and dry year scenarios). Figure K4.24-3 through Figure K4.24-17 illustrate that large, predicted decreases in the amount of suitable habitat would be largely restricted to the tributaries NFK 1.190 and SFK 1.190, and that changes in lower reaches would be minor (yellow lines) or are positive (blue and green lines) in value. Note that the UTC is not portrayed in these figures because only three of the 84 UTC estimates for spawning showed decreases exceeding 2 percent, and none of the UTC estimates for juvenile or adult rearing showed decreases exceeding that value (Table K4.24-1, Table K4.24-2, and Table K4.24-3). Also note that predicted changes in NFK-D would only extend up to the project discharge at tributary NFK 1.200; the remainder of mainstem reach NFK-D would not be subject to changes in streamflow or flow-related changes in suitable habitat. Reaches upstream of NFK-D and SFK-C and other tributaries to the NFK and SFK were not modeled and are therefore not shown in these figures.

Figure K4.24-1: Frequency of Percentage Change in Suitable Spawning Habitat from Pre-Mine to Operations or Closure during an Average Water Year for Pacific Salmon

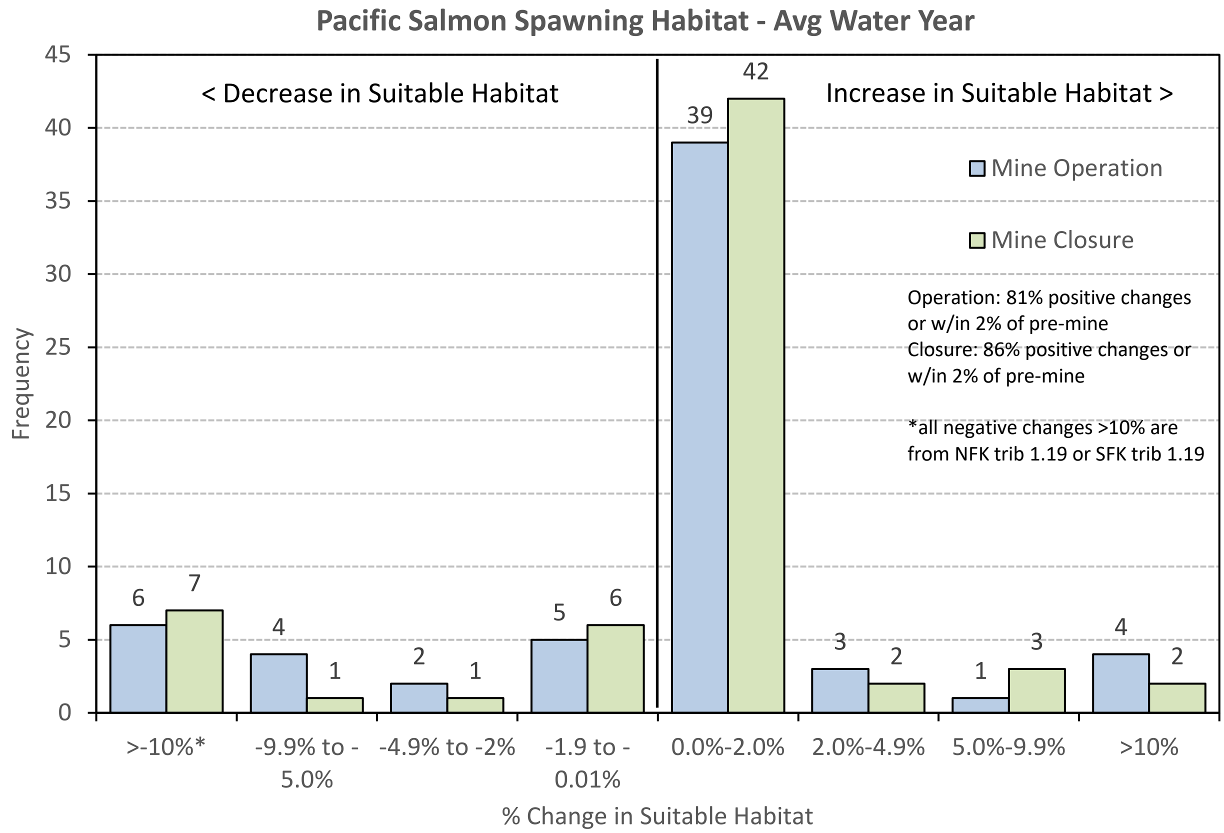


Figure K4.24-2: Predicted Changes in Suitable Habitat for Chinook Salmon Spawning during an Average Water Year According to Reach and Mine Operational Period

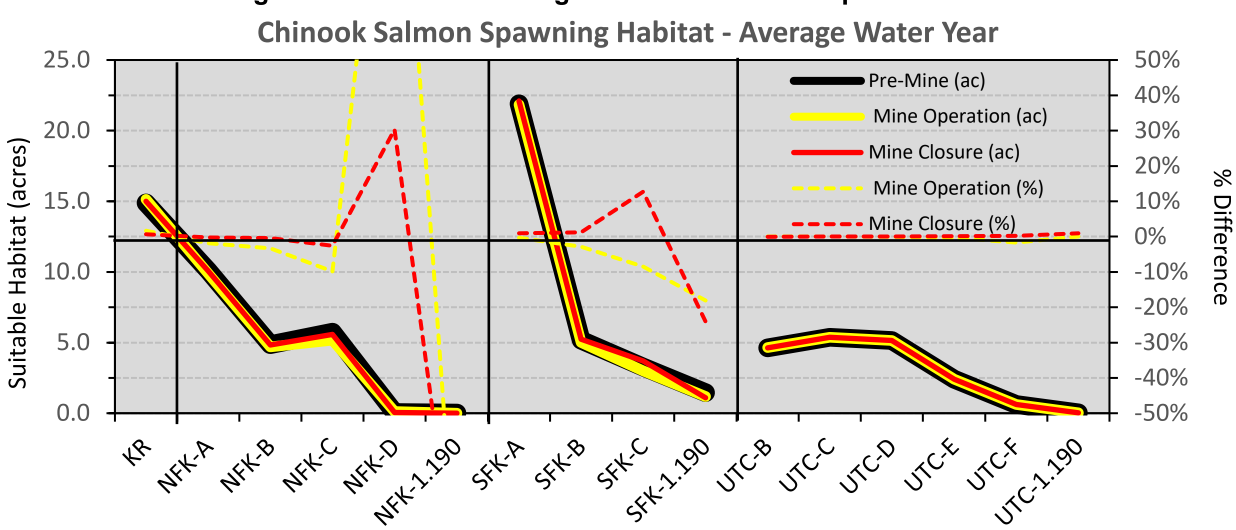


Table K4.24-1: Predicted Quantity (acres) of Suitable Spawning Habitat by Species, Reach, Water Year, and Mine Phase

Basin-Reach	Spawning—Wet Year					Spawning—Average Year					Spawning—Dry Year				
	Pre-Mine	Mine Operations	Mine Closure	Mine Operations	Mine Closure	Pre-Mine	Mine Operations	Mine Closure	Mine Operations	Mine Closure	Pre-Mine	Mine Operations	Mine Closure	Mine Operations	Mine Closure
	(acres)	(acres)	(acres)	(% diff)	(% diff)	(acres)	(acres)	(acres)	(% diff)	(% diff)	(acres)	(acres)	(acres)	(% diff)	(% diff)
Chinook Salmon															
KR	13.80	13.98	13.87	1.3%	0.5%	14.89	15.15	14.99	1.7%	0.7%	11.96	11.72	11.92	**-2.0%**	-0.4%
NFK-A	11.42	11.29	11.49	-1.1%	0.6%	10.08	9.89	10.05	-1.8%	-0.2%	6.57	6.47	6.45	-1.5%	-1.9%
NFK-B	5.74	5.67	5.81	-1.1%	1.3%	4.85	4.69	4.83	**-3.3%**	-0.5%	1.96	1.81	1.85	**-7.8%**	**-5.4%**
NFK-C	7.54	6.96	7.59	**-7.6%**	0.7%	5.73	5.17	5.58	**-9.9%**	**-2.6%**	2.57	2.34	2.33	**-9.0%**	**-9.3%**
NFK-D	0.08	0.17	0.09	112.4%	15.1%	0.05	0.12	0.06	143.5%	30.3%	0.02	0.07	0.03	274.6%	50.7%
NFK-1.190	0.02	0.00	0.00	**-100.0%**	**-100.0%**	0.01	0.00	0.00	**-100.0%**	**-100.0%**	0.00	0.00	0.00	**-100.0%**	**-100.0%**
SFK-A	19.65	19.82	20.05	0.9%	2.0%	21.90	21.84	22.10	-0.3%	0.9%	9.61	9.41	9.89	**-2.1%**	2.9%
SFK-B	4.93	4.97	5.05	0.9%	2.4%	5.17	5.02	5.23	**-2.9%**	1.2%	0.70	0.72	0.75	1.8%	6.6%
SFK-C	3.37	3.35	3.47	-0.8%	3.0%	3.28	3.00	3.69	**-8.5%**	12.7%	0.13	0.06	0.27	**-51.2%**	113.5%
SFK-1.190	2.02	1.84	1.76	**-8.5%**	**-12.7%**	1.45	1.19	1.10	**-18.1%**	**-24.1%**	0.13	0.07	0.07	**-42.5%**	**-47.5%**
UTC-B	3.78	3.78	3.78	0.0%	0.0%	4.64	4.64	4.63	0.1%	-0.1%	6.38	6.40	6.38	0.2%	-0.1%
UTC-C	4.85	4.85	4.85	0.1%	0.0%	5.38	5.38	5.38	0.1%	0.1%	4.51	4.50	4.52	-0.3%	0.2%
UTC-D	5.48	5.48	5.48	0.1%	0.0%	5.15	5.15	5.15	-0.1%	0.1%	3.30	3.28	3.31	-0.6%	0.1%
UTC-E	3.71	3.71	3.72	0.0%	0.1%	2.41	2.40	2.41	-0.3%	0.1%	1.19	1.18	1.19	-1.3%	0.1%
UTC-F	1.01	1.01	1.01	-0.2%	0.3%	0.63	0.62	0.63	-1.7%	0.2%	0.35	0.30	0.34	**-15.3%**	**-3.8%**
UTC-1.190	0.04	0.04	0.04	0.0%	0.8%	0.04	0.04	0.04	0.0%	1.0%	0.02	0.02	0.02	0.5%	4.4%
Coho Salmon															
KR	31.27	31.59	31.33	1.0%	0.2%	35.32	35.58	35.42	0.7%	0.3%	39.91	40.19	39.97	0.7%	0.2%
NFK-A	14.17	14.06	14.10	-0.8%	-0.5%	12.87	12.73	12.74	-1.1%	-1.0%	11.26	11.22	11.14	-0.3%	-1.0%
NFK-B	6.17	6.31	6.21	2.1%	0.6%	5.95	6.04	5.96	1.5%	0.1%	5.80	5.90	5.74	1.7%	-1.1%
NFK-C	12.04	12.25	12.05	1.7%	0.1%	11.75	11.78	11.61	0.3%	-1.2%	10.66	10.51	10.32	-1.4%	**-3.2%**
NFK-D	1.07	1.28	1.09	20.3%	1.7%	0.95	1.20	0.98	26.3%	3.3%	0.75	1.04	0.78	39.1%	4.7%
NFK-1.190	0.02	0.00	0.00	**-98.6%**	**-98.6%**	0.01	0.00	0.00	**-98.8%**	**-98.8%**	0.01	0.00	0.00	**-98.5%**	**-98.5%**
SFK-A	20.17	20.20	20.20	0.2%	0.2%	17.23	17.22	17.43	-0.1%	1.1%	17.13	16.96	17.40	-1.0%	1.6%
SFK-B	4.67	4.70	4.73	0.7%	1.4%	3.58	3.61	3.65	0.7%	1.8%	2.89	2.82	3.00	**-2.4%**	3.9%
SFK-C	6.62	6.68	6.72	1.0%	1.5%	4.87	4.94	5.30	1.5%	9.0%	4.46	4.43	5.27	-0.7%	18.2%
SFK-1.190	3.53	3.14	3.04	**-11.0%**	**-14.0%**	2.33	2.02	1.98	**-13.5%**	**-15.2%**	1.57	1.29	1.24	**-17.6%**	**-20.8%**
UTC-B	3.07	3.07	3.07	0.0%	0.0%	3.32	3.32	3.32	0.0%	-0.1%	3.48	3.49	3.48	0.1%	0.0%
UTC-C	5.97	5.97	5.97	0.0%	0.0%	5.92	5.92	5.92	0.0%	0.0%	6.00	6.00	6.00	0.0%	0.0%
UTC-D	8.51	8.52	8.51	0.1%	0.0%	9.71	9.72	9.72	0.1%	0.1%	10.85	10.86	10.86	0.1%	0.0%
UTC-E	9.89	9.91	9.90	0.2%	0.1%	10.27	10.29	10.29	0.2%	0.1%	8.85	8.84	8.85	-0.1%	0.0%

Table K4.24-1: Predicted Quantity (acres) of Suitable Spawning Habitat by Species, Reach, Water Year, and Mine Phase

Basin-Reach	Spawning—Wet Year					Spawning—Average Year					Spawning—Dry Year				
	Pre-Mine	Mine Operations	Mine Closure	Mine Operations	Mine Closure	Pre-Mine	Mine Operations	Mine Closure	Mine Operations	Mine Closure	Pre-Mine	Mine Operations	Mine Closure	Mine Operations	Mine Closure
	(acres)	(acres)	(acres)	(% diff)	(% diff)	(acres)	(acres)	(acres)	(% diff)	(% diff)	(acres)	(acres)	(acres)	(% diff)	(% diff)
UTC-F	4.51	4.54	4.50	0.7%	-0.2%	4.36	4.39	4.37	0.7%	0.3%	3.79	3.76	3.79	-0.8%	0.0%
UTC-1.190	0.32	0.32	0.32	0.0%	0.2%	0.32	0.32	0.32	0.0%	0.2%	0.31	0.31	0.31	0.0%	0.3%
Sockeye Salmon															
KR	32.21	32.63	32.27	1.3%	0.2%	34.41	34.90	34.46	1.4%	0.1%	42.16	42.51	42.20	0.8%	0.1%
NFK-A	13.05	13.15	13.07	0.7%	0.2%	13.51	13.61	13.55	0.7%	0.3%	12.28	12.19	12.24	-0.7%	-0.3%
NFK-B	5.54	5.78	5.61	4.3%	1.2%	5.94	6.22	6.04	4.6%	1.6%	6.90	6.98	6.93	1.2%	0.4%
NFK-C	11.70	12.30	11.89	5.1%	1.6%	12.53	13.20	12.77	5.3%	1.9%	12.98	13.09	13.00	0.8%	0.1%
NFK-D	1.55	1.73	1.61	11.8%	4.1%	1.27	1.73	1.34	36.3%	6.1%	1.21	1.70	1.29	40.6%	7.2%
NFK-1.190	0.02	0.00	0.00	**-98.8%**	**-98.8%**	0.02	0.00	0.00	**-99.0%**	**-99.0%**	0.01	0.00	0.00	**-98.9%**	**-98.9%**
SFK-A	28.18	28.29	28.15	0.4%	-0.1%	28.98	29.04	29.05	0.2%	0.2%	30.84	30.86	30.97	0.1%	0.4%
SFK-B	8.45	8.39	8.44	-0.7%	0.0%	8.74	8.79	8.80	0.6%	0.6%	8.02	7.76	8.28	**-3.2%**	3.3%
SFK-C	9.45	9.61	9.33	1.7%	-1.2%	9.94	9.93	10.09	-0.1%	1.5%	9.22	8.76	9.95	**-5.0%**	7.9%
SFK-1.190	5.23	4.87	4.76	**-6.8%**	**-9.1%**	5.53	5.06	4.87	**-8.6%**	**-11.9%**	4.15	3.38	3.23	**-18.4%**	**-22.1%**
UTC-B	6.64	6.64	6.64	0.0%	0.0%	7.50	7.51	7.50	0.0%	0.0%	8.05	8.05	8.04	0.0%	0.0%
UTC-C	7.05	7.05	7.05	0.0%	0.0%	7.37	7.37	7.37	0.0%	0.0%	7.45	7.45	7.45	0.0%	0.0%
UTC-D	11.79	11.79	11.79	0.0%	0.0%	13.60	13.60	13.59	0.0%	0.0%	13.64	13.64	13.64	0.0%	0.0%
UTC-E	10.31	10.31	10.31	0.0%	0.0%	10.85	10.86	10.86	0.1%	0.0%	10.04	10.03	10.05	-0.1%	0.1%
UTC-F	5.21	5.17	5.21	-0.6%	0.0%	4.94	4.94	4.94	0.1%	0.1%	4.11	4.06	4.13	-1.3%	0.3%
UTC-1.190	0.97	0.97	0.97	0.1%	-0.2%	1.04	1.04	1.04	0.0%	-0.3%	1.01	1.01	1.00	0.0%	-0.2%
Chum Salmon															
KR	29.00	29.27	28.88	0.9%	-0.4%	32.22	32.67	32.27	1.4%	0.2%	38.23	38.07	38.17	-0.4%	-0.2%
NFK-A	23.96	24.31	24.06	1.5%	0.4%	24.28	24.46	24.35	0.7%	0.3%	22.82	22.78	22.75	-0.2%	-0.3%
NFK-B	11.68	12.22	11.76	4.7%	0.7%	12.43	12.90	12.58	3.7%	1.2%	12.50	12.37	12.39	-1.1%	-0.9%
NFK-C	18.52	19.55	18.75	5.6%	1.3%	19.32	20.00	19.59	3.5%	1.4%	19.27	19.25	18.99	-0.1%	-1.4%
NFK-D	2.70	3.18	2.85	17.9%	5.5%	2.33	3.00	2.49	28.8%	7.1%	1.76	2.72	2.02	54.2%	14.5%
NFK-1.190	0.07	0.00	0.00	**-95.9%**	**-95.9%**	0.06	0.00	0.00	**-96.0%**	**-96.0%**	0.04	0.00	0.00	**-96.2%**	**-96.2%**
SFK-A	36.51	36.71	36.63	0.5%	0.3%	39.68	39.84	39.73	0.4%	0.1%	38.76	38.53	39.15	-0.6%	1.0%
SFK-B	8.02	8.21	8.20	2.4%	2.2%	10.46	10.60	10.53	1.3%	0.7%	6.35	6.39	6.48	0.6%	2.2%
SFK-C	7.68	7.92	7.79	3.2%	1.4%	9.78	9.86	9.86	0.8%	0.8%	2.42	2.02	3.98	**-16.5%**	64.1%
SFK-1.190	5.41	5.45	5.40	0.6%	-0.2%	5.63	5.30	5.17	**-5.9%**	**-8.2%**	3.09	2.56	2.47	**-17.2%**	**-20.2%**
UTC-B	7.80	7.80	7.79	0.1%	0.0%	9.12	9.12	9.11	0.1%	-0.1%	11.31	11.33	11.30	0.2%	-0.1%
UTC-C	9.61	9.61	9.61	0.0%	0.0%	11.08	11.09	11.08	0.1%	-0.1%	13.30	13.31	13.30	0.1%	0.0%

Table K4.24-1: Predicted Quantity (acres) of Suitable Spawning Habitat by Species, Reach, Water Year, and Mine Phase

Basin-Reach	Spawning—Wet Year					Spawning—Average Year					Spawning—Dry Year				
	Pre-Mine	Mine Operations	Mine Closure	Mine Operations	Mine Closure	Pre-Mine	Mine Operations	Mine Closure	Mine Operations	Mine Closure	Pre-Mine	Mine Operations	Mine Closure	Mine Operations	Mine Closure
	(acres)	(acres)	(acres)	(% diff)	(% diff)	(acres)	(acres)	(acres)	(% diff)	(% diff)	(acres)	(acres)	(acres)	(% diff)	(% diff)
UTC-D	11.80	11.81	11.80	0.1%	0.0%	15.61	15.63	15.61	0.1%	0.0%	16.67	16.66	16.68	-0.1%	0.0%
UTC-E	11.76	11.77	11.76	0.1%	0.0%	12.36	12.37	12.37	0.1%	0.1%	10.81	10.77	10.82	-0.3%	0.1%
UTC-F	5.22	5.23	5.22	0.2%	0.0%	5.04	5.04	5.05	-0.1%	0.2%	4.56	4.43	4.54	**-2.8%**	-0.4%
UTC-1.190	0.53	0.53	0.53	0.0%	-0.7%	0.55	0.55	0.54	0.0%	-0.8%	0.61	0.61	0.61	0.0%	0.1%
Rainbow Trout															
KR	19.91	19.82	19.80	-0.4%	-0.5%	25.61	25.97	25.75	1.4%	0.6%	26.67	27.19	26.65	1.9%	-0.1%
NFK-A	15.00	16.50	15.18	10.0%	1.2%	18.21	19.19	18.38	5.4%	0.9%	22.49	22.87	22.48	1.7%	-0.1%
NFK-B	5.04	5.42	5.09	7.6%	1.0%	5.77	6.27	5.88	8.6%	1.8%	7.27	7.60	7.29	4.7%	0.3%
NFK-C	9.98	11.72	10.28	17.4%	3.0%	11.37	12.67	11.59	11.5%	2.0%	14.00	14.54	14.01	3.9%	0.1%
NFK-D	1.99	1.97	1.99	-1.0%	0.0%	1.82	2.13	1.82	17.3%	0.0%	1.78	2.35	1.78	32.2%	-0.1%
NFK-1.190	0.05	0.00	0.00	**-97.5%**	**-97.5%**	0.04	0.00	0.00	**-97.7%**	**-97.7%**	0.04	0.00	0.00	**-99.1%**	**-99.1%**
SFK-A	21.69	21.84	21.99	0.7%	1.3%	24.45	24.57	24.56	0.5%	0.4%	28.95	29.06	28.93	0.4%	-0.1%
SFK-B	4.24	4.36	4.36	2.9%	2.9%	6.17	6.30	6.34	2.1%	2.7%	8.47	8.36	8.60	-1.2%	1.6%
SFK-C	2.98	3.13	3.22	5.1%	8.2%	4.12	4.32	4.31	4.8%	4.6%	5.77	5.78	5.48	0.2%	**-5.0%**
SFK-1.190	3.04	3.11	3.14	2.6%	3.3%	3.59	3.66	3.66	1.8%	2.0%	4.68	4.39	4.30	**-6.1%**	**-8.1%**
UTC-B	5.16	5.17	5.16	0.1%	0.0%	7.03	7.03	7.03	0.0%	0.0%	8.43	8.44	8.43	0.0%	0.0%
UTC-C	4.26	4.27	4.26	0.0%	0.0%	5.06	5.06	5.06	0.0%	0.0%	5.65	5.65	5.65	0.0%	0.0%
UTC-D	5.21	5.21	5.21	0.2%	0.1%	9.15	9.16	9.15	0.1%	0.0%	12.18	12.19	12.19	0.1%	0.1%
UTC-E	5.19	5.20	5.20	0.2%	0.1%	8.14	8.15	8.14	0.1%	0.0%	10.54	10.55	10.55	0.1%	0.1%
UTC-F	5.07	5.10	5.08	0.5%	0.2%	5.01	5.06	5.01	0.9%	0.0%	5.53	5.50	5.51	-0.5%	-0.4%
UTC-1.190	0.95	0.95	0.94	0.0%	-0.6%	0.82	0.82	0.81	0.0%	-0.5%	1.03	1.03	1.03	0.0%	0.1%
Dolly Varden															
KR	36.98	37.34	36.96	1.0%	-0.1%	40.48	41.07	40.50	1.5%	0.1%	57.08	57.77	57.21	1.2%	0.2%
NFK-A	28.31	28.72	28.38	1.4%	0.3%	30.95	31.01	30.88	0.2%	-0.2%	28.29	28.10	28.10	-0.7%	-0.7%
NFK-B	10.28	10.64	10.38	3.5%	0.9%	11.93	12.33	12.07	3.3%	1.1%	12.60	12.71	12.57	0.9%	-0.2%
NFK-C	19.58	20.76	19.87	6.0%	1.5%	22.64	23.24	22.77	2.7%	0.5%	22.26	22.25	22.10	-0.1%	-0.7%
NFK-D	3.13	3.17	3.13	1.2%	0.0%	3.11	3.41	3.11	9.8%	0.0%	2.79	3.36	2.79	20.2%	0.0%
NFK-1.190	0.05	0.00	0.00	**-97.4%**	**-97.4%**	0.04	0.00	0.00	**-97.8%**	**-97.8%**	0.03	0.00	0.00	**-98.2%**	**-98.2%**
SFK-A	39.45	39.62	39.38	0.4%	-0.2%	42.70	42.89	42.67	0.4%	-0.1%	43.57	43.45	44.04	-0.3%	1.1%
SFK-B	9.14	9.29	9.14	1.6%	-0.1%	11.21	11.38	11.17	1.6%	-0.3%	9.35	9.26	9.66	-1.0%	3.3%
SFK-C	8.82	9.12	8.48	3.4%	**-3.9%**	11.07	11.36	10.73	2.6%	**-3.1%**	8.78	8.67	10.21	-1.3%	16.3%
SFK-1.190	6.37	6.45	6.46	1.3%	1.4%	7.21	7.16	7.10	-0.8%	-1.6%	5.76	5.23	5.17	**-9.2%**	**-10.3%**

Table K4.24-1: Predicted Quantity (acres) of Suitable Spawning Habitat by Species, Reach, Water Year, and Mine Phase

Basin-Reach	Spawning—Wet Year					Spawning—Average Year					Spawning—Dry Year				
	Pre-Mine	Mine Operations	Mine Closure	Mine Operations	Mine Closure	Pre-Mine	Mine Operations	Mine Closure	Mine Operations	Mine Closure	Pre-Mine	Mine Operations	Mine Closure	Mine Operations	Mine Closure
	(acres)	(acres)	(acres)	(% diff)	(% diff)	(acres)	(acres)	(acres)	(% diff)	(% diff)	(acres)	(acres)	(acres)	(% diff)	(% diff)
UTC-B	8.39	8.39	8.39	0.0%	0.0%	9.02	9.02	9.02	0.0%	0.0%	10.44	10.44	10.44	0.0%	0.0%
UTC-C	8.23	8.23	8.23	0.0%	0.0%	8.70	8.70	8.70	0.0%	0.0%	9.34	9.35	9.34	0.0%	0.0%
UTC-D	12.87	12.87	12.87	0.0%	0.0%	13.82	13.83	13.83	0.1%	0.1%	18.16	18.18	18.17	0.1%	0.0%
UTC-E	13.02	13.03	13.02	0.0%	0.0%	13.59	13.61	13.60	0.1%	0.1%	14.97	14.98	14.98	0.0%	0.0%
UTC-F	7.97	7.98	7.99	0.1%	0.2%	7.19	7.26	7.25	0.9%	0.8%	7.11	7.04	7.14	-1.0%	0.3%
UTC-1.190	1.21	1.21	1.21	0.0%	-0.2%	1.24	1.24	1.23	0.0%	-0.1%	1.24	1.24	1.24	0.0%	-0.1%
Arctic Grayling															
KR	46.68	47.23	47.00	1.2%	0.7%	52.53	53.76	53.15	2.3%	1.2%	63.33	64.48	63.75	1.8%	0.7%
NFK-A	18.25	18.82	18.41	3.1%	0.9%	12.71	13.97	13.13	9.8%	3.3%	17.13	17.57	17.25	2.6%	0.7%
NFK-B	6.23	6.33	6.29	1.6%	0.9%	4.78	5.48	5.04	14.6%	5.4%	7.23	7.62	7.38	5.4%	2.1%
NFK-C	13.82	13.99	13.96	1.2%	1.0%	9.06	12.02	9.92	32.7%	9.5%	13.58	15.00	13.86	10.4%	2.1%
NFK-D	2.13	2.51	2.29	17.7%	7.2%	1.23	1.93	1.40	57.1%	13.4%	1.12	2.14	1.34	90.3%	18.9%
NFK-1.190	0.04	0.00	0.00	**-100.0%**	**-100.0%**	0.02	0.00	0.00	**-100.0%**	**-100.0%**	0.00	0.00	0.00	**-100.0%**	**-100.0%**
SFK-A	28.10	27.84	27.99	-0.9%	-0.4%	25.21	24.83	25.36	-1.5%	0.6%	29.05	29.12	29.71	0.2%	2.2%
SFK-B	5.47	5.47	5.46	-0.1%	-0.2%	5.05	4.88	4.99	**-3.2%**	-1.2%	6.83	6.89	7.15	0.8%	4.6%
SFK-C	6.52	6.43	6.35	-1.4%	**-2.7%**	4.47	4.51	5.24	1.0%	17.2%	7.78	7.85	8.94	0.8%	14.9%
SFK-1.190	3.40	3.38	3.49	-0.7%	2.6%	2.03	1.94	1.94	**-4.5%**	**-4.3%**	2.32	1.87	1.80	**-19.2%**	**-22.4%**
UTC-B	5.15	5.15	5.15	0.1%	0.0%	5.25	5.26	5.25	0.1%	0.0%	5.54	5.54	5.54	0.0%	0.0%
UTC-C	6.78	6.78	6.78	0.1%	0.0%	6.89	6.90	6.89	0.1%	0.0%	7.43	7.44	7.43	0.0%	0.0%
UTC-D	10.06	10.09	10.06	0.3%	-0.1%	12.16	12.20	12.17	0.3%	0.1%	16.08	16.11	16.09	0.2%	0.0%
UTC-E	10.73	10.76	10.71	0.4%	-0.1%	12.92	12.96	12.92	0.3%	0.0%	15.41	15.42	15.40	0.1%	0.0%
UTC-F	5.44	5.51	5.40	1.3%	-0.7%	6.56	6.62	6.54	0.9%	-0.4%	7.26	7.18	7.18	-1.1%	-1.1%
UTC-1.190	0.65	0.65	0.65	0.0%	0.5%	0.65	0.65	0.65	0.0%	0.5%	0.59	0.59	0.60	0.1%	0.9%

Note:
Percent decreases in habitat from pre-mine period exceeding 2 percent are shown in **bold** font
diff = difference
KR = Koktuli River
NFK = North Fork Koktuli
SFK = South Fork Koktuli
UTC = Upper Talarik Creek
Source: R2 Resource Consultants 2019a

Table K4.24-2: Predicted Quantity (acres) of Suitable Juvenile Rearing Habitat by Species, Reach, Water Year, and Mine Phase

Basin-Reach	Juvenile Rearing—Wet Year					Juvenile Rearing—Average Year					Juvenile Rearing—Dry Year				
	Pre-Mine	Mine Operations	Mine Closure	Mine Operations	Mine Closure	Pre-Mine	Mine Operations	Mine Closure	Mine Operations	Mine Closure	Pre-Mine	Mine Operations	Mine Closure	Mine Operations	Mine Closure
	(acres)	(acres)	(acres)	(% diff)	(% diff)	(acres)	(acres)	(acres)	(% diff)	(% diff)	(acres)	(acres)	(acres)	(% diff)	(% diff)
Chinook Salmon															
KR	14.40	14.67	14.56	1.8%	1.1%	15.01	14.97	15.01	-0.3%	0.0%	14.69	14.79	14.75	0.6%	0.4%
NFK-A	5.03	5.06	5.04	0.5%	0.2%	4.67	4.80	4.71	2.7%	0.8%	4.31	4.64	4.44	7.8%	3.0%
NFK-B	4.68	4.63	4.67	-1.0%	-0.3%	3.85	3.95	3.84	2.7%	-0.2%	4.15	4.28	4.19	2.9%	0.9%
NFK-C	5.77	5.79	5.75	0.5%	-0.2%	5.08	5.45	5.13	7.3%	0.9%	4.77	5.46	5.09	14.4%	6.6%
NFK-D	0.86	0.99	0.93	15.5%	8.1%	0.72	0.95	0.84	32.5%	16.4%	0.71	0.95	0.82	34.1%	14.8%
NFK-1.190	0.05	0.01	0.01	**-79.6%**	**-79.6%**	0.05	0.01	0.01	**-83.6%**	**-83.6%**	0.05	0.01	0.01	**-78.4%**	**-78.4%**
SFK-A	7.54	7.54	7.64	0.0%	1.4%	7.86	7.72	7.90	-1.7%	0.5%	8.94	8.94	9.01	0.0%	0.8%
SFK-B	3.75	3.76	3.80	0.3%	1.3%	3.81	3.77	3.86	-1.0%	1.4%	4.25	4.24	4.32	-0.2%	1.8%
SFK-C	4.15	4.42	4.45	6.6%	7.3%	4.34	4.53	4.66	4.6%	7.5%	5.96	6.33	6.45	6.3%	8.4%
SFK-1.190	1.20	1.10	1.08	**-7.9%**	**-10.0%**	0.97	0.85	0.83	**-12.3%**	**-14.4%**	0.97	0.83	0.80	**-15.2%**	**-18.2%**
UTC-B	1.44	1.44	1.44	-0.1%	-0.1%	1.40	1.40	1.40	-0.1%	-0.1%	1.49	1.49	1.49	-0.1%	-0.1%
UTC-C	4.39	4.39	4.39	0.0%	0.0%	4.17	4.17	4.17	-0.1%	-0.1%	4.36	4.36	4.36	0.0%	0.0%
UTC-D	8.20	8.22	8.21	0.3%	0.1%	8.87	8.87	8.87	0.0%	0.0%	8.63	8.65	8.64	0.3%	0.1%
UTC-E	4.90	4.92	4.91	0.4%	0.2%	5.54	5.56	5.55	0.3%	0.1%	5.02	5.04	5.03	0.4%	0.2%
UTC-F	2.63	2.64	2.64	0.2%	0.1%	2.62	2.63	2.61	0.3%	-0.4%	2.61	2.62	2.62	0.3%	0.1%
UTC-1.190	0.05	0.05	0.05	-0.1%	0.9%	0.04	0.04	0.04	0.0%	1.0%	0.04	0.04	0.04	-0.1%	1.0%
Coho Salmon															
KR	12.03	12.12	12.12	0.8%	0.7%	11.47	11.36	11.45	-0.9%	-0.1%	11.50	11.51	11.52	0.1%	0.2%
NFK-A	6.21	6.20	6.21	-0.3%	-0.1%	6.03	6.11	6.08	1.3%	0.8%	5.50	5.97	5.70	8.6%	3.7%
NFK-B	6.01	5.94	5.99	-1.2%	-0.4%	5.09	5.22	5.11	2.5%	0.2%	5.31	5.54	5.40	4.2%	1.6%
NFK-C	7.41	7.52	7.43	1.4%	0.2%	7.03	7.41	7.09	5.4%	1.0%	6.31	7.29	6.87	15.4%	8.8%
NFK-D	1.37	1.41	1.46	3.3%	6.6%	1.21	1.47	1.42	22.3%	17.8%	1.13	1.41	1.31	25.5%	16.0%
NFK-1.190	0.07	0.02	0.02	**-73.6%**	**-73.6%**	0.07	0.01	0.01	**-79.9%**	**-79.9%**	0.07	0.02	0.02	**-72.9%**	**-72.9%**
SFK-A	5.34	5.35	5.41	0.2%	1.2%	5.71	5.60	5.68	-1.8%	-0.4%	5.76	5.78	5.75	0.3%	-0.1%
SFK-B	2.99	2.98	3.02	-0.3%	0.9%	3.09	3.07	3.09	-0.6%	-0.1%	3.00	3.00	2.99	-0.1%	-0.4%
SFK-C	3.16	3.59	3.61	13.7%	14.5%	3.89	4.26	4.18	9.2%	7.4%	5.71	6.16	5.75	7.9%	0.7%
SFK-1.190	1.04	0.99	0.98	**-5.2%**	**-5.8%**	1.03	0.94	0.93	**-8.8%**	**-9.8%**	1.14	1.05	1.03	**-8.4%**	**-9.8%**
UTC-B	1.15	1.15	1.15	-0.1%	-0.1%	0.95	0.95	0.95	-0.2%	-0.1%	1.01	1.01	1.01	-0.1%	-0.1%
UTC-C	4.07	4.06	4.06	-0.2%	-0.1%	3.59	3.58	3.58	-0.2%	-0.1%	3.88	3.87	3.88	-0.2%	-0.1%
UTC-D	8.31	8.33	8.32	0.2%	0.1%	8.74	8.74	8.74	0.0%	0.0%	8.54	8.56	8.55	0.2%	0.1%
UTC-E	5.41	5.44	5.42	0.4%	0.2%	6.09	6.11	6.10	0.2%	0.1%	5.61	5.64	5.62	0.4%	0.2%
UTC-F	3.57	3.59	3.59	0.5%	0.3%	3.55	3.56	3.51	0.3%	-1.2%	3.57	3.60	3.58	0.8%	0.3%

Table K4.24-2: Predicted Quantity (acres) of Suitable Juvenile Rearing Habitat by Species, Reach, Water Year, and Mine Phase

Basin-Reach	Juvenile Rearing—Wet Year					Juvenile Rearing—Average Year					Juvenile Rearing—Dry Year				
	Pre-Mine	Mine Operations	Mine Closure	Mine Operations	Mine Closure	Pre-Mine	Mine Operations	Mine Closure	Mine Operations	Mine Closure	Pre-Mine	Mine Operations	Mine Closure	Mine Operations	Mine Closure
	(acres)	(acres)	(acres)	(% diff)	(% diff)	(acres)	(acres)	(acres)	(% diff)	(% diff)	(acres)	(acres)	(acres)	(% diff)	(% diff)
UTC-1.190	0.12	0.12	0.13	0.0%	0.2%	0.12	0.12	0.12	0.0%	0.1%	0.12	0.12	0.12	0.0%	0.1%
Sockeye Salmon															
KR	14.31	14.21	14.30	-0.7%	0.0%	12.91	12.92	12.94	0.1%	0.2%	12.92	12.83	12.92	-0.7%	0.0%
NFK-A	4.73	4.75	4.74	0.5%	0.3%	4.40	4.52	4.46	2.9%	1.4%	4.59	4.77	4.67	4.0%	1.7%
NFK-B	6.58	6.48	6.56	-1.5%	-0.2%	5.61	5.78	5.71	3.0%	1.8%	5.90	5.96	5.97	0.9%	1.2%
NFK-C	3.67	3.89	3.72	5.9%	1.3%	3.65	4.13	3.85	13.2%	5.6%	4.32	4.74	4.47	9.7%	3.3%
NFK-D	0.39	0.37	0.46	**-4.0%**	19.0%	0.46	0.51	0.58	11.2%	26.3%	0.63	0.58	0.70	**-7.5%**	11.6%
NFK-1.190	0.03	0.02	0.02	**-40.5%**	**-40.5%**	0.04	0.01	0.01	**-59.0%**	**-59.0%**	0.03	0.01	0.01	**-70.2%**	**-70.2%**
SFK-A	6.33	6.02	6.34	**-4.8%**	0.2%	6.40	6.40	6.42	0.0%	0.2%	6.65	6.68	6.65	0.4%	-0.1%
SFK-B	3.45	3.42	3.46	-1.0%	0.2%	3.25	3.23	3.26	-0.6%	0.1%	3.15	3.14	3.15	-0.2%	0.0%
SFK-C	2.31	2.77	2.69	20.2%	16.7%	2.66	3.21	3.00	20.8%	12.6%	4.43	4.89	4.27	10.3%	**-3.7%**
SFK-1.190	0.80	0.73	0.74	**-8.5%**	**-7.3%**	0.84	0.81	0.82	**-3.1%**	**-2.0%**	1.05	1.02	1.02	**-3.6%**	**-2.9%**
UTC-B	1.35	1.35	1.35	-0.1%	0.0%	1.03	1.03	1.03	-0.2%	-0.1%	0.72	0.72	0.72	-0.2%	-0.1%
UTC-C	3.25	3.25	3.25	-0.1%	0.0%	2.94	2.93	2.93	-0.1%	0.0%	2.63	2.63	2.63	-0.1%	0.0%
UTC-D	5.93	5.94	5.93	0.1%	0.0%	5.94	5.96	5.94	0.2%	0.0%	6.53	6.54	6.53	0.2%	0.1%
UTC-E	3.57	3.57	3.57	0.1%	-0.1%	3.39	3.40	3.39	0.3%	0.0%	3.64	3.65	3.64	0.3%	0.1%
UTC-F	2.25	2.25	2.25	-0.1%	0.2%	2.24	2.24	2.24	0.3%	0.1%	2.38	2.39	2.39	0.7%	0.5%
UTC-1.190	0.15	0.15	0.15	0.0%	-0.2%	0.16	0.16	0.15	0.0%	-0.3%	0.16	0.16	0.16	0.0%	0.0%
Rainbow Trout															
KR	14.24	14.52	14.39	2.0%	1.1%	15.28	15.25	15.30	-0.2%	0.1%	14.77	14.89	14.83	0.9%	0.4%
NFK-A	5.70	5.69	5.70	-0.2%	-0.1%	5.07	5.18	5.10	2.0%	0.5%	5.02	5.29	5.13	5.3%	2.1%
NFK-B	3.62	3.57	3.60	-1.3%	-0.4%	3.01	3.07	3.00	2.1%	-0.1%	3.26	3.36	3.29	3.0%	1.1%
NFK-C	5.90	5.85	5.86	-0.8%	-0.6%	5.05	5.34	5.07	5.7%	0.4%	4.98	5.57	5.24	11.8%	5.2%
NFK-D	0.77	0.94	0.85	22.8%	11.1%	0.64	0.89	0.74	39.8%	16.1%	0.65	0.88	0.74	35.9%	13.6%
NFK-1.190	0.05	0.01	0.01	**-88.3%**	**-88.3%**	0.04	0.00	0.00	**-89.7%**	**-89.7%**	0.05	0.01	0.01	**-87.3%**	**-87.3%**
SFK-A	8.48	8.47	8.59	-0.2%	1.2%	8.33	8.19	8.39	-1.7%	0.7%	9.24	9.21	9.35	-0.3%	1.2%
SFK-B	3.60	3.60	3.66	0.0%	1.7%	3.47	3.42	3.54	-1.5%	1.9%	4.01	3.99	4.11	-0.3%	2.7%
SFK-C	3.31	3.37	3.53	1.7%	6.7%	3.04	3.06	3.27	0.6%	7.5%	3.65	3.82	4.11	4.6%	12.5%
SFK-1.190	1.00	0.91	0.89	**-9.1%**	**-11.4%**	0.82	0.72	0.70	**-12.1%**	**-14.2%**	0.79	0.68	0.66	**-13.4%**	**-16.0%**
UTC-B	2.64	2.64	2.64	0.0%	0.0%	2.74	2.74	2.74	0.0%	0.0%	2.76	2.76	2.76	0.0%	0.0%
UTC-C	4.24	4.24	4.24	0.0%	0.0%	4.26	4.26	4.26	0.0%	0.0%	4.30	4.30	4.29	0.0%	0.0%
UTC-D	6.42	6.43	6.42	0.2%	0.1%	7.03	7.04	7.03	0.1%	0.1%	6.57	6.58	6.57	0.2%	0.1%
UTC-E	4.57	4.59	4.58	0.3%	0.1%	4.87	4.88	4.88	0.3%	0.1%	4.35	4.36	4.35	0.3%	0.1%

Table K4.24-2: Predicted Quantity (acres) of Suitable Juvenile Rearing Habitat by Species, Reach, Water Year, and Mine Phase

Basin-Reach	Juvenile Rearing—Wet Year					Juvenile Rearing—Average Year					Juvenile Rearing—Dry Year				
	Pre-Mine	Mine Operations	Mine Closure	Mine Operations	Mine Closure	Pre-Mine	Mine Operations	Mine Closure	Mine Operations	Mine Closure	Pre-Mine	Mine Operations	Mine Closure	Mine Operations	Mine Closure
	(acres)	(acres)	(acres)	(% diff)	(% diff)	(acres)	(acres)	(acres)	(% diff)	(% diff)	(acres)	(acres)	(acres)	(% diff)	(% diff)
UTC-F	2.09	2.12	2.10	1.5%	0.4%	2.15	2.18	2.21	1.5%	2.6%	2.09	2.11	2.10	1.1%	0.5%
UTC-1.190	0.06	0.06	0.06	0.0%	0.5%	0.06	0.06	0.06	0.0%	0.6%	0.06	0.06	0.06	0.0%	0.6%
Dolly Varden															
KR	14.57	14.70	14.69	0.8%	0.8%	13.80	13.68	13.78	-0.8%	-0.2%	14.00	13.99	14.02	-0.1%	0.2%
NFK-A	5.83	5.80	5.82	-0.6%	-0.2%	5.72	5.78	5.77	1.0%	0.8%	5.16	5.62	5.36	8.9%	3.9%
NFK-B	6.56	6.48	6.53	-1.2%	-0.4%	5.87	6.00	5.91	2.2%	0.7%	5.84	6.24	6.02	6.8%	2.9%
NFK-C	6.75	6.94	6.80	2.9%	0.7%	6.69	7.14	6.80	6.7%	1.7%	5.67	6.76	6.30	19.3%	11.1%
NFK-D	1.38	1.23	1.43	**-11.4%**	3.0%	1.28	1.41	1.52	9.8%	19.1%	1.13	1.33	1.34	17.4%	18.1%
NFK-1.190	0.07	0.02	0.02	**-62.8%**	**-62.8%**	0.07	0.02	0.02	**-73.3%**	**-73.3%**	0.07	0.02	0.02	**-63.7%**	**-63.7%**
SFK-A	8.54	8.56	8.65	0.2%	1.2%	9.13	8.96	9.10	-1.8%	-0.3%	9.29	9.31	9.26	0.2%	-0.3%
SFK-B	4.27	4.27	4.32	0.1%	1.2%	4.60	4.58	4.61	-0.4%	0.3%	4.70	4.71	4.70	0.3%	-0.1%
SFK-C	4.08	4.61	4.59	12.9%	12.4%	4.97	5.41	5.32	9.0%	7.2%	7.32	7.91	7.45	8.1%	1.8%
SFK-1.190	1.58	1.52	1.51	**-4.1%**	**-4.3%**	1.63	1.49	1.48	**-8.5%**	**-9.1%**	1.92	1.77	1.75	**-7.4%**	**-8.6%**
UTC-B	1.22	1.21	1.22	-0.1%	0.0%	0.98	0.98	0.98	-0.1%	-0.1%	0.97	0.97	0.97	-0.1%	0.0%
UTC-C	4.37	4.36	4.37	-0.2%	-0.1%	3.81	3.80	3.81	-0.2%	-0.1%	4.16	4.15	4.15	-0.2%	-0.2%
UTC-D	8.26	8.28	8.27	0.1%	0.1%	8.49	8.48	8.49	-0.1%	0.0%	8.47	8.48	8.48	0.1%	0.1%
UTC-E	5.61	5.63	5.62	0.4%	0.2%	6.22	6.23	6.22	0.2%	0.1%	5.80	5.82	5.81	0.4%	0.2%
UTC-F	3.74	3.76	3.75	0.5%	0.3%	3.75	3.76	3.72	0.3%	-0.8%	3.77	3.79	3.78	0.7%	0.3%
UTC-1.190	0.15	0.15	0.15	0.0%	0.1%	0.14	0.14	0.14	0.0%	0.0%	0.14	0.14	0.14	0.0%	0.1%
Arctic Grayling															
KR	21.91	22.11	22.08	0.9%	0.8%	21.15	21.01	21.13	-0.7%	-0.1%	21.26	21.25	21.29	-0.1%	0.1%
NFK-A	11.63	11.65	11.64	0.1%	0.0%	11.16	11.35	11.25	1.8%	0.8%	10.13	11.02	10.50	8.8%	3.6%
NFK-B	10.61	10.56	10.58	-0.4%	-0.2%	9.77	10.05	9.86	2.9%	0.9%	9.33	10.11	9.67	8.4%	3.6%
NFK-C	11.37	11.86	11.51	4.3%	1.2%	11.25	12.35	11.53	9.8%	2.5%	9.24	11.39	10.34	23.3%	11.9%
NFK-D	1.87	1.46	1.84	**-21.7%**	-1.2%	1.76	1.75	2.10	-0.4%	19.4%	1.51	1.69	1.81	11.5%	19.5%
NFK-1.190	0.12	0.04	0.04	**-70.8%**	**-70.8%**	0.12	0.03	0.03	**-78.0%**	**-78.0%**	0.11	0.03	0.03	**-68.9%**	**-68.9%**
SFK-A	14.95	14.99	15.14	0.3%	1.2%	16.12	15.84	16.08	-1.7%	-0.2%	16.74	16.77	16.69	0.2%	-0.3%
SFK-B	6.68	6.69	6.77	0.2%	1.3%	7.31	7.29	7.32	-0.3%	0.1%	7.55	7.58	7.53	0.4%	-0.3%
SFK-C	5.20	6.01	6.01	15.6%	15.5%	6.40	7.05	6.93	10.2%	8.4%	9.45	10.14	9.51	7.4%	0.7%
SFK-1.190	2.64	2.55	2.56	**-3.3%**	**-2.9%**	2.93	2.70	2.70	**-7.7%**	**-7.7%**	3.50	3.35	3.33	**-4.3%**	**-4.8%**
UTC-B	3.33	3.33	3.33	-0.1%	-0.1%	2.78	2.78	2.78	-0.1%	0.0%	2.81	2.81	2.81	-0.1%	0.0%
UTC-C	6.74	6.73	6.73	-0.1%	-0.1%	6.07	6.06	6.06	-0.1%	-0.1%	6.43	6.42	6.42	-0.1%	-0.1%
UTC-D	11.09	11.11	11.10	0.2%	0.1%	11.50	11.50	11.50	0.0%	0.0%	11.44	11.45	11.44	0.2%	0.1%

Table K4.24-2: Predicted Quantity (acres) of Suitable Juvenile Rearing Habitat by Species, Reach, Water Year, and Mine Phase

Basin-Reach	Juvenile Rearing—Wet Year					Juvenile Rearing—Average Year					Juvenile Rearing—Dry Year				
	Pre-Mine	Mine Operations	Mine Closure	Mine Operations	Mine Closure	Pre-Mine	Mine Operations	Mine Closure	Mine Operations	Mine Closure	Pre-Mine	Mine Operations	Mine Closure	Mine Operations	Mine Closure
	(acres)	(acres)	(acres)	(% diff)	(% diff)	(acres)	(acres)	(acres)	(% diff)	(% diff)	(acres)	(acres)	(acres)	(% diff)	(% diff)
UTC-E	7.94	7.97	7.95	0.4%	0.2%	8.52	8.52	8.52	0.0%	0.0%	8.08	8.12	8.10	0.5%	0.2%
UTC-F	5.51	5.54	5.53	0.5%	0.3%	5.54	5.56	5.50	0.3%	-0.8%	5.58	5.62	5.59	0.8%	0.3%
UTC-1.190	0.33	0.33	0.33	0.0%	-0.4%	0.33	0.33	0.32	0.0%	-0.6%	0.33	0.33	0.32	0.0%	-0.6%

Note:
Percent decreases in habitat from pre-mine period exceeding 2 percent are shown in **bold** font
diff = difference
KR = Koktuli River
NFK = North Fork Koktuli
SFK = South Fork Koktuli
UTC = Upper Talarik Creek
Source: R2 Resource Consultants 2019a

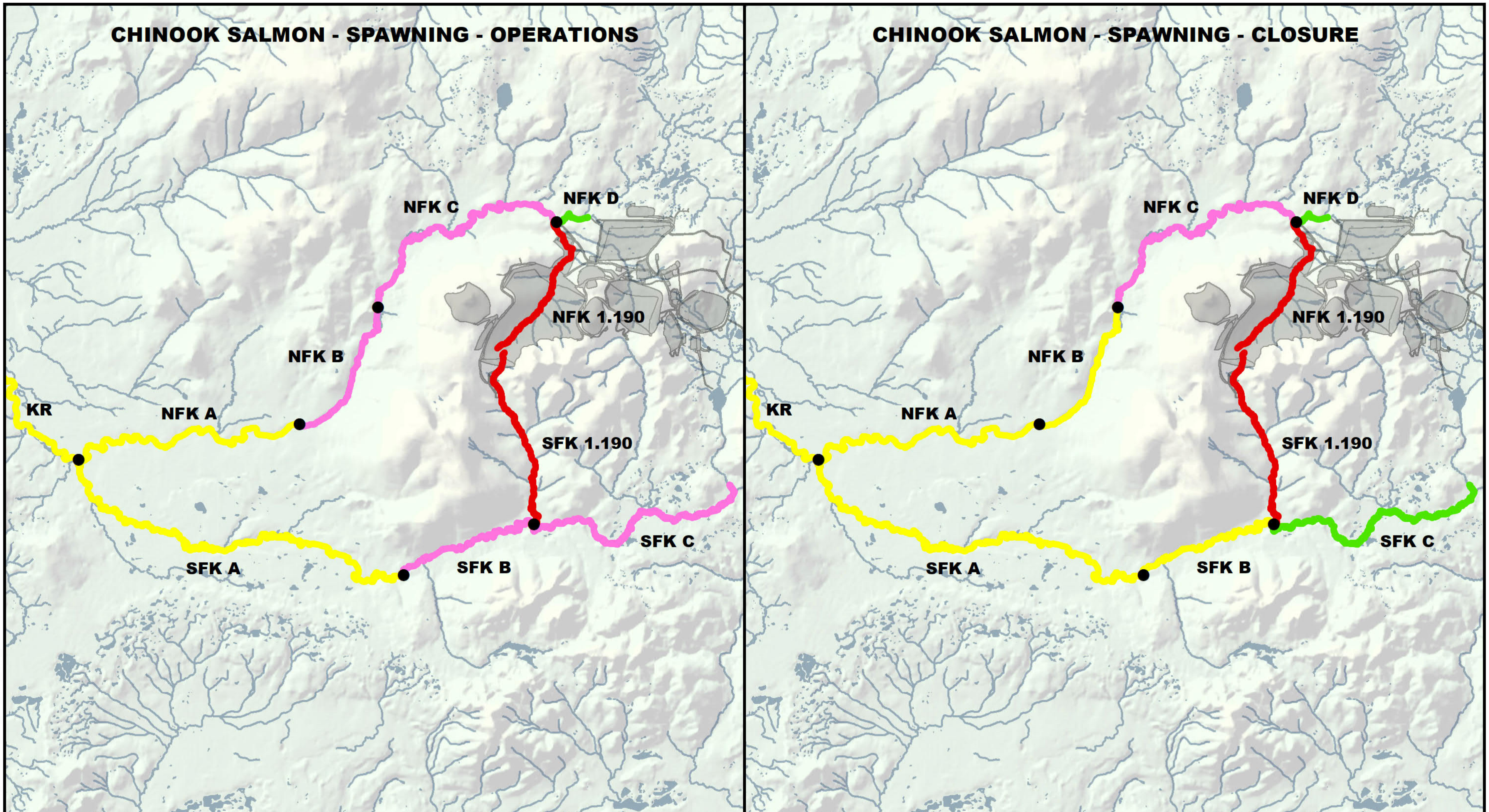
Table K4.24-3: Predicted Quantity (acres) of Suitable Adult Rearing Habitat by Species, Reach, Water Year, and Mine Phase

Basin-Reach	Adult Rearing—Wet Year					Adult Rearing—Avg Year					Adult Rearing—Dry Year				
	Pre-Mine	Mine Operations	Mine Closure	Mine Operations	Mine Closure	Pre-Mine	Mine Operations	Mine Closure	Mine Operations	Mine Closure	Pre-Mine	Mine Operations	Mine Closure	Mine Operations	Mine Closure
	(acres)	(acres)	(acres)	(% diff)	(% diff)	(acres)	(acres)	(acres)	(% diff)	(% diff)	(acres)	(acres)	(acres)	(% diff)	(% diff)
Rainbow Trout															
KR	18.92	19.30	19.14	2.0%	1.2%	19.67	19.69	19.67	0.1%	0.0%	19.67	19.75	19.72	0.4%	0.3%
NFK-A	8.90	9.06	8.95	1.8%	0.6%	8.38	8.73	8.47	4.2%	1.1%	7.34	8.06	7.61	9.8%	3.6%
NFK-B	5.54	5.56	5.54	0.5%	0.1%	4.95	5.13	4.98	3.7%	0.6%	4.86	5.22	5.00	7.4%	2.9%
NFK-C	9.91	10.23	9.98	3.2%	0.7%	8.72	9.83	8.94	12.8%	2.5%	7.80	9.50	8.43	21.9%	8.2%
NFK-D	1.29	1.68	1.45	29.7%	11.6%	1.05	1.53	1.21	46.5%	15.4%	1.09	1.54	1.23	41.8%	13.4%
NFK-1.190	0.09	0.01	0.01	**-87.5%**	**-87.5%**	0.08	0.01	0.01	**-89.4%**	**-89.4%**	0.08	0.01	0.01	**-85.6%**	**-85.6%**
SFK-A	12.28	12.30	12.43	0.2%	1.3%	12.91	12.70	12.96	-1.6%	0.4%	14.45	14.46	14.53	0.1%	0.6%
SFK-B	4.94	4.99	5.02	1.0%	1.8%	5.46	5.43	5.57	-0.6%	1.9%	6.77	6.81	6.90	0.7%	1.9%
SFK-C	5.14	5.32	5.43	3.5%	5.8%	4.78	4.88	5.17	2.0%	8.2%	6.15	6.44	7.01	4.7%	14.1%
SFK-1.190	1.60	1.50	1.48	**-6.6%**	**-7.8%**	1.48	1.33	1.32	**-10.1%**	**-11.1%**	1.64	1.49	1.46	**-9.1%**	**-10.7%**
UTC-B	3.55	3.54	3.54	-0.3%	-0.3%	2.92	2.92	2.92	-0.3%	-0.2%	3.55	3.54	3.54	-0.3%	-0.3%
UTC-C	6.50	6.49	6.49	-0.1%	-0.1%	6.15	6.14	6.14	-0.2%	-0.1%	6.69	6.69	6.69	0.0%	-0.1%
UTC-D	8.52	8.54	8.53	0.2%	0.1%	9.08	9.08	9.08	0.0%	0.0%	8.98	9.00	8.99	0.2%	0.1%
UTC-E	6.88	6.91	6.90	0.4%	0.2%	7.50	7.51	7.51	0.2%	0.1%	6.90	6.93	6.92	0.3%	0.2%
UTC-F	4.01	4.08	4.03	1.7%	0.3%	4.24	4.31	4.39	1.7%	3.5%	4.12	4.18	4.15	1.3%	0.6%
UTC-1.190	0.17	0.17	0.17	0.0%	-0.6%	0.18	0.18	0.18	0.0%	-0.7%	0.18	0.18	0.18	0.0%	-0.7%
Dolly Varden															
KR	15.16	15.29	15.27	0.8%	0.7%	14.33	14.22	14.31	-0.8%	-0.1%	14.50	14.50	14.53	0.0%	0.2%
NFK-A	5.67	5.60	5.65	-1.3%	-0.4%	5.73	5.75	5.78	0.2%	0.8%	5.08	5.56	5.30	9.6%	4.4%
NFK-B	6.25	6.14	6.22	-1.8%	-0.5%	5.48	5.59	5.51	2.0%	0.6%	5.54	5.84	5.67	5.5%	2.4%
NFK-C	7.07	7.23	7.12	2.3%	0.7%	7.24	7.59	7.36	4.8%	1.6%	6.08	7.19	6.79	18.2%	11.7%
NFK-D	1.60	1.44	1.68	**-10.3%**	4.5%	1.49	1.66	1.77	11.6%	19.1%	1.31	1.54	1.55	17.2%	17.7%
NFK-1.190	0.07	0.02	0.02	**-67.5%**	**-67.5%**	0.08	0.02	0.02	**-76.3%**	**-76.3%**	0.07	0.02	0.02	**-66.1%**	**-66.1%**
SFK-A	8.47	8.48	8.57	0.1%	1.2%	8.97	8.81	8.95	-1.8%	-0.3%	9.11	9.12	9.09	0.1%	-0.2%
SFK-B	4.43	4.44	4.49	0.0%	1.3%	4.85	4.83	4.85	-0.3%	0.1%	4.90	4.91	4.88	0.4%	-0.4%
SFK-C	4.43	4.92	4.91	11.0%	10.9%	5.20	5.62	5.55	8.0%	6.7%	7.55	8.16	7.76	8.1%	2.9%
SFK-1.190	1.62	1.53	1.52	**-5.5%**	**-6.2%**	1.63	1.48	1.47	**-9.1%**	**-9.8%**	1.84	1.72	1.70	**-6.9%**	**-8.0%**
UTC-B	1.07	1.07	1.07	-0.1%	0.0%	0.89	0.88	0.89	-0.1%	0.0%	0.86	0.86	0.86	-0.1%	0.0%
UTC-C	4.50	4.49	4.49	-0.2%	-0.2%	3.85	3.85	3.85	-0.2%	-0.1%	4.28	4.27	4.27	-0.2%	-0.2%
UTC-D	9.12	9.14	9.13	0.1%	0.1%	9.42	9.42	9.42	0.0%	0.0%	9.33	9.35	9.34	0.1%	0.1%
UTC-E	6.25	6.27	6.26	0.4%	0.2%	6.90	6.91	6.90	0.2%	0.1%	6.43	6.45	6.44	0.4%	0.2%

Table K4.24-3: Predicted Quantity (acres) of Suitable Adult Rearing Habitat by Species, Reach, Water Year, and Mine Phase

Basin-Reach	Adult Rearing—Wet Year					Adult Rearing—Avg Year					Adult Rearing—Dry Year				
	Pre-Mine	Mine Operations	Mine Closure	Mine Operations	Mine Closure	Pre-Mine	Mine Operations	Mine Closure	Mine Operations	Mine Closure	Pre-Mine	Mine Operations	Mine Closure	Mine Operations	Mine Closure
	(acres)	(acres)	(acres)	(% diff)	(% diff)	(acres)	(acres)	(acres)	(% diff)	(% diff)	(acres)	(acres)	(acres)	(% diff)	(% diff)
UTC-F	4.18	4.22	4.20	1.0%	0.5%	4.20	4.24	4.19	0.8%	-0.3%	4.21	4.26	4.24	1.2%	0.5%
UTC-1.190	0.11	0.11	0.11	0.0%	0.2%	0.11	0.11	0.11	0.0%	0.1%	0.11	0.11	0.11	0.0%	0.1%
Arctic Grayling															
KR	10.18	10.41	10.30	2.3%	1.2%	11.28	11.27	11.29	-0.1%	0.1%	10.72	10.81	10.76	0.8%	0.4%
NFK-A	3.62	3.64	3.62	0.6%	0.1%	3.04	3.14	3.05	3.2%	0.3%	3.14	3.25	3.17	3.5%	1.1%
NFK-B	2.06	2.05	2.06	-0.5%	-0.3%	1.68	1.70	1.67	1.2%	-0.7%	1.94	1.99	1.95	2.2%	0.6%
NFK-C	4.12	4.08	4.07	-0.9%	-1.1%	3.15	3.42	3.14	8.6%	-0.3%	3.38	3.71	3.45	9.9%	2.0%
NFK-D	0.30	0.45	0.33	52.7%	10.7%	0.20	0.35	0.22	78.3%	9.1%	0.25	0.40	0.27	63.3%	10.0%
NFK-1.190	0.03	0.00	0.00	**-98.9%**	**-98.9%**	0.02	0.00	0.00	**-99.0%**	**-99.0%**	0.03	0.00	0.00	**-98.5%**	**-98.5%**
SFK-A	5.55	5.53	5.61	-0.4%	1.2%	5.21	5.12	5.26	-1.7%	1.1%	5.97	5.94	6.08	-0.5%	1.8%
SFK-B	2.29	2.28	2.33	-0.2%	1.8%	1.97	1.92	2.03	**-2.6%**	2.9%	2.40	2.37	2.51	-1.1%	4.6%
SFK-C	2.37	2.32	2.51	-1.8%	6.0%	1.87	1.80	2.05	**-4.0%**	9.6%	1.91	1.91	2.34	-0.1%	22.2%
SFK-1.190	0.53	0.47	0.46	**-10.8%**	**-13.8%**	0.40	0.34	0.33	**-13.4%**	**-16.3%**	0.32	0.27	0.25	**-17.9%**	**-21.4%**
UTC-B	1.98	1.98	1.98	0.0%	0.0%	1.91	1.91	1.91	-0.2%	-0.2%	2.04	2.04	2.04	0.0%	0.0%
UTC-C	3.20	3.21	3.21	0.1%	0.0%	3.44	3.44	3.44	0.1%	0.0%	3.36	3.37	3.37	0.1%	0.0%
UTC-D	3.34	3.36	3.35	0.4%	0.2%	3.88	3.89	3.88	0.2%	0.1%	3.53	3.54	3.54	0.3%	0.1%
UTC-E	2.86	2.87	2.87	0.3%	0.1%	2.96	2.97	2.96	0.3%	0.1%	2.58	2.58	2.58	0.2%	0.1%
UTC-F	1.13	1.14	1.13	0.7%	-0.1%	1.17	1.19	1.22	1.2%	3.6%	1.11	1.11	1.11	0.0%	-0.1%
UTC-1.190	0.02	0.02	0.02	0.0%	0.5%	0.02	0.02	0.02	0.0%	0.7%	0.02	0.02	0.02	0.0%	0.7%

Note:
Percent decreases in habitat from pre-mine period exceeding 2 percent are shown in **bold** font
diff = difference
KR = Koktuli River
NFK = North Fork Koktuli
SFK = South Fork Koktuli
UTC = Upper Talarik Creek
Source: R2 Resource Consultants 2019a



Sources:PLP 2019-RFI153; PLP 2019-RFI149

US Army Corps of Engineers

2 0 2 4
Miles

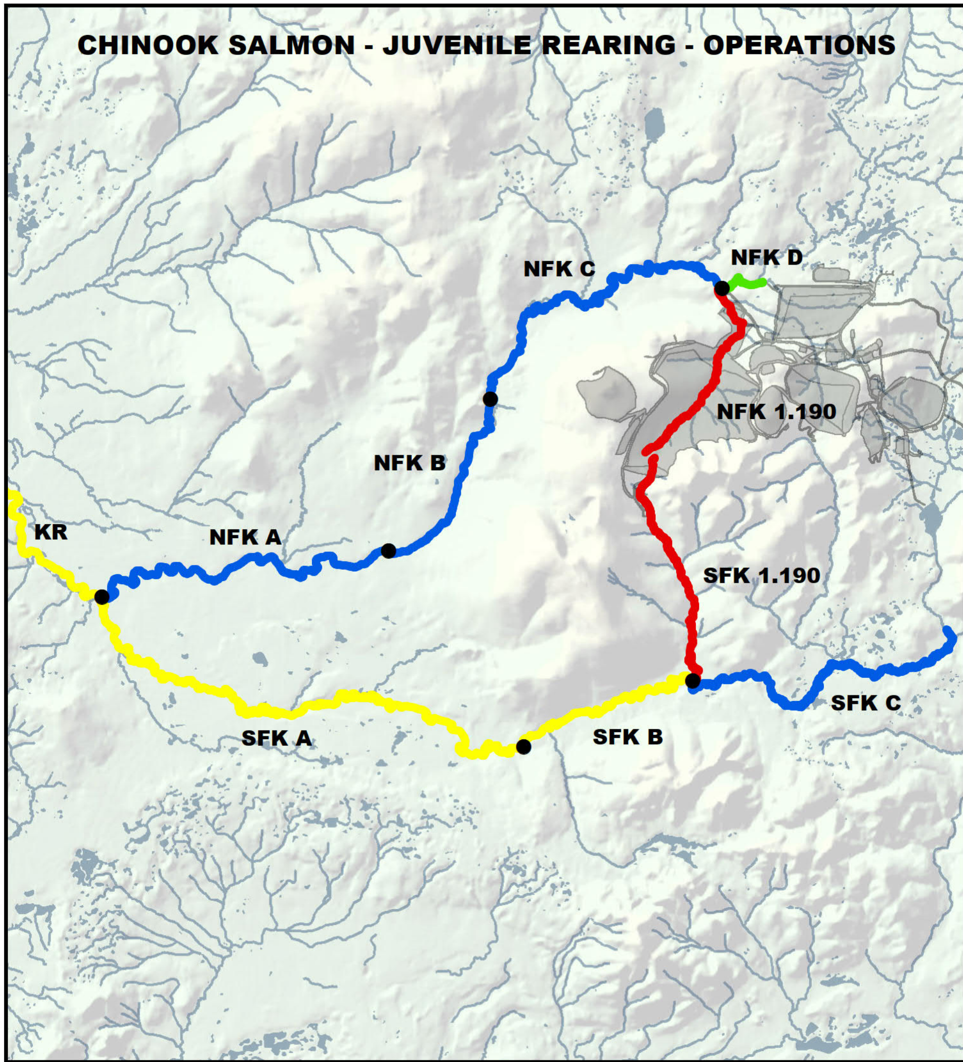
Predicted Change

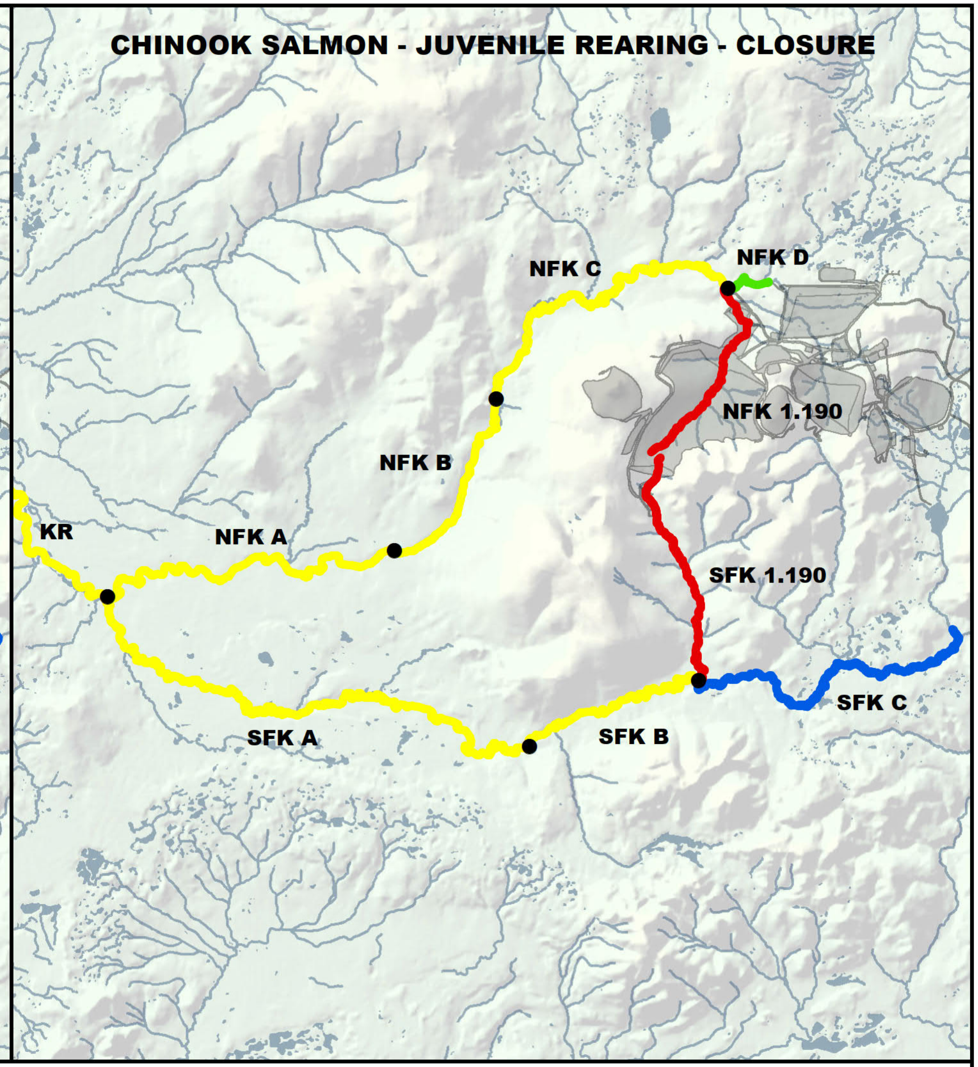
- Habitat Decrease >10%
- Habitat Decrease 2%-10%
- No Habitat Change +/- 2%
- Habitat Increase 2%-10%
- Habitat Increase >10%
- Alternative 1a

PREDICTED CHANGES IN THE AMOUNT (ACRES) OF SUITABLE HABITAT FROM PRE-MINE TO MINE OPERATIONS (LEFT) OR TO MINE CLOSURE (RIGHT) DURING AN AVERAGE WATER YEAR FOR SELECT RESIDENT AND ANADROMOUS FISH

PEBBLE PROJECT EIS

FIGURE K4.24-3





Sources:PLP 2019-RFI153; PLP 2019-RFI149

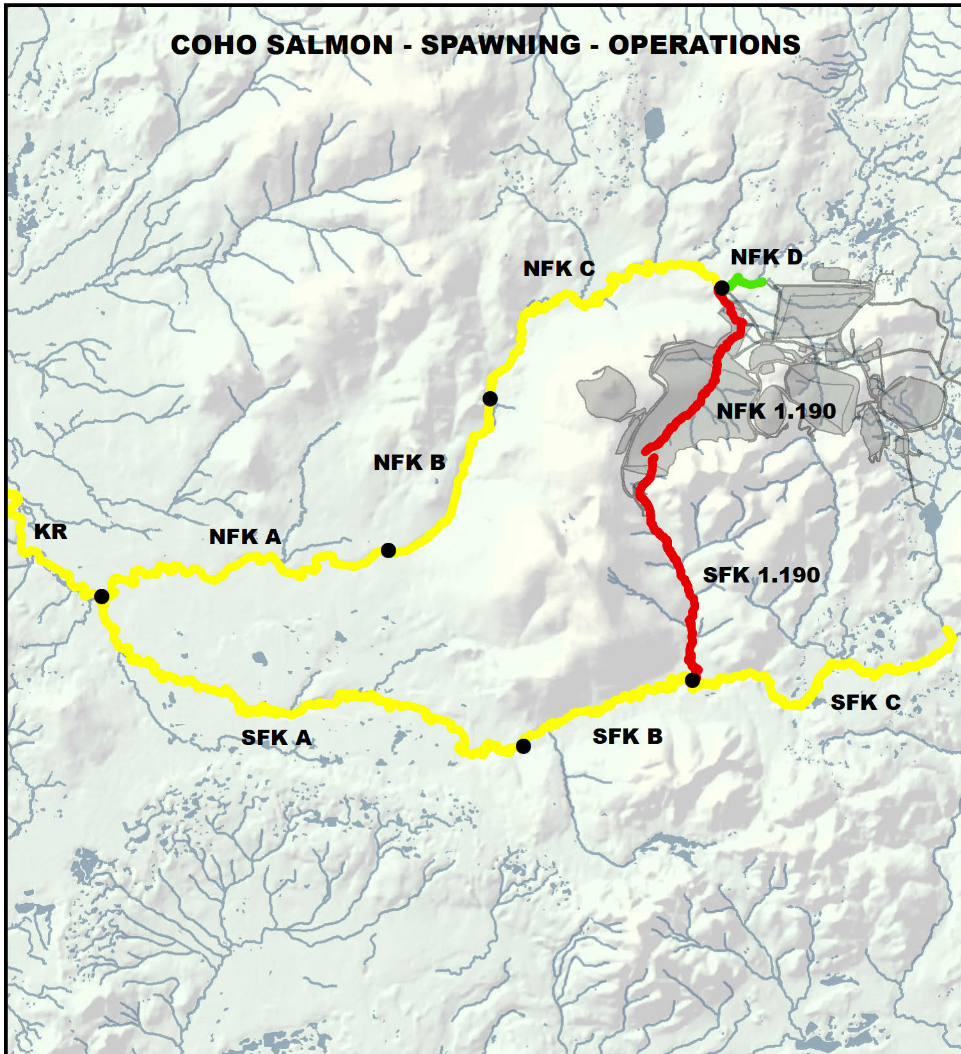
US Army Corps of Engineers

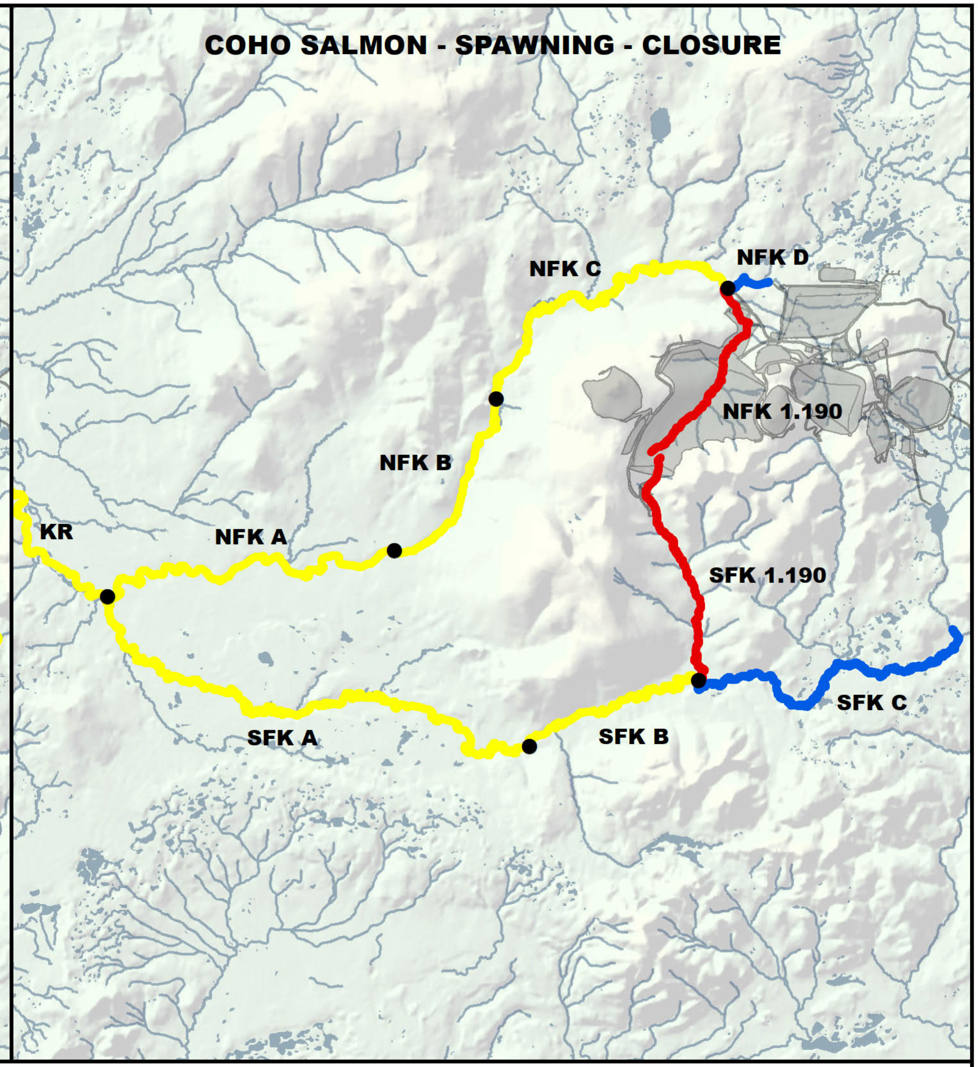
2 0 2 4
Miles

Predicted Change

- Habitat Decrease >10%
- Habitat Decrease 2%-10%
- No Habitat Change +/- 2%
- Habitat Increase 2%-10%
- Habitat Increase >10%
- Alternative 1a

PREDICTED CHANGES IN THE AMOUNT (ACRES) OF SUITABLE HABITAT FROM PRE-MINE TO MINE OPERATIONS (LEFT) OR TO MINE CLOSURE (RIGHT) DURING AN AVERAGE WATER YEAR FOR SELECT RESIDENT AND ANADROMOUS FISH





Sources:PLP 2019-RFI153; PLP 2019-RFI149

US Army Corps of Engineers®

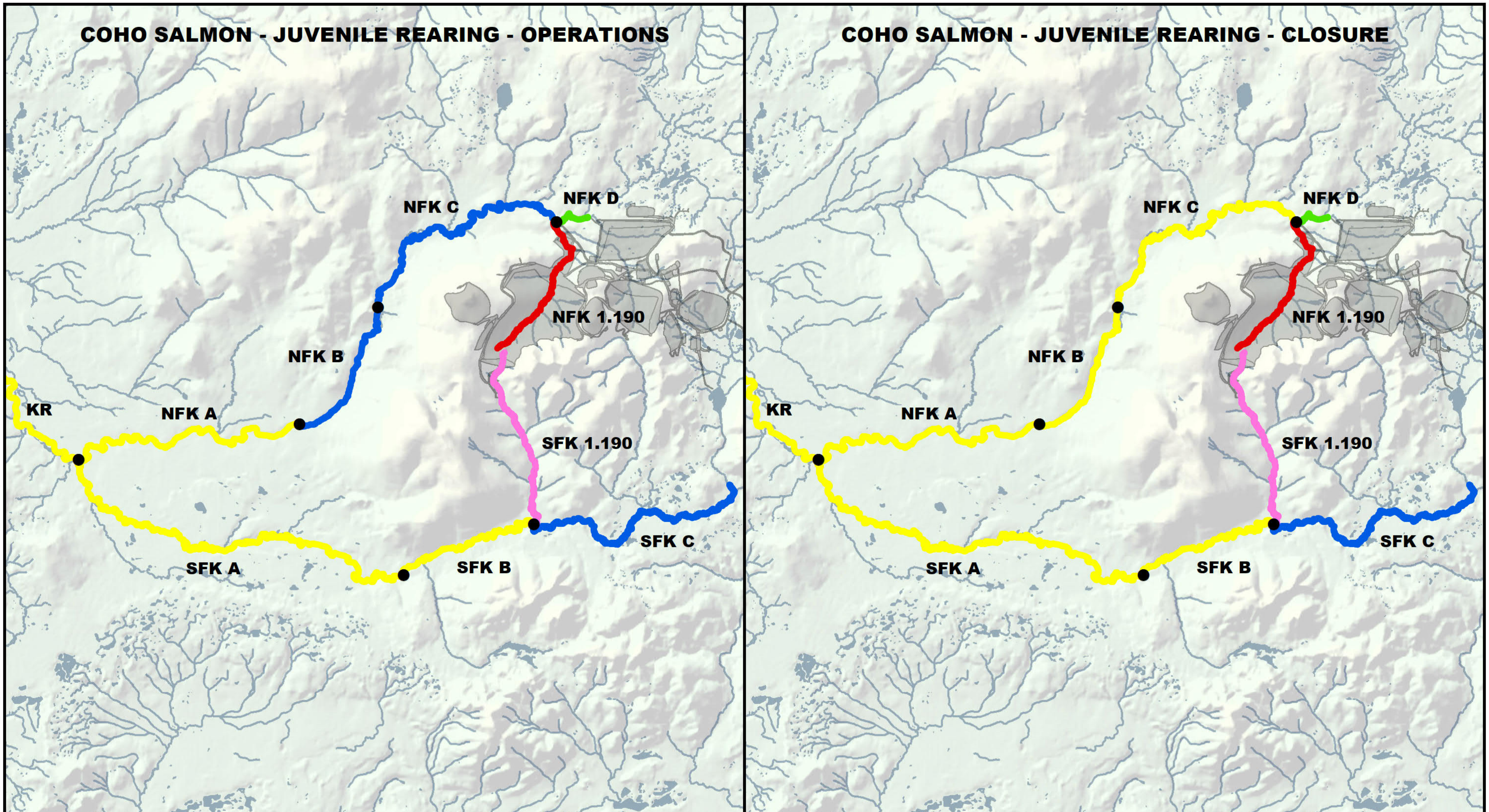
2 0 2 4

Miles

Predicted Change

- Habitat Decrease >10%
- Habitat Decrease 2%-10%
- No Habitat Change +/- 2%
- Habitat Increase 2%-10%
- Habitat Increase >10%
- Alternative 1a

PREDICTED CHANGES IN THE AMOUNT (ACRES) OF SUITABLE HABITAT FROM PRE-MINE TO MINE OPERATIONS (LEFT) OR TO MINE CLOSURE (RIGHT) DURING AN AVERAGE WATER YEAR FOR SELECT RESIDENT AND ANADROMOUS FISH



Sources:PLP 2019-RFI153; PLP 2019-RFI149

US Army Corps of Engineers®

N

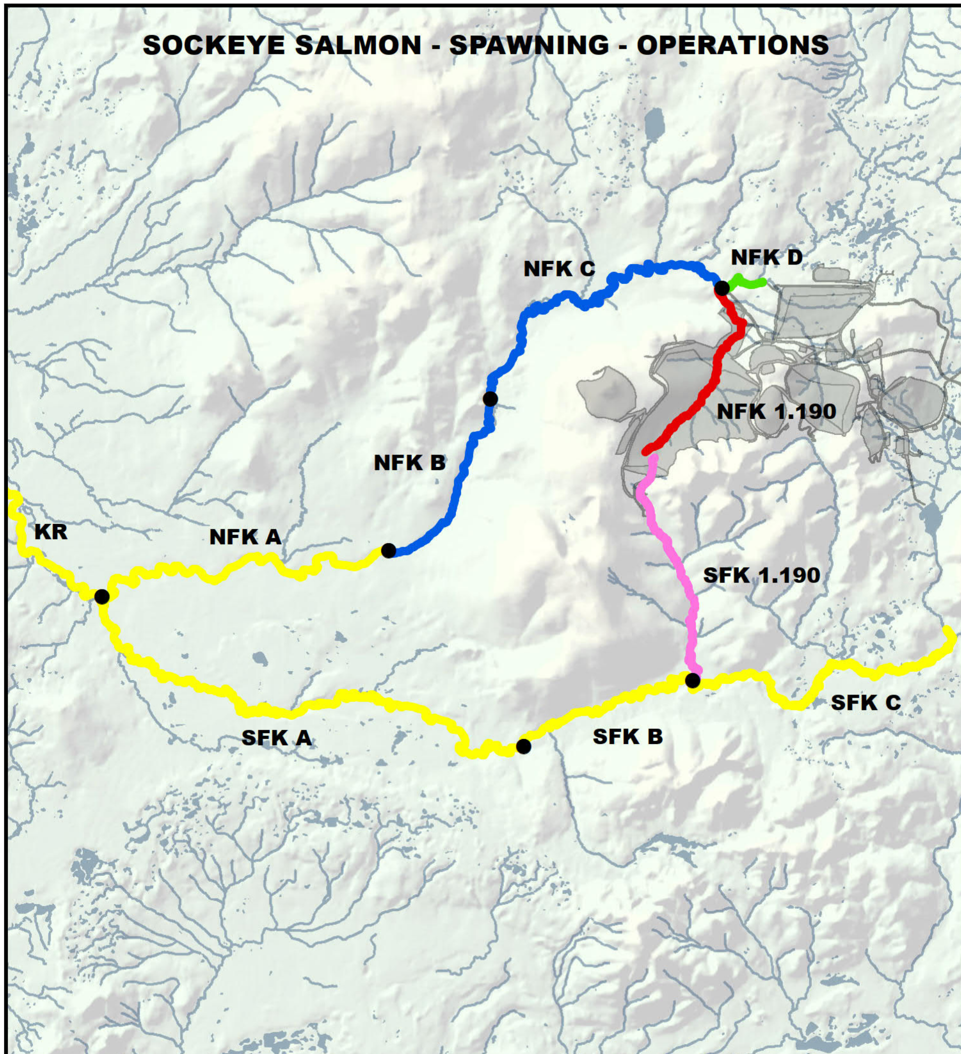
2 0 2 4

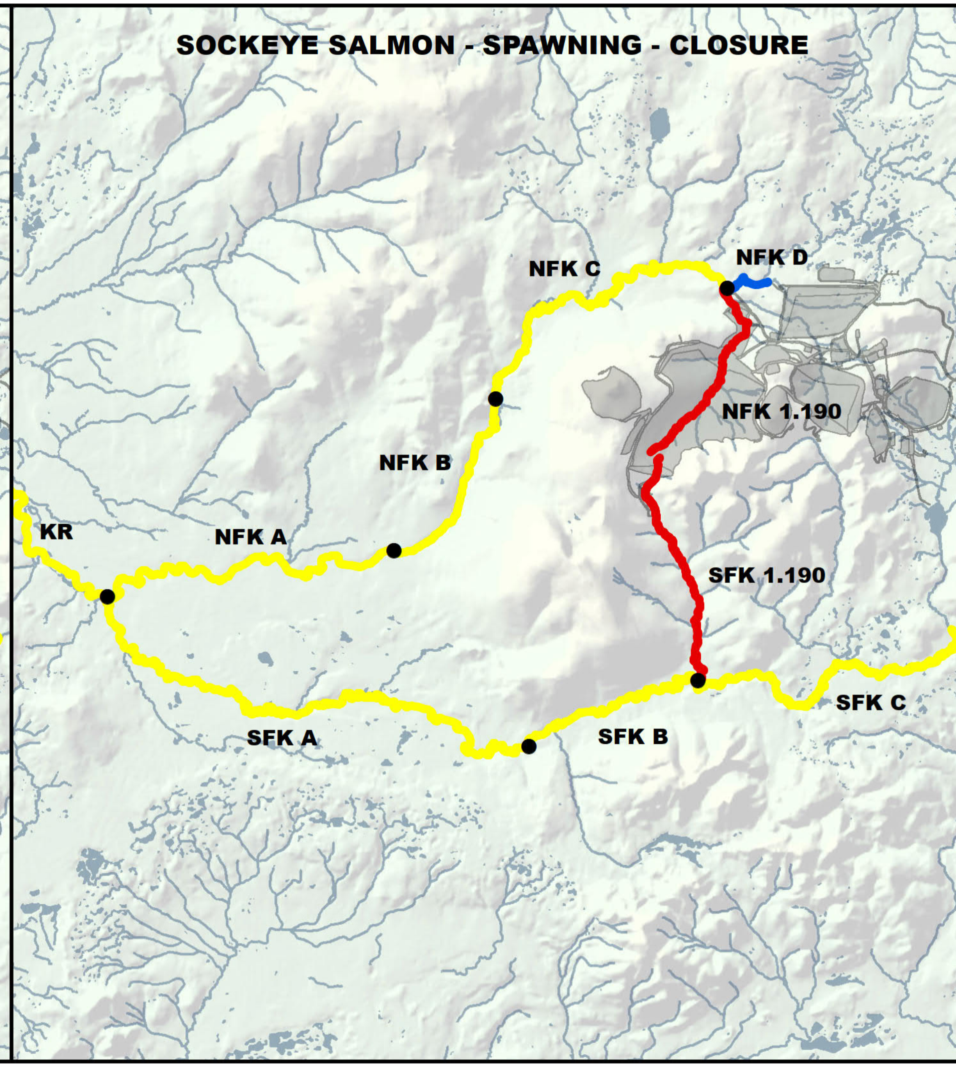
Miles

Predicted Change

- Habitat Decrease >10%
- Habitat Decrease 2%-10%
- No Habitat Change +/- 2%
- Habitat Increase 2%-10%
- Habitat Increase >10%
- Alternative 1a

PREDICTED CHANGES IN THE AMOUNT (ACRES) OF SUITABLE HABITAT FROM PRE-MINE TO MINE OPERATIONS (LEFT) OR TO MINE CLOSURE (RIGHT) DURING AN AVERAGE WATER YEAR FOR SELECT RESIDENT AND ANADROMOUS FISH





Sources:PLP 2019-RFI153; PLP 2019-RFI149

US Army Corps of Engineers®

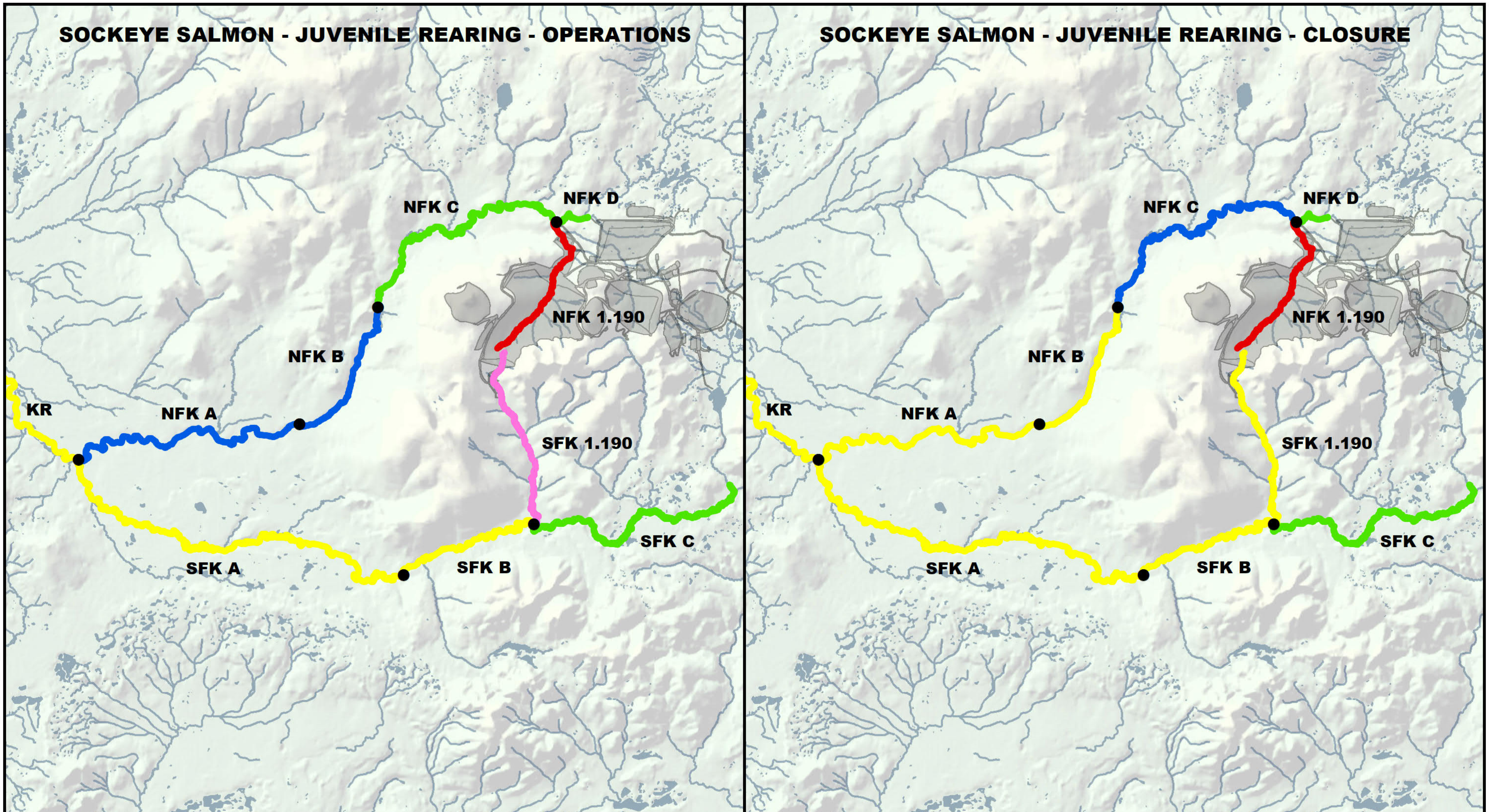
2 0 2 4
Miles

Predicted Change
- Habitat Decrease >10%
- Habitat Decrease 2%-10%
- No Habitat Change +/- 2%
- Habitat Increase 2%-10%
- Habitat Increase >10%
- Alternative 1a

PREDICTED CHANGES IN THE AMOUNT (ACRES) OF SUITABLE HABITAT FROM PRE-MINE TO MINE OPERATIONS (LEFT) OR TO MINE CLOSURE (RIGHT) DURING AN AVERAGE WATER YEAR FOR SELECT RESIDENT AND ANADROMOUS FISH

PEBBLE PROJECT EIS

FIGURE K4.24-7



Sources:PLP 2019-RFI153; PLP 2019-RFI149

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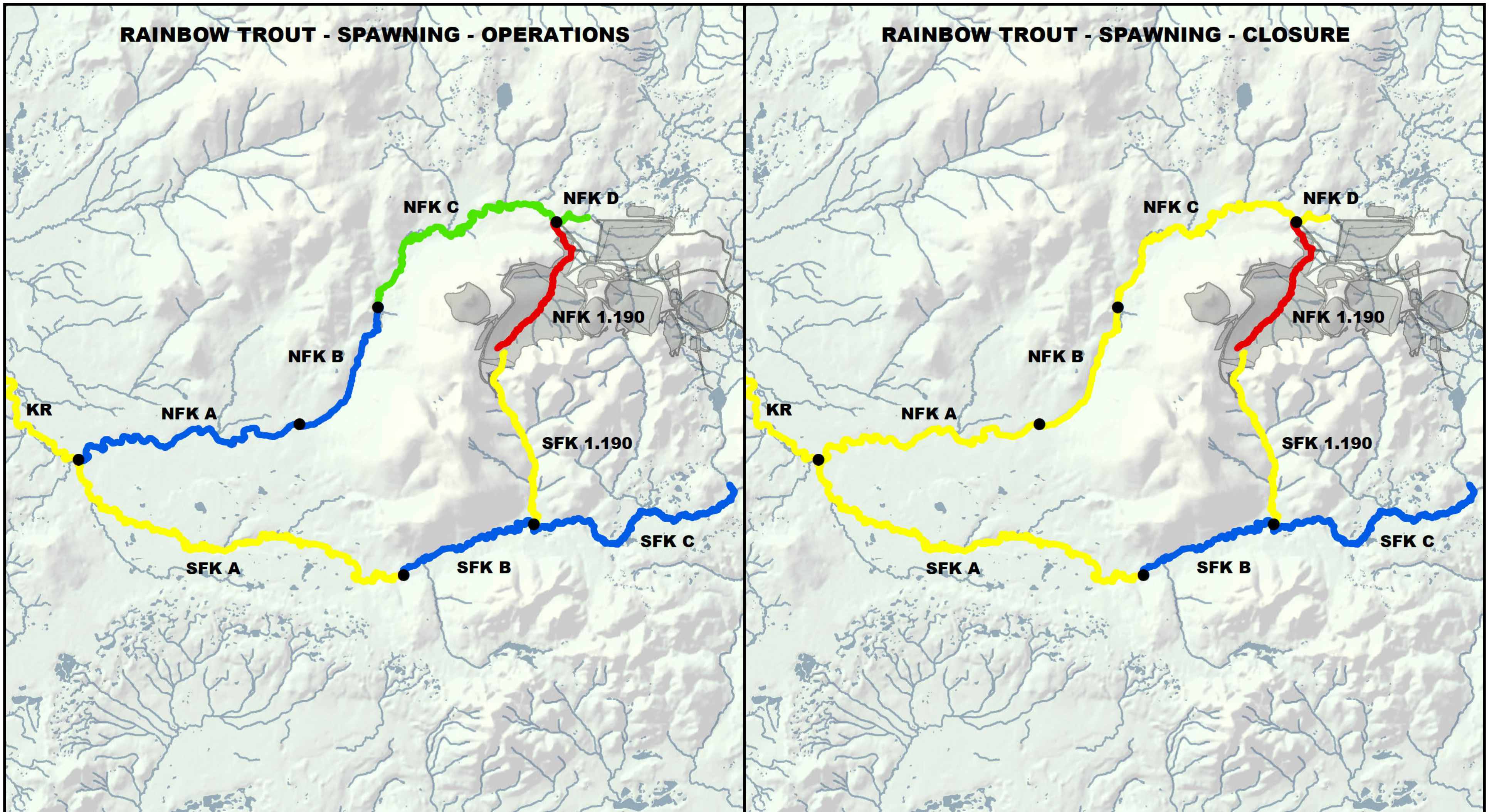
2 0 2 4
Miles

Predicted Change

- Habitat Decrease >10%
- Habitat Decrease 2%-10%
- No Habitat Change +/- 2%
- Habitat Increase 2%-10%
- Habitat Increase >10%
- Alternative 1a

PREDICTED CHANGES IN THE AMOUNT (ACRES) OF SUITABLE HABITAT FROM PRE-MINE TO MINE OPERATIONS (LEFT) OR TO MINE CLOSURE (RIGHT) DURING AN AVERAGE WATER YEAR FOR SELECT RESIDENT AND ANADROMOUS FISH



Sources: PLP 2019-RFI153; PLP 2019-RFI149

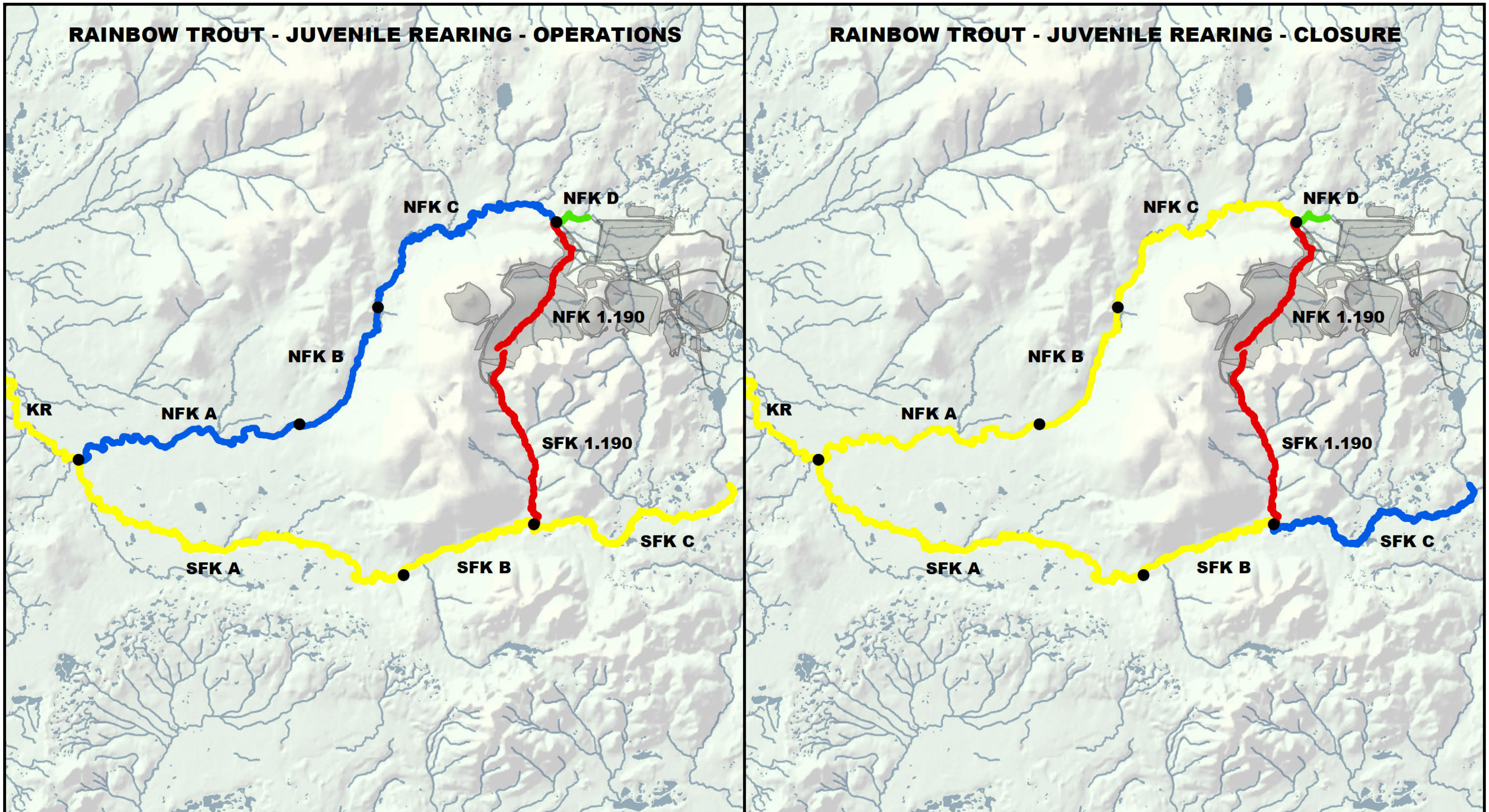
US Army Corps of Engineers

2 0 2 4
Miles

Predicted Change

- Habitat Decrease >10%
- Habitat Decrease 2%-10%
- No Habitat Change +/- 2%
- Habitat Increase 2%-10%
- Habitat Increase >10%
- Alternative 1a

PREDICTED CHANGES IN THE AMOUNT (ACRES) OF SUITABLE HABITAT FROM PRE-MINE TO MINE OPERATIONS (LEFT) OR TO MINE CLOSURE (RIGHT) DURING AN AVERAGE WATER YEAR FOR SELECT RESIDENT AND ANADROMOUS FISH



Sources: PLP 2019-RFI153; PLP 2019-RFI149

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N

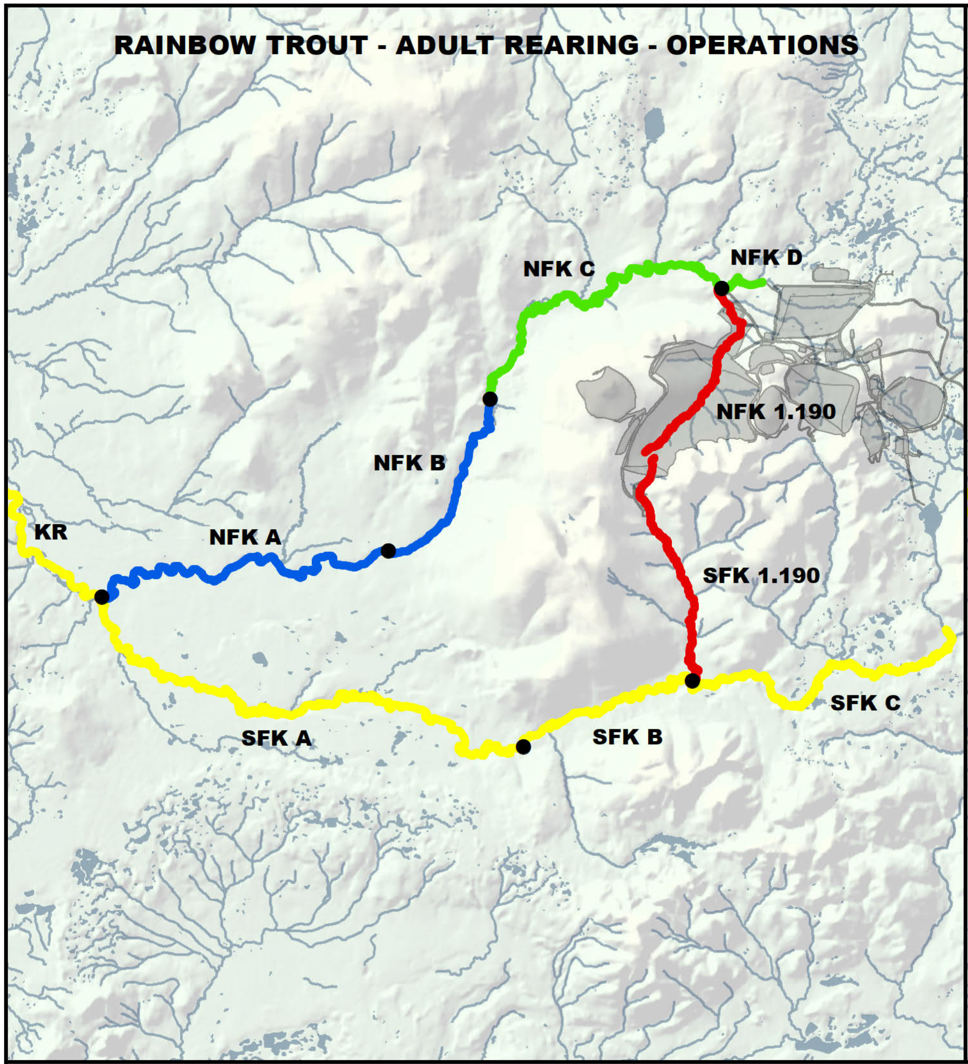
2 0 2 4

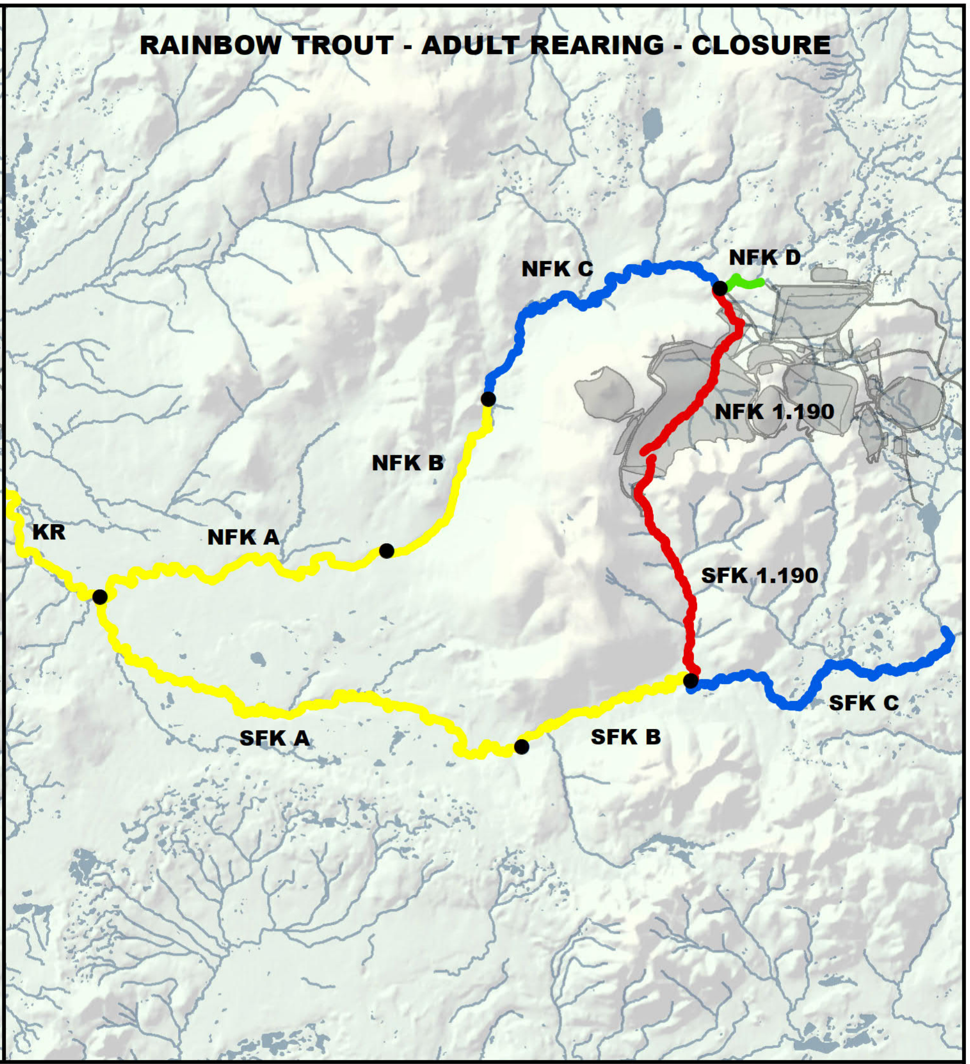
Miles

Predicted Change

- Habitat Decrease >10%
- Habitat Decrease 2%-10%
- No Habitat Change +/- 2%
- Habitat Increase 2%-10%
- Habitat Increase >10%
- Alternative 1a

PREDICTED CHANGES IN THE AMOUNT (ACRES) OF SUITABLE HABITAT FROM PRE-MINE TO MINE OPERATIONS (LEFT) OR TO MINE CLOSURE (RIGHT) DURING AN AVERAGE WATER YEAR FOR SELECT RESIDENT AND ANADROMOUS FISH





Sources: PLP 2019-RFI153; PLP 2019-RFI149

US Army Corps of Engineers

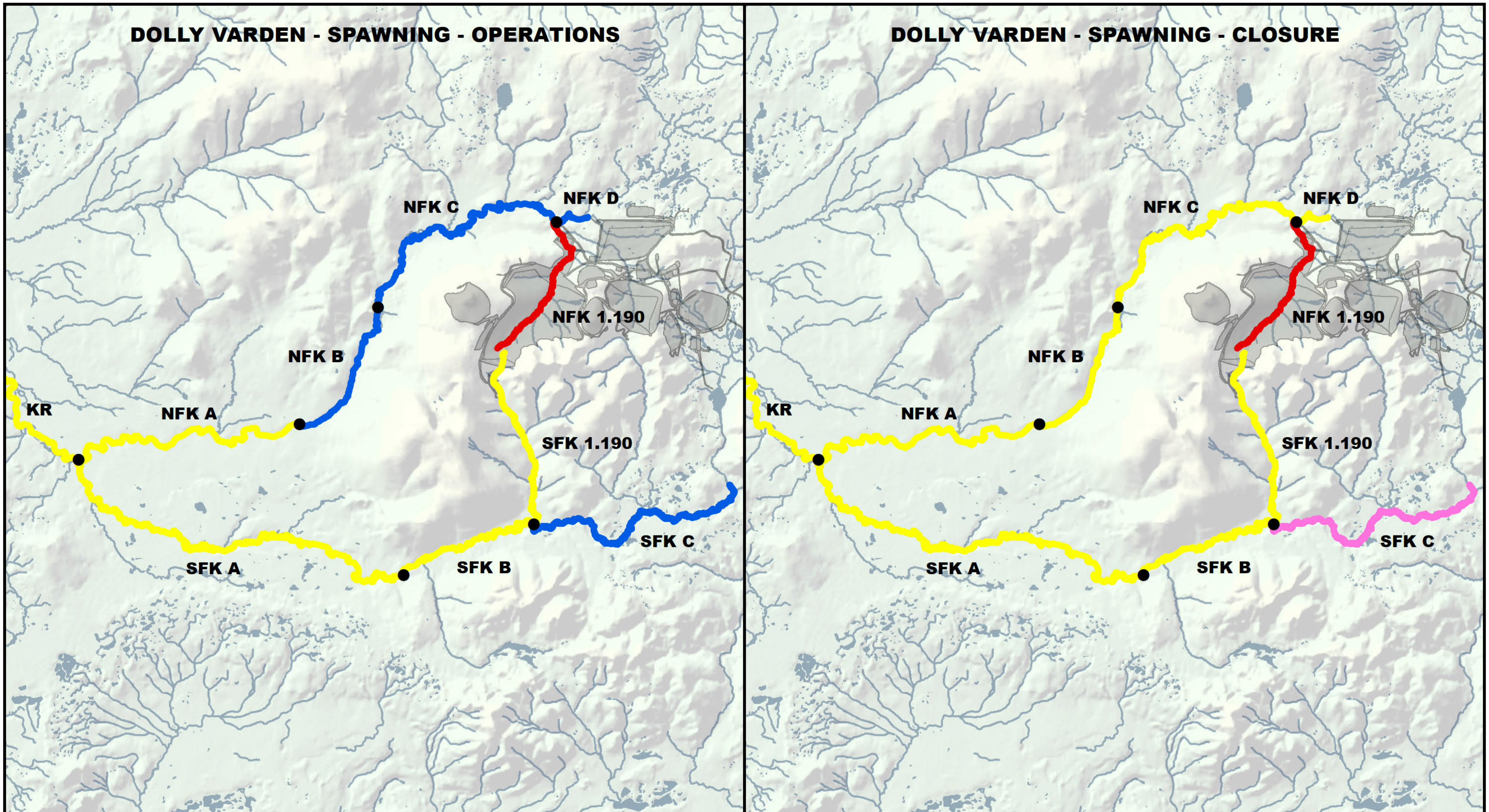
2 0 2 4

Miles

Predicted Change

- Habitat Decrease >10%
- Habitat Decrease 2%-10%
- No Habitat Change +/- 2%
- Habitat Increase 2%-10%
- Habitat Increase >10%
- Alternative 1a

PREDICTED CHANGES IN THE AMOUNT (ACRES) OF SUITABLE HABITAT FROM PRE-MINE TO MINE OPERATIONS (LEFT) OR TO MINE CLOSURE (RIGHT) DURING AN AVERAGE WATER YEAR FOR SELECT RESIDENT AND ANADROMOUS FISH



Sources: PLP 2019-RFI153; PLP 2019-RFI149

US Army Corps of Engineers

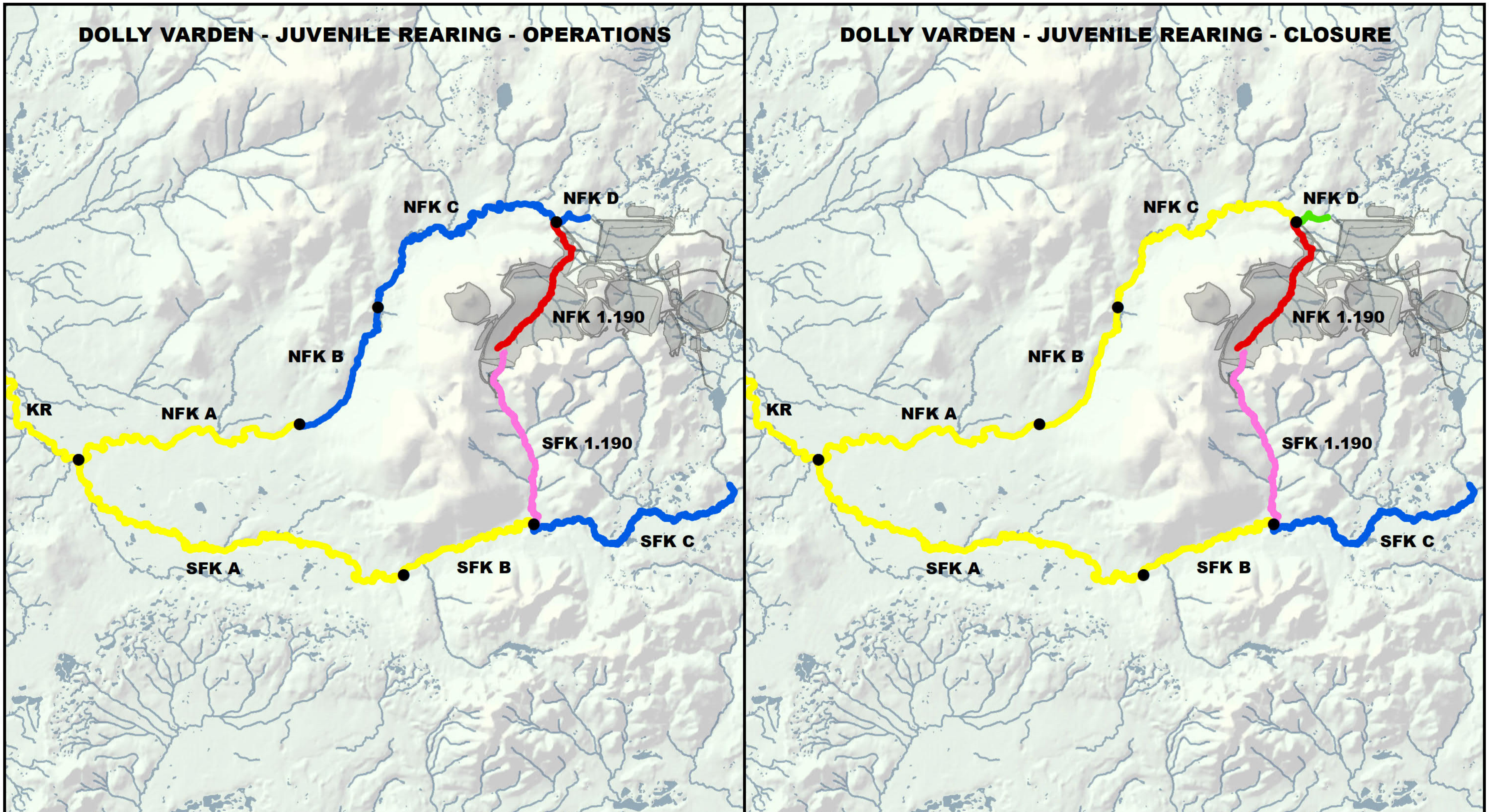
2 0 2 4

Miles

Predicted Change

- Habitat Decrease >10%
- Habitat Decrease 2%-10%
- No Habitat Change +/- 2%
- Habitat Increase 2%-10%
- Habitat Increase >10%
- Alternative 1a

PREDICTED CHANGES IN THE AMOUNT (ACRES) OF SUITABLE HABITAT FROM PRE-MINE TO MINE OPERATIONS (LEFT) OR TO MINE CLOSURE (RIGHT) DURING AN AVERAGE WATER YEAR FOR SELECT RESIDENT AND ANADROMOUS FISH



Sources: PLP 2019-RFI153; PLP 2019-RFI149

US Army Corps of Engineers®

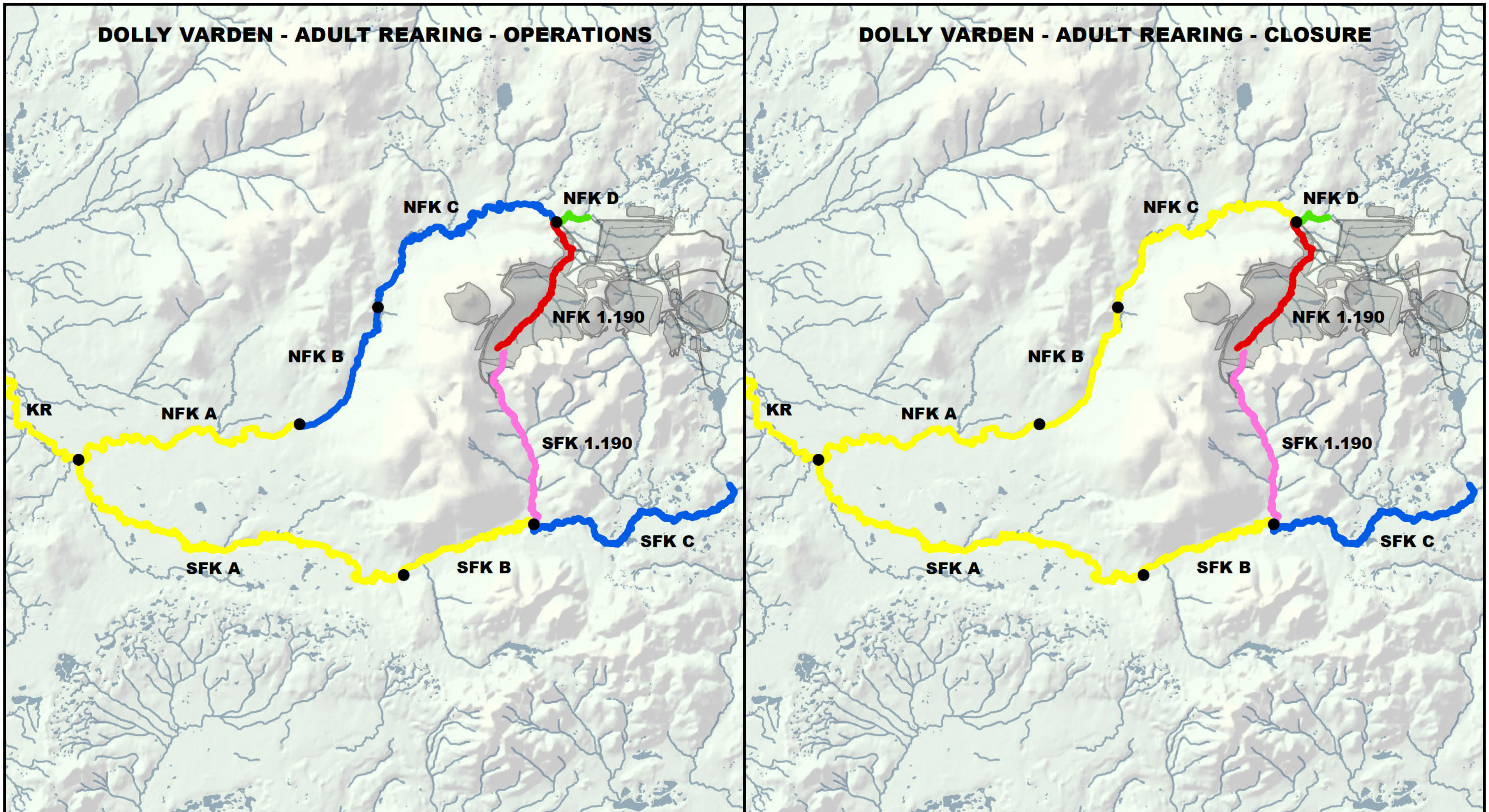
2 0 2 4

Miles

Predicted Change

- Habitat Decrease >10%
- Habitat Decrease 2%-10%
- No Habitat Change +/- 2%
- Habitat Increase 2%-10%
- Habitat Increase >10%
- Alternative 1a

PREDICTED CHANGES IN THE AMOUNT (ACRES) OF SUITABLE HABITAT FROM PRE-MINE TO MINE OPERATIONS (LEFT) OR TO MINE CLOSURE (RIGHT) DURING AN AVERAGE WATER YEAR FOR SELECT RESIDENT AND ANADROMOUS FISH



Sources: PLP 2019-RFI153; PLP 2019-RFI149

US Army Corps of Engineers

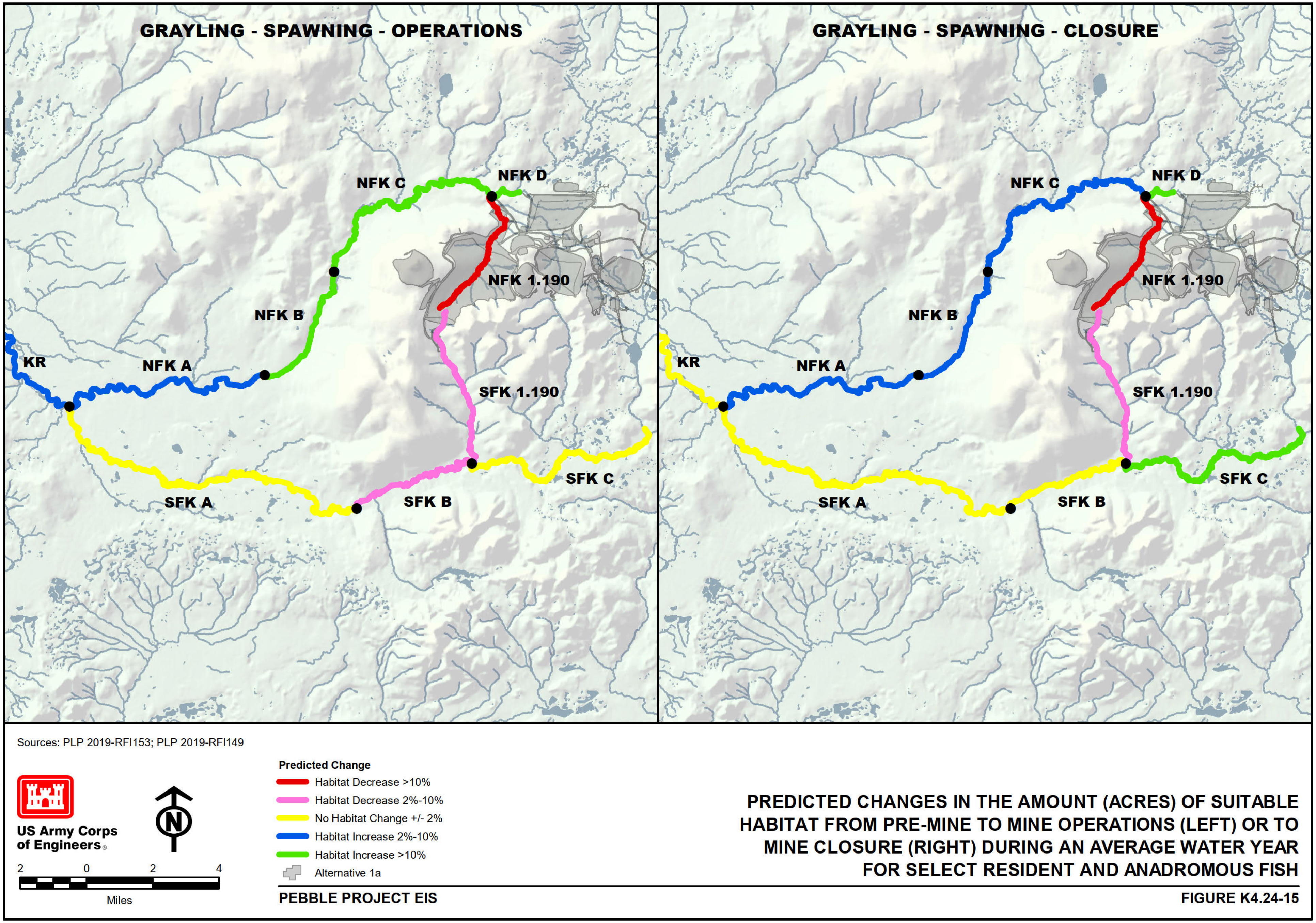
2 0 2 4
Miles

Predicted Change

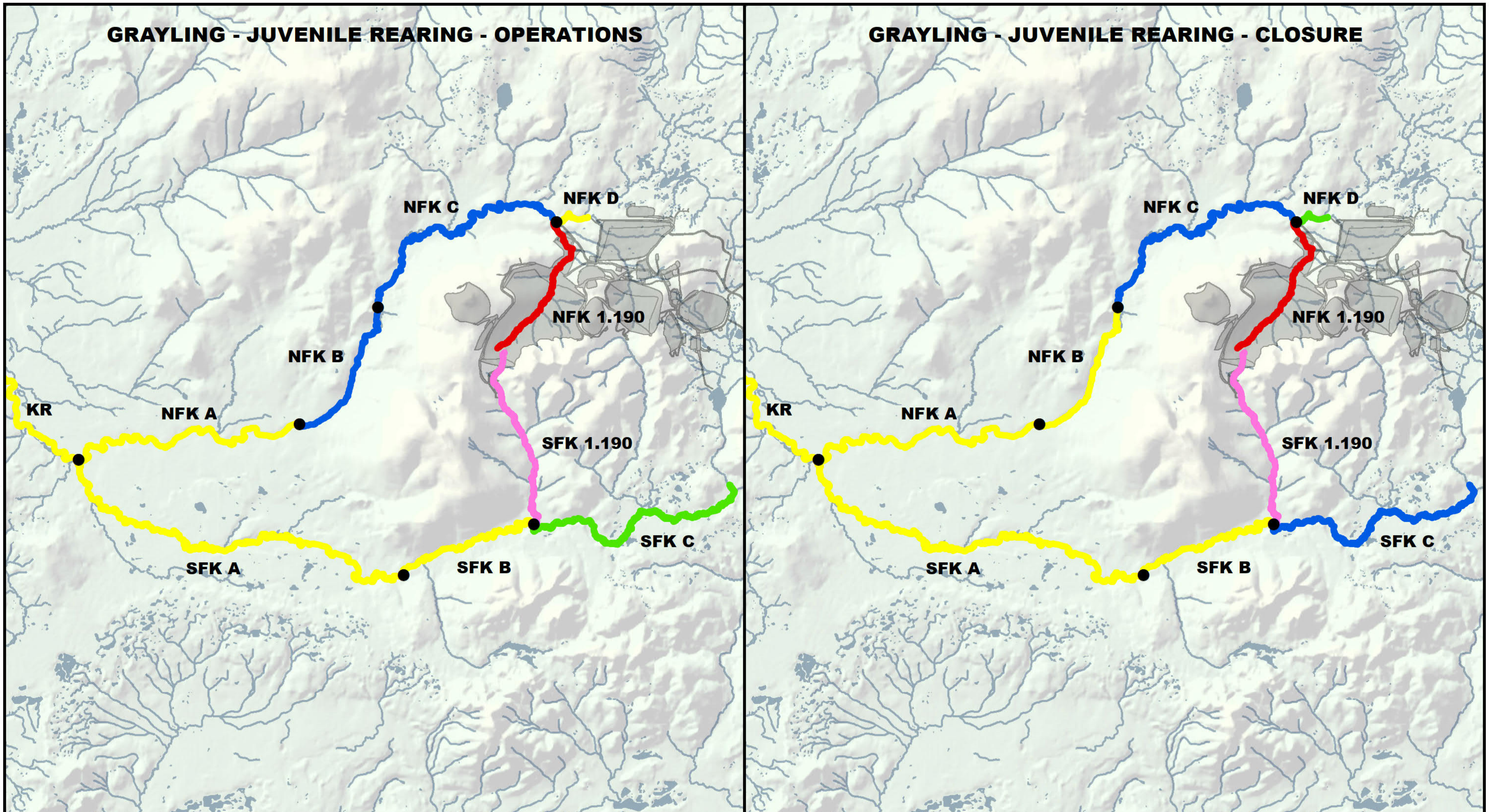
- Habitat Decrease >10%
- Habitat Decrease 2%-10%
- No Habitat Change +/- 2%
- Habitat Increase 2%-10%
- Habitat Increase >10%
- Alternative 1a

PREDICTED CHANGES IN THE AMOUNT (ACRES) OF SUITABLE HABITAT FROM PRE-MINE TO MINE OPERATIONS (LEFT) OR TO MINE CLOSURE (RIGHT) DURING AN AVERAGE WATER YEAR FOR SELECT RESIDENT AND ANADROMOUS FISH

FIGURE K4.24-14



PREDICTED CHANGES IN THE AMOUNT (ACRES) OF SUITABLE HABITAT FROM PRE-MINE TO MINE OPERATIONS (LEFT) OR TO MINE CLOSURE (RIGHT) DURING AN AVERAGE WATER YEAR FOR SELECT RESIDENT AND ANADROMOUS FISH



Sources: PLP 2019-RFI153; PLP 2019-RFI149

US Army Corps of Engineers®

N

2 0 2 4

Miles

Predicted Change

- Habitat Decrease >10%
- Habitat Decrease 2%-10%
- No Habitat Change +/- 2%
- Habitat Increase 2%-10%
- Habitat Increase >10%
- Alternative 1a

PREDICTED CHANGES IN THE AMOUNT (ACRES) OF SUITABLE HABITAT FROM PRE-MINE TO MINE OPERATIONS (LEFT) OR TO MINE CLOSURE (RIGHT) DURING AN AVERAGE WATER YEAR FOR SELECT RESIDENT AND ANADROMOUS FISH

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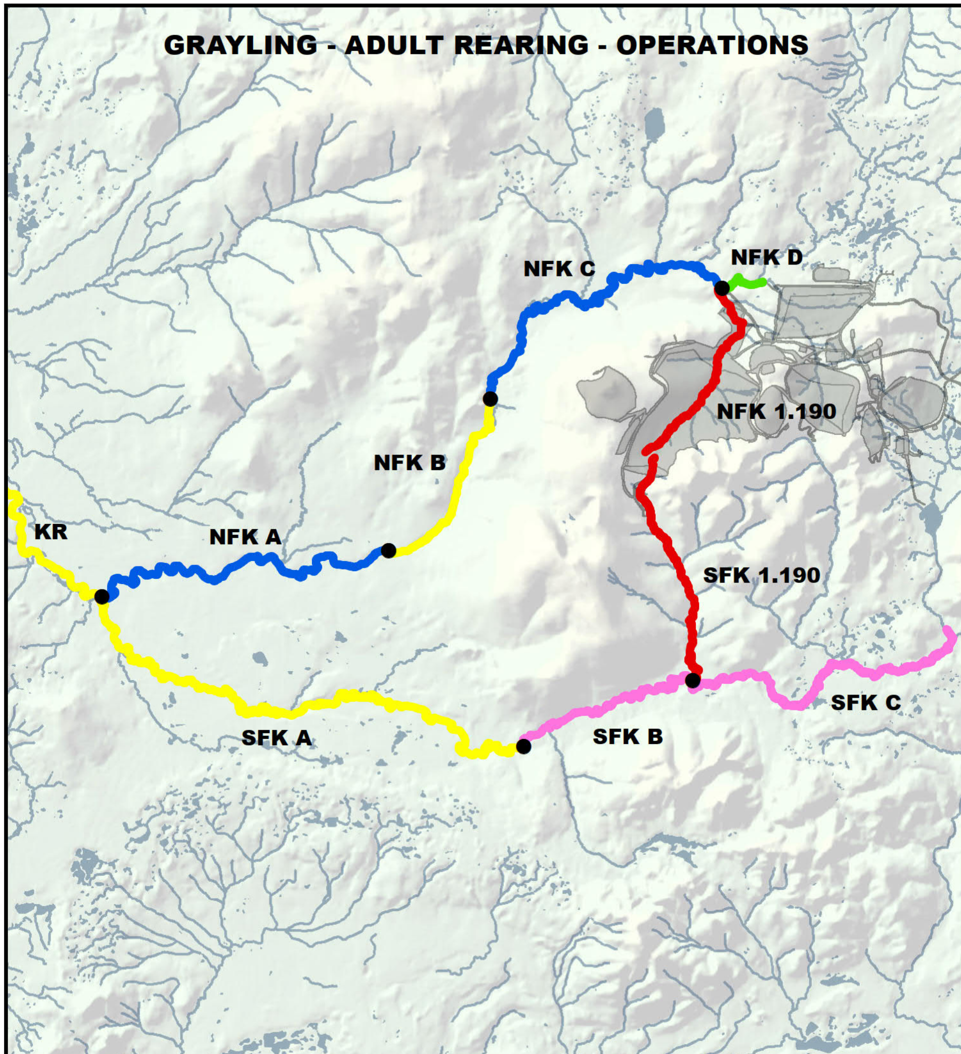
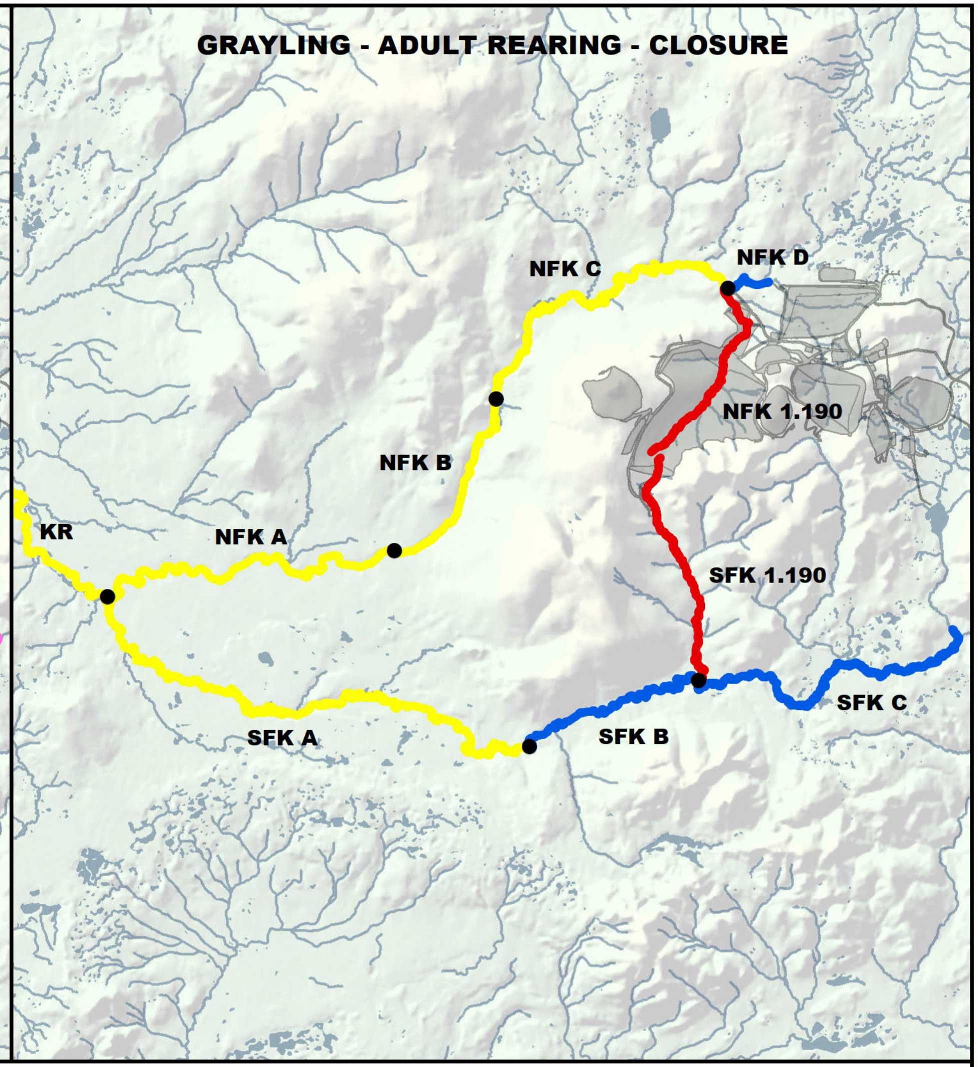
FIGURE K4.24-16





Sources: PLP 2019-RFI153; PLP 2019-RFI149

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2 0 2 4
Miles

Predicted Change

- Habitat Decrease >10%
- Habitat Decrease 2%-10%
- No Habitat Change +/- 2%
- Habitat Increase 2%-10%
- Habitat Increase >10%
- Alternative 1a

PREDICTED CHANGES IN THE AMOUNT (ACRES) OF SUITABLE HABITAT FROM PRE-MINE TO MINE OPERATIONS (LEFT) OR TO MINE CLOSURE (RIGHT) DURING AN AVERAGE WATER YEAR FOR SELECT RESIDENT AND ANADROMOUS FISH

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FIGURE K4.24-17

ATTACHMENTS

1. **PLP 2018-RFI 048**
2. **PLP 2019-RFI 147**

HABSYN is the term coined for the modeling approach that involves synthesis of habitat-flow relationships for unmeasured habitat units based on proximally measured transects. This modeling approach incorporates a "habitat-mapping" component that enables predictions of habitat-flow relationships for each habitat unit within a given reach. Using this methodology, the total habitat can be predicted under different scenarios with mine operation or treated water release. Data requirements of the HABSYN model include:

- Weighted usable area curves (obtained from the PHABSIM Analysis)
- Priority species and life stage for each stream and each month
- Mine operation conditions (obtained from The Pebble Partnership)
- Hydrology (obtained from the surface water-groundwater model developed by Knight Piésold)

The HABSYN model can be simulated under different water treatment plant flow release scenarios.

Instream Flow Data Collection and PHABSIM Analysis

The Mainstem Instream Flow Study was initiated in 2004, with Phase 1 modeling of baseline conditions conducted through 2008. Detailed descriptions of the field data collection and methods of this phase are provided in Appendix 15.1C of the EBD (PLP, 2011) with salient methods summarized herein to provide a comprehensive description of the model analysis to date. Over the course of the study, two strategies were applied in selecting transects; habitat representative transects were established from 2004 – 2007 and in 2008 transects were established to provide intensive characterization of selected reaches. Transect placement from 2004 to 2007 were located to represent habitat types within reaches spanning a significant portion of the lengths of the mainstem North Fork Koktuli (NFK), South Fork Koktuli (SFK), and Upper Talarik (UT), the upper segment of Koktuli River (KR), and one of the major tributaries in UT. The 2004 transects were selected based on professional judgment to represent various habitat types within typical reach habitats. Transects selected in 2005 were based on a stratified – random selection process that focused on sampling habitat types within different reaches; eight additional transects were established in 2007 using similar procedures.
In 2008, transect selection focused on intensive reach sampling. Multiple transects were established within targeted reaches of each stream (identified during an aerial helicopter survey) that contained important habitat features, including known salmon spawning habitat. Transect placement within the reaches was based on capturing representative habitat types (e.g., pool, riffle, run, etc.) that comprised such features.

Combining both transect selection approaches, 36 transects in 2004 (distributed as NFK – 10 transects, SFK – 10 transects, UT – 11 transects, and KR – 5 transects), 48 in 2005 (NFK – 10 transects, SFK – 17 transects, UT – 15 transects, and UT1.190 tributary – 6 transects), 8 in 2007 (NFK – 1 transect, SFK- 1 transect, UT – 6 transects), and 46 in 2008 (NFK – 14 transects, NFK1.190 tributary – 3 transects, SFK – 12 transects, SFK1.190 tributary – 6 transects, UT – 11 transects). A total of 138 transects were established from 2004 to 2008.

During the data review process, several issues were identified on a subset of the transects that would potentially complicate the model calibration process. The issues included, primarily, a) changes in stream bed elevations and profiles over time and between field surveys, and b) development of inconsistent flow vs. water surface elevation (Q vs. WSE) rating curves. A total of 21 transects, distributed as follows: 8 transects in the NFK, 3 transects in the SFK, 9 transects in UT, and 1 transect on KR, had one or both of these issues and could not be used in the model. As a result, field surveys to re-establish 21 transects were undertaken in early June 2010.

The current analysis used 20 of the 21 transects bringing the total number of transects analyzed up to 137. One transect in UT (Transect 07-UTC2-RN6) was discovered to have already been reestablished in 2008 and was subsequently dropped from the 2010 field effort, reducing the total number of transects replaced in 2010 to 20. The distribution of these 20 transects included 38 transects in the NFK (including 3 transects on NFK 1.190) (see Figure 1); 46 transects in the SFK (including 6 transects on SFK 1.190) (see Figure 2); 48 transects in UT (including 6 transects in UT 1.190) (see Figure 3), and 5 transects in KR (see Figure 4).

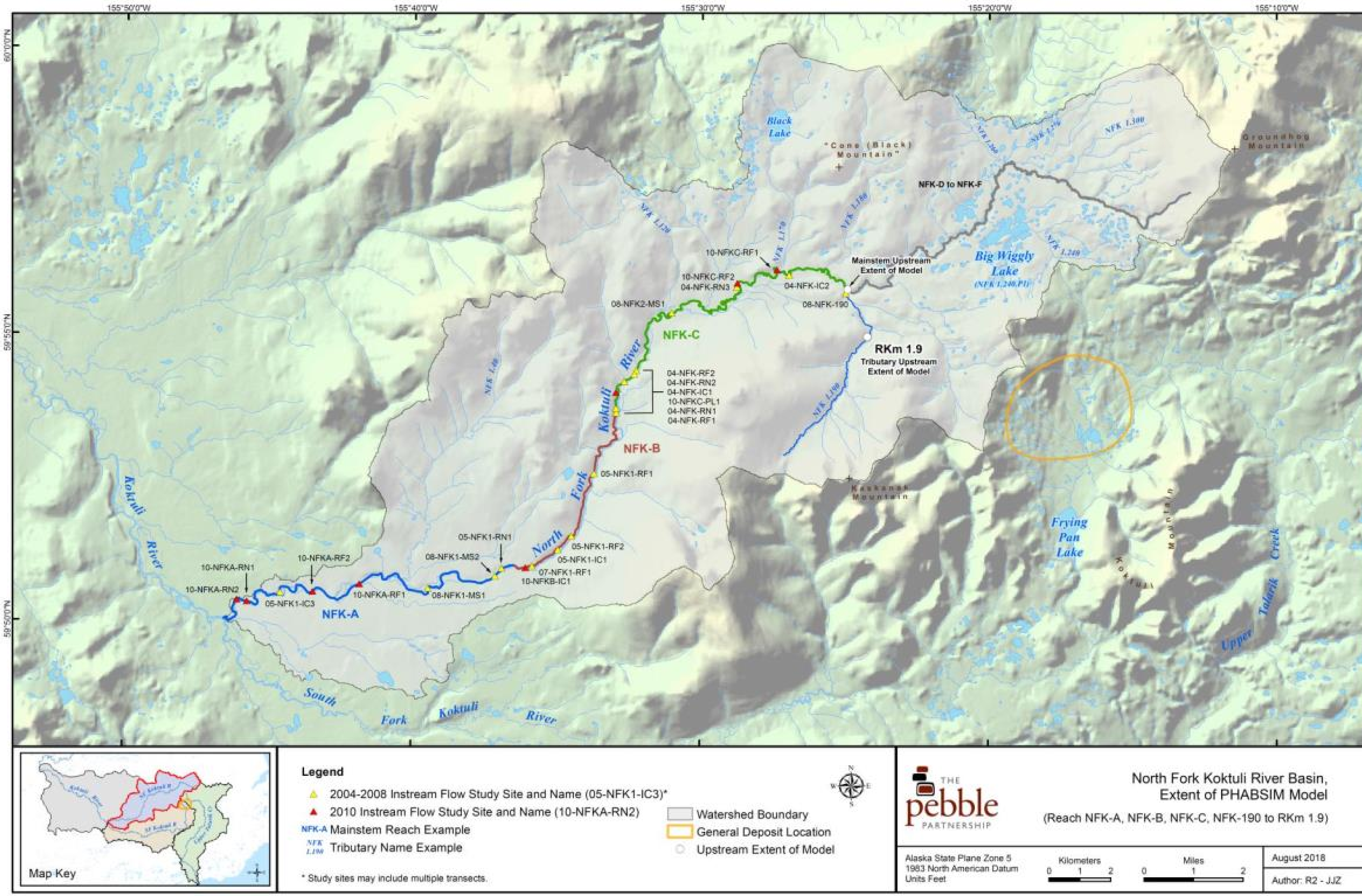


Figure 1. Locations of the 38 transects and model extent in the NFK used in the HABSYN modeling.

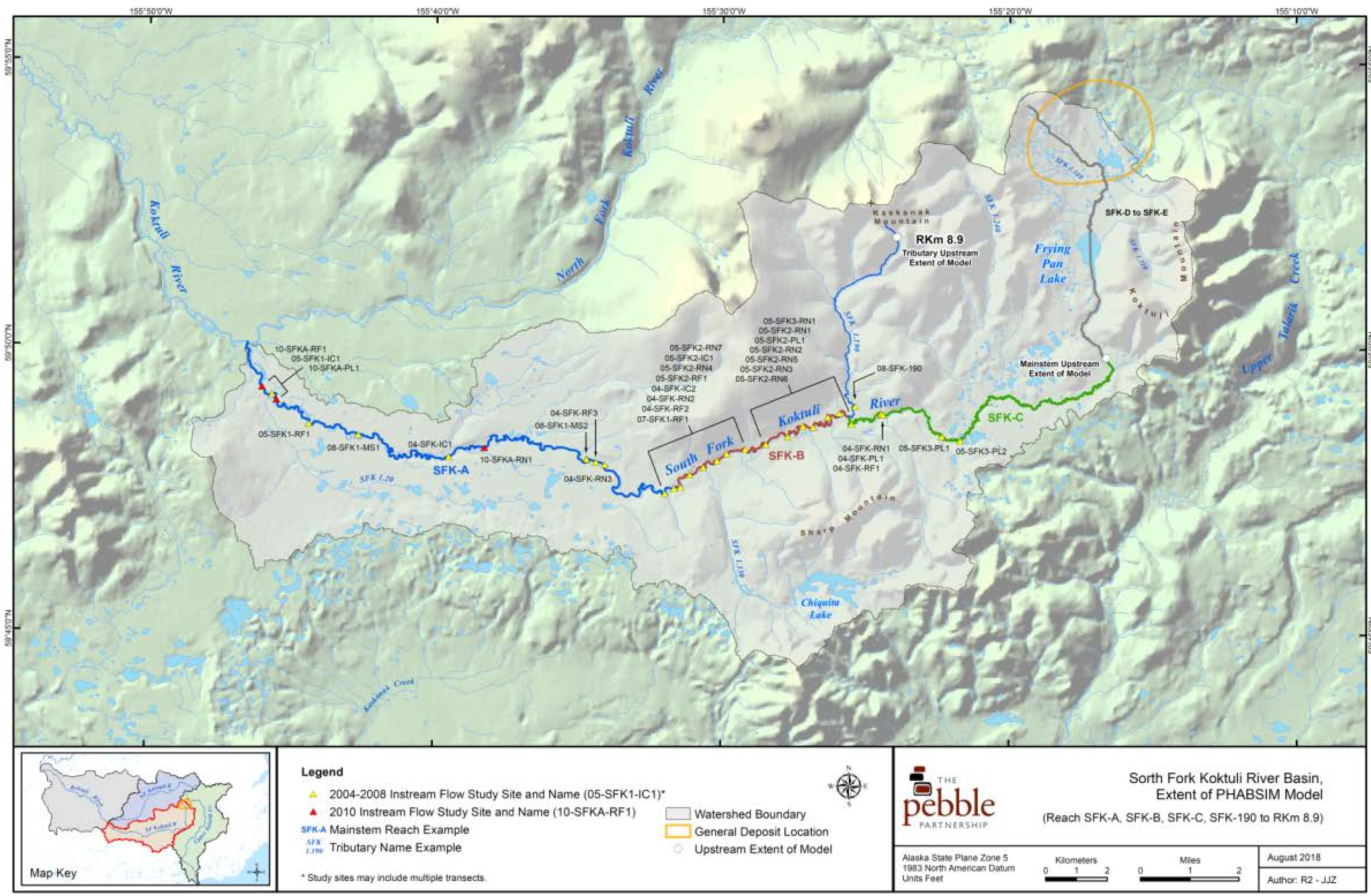


Figure 2. Locations of the 46 transects and model extent in the SFK used in the HABSYN modeling.

Figure 3. Locations of the 48 transects and model extent in the UT used in the HABSYN modeling.

Figure 4. Locations of the five transects in the KR used in the HABSYN modeling.

Species/Lifestage Periodicity and Priority

Hydrologic analysis and simulation of the HABSYN model require incorporation of species and lifestage periodicity as well as an assigned priority. The PHABSIM component of the model employs a lifestage/species prioritization process from which to derive monthly habitat flow needs for each watershed. This prioritization process was based on the same periodicity chart presented in the EBD and repeated in Figure 5. The periodicity developed was based on a general understanding of the local fish species described in the published literature, as well as site specific data collected as part of the fish and instream flow studies.

Using periodicity and existing data on fish distribution and abundance (PLP, 2011) the target species priority was determined for each basin. Following species prioritization, the lifestage prioritization was developed. The spawning lifestage was given a higher priority than juvenile rearing which was given a higher priority than fry. The species/lifestage priorities depicted in Table 1 were applied in the PHABSIM modeling.

Hydrologic Analysis

Hydrologic data were provided to R2 by Knight Piésold for Pre-Mine, Mine Affected during operations, and Mine Affected Post Closure conditions. The hydrologic data used in the analysis is the May 2018 Hydrology developed in support of the updated mine plan (termed May 2018 Hydrology for future reference). The hydrology used in the HABSYN Analysis was recently expanded from a 68-year period of record (1942-2009) to a 76-year period of record (1942-2017). These flow data consisted of 76 years of synthesized monthly flows from January 1942 to December 2017 at a total of 30 habitat-hydrology node locations summarized in Table 2. Flows between nodes were interpolated based on ground water versus surface water contributions or, if those data were not available, drainage area. The longitudinal variation of drainage area with river kilometer is shown in Figures 6, 7, and 8 for the North Fork Koktuli, South Fork Koktuli, and Upper Talarik Basins, respectively.

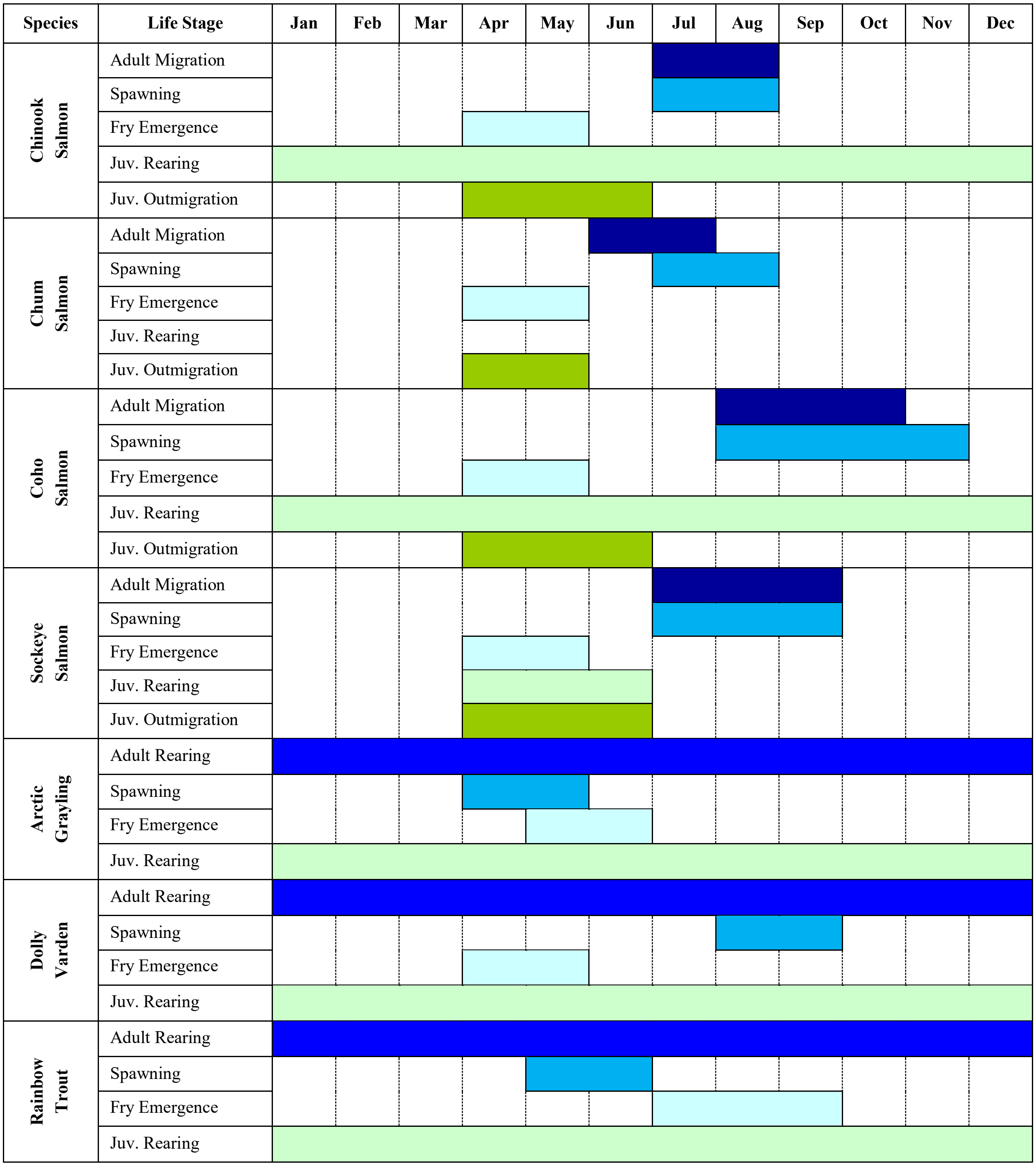


Figure 5. Life-history stage periodicity for select target species in the fish resource study area based on general understanding of local populations and empirical data.

Table 1. Priority species and life stages currently used to determine the habitat flow needs in the South Fork Koktuli River (SFK), North Fork Koktuli River (NFK), and Upper Talarik Creek (UT).

Month	Priority Species/Life Stages		
	SFK	NFK	UT
Jan	Chinook Juvenile Rearing	Chinook Juvenile Rearing	Coho Juvenile Rearing
Feb			
Mar			
Apr	Arctic Grayling Spawning	Arctic Grayling Spawning	Arctic Grayling Spawning
May			
Jun	Rainbow Spawning	Rainbow Spawning	Rainbow Spawning
Jul	Chinook Spawning	Chinook Spawning	Sockeye Spawning
Aug			
Sep	Coho Spawning	Coho Spawning	Coho Spawning
Oct			
Nov			
Dec	Chinook Juvenile Rearing	Chinook Juvenile Rearing	Coho Juvenile Rearing

Table 2. Habitat-hydrology nodes.

Basin	Hydrologic Node	Reach	Location (River KM)
NFK	NK100A	NFK-A	5.27
	FRS-4	NFK-A	9.31
	NK100A1	NFK-B	13.7
	NK100LF3	NFK-C	27.93
	NK100B	NFK-C	35.75
	NK100C	NFK-D	36.75
	NK119A	NFK 1.190	1.90
	NK119B	NFK 1.190	0.09
	FRS-NK119	NFK 1.190	7.74
SFK	SF100A	SFK-A	0.11
	FRS-2	SFK-A	2.97
	FRS-3	SFK-A	13.91
	SK100B	SFK-B	24.90
	SK100LF6	SFK-B	34.02
	SK100C	SFK-C	35.81
	SK100LF4	SFK-C	43.64
	SK100LF2	SFK-C	51.09
	SK100F	SFK-D	54.67
	SK119A	SFK 1.190	1.80
	FRS-SK119	SFK 1.190	6.01
UT	UT100APC1	UT-B	9.85
	UT100B	UT-C	24.50
	FRS-5	UT-D	25.00
	UT100C2	UT-D	44.63
	UT100D	UT-E	51.62
	UT100E	UT-E	59.98
	UT119A	UT 1.190	0.32
	FRS-UT119A	UT 1.190	3.25
	UT135A	UT 1.350	1.31

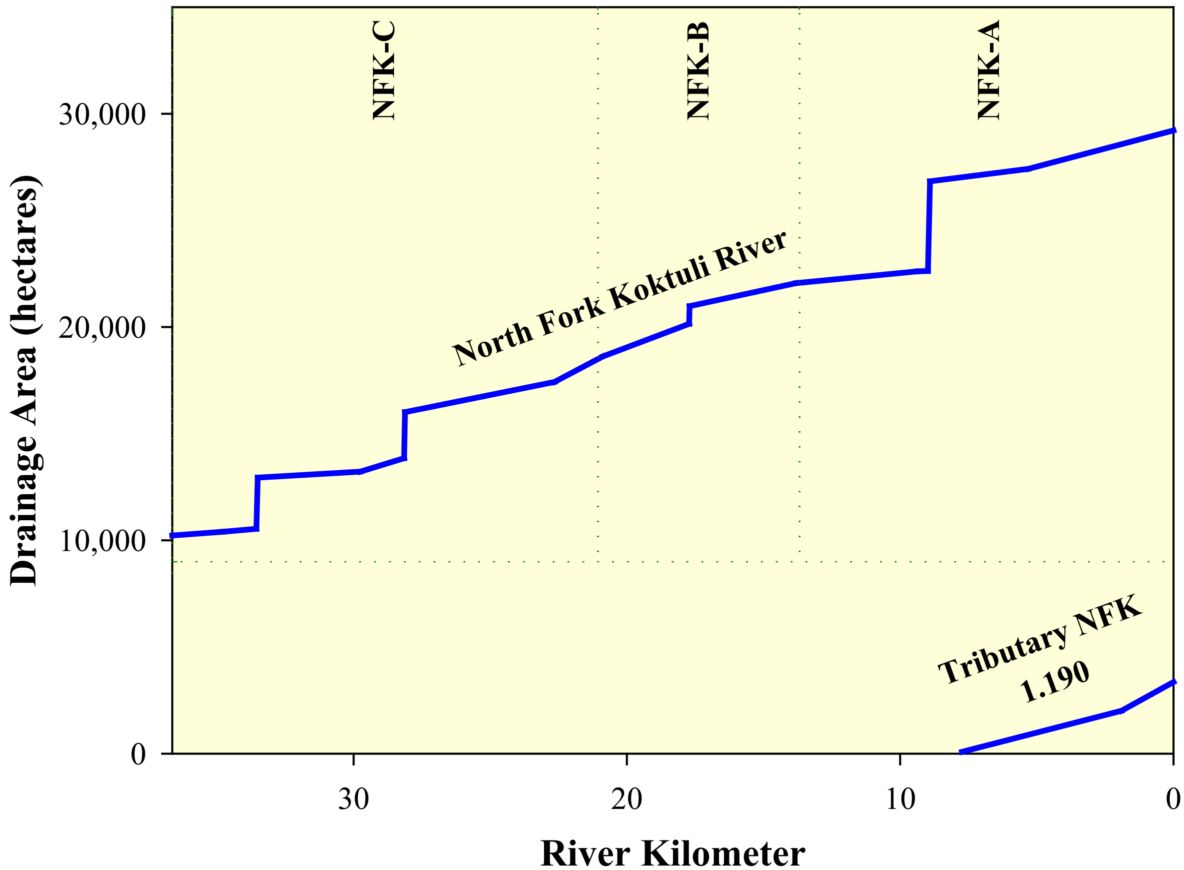


Figure 6. Longitudinal variation of drainage area along the North Fork Koktuli River in reaches NFK-A, NFK-B, and NFK-C, and in Tributary NFK 1.190.

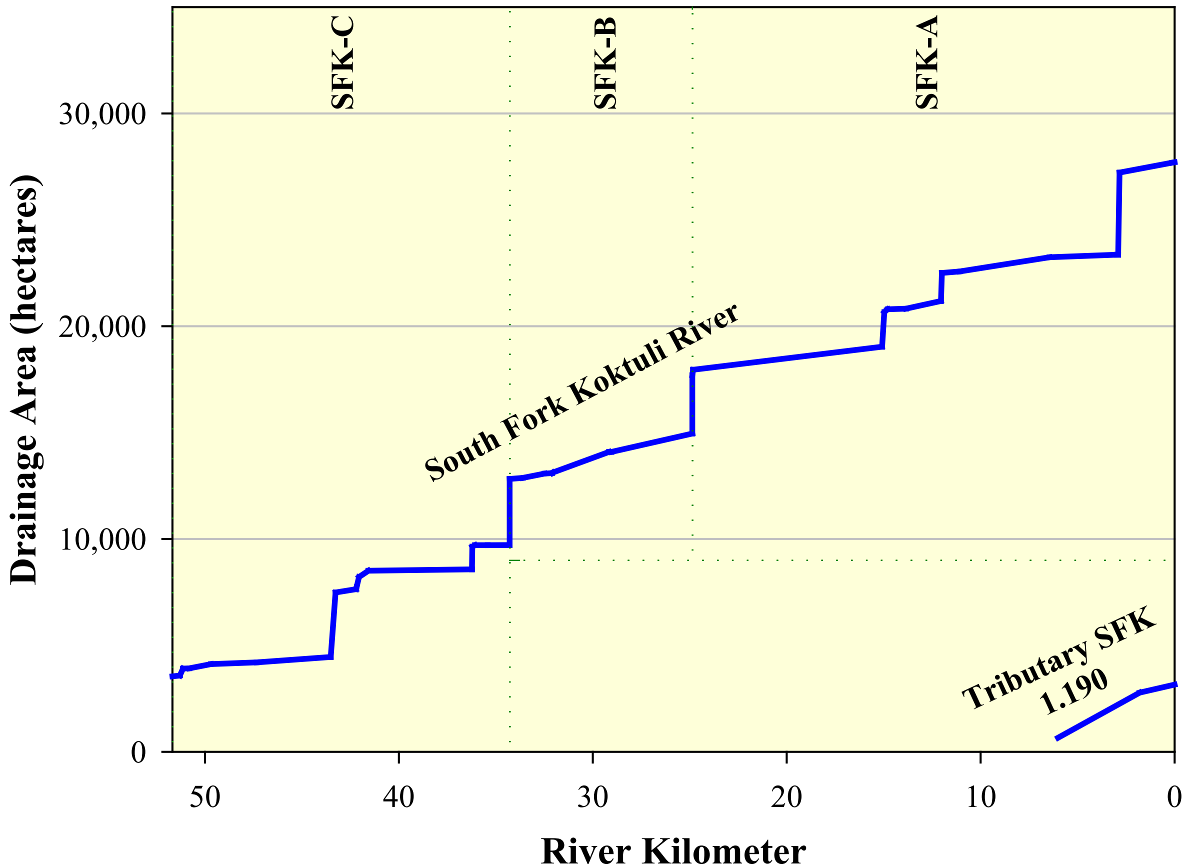


Figure 7. Longitudinal variation of drainage area along the South Fork Koktuli River in reaches SFK-A, SFK-B, and SFK-C, and in Tributary SFK 1.190.

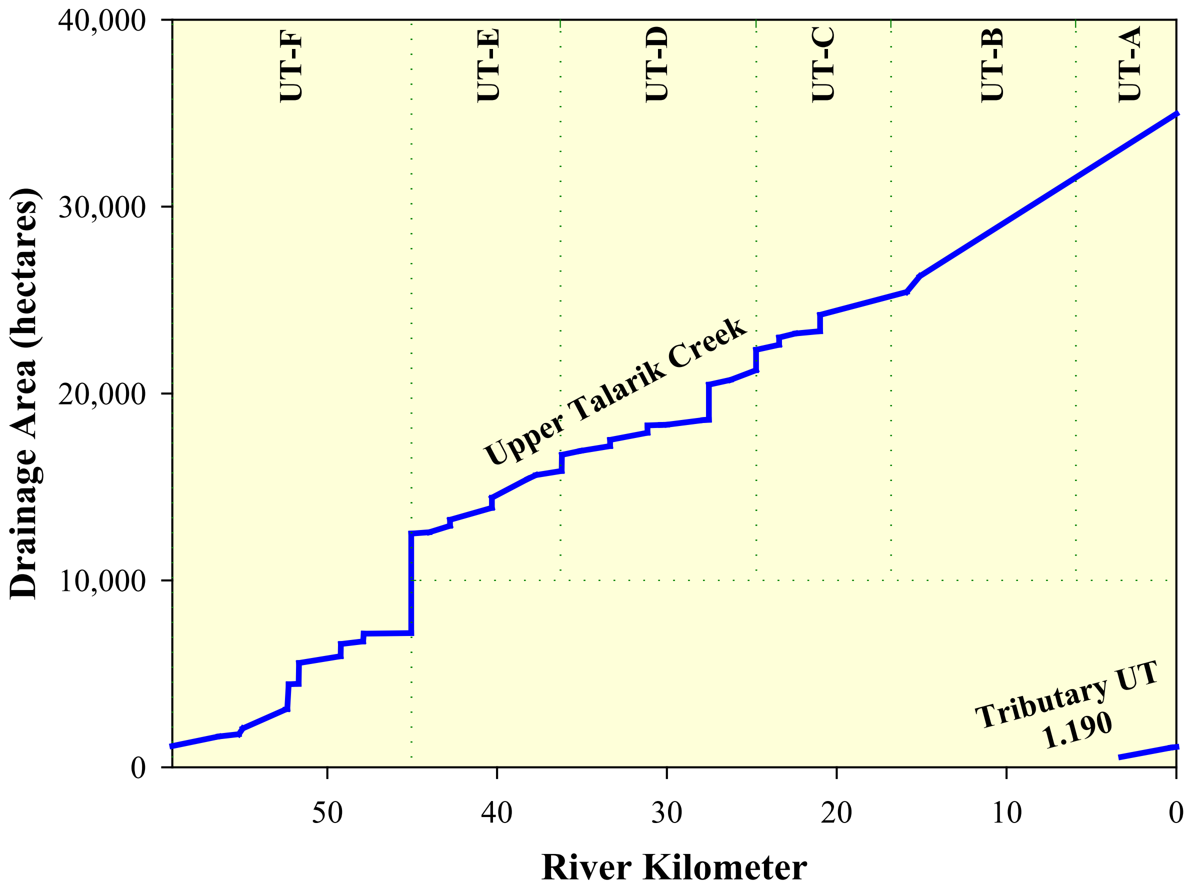


Figure 8. Longitudinal variation of drainage area along in Upper Talarik Creek in reaches UT-A, UT-B, UT-C, UT-D, UT-E and UT-F, and in Tributary UT 1.190.

Wet, Average, and Dry Years

The May 2018 monthly flow hydrology provided by Knight Piésold were analyzed to select representative wet, average, and dry years for analysis of fish habitat availability within the 76-year period of record. Wet, average, and dry years were determined for each target species/life stage, based on the corresponding periodicity. For example, Chinook salmon spawn in July and August. The average flow during the July/August period was determined for each year from 1942 through 2017. Then representative wet, average, and dry years were selected based on the 10% exceedance, average, and 90% percent exceedance flows, respectively. The representative wet year is the year with the calculated value closest to the 10% exceedance over the period of record. The representative dry year is the year with the calculated value closest to the 90% exceedance over the period of record. The average year is the year with the calculated value closest to the average over the period of record. Similarly, Coho salmon juvenile outmigration occurs in April through June so wet, normal, and dry conditions were also determined for the April through June period only. A similar procedure was followed for the other target species/life stages based on the corresponding months of the year for each periodicity. The month combinations allow you to determine the applicable periodicity for each target species/lifestage. Overall, there were 11 different month combinations for which wet, normal, and dry conditions were determined (see Table 3 Lifestage Periodicity column).

Representative wet, average, and dry years were selected for the following four locations:

1. **Hydrology Gage NK100A (USGS Gage 15302250)** – considered to be representative of hydrology in the North Fork Koktuli River Basin.
2. **Hydrology Gage SK100B (USGS Gage 15302200)** – considered to be representative of hydrology in the South Fork Koktuli River Basin.
3. **Hydrology Gage UT100B (USGS Gage 15300250)** – considered to be representative of hydrology in the Upper Talarik Creek Basin.
4. **IFIM Transect 04MSK-RF2** – considered to be representative of hydrology in the Koktuli River.

Using the January 1942 – December 2017 hydrology, representative wet, average, and dry years were determined for each target species/life stages at these four locations, and the results summarized in Tables 3, 4, 5, and 6, respectively.

Table 3. Representative Wet (10% exceedance), Average, and Dry (90% exceedance) years in the North Fork Koktuli River Basin for target species and life stages, derived from updated synthesized monthly flows at Hydrology Gage NK100A (USGS Gage 15302250), 1942 through 2017.

Species	Life Stage	Lifestage Periodicity	Wet		Average		Dry	
			Year	Average Flow (cfs)	Year	Average Flow (cfs)	Year	Average Flow (cfs)
Chinook Salmon	Adult Migration	Jul-Aug	1952	457	1948	304	1990	157
	Spawning	Jul-Aug	1952	457	1948	304	1990	157
	Fry Emergence	Apr-May	1944	530	1958	309	1999	134
	Juvenile Rearing	Jan-Dec	2002	349	1963	262	1974	180
	Juvenile Outmigration	Apr-Jun	1985	608	2001	388	1978	194
Coho Salmon	Adult Migration	Aug-Oct	2006	531	2004	348	1962	195
	Spawning	Aug-Nov	2006	482	1952	317	1984	191
	Fry Emergence	Apr-May	1944	530	1958	309	1999	134
	Juvenile Rearing	Jan-Dec	2002	349	1963	262	1974	180
	Juvenile Outmigration	Apr-Jun	1985	608	2001	388	1978	194
Chum Salmon	Adult Migration	Jun-Jul	1944	784	1994	437	2015	198
	Spawning	Jul-Aug	1952	457	1948	304	1990	157
	Fry Emergence	Apr-May	1944	530	1958	309	1999	134
	Juvenile Outmigration	Apr-May	1944	530	1958	309	1999	134
Sockeye Salmon	Adult Migration	Jul-Sep	2016	472	1987	335	1968	190
	Spawning	Jul-Sep	2016	472	1987	335	1968	190
	Fry Emergence	Apr-May	1944	530	1958	309	1999	134
	Juvenile Rearing	Apr-Jun	1985	608	2001	388	1978	194
	Juvenile Outmigration	Apr-Jun	1985	608	2001	388	1978	194
Rainbow Trout	Adult Rearing	Jan-Dec	2002	349	1963	262	1974	180
	Spawning	May-Jun	1985	874	1960	543	1978	270
	Fry Emergence	Jul-Sep	2016	472	1987	335	1968	190
	Juvenile Rearing	Jan-Dec	2002	349	1963	262	1974	180
Dolly Varden Trout	Adult Rearing	Jan-Dec	2002	349	1963	262	1974	180
	Spawning	Aug-Sep	2012	561	1943	357	1990	183
	Fry Emergence	Apr-May	1944	530	1958	309	1999	134
	Juvenile Rearing	Jan-Dec	2002	349	1963	262	1974	180
Arctic Grayling	Adult Rearing	Jan-Dec	2002	349	1963	262	1974	180
	Spawning	Apr-May	1944	530	1958	309	1999	134
	Fry Emergence	May-Jun	1985	874	1960	543	1978	270
	Juvenile Rearing	Jan-Dec	2002	349	1963	262	1974	180

Table 4. Representative Wet (10% exceedance), Average, and Dry (90% exceedance) years in the South Fork Koktuli River Basin for target species and life stages, derived from updated synthesized monthly flows at Hydrology Gage SK100B (USGS Gage 15302200), 1942 through 2017.

Species	Life Stage	Lifestage Periodicity	Wet		Average		Dry	
			Year	Average Flow (cfs)	Year	Average Flow (cfs)	Year	Average Flow (cfs)
Chinook Salmon	Adult Migration	Jul-Aug	1946	369	1969	218	2004	109
	Spawning	Jul-Aug	1946	369	1969	218	2004	109
	Fry Emergence	Apr-May	1967	390	1977	236	2007	118
	Juvenile Rearing	Jan-Dec	2016	250	1965	188	1974	127
	Juvenile Outmigration	Apr-Jun	1967	441	1960	287	1996	166
Coho Salmon	Adult Migration	Aug-Oct	1944	372	1977	248	1974	138
	Spawning	Aug-Nov	2006	336	1977	224	1974	131
	Fry Emergence	Apr-May	1967	390	1977	236	2007	118
	Juvenile Rearing	Jan-Dec	2016	250	1965	188	1974	127
	Juvenile Outmigration	Apr-Jun	1967	441	1960	287	1996	166
Chum Salmon	Adult Migration	Jun-Jul	1944	634	2005	312	2015	120
	Spawning	Jul-Aug	1946	369	1969	218	2004	109
	Fry Emergence	Apr-May	1967	390	1977	236	2007	118
	Juvenile Outmigration	Apr-May	1967	390	1977	236	2007	118
Sockeye Salmon	Adult Migration	Jul-Sep	1955	352	2013	242	1978	128
	Spawning	Jul-Sep	1955	352	2013	242	1978	128
	Fry Emergence	Apr-May	1967	390	1977	236	2007	118
	Juvenile Rearing	Apr-Jun	1967	441	1960	287	1996	166
	Juvenile Outmigration	Apr-Jun	1967	441	1960	287	1996	166
Rainbow Trout	Adult Rearing	Jan-Dec	2016	250	1965	188	1974	127
	Spawning	May-Jun	2005	626	2001	411	1950	220
	Fry Emergence	Jul-Sep	1955	352	2013	242	1978	128
	Juvenile Rearing	Jan-Dec	2016	250	1965	188	1974	127
Dolly Varden Trout	Adult Rearing	Jan-Dec	2016	250	1965	188	1974	127
	Spawning	Aug-Sep	1998	393	1950	254	1978	129
	Fry Emergence	Apr-May	1967	390	1977	236	2007	118
	Juvenile Rearing	Jan-Dec	2016	250	1965	188	1974	127
Arctic Grayling	Adult Rearing	Jan-Dec	2016	250	1965	188	1974	127
	Spawning	Apr-May	1967	390	1977	236	2007	118
	Fry Emergence	May-Jun	2005	626	2001	411	1950	220
	Juvenile Rearing	Jan-Dec	2016	250	1965	188	1974	127

Table 5. Representative Wet (10% exceedance), Average, and Dry (90% exceedance) years in the Upper Talarik Creek Basin for target species and life stages, derived from updated synthesized monthly flows at Hydrology Gage UT100B (USGS Gage 15300250), 1942 through 2017.

Species	Life Stage	Lifestage Periodicity	Wet		Average		Dry	
			Year	Average Flow (cfs)	Year	Average Flow (cfs)	Year	Average Flow (cfs)
Chinook Salmon	Adult Migration	Jul-Aug	1952	355	1979	239	2017	153
	Spawning	Jul-Aug	1952	355	1979	239	2017	153
	Fry Emergence	Apr-May	2005	406	2001	258	1943	146
	Juvenile Rearing	Jan-Dec	1987	292	2001	229	1993	168
	Juvenile Outmigration	Apr-Jun	1980	433	1986	306	2015	177
Coho Salmon	Adult Migration	Aug-Oct	2015	363	2007	262	1974	156
	Spawning	Aug-Nov	2006	358	2011	250	1974	161
	Fry Emergence	Apr-May	2005	406	2001	258	1943	146
	Juvenile Rearing	Jan-Dec	1987	292	2001	229	1993	168
	Juvenile Outmigration	Apr-Jun	1980	433	1986	306	2015	177
Chum Salmon	Adult Migration	Jun-Jul	1972	541	1966	318	2017	179
	Spawning	Jul-Aug	1952	355	1979	239	2017	153
	Fry Emergence	Apr-May	2005	406	2001	258	1943	146
	Juvenile Outmigration	Apr-May	2005	406	2001	258	1943	146
Sockeye Salmon	Adult Migration	Jul-Sep	1955	328	1956	252	1978	156
	Spawning	Jul-Sep	1955	328	1956	252	1978	156
	Fry Emergence	Apr-May	2005	406	2001	258	1943	146
	Juvenile Rearing	Apr-Jun	1980	433	1986	306	2015	177
	Juvenile Outmigration	Apr-Jun	1980	433	1986	306	2015	177
Rainbow Trout	Adult Rearing	Jan-Dec	1987	292	2001	229	1993	168
	Spawning	May-Jun	1994	598	1986	394	1943	204
	Fry Emergence	Jul-Sep	1955	328	1956	252	1978	156
	Juvenile Rearing	Jan-Dec	1987	292	2001	229	1993	168
Dolly Varden Trout	Adult Rearing	Jan-Dec	1987	292	2001	229	1993	168
	Spawning	Aug-Sep	1998	372	1950	259	1993	153
	Fry Emergence	Apr-May	2005	406	2001	258	1943	146
	Juvenile Rearing	Jan-Dec	1987	292	2001	229	1993	168
Arctic Grayling	Adult Rearing	Jan-Dec	1987	292	2001	229	1993	168
	Spawning	Apr-May	2005	406	2001	258	1943	146
	Fry Emergence	May-Jun	1994	598	1986	394	1943	204
	Juvenile Rearing	Jan-Dec	1987	292	2001	229	1993	168

Table 6. Representative Wet (10% exceedance), Average, and Dry (90% exceedance) years in the Koktuli River for target species and life stages, derived from updated synthesized monthly flows at IFIM Transect 04MSK-RF2, 1942 through 2017.

Species	Life Stage	Lifestage Periodicity	Wet		Average		Dry	
			Year	Average Flow (cfs)	Year	Average Flow (cfs)	Year	Average Flow (cfs)
Chinook Salmon	Adult Migration	Jul-Aug	1952	1365	1972	883	1990	448
	Spawning	Jul-Aug	1952	1365	1972	883	1990	448
	Fry Emergence	Apr-May	2016	1607	1970	998	2003	459
	Juvenile Rearing	Jan-Dec	2002	1041	1963	798	1993	555
	Juvenile Outmigration	Apr-Jun	1979	1779	2001	1166	1996	607
Coho Salmon	Adult Migration	Aug-Oct	2006	1580	1964	1048	1992	614
	Spawning	Aug-Nov	2006	1438	1969	970	2001	588
	Fry Emergence	Apr-May	2016	1607	1970	998	2003	459
	Juvenile Rearing	Jan-Dec	2002	1041	1963	798	1993	555
	Juvenile Outmigration	Apr-Jun	1979	1779	2001	1166	1996	607
Chum Salmon	Adult Migration	Jun-Jul	1944	2018	1966	1141	1951	550
	Spawning	Jul-Aug	1952	1365	1972	883	1990	448
	Fry Emergence	Apr-May	2016	1607	1970	998	2003	459
	Juvenile Outmigration	Apr-May	2016	1607	1970	998	2003	459
Sockeye Salmon	Adult Migration	Jul-Sep	2016	1394	1948	981	1974	548
	Spawning	Jul-Sep	2016	1394	1948	981	1974	548
	Fry Emergence	Apr-May	2016	1607	1970	998	2003	459
	Juvenile Rearing	Apr-Jun	1979	1779	2001	1166	1996	607
	Juvenile Outmigration	Apr-Jun	1979	1779	2001	1166	1996	607
Rainbow Trout	Adult Rearing	Jan-Dec	2002	1041	1963	798	1993	555
	Spawning	May-Jun	1963	2419	1954	1595	1978	770
	Fry Emergence	Jul-Sep	2016	1394	1948	981	1974	548
	Juvenile Rearing	Jan-Dec	2002	1041	1963	798	1993	555
Dolly Varden Trout	Adult Rearing	Jan-Dec	2002	1041	1963	798	1993	555
	Spawning	Aug-Sep	1944	1660	1950	1066	1974	533
	Fry Emergence	Apr-May	2016	1607	1970	998	2003	459
	Juvenile Rearing	Jan-Dec	2002	1041	1963	798	1993	555
Arctic Grayling	Adult Rearing	Jan-Dec	2002	1041	1963	798	1993	555
	Spawning	Apr-May	2016	1607	1970	998	2003	459
	Fry Emergence	May-Jun	1963	2419	1954	1595	1978	770
	Juvenile Rearing	Jan-Dec	2002	1041	1963	798	1993	555

Reach and Basin-scale Expansions

Mainstem Meso-Habitat Analysis

As described in Appendix 15.1C of the EBD (PLP, 2011), habitat mapping analysis provided estimates of the overall quantity of mesohabitats available in the NFK, SFK, and UT systems. The mapping effort was based on combined field and remote-sensing information. Mesohabitats are hydromorphological units exhibiting similar depth, water surface slope, flow velocity, and substrate characteristics. Four mesohabitat types were delineated including pools, riffles, runs, and island channel complexes.

Habitat units were delineated within the wetted mainstem channel using data from three sources:

1. Mesohabitat field surveys conducted by HDR in 2004-2007,
2. A shapefile produced by HDR that consisted of habitat polygons delineated using aerial photographs and video, and
3. Aerial photo interpretation conducted by R2.

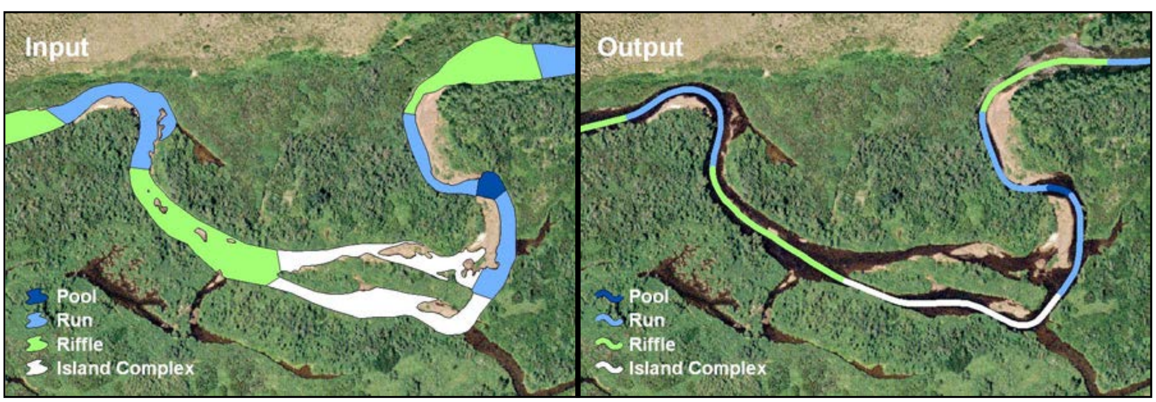
The data sources listed above are ranked in the order of their perceived accuracy; where the spatial extent of each dataset overlapped, mesohabitat mapping relied on the most accurate information source. Data derived from field surveys are considered to have the highest accuracy.

The base GIS data used in the mesohabitat analysis consisted of wetted edges of the mainstem North Fork Koktuli River, South Fork Koktuli River, and Upper Talarik Creek, which were digitized from the 2004 Eagle Mapping orthophotos (1:2,400 and 1:4,800 scale). The mainstem wetted area was defined as locations within the main channel margins that appeared to convey at least 10 percent of the discharge on the date the photos were flown. Isolated pools on top of gravel bars, partially wetted secondary flow channels connected to the river at the downstream end only, and off channel habitats (i.e., wetted areas that are surrounded by permanent vegetation and generally located outside of the bankfull channel margin) were not considered mainstem habitat areas and were thus not included in delineating mesohabitats.

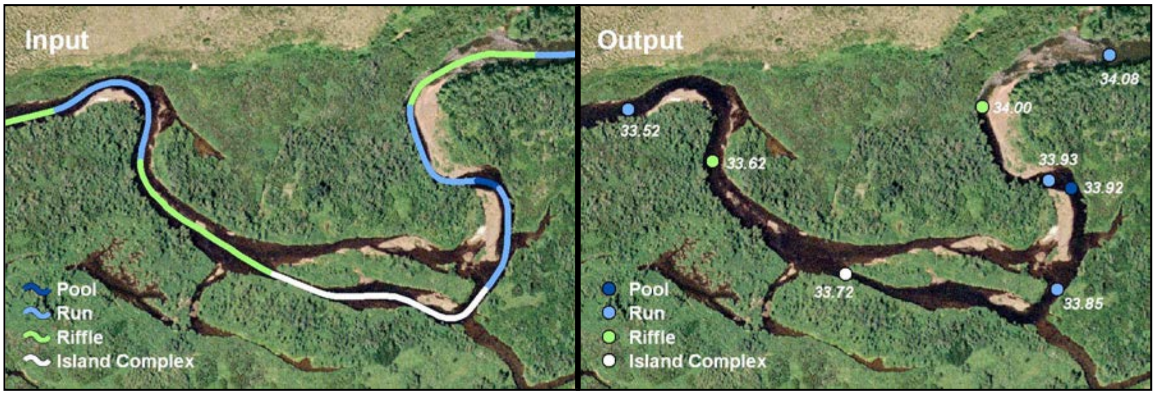
The steps subsequently used to calculate spatial habitat metrics for the mainstem streams for input into the flow-habitat impact model are briefly summarized below.

4. Generate stream centerline from the mesohabitat low-flow wetted area edges to improve habitat length and location (river kilometer) calculations over the Project's standard linear referencing system. The resultant line was edited to follow main channel within island complexes, around large islands, and through important paralleling habitats (see SFK-A example below).

5. Combine adjacent mesohabitat units of the same type (i.e., pool, run, riffle) and then transfer habitat type and area metrics from the unit polygon to the stream centerline generated using the procedure in step 1. The following NFK-C example shows the input and output file characteristics for this step.



6. Transfer mesohabitat unit metrics from stream centerline (output from step 2) to the downstream endpoint of the unit centerline and assign a river kilometer to each point.



7. Visually inspect polygons to check for parallel habitats. Parallel habitats are present when the habitat type on one bank is different from the habitat type on the other bank, such as a lateral scour pool located adjacent to a riffle. When this occurs, the river kilometer centerline was adjusted to ensure it goes thru the transition point from one habitat type to the other. The habitat areas must also be recalculated to account for multiple habitat types. The graphic below points to parallel habitats in SFK-A.

8. Calculate habitat unit length and average unit width (based on low-flow conditions) using GIS database fields that were exported to Excel for input into the flow-habitat impact model (see example in table below).

RiverKm	Stream Name	Reach	Habitat Type	Area (ft²)	Unit Length (ft)	Avg Unit Width (ft)
0.000	NFK	A	RN	3151.60	75.58	41.70
0.023	NFK	A	IC	47215.85	890.33	53.03
0.294	NFK	A	RF	29363.76	321.89	91.22
0.393	NFK	A	IC	39659.76	572.90	69.23
0.567	NFK	A	RF	33907.64	442.90	76.56
0.702	NFK	A	IC	45457.17	850.49	53.45
0.961	NFK	A	RF	10746.25	112.00	95.95
0.996	NFK	A	RN	11919.14	164.68	72.38
1.046	NFK	A	IC	29412.83	365.68	80.43
1.157	NFK	A	RN	4638.59	121.03	38.33
1.194	NFK	A	RF	17437.10	268.04	65.05
1.276	NFK	A	RN	15857.41	411.08	38.57
1.401	NFK	A	RF	7046.08	73.82	95.45
1.424	NFK	A	RN	55431.48	750.12	73.90
1.652	NFK	A	RF	39104.97	517.07	75.63

A GIS shapefile was then produced to facilitate the calculation of the wetted area by habitat type within the mainstem NFK, SFK, UT, and KR to support the instream flow modeling.

Tributary Meso-Habitat Analysis

Due to the smaller size of tributaries NFK 1.190, SFK 1.190, and UT 1.190, the length-based habitat composition of these streams could not be estimated with the GIS methods used for mainstem reaches as described above. Instead, habitat compositions and length were obtained from field habitat surveys conducted under the Fish and Aquatics program from 2004-2008. The location (RK) of individual habitat units was assigned by cumulatively adding the measured length of individual habitat units beginning at the mainstem confluence and extending to the upstream survey extent.

For NFK 1.190 and SFK 1.190, the wetted width of each unit was calculated as the average of three measurements. Wetted width was not measured in UT 1.190. However, bed width was measured in several locations and this information was used to approximate wetted width for habitat units in UT 1.190.

Habitat-Flow Analysis

R2 refined the modeling approach that was used in 2008 to allow the derivation of habitat-flow relationships on a habitat-unit basis. This approach provided greater spatial resolution and reliability of results. To quantify the change in habitat area for each of the habitat units, synthesized habitat ~ flow relationships (i.e., WUA or Weighted Usable Area curves) were derived using the modeled WUA from the PHABSIM transects within the river reach. There are nearly two thousand habitat units (Table 7) within the three stream basins (NFK, SFK, UT), and 132 transects (Table 8) with hydraulic data and habitat ~ flow relationships modeled. As a result, the modeled habitat ~ flow relationships of those transects were expanded to synthesize WUA for each of the habitat units using the procedure described below. The synthesized WUAs were calculated at the mid-point of each habitat unit and were used to represent the entire habitat unit.

Table 7. Number of habitat units in the North Fork Koktuli River (NFK), South Fork Koktuli River (SFK) and Upper Talarik Creek (UT).

Stream	Reach	# of Habitat Units on each River Reach	Total # of Habitat Units	Total # of Habitat Units on each Stream
NFK	NFK-A	75	269	542
	NFK-B	42		
	NFK-C	152		
	NFK-190	273	273	
SFK	SFK-A	179	458	574
	SFK-B	78		
	SFK-C	201		
	SFK-190	116	116	
UT	UT-B	72	853	861
	UT-C	93		
	UT-D	158		
	UT-E	131		
	UT-F	399		
	UT-190	8	8	
			Total Number of Habitat Units =	1977

Table 8. Number of PHABSIM Transects in the North Fork Koktuli River (NFK), South Fork Koktuli River (SFK) and Upper Talarik Creek (UT)

Stream	Reach	# of PHABSIM Transects on each River Reach	Total # of PHABSIM Transects	# of PHABSIM Transects on each Stream
NFK	NFK-A	17	35	38
	NFK-B	6		
	NFK-C	12		
	NFK-190	3	3	
SFK	SFK-A	22	40	46
	SFK-B	12		
	SFK-C	6		
	SFK-190	6	6	
UT	UT-B	6	42	48
	UT-C	9		
	UT-D	10		
	UT-E	11		
	UT-F	6		
	UT-190	6	6	
		Total Number of PHABSIM Transects =		132

The current habitat flow analysis assumed the synthesized WUA at a stream location between any two transects (e.g., TR-A and TR-B) varies gradually from one to another. Thus, it also was assumed that the synthesized WUA for a location adjacent to one transect, TR-A, would have a relationship similar to that of TR-A. As the synthesized WUA location moves more toward a second transect, TR-B, the synthesized WUA would become less influenced by TR-A and more by TR-B, and therefore the synthesized WUA would resemble more of that depicted at TR-B than TR-A, as illustrated in Figure 9. The variations in WUA were related to the bankfull flow width and mean annual flow of the species/life stage being considered. In order to synthesize WUA curves at unsampled locations for a particular type of mesohabitat, bank full width is used first to normalize the WUA curves at each of the measured locations (as described in steps a-n below and Figure 9). Bankfull width at the unsampled locations is then used to restore the normalized synthesized WUA to the unsampled location. Bankfull flow width was obtained from data summarized in the EBD Appendix F (PLP, 2011). These data were used to develop regression equations to estimate bankfull flow width by river kilometer.

The influence of a transect on a given stream location within a habitat unit is called weighting. The weighting of the transect on a stream location was determined as the reciprocal of the distance from the location to the respective transect. If the distance from the desired calculation point to TR-A is d_A and is d_B to TR-B, then the weightings of TR-A and TR-B on this point would be1/d_A and 1/d_B, respectively. Calculations were made for each habitat unit and the mid-point of the unit was used to represent the unit, so the distance would be from the transect to the mid-point of the habitat unit.

With transect weightings and measured WUAs, synthesized habitat ~ flow relationships for an unmeasured habitat unit can be calculated. An equivalent mathematical formula for the synthesized relationship (WUA_{syn}) was derived as

$$WUA_{syn} = \frac{WUA^{sim}_{TR-A} \times 1/d_A + WUA^{sim}_{TR-B} \times 1/d_B}{1/d_A + 1/d_B}, \tag{1}$$

where the subscript *syn* indicates that the habitat ~ flow relationships are synthesized but not modeled from hydraulic data as in the case of PHABSIM transects, and the superscript *sim* denotes a simulated WUA, which is calculated from the normalized WUA, which is explained in the steps depicted below.

It should be noted that the transects (e.g., TR-A and TR-B) and the synthesized calculation point must have the same habitat type and be situated within the same river reach. Due to different hydrology and river morphology in each river reach, the weighting was not calculated beyond the reach breakpoint. For reaches having more than two transects with the same habitat type, the prior formula can be extended to include the additional transect (e.g., TR-C, with distance d_C to the stream location of interest) by adding $WUA^{sim}_{TR-C} \times 1/d_C$ to the denominator and $1/d_c$ to the numerator.

The following steps illustrate the procedures that were used for calculating the normalized WUA and simulated WUA for a given habitat unit. Chinook salmon spawning for "Run" habitat is used for the illustration, but the same steps were applied to other salmon species/life stages (Table 1) and habitat types by changing the periodicity months and the associated hydrology. The steps are graphically illustrated in Figure 9.

(a) Determine the habitat unit of interest and obtain the river kilometer (L^{meso}) at the mid-point of the unit from the mesohabitat mapping.
(b) Identify the habitat type of the habitat unit (e.g., run).

(c) Determine the length of the habitat unit.

(d) Determine the bankfull flow width, W_{BF}^{meso}, of the habitat unit.

(e) Determine a common flow range consisting of 30 flows to be used for the synthesized habitat ~ flow relationships for all habitat units in the river reach.

(f) Determine the mean annual flow for the habitat unit during the periodicity months (e.g., July and Aug for Chinook salmon spawning) from the 76 years of monthly hydrology ($Q_{Annual,Chinook,spawning}^{meso}$).

(g) Identify all PHABSIM transects of the same habitat type as the habitat unit (i.e., Run) within the river reach (e.g., TR-A and TR-B).

(h) Determine river kilometer (L^{TR-A}, L^{TR-B}), bankfull width (W_{BF}^{TR-A}, W_{BF}^{TR-B}), mean annual flow ($Q_{Annual,Chinook,spawning}^{TR-A}$, $Q_{Annual,Chinook,spawning}^{TR-B}$) for both Run transects. The associations of each parameters with the transects are self-explanatory from the superscripts.

(i) Calculate the distance from each transect to the mid-point of the unit (i.e., $d_A = L^{meso} - L^{TR-A}$ for TR-A and $d_B = L^{meso} - L^{TR-B}$ for TR-B).

(j) Calculate the weighting of each transect on the habitat unit, which is the reciprocal of the distance (i.e., $1/d_A$ for TR-A and $1/d_B$ for TR-B).

(k) Use the transect modeled WUA to calculate the normalized WUA (i.e., WUA^n) by dividing [1] each of 30 flows on the WUA by mean annual flow (i.e., $Q_{Annual,Chinook,spawning}^{TR-A}$, or $Q_{Annual,Chinook,spawning}^{TR-B}$) to obtain normalized flows and [2] each of the 30 habitat values on the WUA by bankfull flow width (W_{BF}^{TR-A}, or W_{BF}^{TR-B}) to obtain normalized habitat values. Perform the normalization for both Run transects.

(l) Calculate intermediate habitat ~ flow relationships using the WUA^n derived in the previous step by multiplying each of the 30 normalized flows with Q_{Annual}^{meso} and the each of the 30 normalized habitat values with W_{BF}^{meso}. Derive the intermediate relationships for both Run transects.

(m) Calculate simulated habitat ~ flow relationships (WUA_{TR-A}^{sim}, WUA_{TR-B}^{sim}) from the intermediate WUA in step (l) for the common flow range depicted in (e). This step is necessary because the 30 flows on each of the intermediate WUA are usually different.

(n) Use Equation (1) to calculate the synthesized habitat area ~ flow relationships (i.e., WUA_{syn}) for the habitat unit. The WUA_{syn}, calculated at the mid-point of the habitat unit synthesized WUA, is used to represent the habitat ~ flow relationship for the entire unit.

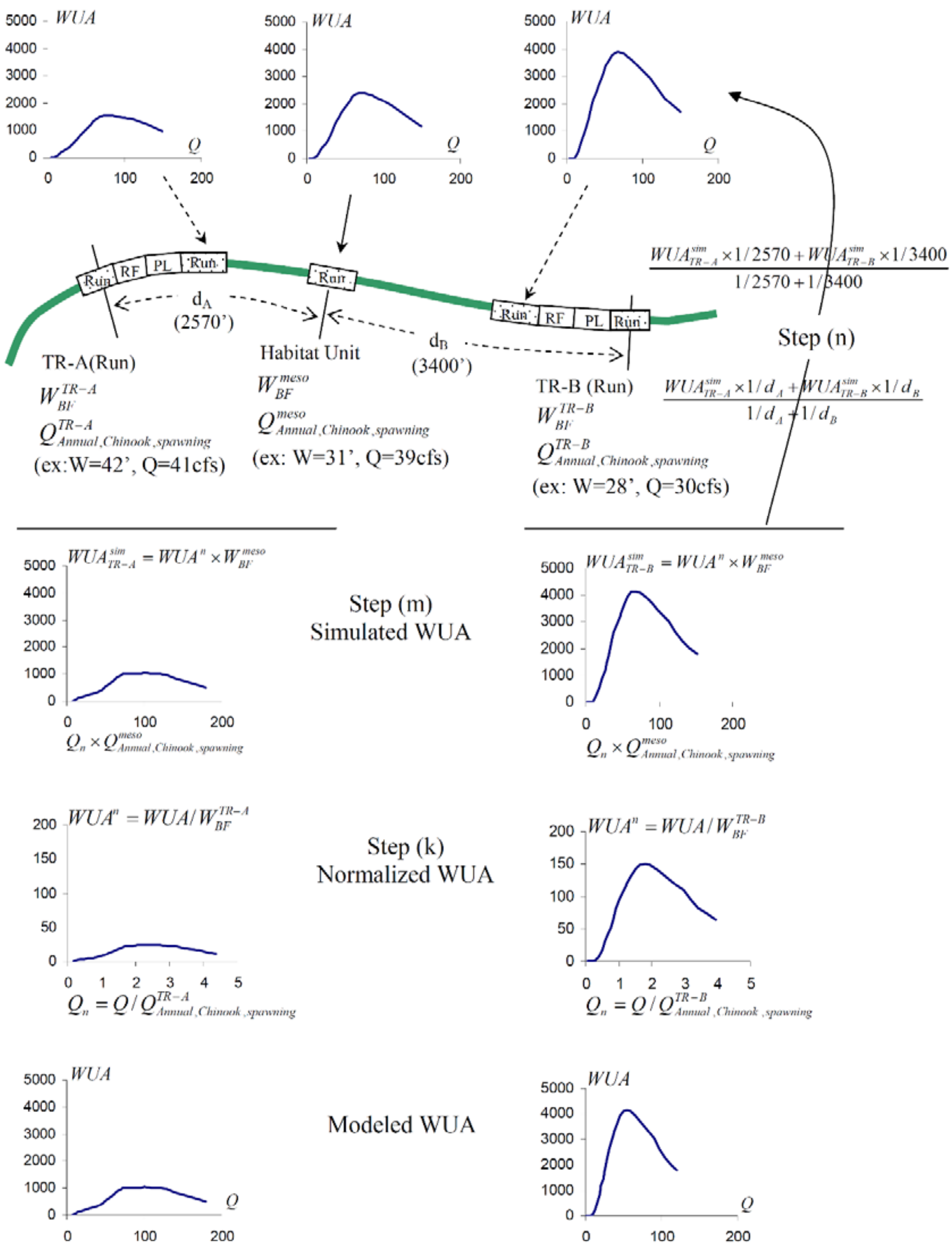


Figure 9. Graphical depiction of the HABSYN modeling procedures used to compute synthesized WUA for each habitat unit within a stream reach. Graphic should be read from bottom to top. The modeled WUA is taken from the PHABSIM analysis of the measured transects. WUA from TR-A and TR-B are combined to generate WUA for the location of interest.

Habitat Area Comparisons

The hydrology for each habitat unit was calculated by linear interpolation based on river kilometer using the flows at two adjacent hydrology locations, which included hydrology nodes, reach breakpoints, or PHABSIM transects (see above). Two hydrology scenarios, Pre-Mine and Mine-Affected with Treated Water, were analyzed. Each scenario incorporated hydrology simulations from 76 years of monthly flows at all hydrology node locations.

After the synthesized habitat ~ flow relationships were calculated for each habitat unit, the habitat area of each unit was computed at different flows. The WUA curve was used to obtain the habitat value (in $ft^2/1000ft$) corresponding to a given flow. The habitat value was multiplied by the length of the habitat unit which was obtained from the mesohabitat mapping to give the total habitat area of each mesohabitat unit for each subreach. There was no mesohabitat mapping in the three tributaries (NFK 1.190, SFK 1.190, and UT 1.190). Instead, the habitat length was taken from the results of field habitat surveys conducted from 2004-2008. The habitat areas were calculated for each priority species and life stage for each habitat unit along the stream for each month of the 76 years for Pre-Mine and Mine Affected conditions. Each of these conditions is described in more detail below.

Modeling Mine Affected Conditions

Mine affected conditions were modeled both during operations and post closure. The during operations conditions uses the hydrology that would be expected when the mine is in operation. The post closure condition uses the hydrology that is expected after mining is complete. Both the mine affected during operations and mine affected post closure scenarios were modeled with and without treated water release. Monthly treated water releases are described in the section below.

Modeling the Mine Affected with Treated Water Condition

In order to determine flows available under the mine affected condition we developed allocations for release of treated water in a way that optimized the habitat available for target species and life stages. To do this required an interim step of assessing habitat suitability with the mine but without the release of treated water from the water treatment plant. The detailed methods used for the modeling the Mine Affected with Treated Water conditions are provided below.

Flow Reduction

The impact on hydrologic conditions and the total flow reduction in each basin was determined by taking the monthly Pre-Mine flows (as obtained from Knight Piésold) and subtracting from them the monthly mine affected conditions without treated water flow (as obtained from Knight Piésold). This analysis was conducted for both the mine affected condition during operations and the mine affected conditions post closure. The difference was then averaged for each month over the 76-year period of record. Flow reduction calculations were conducted at the USGS gage sites in each basin (i.e., NK100A, SK100B, and UT100B). Monthly and annual flow reduction associated with the May 2018 Hydrology are summarized by basin in Tables 9 and 10 for the during operations and post closure conditions respectively. The amount of flow reduction in each subbasin under during operation or post closure conditions was used to determine how to distribute treated water under the mine-affected scenario.

Table 9. Estimated monthly and annual flow reduction (cfs) associated with constructing and operations of the proposed mine prior to releases of treated water with the May 2018 Hydrology for the North Fork Koktuli, South Fork Koktuli, and Upper Talarik basins.

Month	**NFK**	**SFK**	**UT**	**Total**
January	20.1	5.6	1.1	***26.8***
February	17.8	4.8	1.1	***23.6***
March	15.6	5.0	1.0	***21.6***
April	14.8	5.2	1.0	***20.9***
May	67.8	13.2	0.9	***82.0***
June	90.6	19.0	1.0	***110.6***
July	41.1	13.9	1.0	***56.0***
August	45.2	14.2	1.0	***60.5***
September	55.4	15.7	1.1	***72.2***
October	46.3	14.4	1.1	***61.9***
November	31.3	11.0	1.1	***43.4***
December	24.3	7.2	1.1	***32.6***
Annual*	***39.2***	***10.8***	***1.0***	***51.1***

*Calculation of the annual average is weighted by the days per month

Table 10. Estimated monthly and annual flow reduction (cfs) associated with post closure of the proposed mine prior to releases of treated water with the May 2018 Hydrology for the North Fork Koktuli, South Fork Koktuli, and Upper Talarik basins.

Month	NFK	SFK	UT	Total
January	9.7	3.5	0.7	***13.9***
February	8.3	3.0	0.7	***12.0***
March	7.0	3.3	0.7	***11.0***
April	6.6	3.5	0.6	***10.7***
May	36.2	7.7	0.6	***44.6***
June	39.6	12.0	0.6	***52.3***
July	15.7	9.2	0.7	***25.6***
August	25.8	8.9	0.7	***35.4***
September	31.7	9.9	0.7	***42.3***
October	25.8	9.2	0.7	***35.7***
November	16.6	7.0	0.7	***24.3***
December	12.2	4.6	0.7	***17.5***
Annual*	***19.7***	***6.8***	***0.7***	***27.2***

*Calculation of the annual average is weighted by the days per month

Treated Water Releases

The Pebble Project will reduce flows to the SFK, NFK, and UT by capturing water within the mine footprint located at the headwaters of each of the three basins. The current plan is for water that is captured in the mine footprint to be routed to and, treated in a water treatment plant, then released back into the streams. The methodology for determining the apportionment of treated water across basins is coined hybrid allocation and is a combination of a hydrologic-based method and a habitat-based method. This hybrid approach was selected as it offers a presumed biological advantage in the form of supplemental winter flows under ice; presumed because PHABSIM cannot predict under ice flow or habitat conditions. Estimate releases of treated water were 29 cfs during operations and 13 cfs under post closure conditions (as obtained from Knight Piésold).

Hydrologic Based Calculations for Treated Water Releases

A hydrologic-based approach for releases of treated water is based on defining flows on a monthly basis to the SFK, NFK, and UT in direct proportion to the water captured from each of the three basins in the mine footprint area (not driven by PHABSIM model). The water captured, or flow reduction, in each of the three basins was calculated by subtracting the water remaining in each basin under the Mine Affected, both during operations and post closure, without Treated Water conditions from the water in each basin under Pre-Mine conditions (see Tables 9 and10). This hydrologic approach is similar in philosophy to the Indicators of Hydrologic Alterations approach (Mathews and Richter, 2007). For example, using the mine affected during operations hydrology for the month of January, the treated water flow in the North Fork Koktuli River is 21.8 cfs which is 75% (20.1 cfs reduction in the North Fork Koktuli from Table 9 divided by a total reduction of 26.8 cfs) of the total available treated water flow during operations of 29 cfs. A similar calculation is performed for each basin for each month to determine the hydrologic based discharge.

Habitat-Based Based Calculations for Treated Water Releases

Habitat-based calculations distribute treated water as a function of the amount of water necessary to fully restore the designated priority species' habitat lost for the entire stream length. The priority species/lifestage present in each watershed each month follows those provided in Table 1. Once the priority species/life stage is selected for each month, the PHABSIM model is used to quantify the optimal monthly flow conditions for priority species and life stages. These monthly flow values indicate how much surface flow is needed to fully restore lost habitat each month for the priority species/life stage. These restoration flows were developed by creating an optimization tool whereby the PHABSIM model was simulated in one cfs increments up to 50 cfs to create a habitat area curve as a function of increasing treated water flow. The incremental flow was added in SFK-C in the SFK basin, at NFK190 at the mine footprint edge in the NFK basin, and in the UT basin between UT100E and UT100D. Methods were incorporated to include changes in the additional flow as it travels downstream (i.e., potential losses due to groundwater infiltration). The total weighted usable area for each stream was calculated for each incremental cfs such that a habitat area versus change in flow curve could be developed. This type of curve was created for all three basins for each month in the period of record from 1942 through 2017, for the applicable priority species/lifestage (as determined from Table 1).

An example curve for Chinook salmon spawning for the SFK in the month of August 2000 is shown in Figure 10. In this figure, 30.1 acres is the amount of habitat available under Pre-Mine conditions and is used to find the associated target treated water flow needed to provide the same amount of habitat available under Mine-Affected levels. For the SFK in August of 2000, the 30.5 acres of original habitat is restored with an additional 7.1 cfs of treated water. This target flow was developed for each month in each basin for the selected priority species for all 76 years of record. This process was time intensive since it required hundreds of repeated PHABSIM simulations.

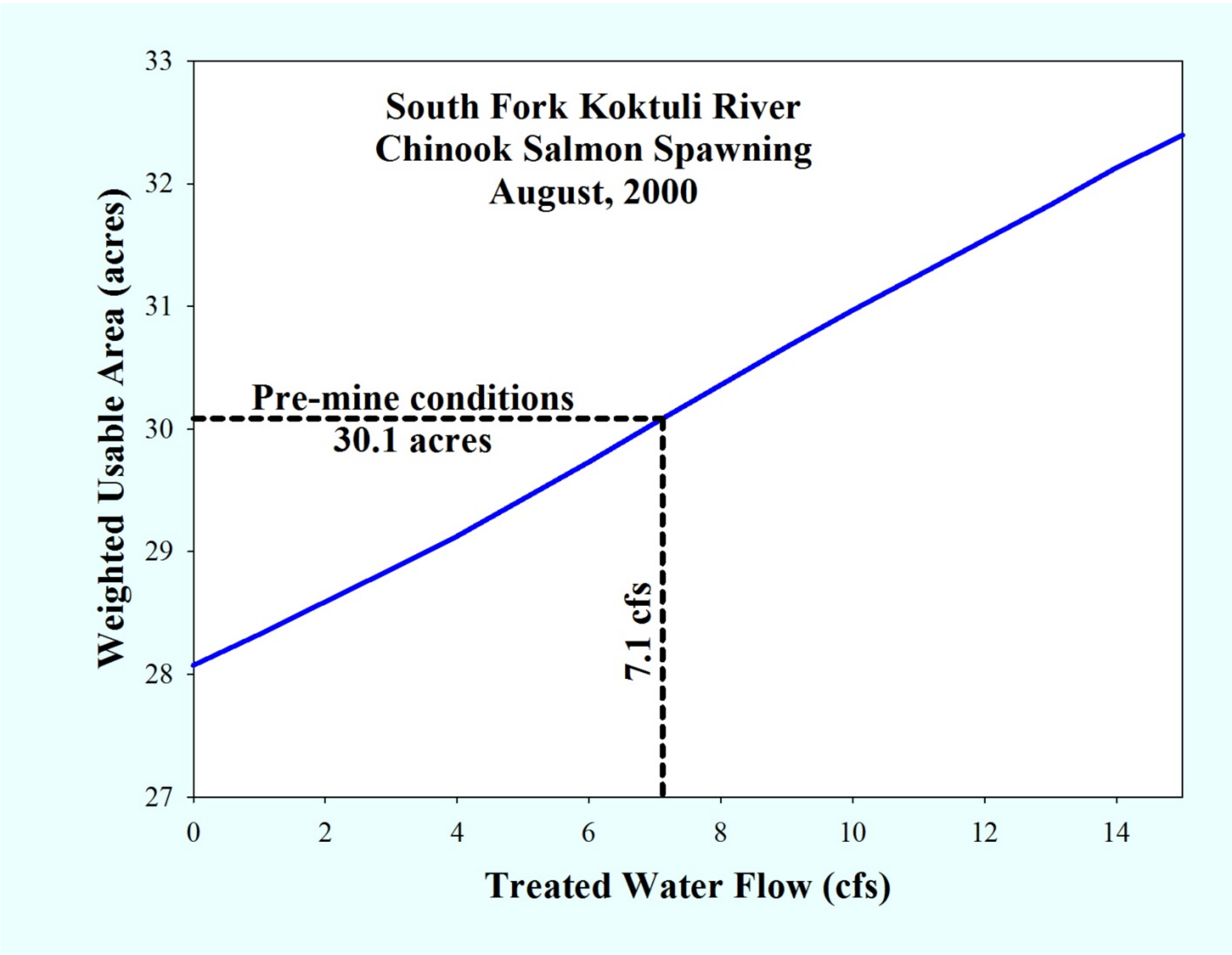


Figure 10. Example habitat-treated water curve for Chinook salmon spawning in the South Fork Koktuli River in August 2000.

From these curves, the monthly flow needed to fully restore Weighted Usable Area for the three basins under the Mine Affected conditions, both during operations and post closure, is determined for each month of the 76-year period of record and then averaged for all 12 months in the year. The monthly averages are provided in Tables 11 and 12 and represent the optimal flow needed in each basin to fully restore habitat to Pre-Mine conditions. Note that the average annual flow reduction across all basins during operations, as shown in Table 9 is 51.1 cfs for the May 2018 Hydrology. However, the flow of treated water needed to optimize the habitat in the three basins is only 21.9 cfs as shown in Table 11 while a total flow to be discharged from the water treatment plants during operations is 29 cfs.

Under the habitat-based flow release scenario during project operations, the total flow of 29 cfs of treated water is released to each subbasin in the same monthly proportions as determined by the optimization flow and as shown in Table 11. For example, in the month of July, the habitat-based treated flow for the North Fork Koktuli River is 22.8 cfs which is 78.7% of total available treated water flow of 29 cfs (84.9% is calculated from an optimization flow of 26.2 cfs in July divided by a total optimal flow of 33.3 cfs in July as shown in Table 11). A similar calculation is performed for each basin for each month where a habitat-based approach is used.

Table 11. Optimization flow (cfs) required to fully restore habitat in the North Fork Koktuli, South Fork Koktuli, and Upper Talarik basins during operations under the May 2018 hydrology.

Month	NFK	SFK	UT	Total
January	11.2	6.8	0.0	***18.0***
February	9.1	5.7	0.0	***14.8***
March	7.8	4.6	0.1	***12.5***
April	7.3	4.3	0.6	***12.1***
May	11.0	2.2	0.4	***13.6***
June	8.9	0.4	0.1	***9.4***
July	26.2	6.6	0.6	***33.3***
August	25.2	8.6	0.8	***34.6***
September	20.6	7.9	0.6	***29.1***
October	22.8	8.7	0.5	***32.1***
November	20.0	9.7	0.8	***30.5***
December	13.8	8.2	0.0	***22.1***
Annual	***15.4***	***6.1***	***0.4***	***21.9***

Table 12. Optimization flow (cfs) required to fully restore habitat in the North Fork Koktuli, South Fork Koktuli, and Upper Talarik basins post closure under the May 2018 hydrology.

Month	**NFK**	**SFK**	**UT**	**Total**
January	10.1	4.7	0.0	***14.8***
February	8.4	4.0	0.0	***12.4***
March	7.3	3.1	0.0	***10.4***
April	6.9	2.9	0.3	***10.1***
May	5.4	0.9	0.2	***6.5***
June	4.0	0.3	0.0	***4.3***
July	13.1	4.3	0.3	***17.6***
August	12.9	5.4	0.4	***18.6***
September	10.0	5.3	0.3	***15.6***
October	11.8	5.4	0.3	***17.4***
November	13.1	6.5	0.5	***20.0***
December	12.2	5.6	0.0	***17.9***
Annual	***9.6***	***4.0***	***0.2***	***13.8***

Hybrid Scenario for Treated Water Releases

The hybrid approach to appropriating treated water among basins used a combination of the hydrologic and habitat-based approaches during different months of the year (each described above). The hydrologic-based flows were used from December to March, while the habitat-based flows were used in the other months from April through November. Under the Hybrid approach, the flows are distributed in the NFK at the confluence of Tributary 190 and the mainstem, in the SFK at the upstream end of Frying Pan Lake, and in the UT at Tributary UT 1.460 in Reach UT-F. The monthly average flow applied under the Hybrid scenario is provided in Table 13 for the during operations conditions and in Table 14 for the post closure conditions.

Table 13. Hybrid scenario for releases of treated water (cfs) during operations in the North Fork Koktuli, South Fork Koktuli, and Upper Talarik basins under the May 2018 hydrology.

Month	**NFK**	**SFK**	**UT**	**Total**
January	21.8	6.0	1.2	***29.0***
February	21.8	5.9	1.3	***29.0***
March	20.9	6.7	1.4	***29.0***
April	17.5	10.2	1.3	***29.0***
May	23.5	4.7	0.8	***29.0***
June	27.5	1.3	0.2	***29.0***
July	22.8	5.7	0.5	***29.0***
August	21.1	7.2	0.7	***29.0***
September	20.5	7.9	0.6	***29.0***
October	20.6	7.9	0.5	***29.0***
November	19.0	9.2	0.8	***29.0***
December	21.6	6.4	1.0	***29.0***
Annual	***21.6***	***6.6***	***0.8***	***29.0***

Table 14. Hybrid scenario for releases of treated water (cfs) after post closure in the North Fork Koktuli, South Fork Koktuli, and Upper Talarik basins under the May 2018 hydrology.

Month	**NFK**	**SFK**	**UT**	**Total**
January	9.1	3.2	0.7	***13.0***
February	9.0	3.2	0.7	***13.0***
March	8.3	3.9	0.8	***13.0***
April	8.9	3.7	0.4	***13.0***
May	10.7	1.9	0.4	***13.0***
June	12.1	0.8	0.0	***13.0***
July	9.6	3.1	0.2	***13.0***
August	9.0	3.7	0.3	***13.0***
September	8.3	4.4	0.2	***13.0***
October	8.8	4.0	0.2	***13.0***
November	8.5	4.2	0.3	***13.0***
December	9.1	3.4	0.5	***13.0***
Annual	***9.3***	***3.3***	***0.4***	***13.0***

Citations

Mathews, R. and B.D. Richter. 2007. Application of the indictors of hydrologic alteration software in environmental flow setting. Journal of the American Water Resources Association 43, 1400-1413.

Pebble Limited Partnership (PLP). 2011. Pebble Project Environmental Baseline Document, 2004 through 2008. Report collated by the Pebble Partnership in accordance with 53 chapters and appendices representing various scientific disciplines and drainage basins. Chapter 15: Fish and Aquatic Invertebrates (Bristol Bay Drainages) Available online at: https://pebbleresearch.files.wordpress.com/2014/03/ch_15_fish_and_aquatic_inverts_bb.pdf

Response to Pebble Project EIS RFI 147

Technical Appendix

Prepared for:

Pebble Limited Partnership

November 1, 2019

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ACRONYMS AND ABBREVIATIONS

EBD	Environmental Baseline Document
EIS	Environmental Impact Statement
HABSYN	R2 proprietary habitat synthesis model
HDR	HDR Alaska, Inc.
HSC	Habitat Suitability Criteria
IFG4	Program used to estimate velocity-depth pairs over a range of flows
IFIM	Instream Flow Incremental Methodology
KR	Koktuli River Mainstem
MANSQ	Program used to estimate water surface elevations
NFK	North Fork Koktuli River
PHABSIM	Physical Habitat Simulation
PLP	Pebble Limited Partnership
QA/QC	Quality Assurance/Quality Control
QC	Quality Control
R2	R2 Resource Consultants, Inc.
RFI	Request for Information
SFK	South Fork Koktuli River
USGS	U.S. Geological Survey
UT	Upper Talarik Creek
WSE	Water Surface Elevation
WUA	Weighted Usable Area

This Technical Appendix provides responses to the seven requests for information (RFIs) contained in RFI 147 dated October 10, 2019.

1. A brief summary of current use of PHABSIM and associated modeling components for assessing instream flow in the US, including a justification of why used for the Pebble Project.

The flow regime of a river is a significant determinant of the aquatic habitat available for use by different species and lifestages of fish. As described in the Environmental Baseline Document (EBD) (PLP 2011), there are many different methods and models that have been developed and used for assessing how available fish habitat may change in response to flow alterations. In addition there have been several reviews of the most commonly applied instream flow methods, including: Wesche and Rechard (1980), Morhardt (1986), Stalnaker and Arnett (1976), the Proceedings of the Symposium on Instream Flow Needs (Orsborn and Allman eds. 1976), Lewis et al. (2004), and the Instream Flow Council (Annear et al. 2004; Locke et al. 2008). As addressed in these reviews, each of the flow-habitat modeling methods has strengths and weaknesses that should be considered when selecting an instream flow methodology for application to a project.

For the Pebble Project, the selection of an instream flow methodology was based on the consideration of the following criteria that were deemed important to defining baseline conditions and to evaluating potential project effects:

- The predictive capability of the method or model to extrapolate results over a range of flows;
- The ability of the method to depict flow and habitat changes incrementally;
- The applicability of the methodology to different fish species, including anadromous and resident salmonids;
- The number of lifestages considered in the method (e.g., spawning, fry, juvenile, and passage);
- The biological soundness of the methodology results (i.e., habitat-flow relationship curves and criteria that relate directly to the fish species present in the project area watersheds);
- The sensitivity of the method/model output to the individual user (i.e., the ability to control bias);
- The reproducibility of results, both field data collection and modeling; and
- The acceptability of the method/model by state and federal agencies in Alaska.

In addition, given the size and complexity of the project, R2 selected and applied the U.S. Fish and Wildlife Service's Instream Flow Incremental Methodology (IFIM) and its associated Physical Habitat Simulation System (PHABSIM) suite of computer programs for collecting and analyzing habitat and flow data, quantifying fish habitat, and formulating instream flow recommendations for aquatic biota. PHABSIM, as a component of habitat modeling, is a technically sound, transparent, and scientifically defensible method of developing site-specific ecological response functions (or habitat-flow relationships) and is one of the most widely applied and jurisdictionally recognized analytical tools for assessing instream flow issues (Reiser and Hilgert 2018).

PHABSIM uses a multidisciplinary approach that allows for the integration of site-specific hydraulic data with species- and lifestage-specific habitat data to predict ecological response functions. The PHABSIM methodology consists of both a hydraulic and a habitat model to estimate fish habitat area as a function of streamflow, combining the physical and hydraulic characteristics of a stream with information that describes the habitat preferences of different fish species and lifestages. The habitat preferences are expressed as habitat suitability criteria (HSC) curves that are species- and lifestage-specific. The ecological response functions (output) developed using PHABSIM take the form of a Weighted Usable Area (WUA) curve depicting the relationship between available habitat area and flow. It is important to note that the results of PHABSIM, (WUA curves), are not the endpoint of habitat modeling (Stalnaker et al. 2017). For the Pebble Project, the WUA curves developed using PHABSIM are used with habitat mapping data and hydrological time series to produce time series of available habitat that can be summarized as habitat area in acres.

2. Summarize the number and location of transects used to develop habitat indices.

Because we were not certain as to which habitat indices the authors were referring, we have provided data collection information pertinent to generation of HSC and WUA curves.

Site-specific microhabitat data were collected by R2 Resource Consultants, Inc. (R2) in 2008 and, previously, by HDR Alaska, Inc. (HDR) from 2005 to 2007 (Table 2-1). Because of their commercial, recreational, and ceremonial/subsistence value, field efforts focus on data collection for certain fish species, collectively termed target fish species, and included:

- Sockeye Salmon (*Oncorhynchus nerka*);
- Coho Salmon (*O. kisutch*);
- Chinook Salmon (*O. tshawytscha*);
- Chum Salmon (*O. keta*);

Table 2-1. Summary of microhabitat measurements made by R2 and HDR in the North Fork Koktuli River, South Fork Koktuli River, and Upper Talarik Creek by species and lifestage. Data collected from 2004 to 2008.

	North Fork Koktuli			South Fork Koktuli			Upper Talarik			All Basins		
Species/Lifestage	**HDR**	**R2**	**Subtotal**	**HDR**	**R2**	**Subtotal**	**HDR**	**R2**	**Subtotal**	**HDR**	**R2**	**Total**
Coho	16	114	130	21	83	104	48	125	173	85	322	407
Spawning		52	52		43	43		3	3		98	98
Fry		31	31		16	16		41	41		88	88
Juvenile	16	31	47	21	24	45	48	81	129	85	136	221
Sockeye	41	122	163	90	82	172	41	118	159	172	322	494
Spawning	40	122	162	85	79	164	32	117	149	157	318	475
Juvenile	1		1	5	3	8	9	1	10	15	4	19
Chinook	58	66	124	51	50	101	24	35	59	133	151	286*
Spawning	47	49	96	40	35	75				87	84	173*
Fry		9	9		4	4		6	6		19	19
Juvenile	11	8	19	11	11	22	24	29	53	46	48	94
Chum					7	7					7	7
Spawning					7	7					7	7
Rainbow		7	7				8	25	33	8	32	40
Fry								23	23		23	23
Juvenile							7	2	9	7	2	9
Adult		7	7				1		1	1	7	8
Grayling	2	22	24	14	2	16	14	10	24	30	34	64
Juvenile	1		1	11		11	12		12	24		24
Adult	1	22	23	3	2	5	2	10	12	6	34	40
Dolly Varden	2	1	3	7	4	11	4	2	6	13	7	20
Fry		1	1		2	2					3	3
Juvenile	2		2	7	2	9	4	1	5	13	3	16
Adult								1	1		1	1
Total	**119**	**332**	**451**	**183**	**228**	**411**	**139**	**315**	**454**	**442**	**879**	**1318***

* includes two redds from mainstem Koktuli River.

- Rainbow Trout (*O. mykiss*);
- Grayling (*Thymallus arcticus*); and
- Dolly Varden (*Salvelinus malma*).

The HSC study focused on collecting physical habitat data related to spawning, juvenile rearing and rearing of adult trout and char.

However, not all these species were readily observable due to stream flow conditions, or sufficiently abundant to allow for the collection of site-specific data. Therefore, while the derivation of HSC curves for some of the target species was be based on site specific data, HSC curves for other species required a combination of site-specific data and literature information. More detail regard HSC development is presented in Item 4.

The PHABSIM model produced WUA curves based on physical habitat data collected along 143 transects, including 137 transects that were established between 2004 and 2008, and six established in 2018. Table 2-2 shows the number of transects per major watershed. The six new transects were established in the mainstem Nork Fork Koktuli (NFK) in reach NFK-D to refine the habitat modeling upstream of the NFK 1.190 confluence. Figures 2-1 through 2-4 show the locations of each transect in the major watersheds, NFK, South Fork Koktuli River (SFK), Upper Talarik Creek (UT), and Koktuli River (KR), respectively.

Table 2-2. Transects per watershed. This table shows the number of transects used to develop habitat indices per major watersheds in the study area. Transects were established between 2004 and 2018.

Watershed	Number of Transects
North Fork Koktuli River	44
South Fork Koktuli River	46
Upper Talarik Creek	48
Koktuli River	5
Total	143

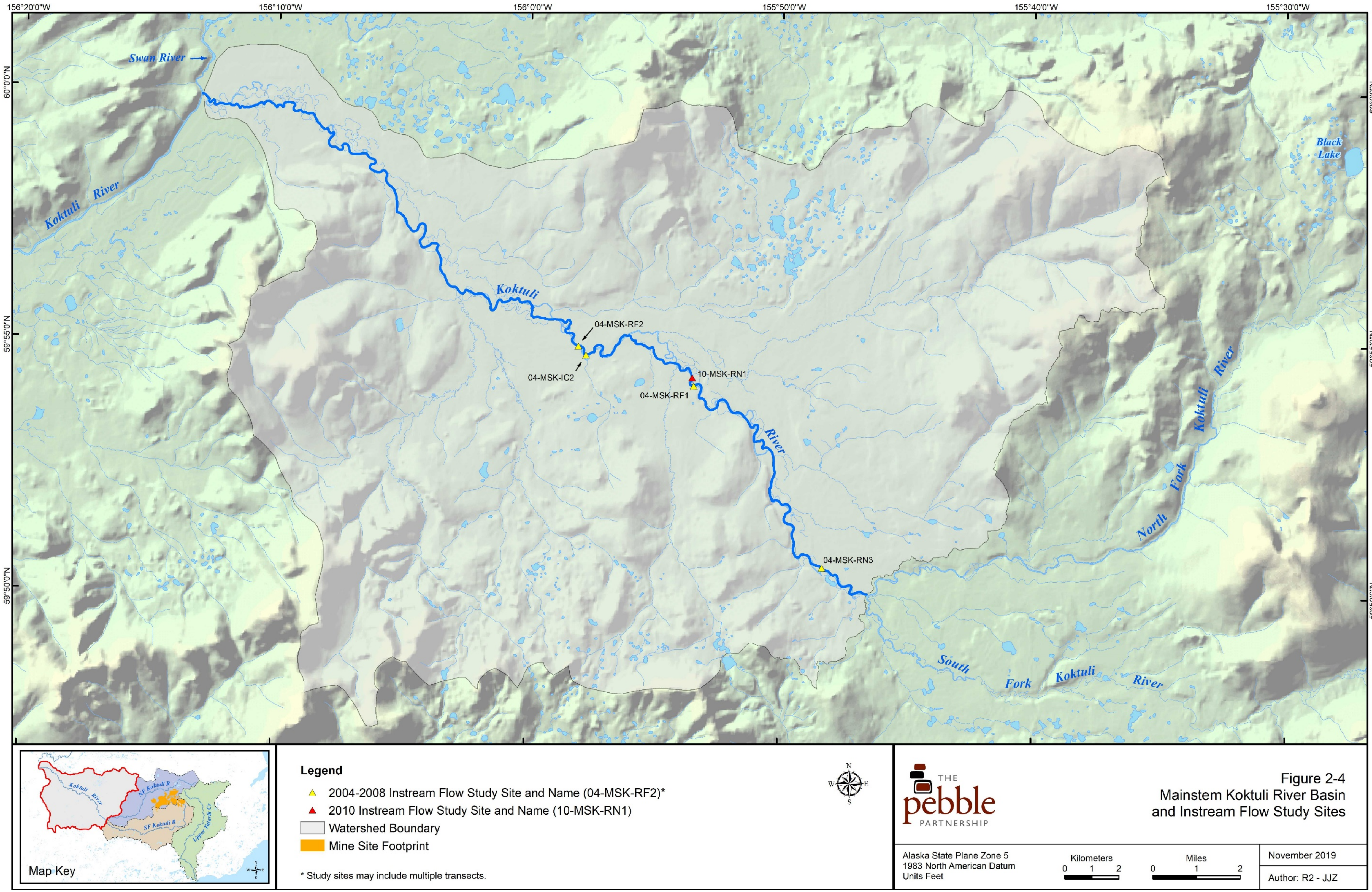

Figure 2-1. **North Fork Koktuli River Transect Locations. Locations of the 44 transects (38 transects established between 2004 and 2008, and 6 transects established in 2018) and model extent in the North Fork Koktuli River basin used in habitat modeling.**

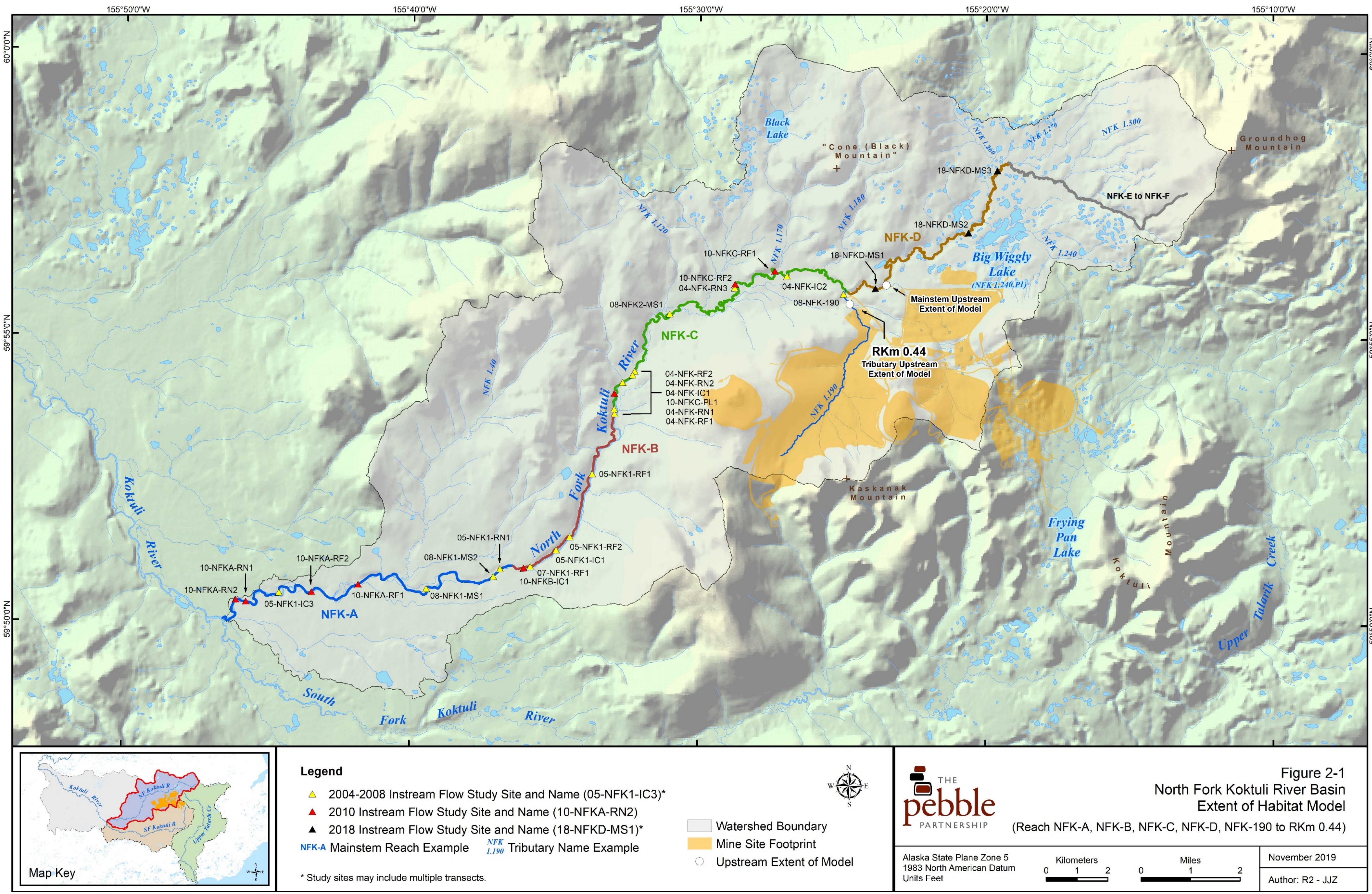

Figure 2-2. South Fork Koktuli River Transect Locations. Locations of the 46 transects (transects established between 2004 and 2008) and model extent in the South Fork Koktuli River basin used in habitat modeling.

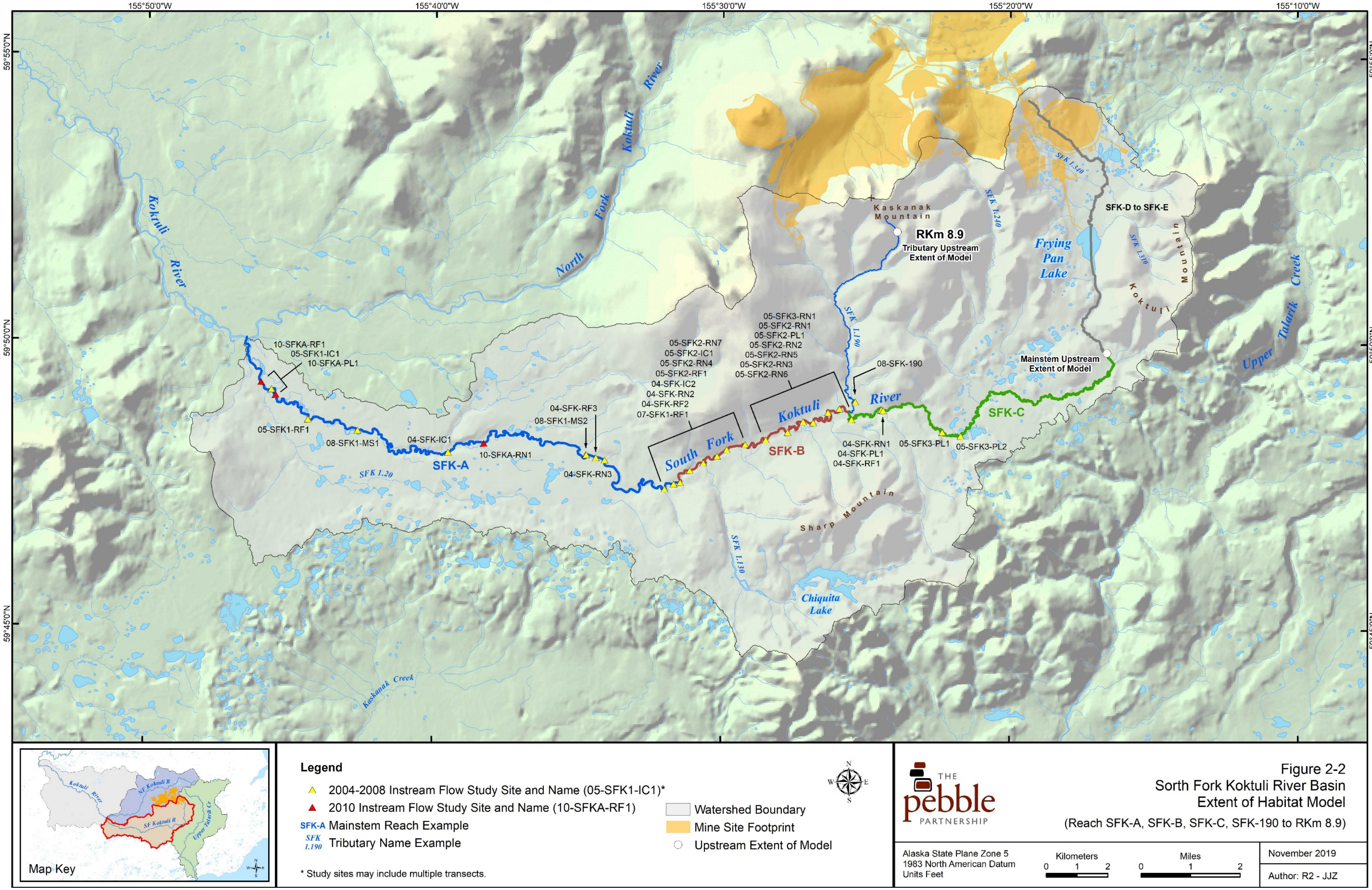

Figure 2-3. Upper Talarik Creek Transect Locations. Locations of the 48 transects (transects established between 2004 and 2008) and model extent in the Upper Talarik Creek basin used in habitat modeling.

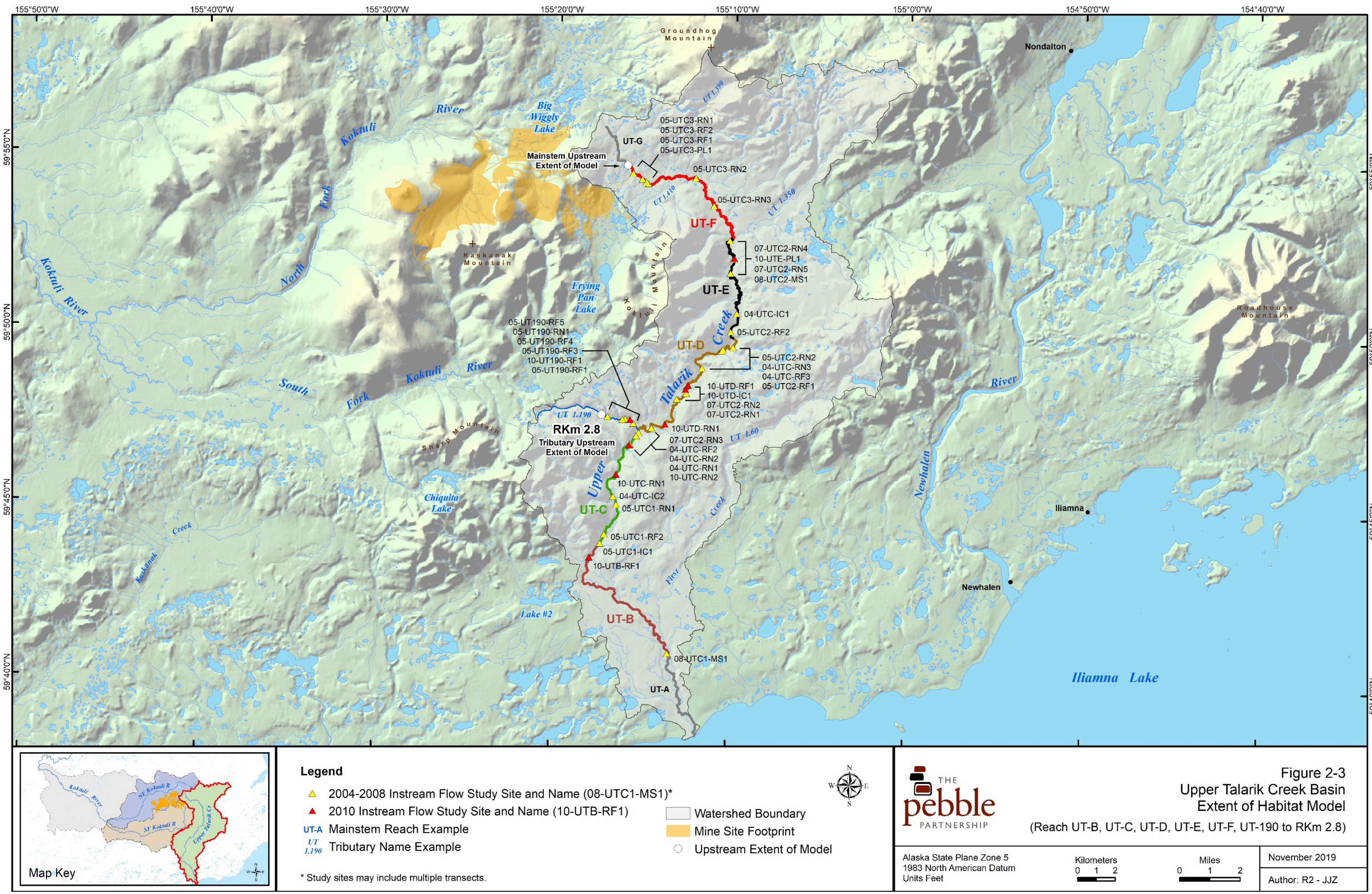

Figure 2-4. **Koktuli River Transect Locations. Locations of the 5 transects (transects established between 2004 and 2008) and model extent in the Mainstem Koktuli River basin used in habitat modeling.**

3. Summarize field methodologies used to collect hydraulic flow measurements with reference to standardization and QA/QC criteria.

There were several steps to standardize and QA/QC the data inputs to the PHABSIM model that ranged from review and validation of previously collected data to standardized calibration QA/QC of field measurements, and hydraulic model development.

Per the PHABSIM methodology, hydraulic flow data (e.g., water depth and mean column velocity) used in habitat modeling were collected along transects (detailed methods for the hydraulic field data collection are provided in Appendix 15.1C of the EBD [PLP 2011]). Over the course of the study, two strategies were applied in selecting transect locations; habitat representative transects were established from 2004-2007, and in 2008 transects were established to provide intensive characterization of selected reaches.

All transect data was QA/QC'd and validated during model development. During a review of 2004-2007 data, it was noted that a subset of the transects would pose challenges in the model due to either: a) detectable changes in stream bed elevations and profiles over time and between field surveys and/or b) the development of inconsistent flow vs. water surface elevation rating curves. It was determined that 21 transects had issues and could not be used in the model. To rectify these concerns, field surveys were conducted in 2010 to re-establish 21 transects (R2 2011) and the new data were incorporated into the PHABSIM model.

At all 143 transects, hydraulic flow data (e.g., water depth and mean column velocity) were collected at set intervals across each transect under different flow conditions using various meters and profilers including Pygmy, Price AA, Marsh McBirney, and Swoffer current meters (2004-2008), and acoustic Doppler current profilers (2018). Velocity and depth measurements were made following standard US Geological Survey (USGS) methods (Turnipseed and Sauer 2010). All meters/profilers were calibrated (as appropriate) prior to their first use in the field on each data collection event per manufacture's specifications, and throughout the sampling event per the manufacturer's specifications, or following USGS methods as applicable for each meter/profiler type. Calibration records were collected for each meter/profiler used. For each meter/profiler used to collect velocity measurements at transects, the type number was noted on the data sheet.

- Meters/profilers were mounted on top-set wading rods.
- Each transect was divided into at least 20 transect locations spaced across the channel.
- Along each transect, water depth was measured using the topset wading rod. Water depths were measured to the nearest 0.10-feet for data collected during 2004-2007, and to the nearest 0.05-feet from data collected in 2008 - 2018.

- Along each transect, water velocity was measured as follows:
    - at 6/10th of the depth for water depth less than 2.5 feet
    - at 2/10th of the depth and 8/10th of the depth for water depths equal to or greater than 2.5 feet
    - For current meters (2004-2010):
        - at 6/10th of the depth for water depth less than 2.5 feet
        - at 2/10th of the depth and 8/10th of the depth for water depths equal to or greater than 2.5 feet
    - For current profilers (2018):
        - at 6/10th of the depth for water depth less than 1.5 feet
        - at 2/10th of the depth and 8/10th of the depth for water depths equal to or greater than 1.5 feet

The data collected during field efforts were subjected to a thorough quality control review. Level 1 quality control (QC1) consisted of a review of current meter and current profiler velocity and depth profile for accuracy and completeness. Following each field effort, field notes were photocopied, and data were entered into computer data files. Following data entry, a line-by-line comparison was made of field data measurements with the computer data file entries, constituting Level 2 quality control (QC2).

Additional review was conducted to assess data adequacy for use in developing valid, reliable hydraulic models. The review included an evaluation of field notes and survey data including checks of level loops and water survey elevation data. Cross-sectional profiles were plotted and reviewed to determine whether bed elevations had changed between survey dates. Current meter and current profiler recorded depth and velocity measurements were used to calculate flows (discharge) for each site visit.

In addition, transect photographs were assembled, labeled and reviewed to provide a visual comparison of flow conditions. The entire review process resulted in the development of transect-specific data sets for use in hydraulic and habitat modeling.

The hydraulic model of data collected from 2004 through 2010 was developed using the DOS version of PHABSIM. The hydraulic model of data collected in 2018 was developed using PHABSIM for Windows Version 1.5.2 created by the USGS (Waddle 2001). Details of all modeling and calibration steps were documented and retained. Hydraulic modeling followed the three steps below that included QA/QC and calibration.

- Model Setup: Once quality control checks were completed, data from the QC'd spreadsheets were then used to create a windows PHABSIM file. The program was set up to model 30 flows. Typically, these flows range from 0.4 times the lowest measured flow up to 2.5 times the highest measured flow. Due to unexpected high summer flows during the 2018 study, the modeled flow range for each the six NFK transects was applied to a single measured flow.

- Water Surface Elevation (WSE) Calibration: Stage-discharge relationships were developed using the the PHABSIM program. Stage-discharge relationships were primarily developed using the three-point IFG4 method. For a small number of transects the MANSQ method was used to develop the stage-discharge method. The water surface elevation rating curves developed at each transect were also compared to those at other transects within a site to ensure no discrepancies.
- Velocity Calibration: Velocity calibration involved two steps. The first step was to calibrate to the measured flow and the second step included developing a simulated velocity profile at twice the measured flow to ensure a realistic distribution of velocities for the entire range of simulation flows. To make velocity calibration adjustments, the Manning's n was varied for specific cells. Typically, adjustments were made to the edge velocities and to reduce the peak or increase the low velocities at high flows.

4. Summarize the development of site-specific Habitat Suitability Criteria for target species and lifestages as well as selection of habitat suitability criteria for infrequently observed species.

Habitat Suitability Criteria curves are a required element for defining habitat-flow relationships as the reflect species and lifestage use and preference for selected habitat parameters (depth, velocity, and substrate). When the HSC curves are linked with the hydraulic models developed for each transect, PHABSIM can then calculate a measure of suitable habitat area over a range of flows. Depending on the extent of data available, HSC curves can be developed from the literature (Category 1 curves), or from physical and hydraulic measurements made in the field over species microhabitats (Category 2 curves). When adjusted for availability, these latter curves may more accurately reflect species preference (Category 3 curves; Bovee et al. 1998).

For the Pebble Project, HSC curves were derived from both existing literature and site-specific data dependent upon the target species and lifestages. The site-specific data collected related to use of spawning and rearing habitat and included microhabitat data (depth, velocity, and substrate data) over redds and at observed locations of juvenile and adult resident trout or char rearing in the stream.

The HSC data collection included microhabitat data (e.g., water depth, velocity, and substrate data) over redds in 2005, 2006, and 2008, and at observed locations of juvenile and adult habitat use in 2007 and 2008. The dates of both the redd and juvenile/adult surveys were based on the periodicity information available at the time of study planning and was updated with new information through the study period (see Figure 4-1).

From 2004-2008, 1,318 site-specific microhabitat utilization measurements were collected for target fish species using snorkel and redd survey methods (Table 2-1). Only fish holding over a fixed position were included in the microhabitat surveys; moving fish were not enumerated in order to minimize inaccurate habitat measurements, and to prevent double-counting of fish. Since the overall objective of the surveys was to collect sufficient data from which to generate site-specific HSC curves for use in PHABSIM modeling, the greater the number of observations the more reliable the data set from which to derive the HSC curves. Researchers often use the rule of thumb of having 75-150 observations from which to base curves, but fewer observations can also be used provided they are representative of a range of habitat types. Curves developed using fewer than 75 observations can also be used for making comparisons with literature derived curves to see if utilization trends are similar and for making suggested modifications to site-specific HSC curves.

For this study, site-specific HSC (Category 2) curves were developed for NFK and SFK spawning Sockeye and Chinook salmon, and UT Spawning Sockeye Salmon and juvenile Coho Salmon. Category 3 curves were developed for the remaining priority species and lifestages developed based on a combination of site-specific microhabitat data and literature- based curves. Attachment 1 of EBD Appendix 15C.1 provides a detailed description of HSC curve development along with the HSC curves used in the PHABSIM model.

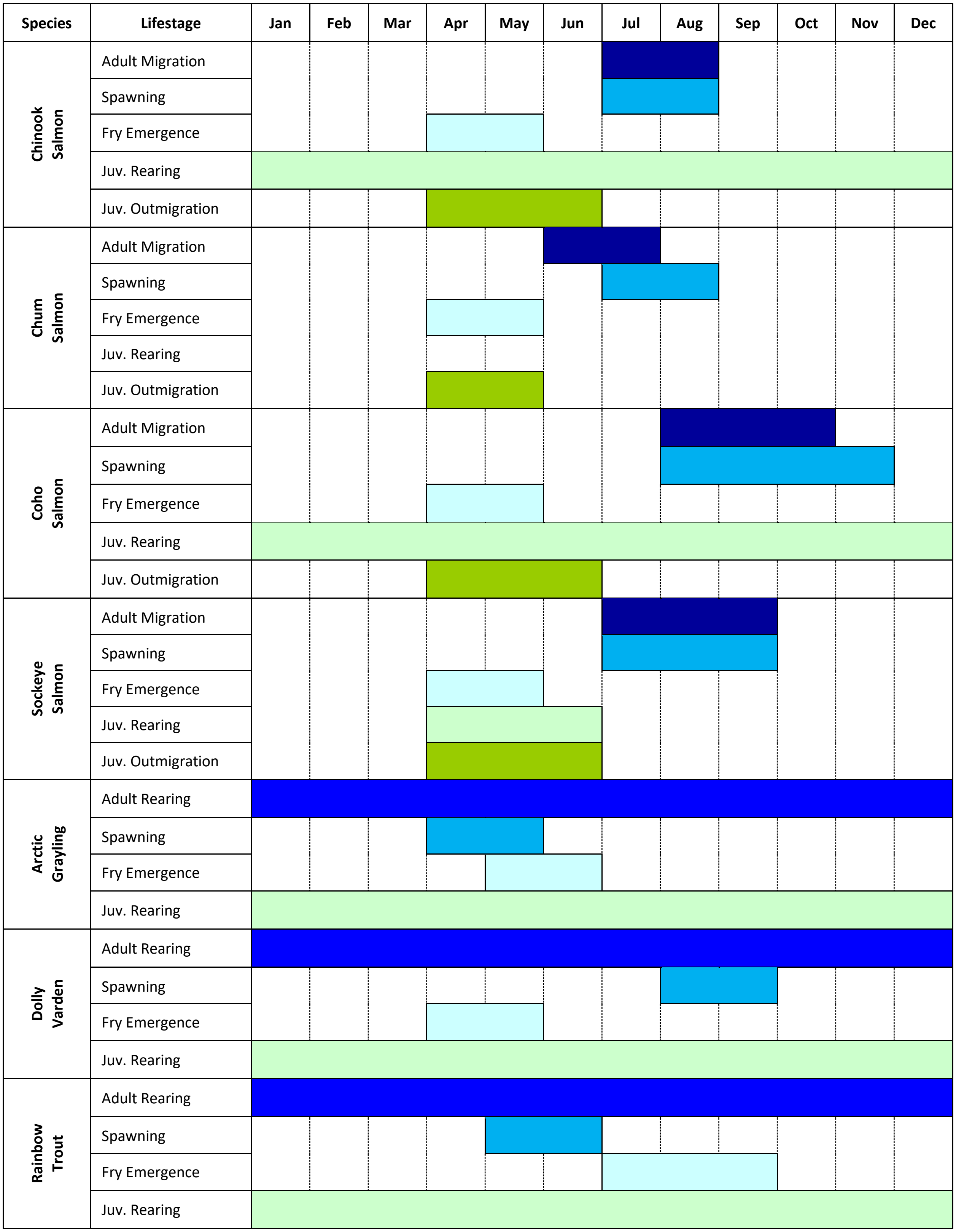

Figure 4-1. **Life-history periodicity matrix. Life-history stage periodicity for select target species in the fish resource study area based on a general understanding of local populations and empirical data (adapted from PLP 2011).**

5. Summarize how the habitat mapping process was used to expand the habitat estimates to reach-scale levels.

R2 used their proprietary model, HABSYN, to derive flow-habitat relationships for each mesohabitat unit within the mainstem channels of the NFS, SFK, UT, KR and to predict the available habitat for each habitat unit specific to each species and lifestage of fish. The available habitat for all mesohabitat units within a reach were then summed to estimate the amount of available habitat by species and lifestage at the reach scale. Details on HABSYN model development and use are presented below.

R2 refined the modeling approach that was described in EBD Chapter 15.1C (PLP 2011) to allow for the derivation of synthesized habitat-flow relationships on a habitat-unit basis. Instead of applying one modeled habitat-flow relationship across an entire habitat unit, this alternate approach relied upon synthesizing a habitat-flow relationship for each of the habitat units based on the modeled WUA curves developed for nearby measured PHABSIM transects within the reach. The synthesized WUAs were calculated at the mid-point of each habitat unit and were used to represent the entire habitat unit. This modeling approach incorporated a "habitat-mapping" component that enables predictions of habitat-flow relationships within each habitat unit within a given reach. Using this methodology, the total available habitat was predicted under pre-mine, with-mine, and mine closure scenarios.

We mapped 1,984 habitat units within the four streams (NFK, SFK, UT, KR) that required synthesized WUA curves. There were 143 transects (Table 5-1) with hydraulic data and modeled habitat - flow relationships. The modeled habitat - flow relationships from the 143 transects were expanded to synthesize WUA for each of the two thousand habitat units using the procedure described below. This alternate approach provided greater spatial resolution and reliability of results than the traditional weighting methodology.

In developing the HABSYN model we assumed that the synthesized WUA at a stream location between any two transects (e.g., TR-A and TR-B) varies gradually from one to another. Thus, it also assumed that the synthesized WUA for a location adjacent to one transect, TR-A, would have a relationship similar to TR-A. As the synthesized WUA location moved more toward a second transect, TR-B, the synthesized WUA becomes less influenced by TR-A and more by TR-B, and therefore the synthesized WUA resembled more of that depicted at TR-B than TR-A, as illustrated in Figure 5-1. The variations in WUA were related to the bankfull flow width and mean annual flow of the species/lifestage being considered.

Table 5-1. PHABSIM Transects. The number of PHABSIM Transects in the North Fork Koktuli River (NFK), South Fork Koktuli River (SFK) and Upper Talarik Creek (UT).

Stream	Reach	# of PHABSIM Transects on each River Reach	# of PHABSIM Transects by Stream	Total # of PHABSIM Transects
NFK	NFK-A	17	41	44
	NFK-B	6		
	NFK-C	12		
	NFK-D	6		
	NFK-190	3	3	
SFK	SFK-A	22	40	46
	SFK-B	12		
	SFK-C	6		
	SFK-190	6	6	
UT	UT-B	6	42	48
	UT-C	9		
	UT-D	10		
	UT-E	11		
	UT-F	6		
	UT-190	6	6	
KR	--	5	5	5

Total Number of PHABSIM Transects = 143

In order to synthesize WUA curves at unsampled locations for a particular type of mesohabitat, bank full width was used first to normalize the WUA curves at each of the measured locations (as described in steps a-n below and Figure 5-1). Bankfull width at the unsampled locations was then used to restore the normalized synthesized WUA to the unsampled location. Bankfull flow width was obtained from data summarized in the EBD Appendix 15.1F (PLP 2011). These data were used to develop regression equations to estimate bankfull flow width by river kilometer.

Mathematically applying the influence of a transect on a given stream location within a habitat unit was called "weighting." The weighting of the transect on a stream location was determined as the reciprocal of the distance from the location to the respective transect. If the distance from the desired calculation point to TR-A was d_A and was d_B to TR-B, then the weightings of TR-A and TR-B on this point would be $1/d_A$ and $1/d_B$, respectively. Calculations were made for each habitat unit and the mid-point of the unit was used to represent the unit, so the distance would be from the transect to the mid-point of the habitat unit.

With transect weightings and measured WUAs, synthesized habitat - flow relationships for an unmeasured habitat unit can be calculated. An equivalent mathematical formula for the synthesized relationship (WUA_{syn}) was derived as

$$WUA_{syn} = \frac{WUA_{TR-A}^{sim} \times 1/d_A + WUA_{TR-B}^{sim} \times 1/d_B}{1/d_A + 1/d_B}, \qquad (1)$$

where the subscript *syn* indicates that the habitat - flow relationships were synthesized but not modeled from hydraulic data as in the case of PHABSIM transects, and the superscript *sim* denotes a simulated WUA, which was calculated from the normalized WUA, as explained in the steps depicted below.

It should be noted that the transects (e.g., TR-A and TR-B) and the synthesized calculation point were required to have the same habitat type and be situated within the same river reach. Due to different hydrology and river morphology in each river reach, the weighting was not calculated beyond the reach breakpoint. For reaches having more than two transects with the same habitat type, the prior formula was extended to include the additional transect (e.g., TR-C, with distance d_C to the stream location of interest) by adding $WUA_{TR-C}^{sim} \times {}^{1}/_{d_c}$ to the denominator and ${}^{1}/_{d_c}$ to the numerator.

The following steps illustrate the procedures that were used for calculating the normalized WUA and simulated WUA for a given habitat unit. Chinook Salmon spawning for “Run” habitat is used for here for the purpose of illustration; the same steps were applied to all other fish species/lifestages and habitat types by changing the periodicity months and the associated hydrology. The steps are graphically illustrated in Figure 5-1.

(a) Determine the habitat unit of interest and obtain the river kilometer (L^{meso}) at the mid-point of the unit from the mesohabitat mapping.

(b) Identify the habitat type of the habitat unit (e.g., run).

(c) Determine the length of the habitat unit.

(d) Determine the bankfull flow width, W_{BF}^{meso}, of the habitat unit.

(e) Determine a common flow range consisting of 30 flows to be used for the synthesized habitat - flow relationships for all habitat units in the river reach.

(f) Determine the mean annual flow for the habitat unit during the periodicity months (e.g., July and Aug for Chinook salmon spawning) from the daily flow record ($Q_{Annual,Chinook,spawning}^{meso}$).

(g) Identify all PHABSIM transects of the same habitat type as the habitat unit (e.g., run) within the river reach (e.g., TR-A and TR-B).

(h) Determine river kilometer (L^{TR-A} , L^{TR-B}), bankfull width (W_{BF}^{TR-A} , W_{BF}^{TR-B}), mean annual flow ($Q_{Annual,Chinook,spawning}^{TR-A}$, $Q_{Annual,Chinook,spawning}^{TR-B}$) for both Run transects. The associations of each parameters with the transects are self-explanatory from the superscripts.

(i) Calculate the distance from each transect to the mid-point of the unit (i.e., $d_A = L^{meso} - L^{TR-A}$ for TR-A and $d_B = L^{meso} - L^{TR-B}$ for TR-B).

(j) Calculate the weighting of each transect on the habitat unit, which is the reciprocal of the distance (i.e., $1/d_A$ for TR-A and $1/d_B$ for TR-B).

(k) Use the transect modeled WUA to calculate the normalized WUA (i.e., WUA^n) by dividing [1] each of 30 flows on the WUA by mean annual flow (i.e., $Q_{Annual,Chinook,spawning}^{TR-A}$, or $Q_{Annual,Chinook,spawning}^{TR-B}$) to obtain normalized flows and [2] each of the 30 habitat values on the WUA by bankfull flow width (W_{BF}^{TR-A} , or W_{BF}^{TR-B}) to obtain normalized habitat values. Perform the normalization for both Run transects.

(l) Calculate intermediate habitat - flow relationships using the WUA^n derived in the previous step by multiplying each of the 30 normalized flows with Q_{Annual}^{meso} and the each of the 30 normalized habitat values with W_{BF}^{meso} . Derive the intermediate relationships for both Run transects.

(m) Calculate simulated habitat - flow relationships (WUA_{TR-A}^{sim} , WUA_{TR-B}^{sim}) from the intermediate WUA in step (l) for the common flow range depicted in (e). This step is necessary because the 30 flows on each of the intermediate WUA are usually different.

(n) Use Equation (1) to calculate the synthesized habitat area - flow relationships (i.e., WUA_{syn}) for the habitat unit. The WUA_{syn} , calculated at the mid-point of the habitat unit synthesized WUA, is used to represent the habitat - flow relationship for the entire unit.

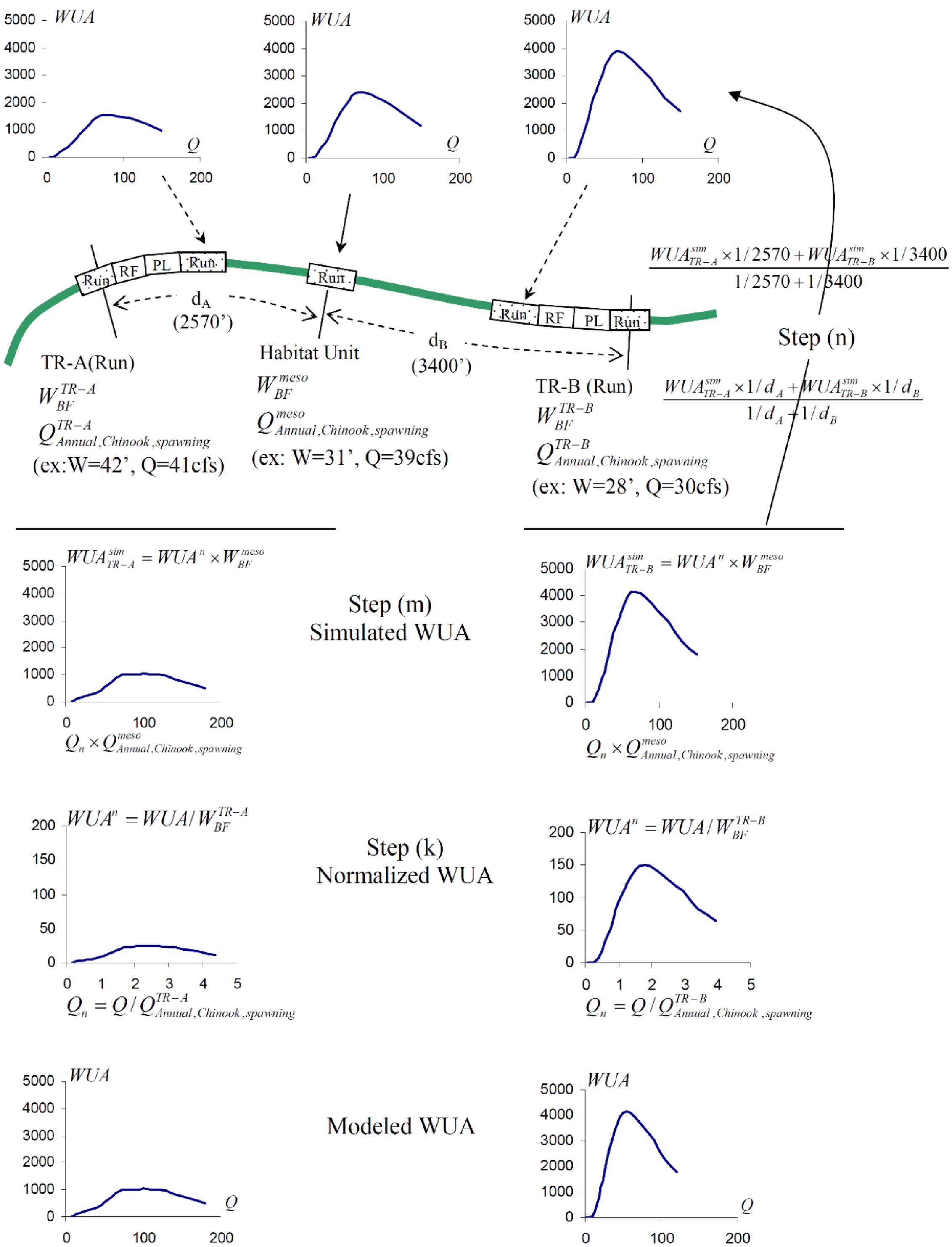

Figure 5-1. **Graphical depiction of the HABSYN modeling procedures used to compute synthesized WUA for each habitat unit within a stream reach. Graphic should be read from bottom to top. The modeled WUA is taken from the PHABSIM analysis of the measured transects. WUA from TR-A and TR-B are combined to generate WUA for the location of interest.**

6. Describe species prioritization and periodicity decisions.

The PHABSIM modeling employed a lifestage/species prioritization process from which to derive monthly habitat flow needs for each watershed. This was based on the same periodicity chart presented in the EBD (Figure 6-1). The specific times noted were in part based on a general understanding of the local fish species described in the published literature, as well as site specific data collected as part of the fish and instream flow studies.

The target species priority for each basin was determined by the PLP contractors and generally reflected the primary species that occurred in each basin, with consideration given to its management status by the Alaska Department of Fish and Game. For example, in the case of NFK and SFK, Chinook Salmon represented the primary target species due to its commercial importance and its, at the time, depressed state-wide run size. Coho Salmon, another commercially important species are also found in these basins and was included as a secondary target species. Two resident species, Rainbow Trout and Arctic Grayling were included as tertiary target species due to their sport fishery value. For UT, the primary target species was Sockeye Salmon due to its commercial importance and abundance in that watershed. Coho Salmon was included as a secondary target species, and Rainbow Trout and Arctic Grayling were included as tertiary target species; Chinook Salmon are not found in the UT.

The lifestage prioritization process was developed by R2 biologists and reflected a similar process R2 has applied on other instream flow studies, including state water rights adjudications in Oregon and Idaho and several hydroelectric projects in Washington and Oregon. The process reflected a lifestage prioritization of spawning > juvenile rearing > fry. Placing the highest priority on the spawning lifestage was done with the recognition that it represents the reproductive component of a fish population and that the provision of spawning habitat is important for the future propagation of the target species. Juvenile rearing was the second priority lifestage and occurs between the fry and spawning lifestages. The period of juvenile rearing encompasses a time when the fish is actively feeding and growing during warmer months and as well overwintering during colder months and extends in the case of anadromous salmonids until smoltification occurs and the fish begin their outmigration to saltwater. The fry lifestage ranked third in prioritization. This lifestage encompasses the period between fry emergence and the transition to the juvenile lifestage. Because fry seek shelter in areas with low velocity and that contain cover, the habitat needs of fry are generally met with flows much lower than those for other lifestages. Moreover, fry habitat is generally not limiting in fish populations. As a result, the fry lifestage was never a driver in determining any of the habitat-based flows for the NFK, SFK, or UT.

The application of the lifestage/species prioritization process initially entailed a preference for anadromous species for the SFK and NFK, while for the UT, the prioritization was for anadromous species and in addition, Rainbow Trout because of its sportfish value. The species/lifestage prioritization for all basins was subsequently modified with the inclusion of Arctic Grayling spawning in April and May, and Rainbow Trout spawning in June. These changes were made based on the difference in flow needs between Coho and Chinook juvenile rearing, and Arctic Grayling and Rainbow Trout spawning. Because the spawning lifestages reflected higher flow needs for those months, they were selected as the species/lifestage priorities. The species/lifestage priorities depicted in Table 6-1 are those currently being applied in the PHABSIM modeling.

Table 6-1. Priority species and lifestages. Priority species and lifestages used in PHABSIM to determine the habitat flow needs in the SFK, NFK, and UT (adapted from PLP 2011).

	Priority Species/Lifestages		
Month	**SFK**	**NFK**	**UT**
Jan	Chinook Juvenile Rearing	Chinook Juvenile Rearing	Coho Juvenile Rearing
Feb			
Mar			
Apr	Arctic Grayling Spawning	Arctic Grayling Spawning	Arctic Grayling Spawning
May			
Jun	Rainbow Spawning	Rainbow Spawning	Rainbow Spawning
Jul	Chinook Spawning	Chinook Spawning	Sockeye Spawning
Aug			
Sep	Coho Spawning	Coho Spawning	Coho Spawning
Oct			
Nov			
Dec	Chinook Juvenile Rearing	Chinook Juvenile Rearing	Coho Juvenile Rearing

The PHABSIM/HABSYN models were used to evaluate potential with- and without-mine effects on available fish habitat. For this comparative analysis, the total habitat area was predicted for the 10 year period of record for daily flows which included a range of different climatological conditions (wet, average, and dry). The habitat area was simulated and results were compiled for all target species and lifestages regardless of the priority used to establish restoration flows.

7. Illustrate how the various components of the various modeling processes (PHABSIM, hydrology, groundwater, water releases) work together to estimate flow-habitat relationships according to the project scenarios (pre-project, operation, closure; and dry, average, vs. wet years).

There are numerous models involved in the development of habitat area estimates at different flows for the proposed Pebble Project; all models are either components of the Pebble Comprehensive Modeling System or the R2 Habitat Model. The Pebble Comprehensive Modeling System encompasses the Groundwater Model, the Watershed Model, and the Mine Site Water Balance Model. The R2 Habitat Model includes PHABSIM and the R2 HABSYN Model. Figures 7-1 and 7-2 illustrate how the outputs and inputs of the various model components work together to develop the habitat area time series on which water management decisions can be made.

Note that some of the terminology in the RFI has been updated in the response to reflect the most recent Project-related language (e.g., pre-mine/pre-project, mine-affected/operational, and mine-affected with treated water/closure).

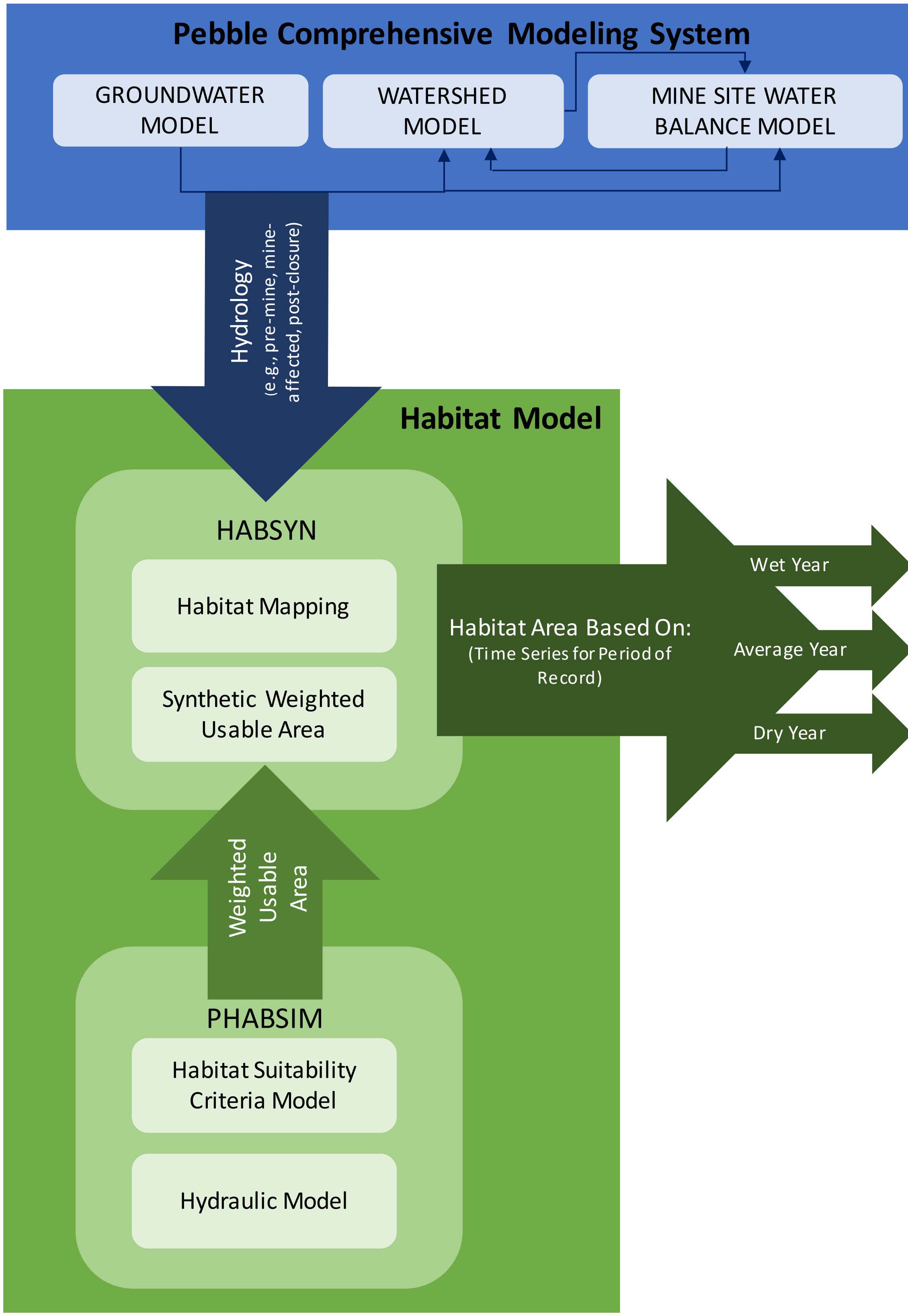

Figure 7-1. **Schematic showing the integration of the Pebble Comprehensive Modeling System and the Habitat Model that were used together to estimate available fish habitat.**

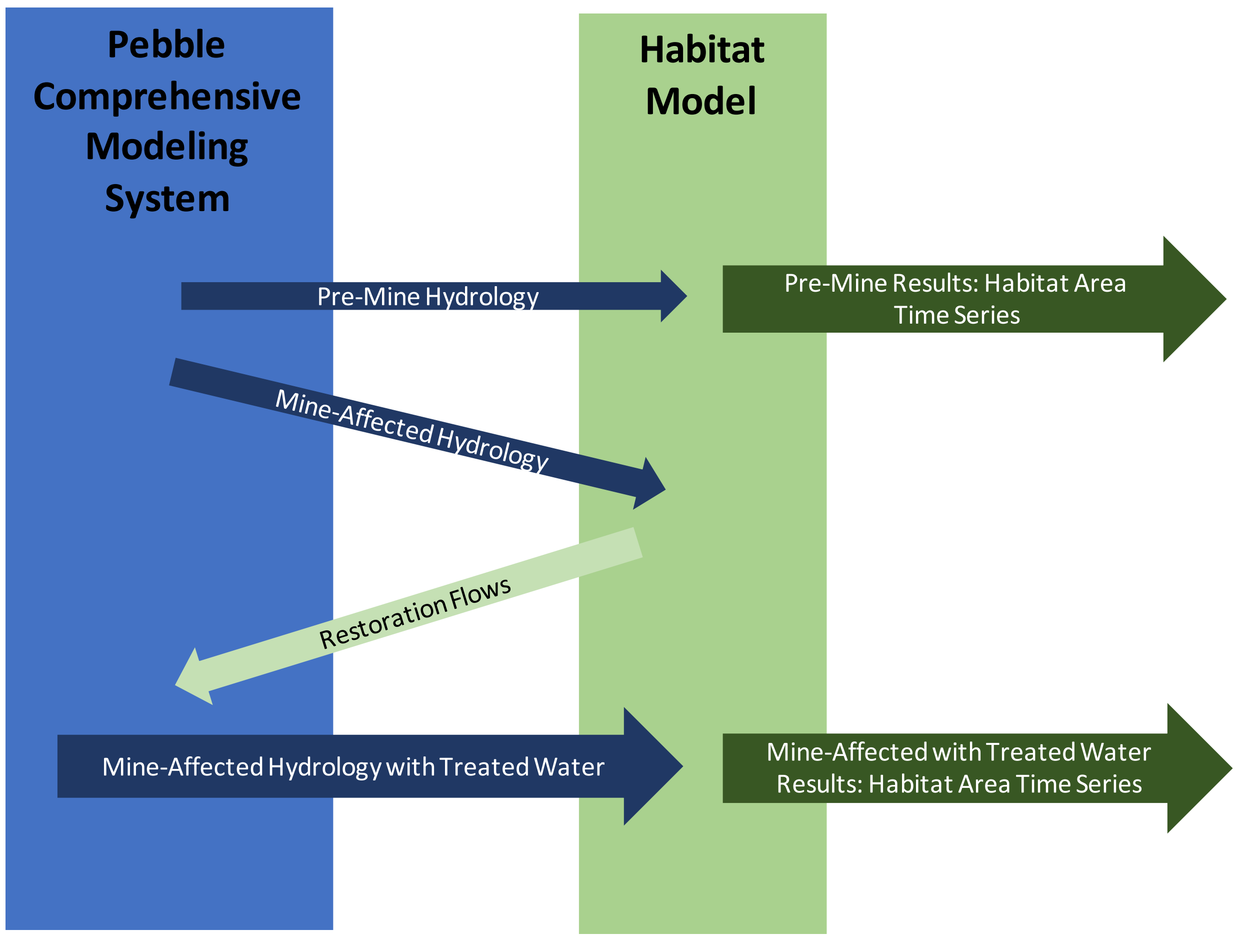

Figure 7-2. Schematic showing conceptual hydrology interactions between the Pebble Comprehensive Modeling System and the Habitat Model. Note: Restoration flows were developed with simulations. Habitat area increases were simulated by adding flow in one cubic feet per second increments to the mine-affected condition in order to calculate habitat area as a function of increasing mitigation flow until pre-mine habitat area was restored. This type of analysis was performed for all three basins for each month in the period of record and for the applicable priority species/lifestage (as determined from Table 6-1).

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