APPENDIX B10. EXISTING ENVIRONMENTAL CONDITIONS

1. INTRODUCTION

Understanding environmental conditions that influence fish behavior and movement and how these conditions may be altered as a result of proposed Susitna-Watana Project operations is essential to the development of sound fish passage concepts. Potential Project effects on ambient environmental conditions that can affect fish behavior include changes in flow, temperature, and turbidity/light penetration. In the sections that follow, relevant existing environmental conditions within the Susitna River drainage are briefly summarized and then followed by a bulleted list of literature-based information on how these conditions have the ability to influence fish movement and behavior and to ultimately affect the success of a fish passage program.

2. FLOW CONDITIONS

2.1. Existing Conditions

Annual stream flow patterns in the Susitna River basin (20,010 square miles) are governed by the relative timing and magnitude of glacier melt, snowmelt, and rainfall (Curran 2012). The relative contribution of each of these sources to the total flow varies among streams as a result of different subbasin characteristics (e.g., glacier cover). Nonetheless, annual stream flows in the basin typically follow a seasonal pattern. The low-flow period occurs during winter (i.e., approximately November through April), when ice and snow conditions are predominate the landscape. Breakup typically occurs in April or early May and coincides with an abrupt increase in flow as a result of ice and snow melt. In streams that are dominated by snowmelt contributions, peak flows typically occur between May and mid-June, although contributions from snowmelt continue throughout the summer months. Peak discharges in streams dominated by glacial melt typically occur later in the summer (e.g., July). After the glacial melt peak is reached, flows generally begin to decline, but may still remain relatively high. In lower elevation streams that are less driven by glacial melt, a second peak in flow may be observed in response to fall rains. Using the gaging station on the Susitna River at Gold Creek as an index, mean daily discharge for the Susitna River ranges from approximately 1,300 cubic feet per second (cfs) in January to approximately 28,000 cfs in July (USGS Gage 15292000 data from October 1, 1948 to September 30, 2011).

2.2. Effects on Fish Behavior and Movement

- Seasonal stream flow patterns are known to play an important role in triggering fish movement. See Appendix B4 for target species migratory characteristics.
- Using random-effects meta-analyses, Taylor and Cooke (2012) assessed the effects of flow magnitude on non-migratory fish movements, upstream migratory movements, downstream migratory movements, and fine-scale activity. River discharge had a positive and significant effect on non-migratory movement, and the magnitude of the effect appeared to be greater for non-salmonid species compared to salmonids. Discharge was also positively correlated with the rate, frequency, and probability of upstream migratory movement. Discharge was not significantly related to downstream

migratory movements or fine-scale activity, possibly due to differences in fish species, ambient stream conditions (e.g., temperature), season, habitat preferences, individual variation, and energy trade-offs associated with swimming and prey availability.

- In the Susitna River, Hale (1987, cited in Feist and Anderson 1991) found that the outmigrations of Chinook and sockeye salmon peaked along with river flow and sediment discharge peaks. However, separating the effects of increased turbidity from increased flow can be difficult (Bell 1991).
- Downstream migration rates have been directly related to flow velocities, since most downstream migrants move passively during high flows associated with runoff and snowmelt (Raymond 1968; Ruggles 1980 cited in Clarke et al. 2008; McCormick et al. 1998 cited in Clarke et al. 2008).
- In a regulated system, when spring runoff and snowmelt are stored, natural seasonal flows are reduced and can delay downstream migration (e.g., Raymond 1979 cited in Clarke et al. 2008).
- Flow regulation of tributaries to the Sacramento River has resulted in increased spring-summer flows and decreased flows in the fall, winter, and early spring, which has impeded Chinook salmon migration (Yoshiyama et al. 1998). Consequently, spawning and outmigration have been delayed compared to pre-regulation conditions, and these delays have contributed to the decline of Chinook salmon in the Central Valley Region (Yoshiyama et al. 1998).
- Spawning migration timing has been correlated with riverine conditions, particularly flow and water temperature. For example, Keefer et al. (2008) found that spring Chinook salmon migrations in the Columbia River occurred earliest in years with low river discharge or warm water temperatures and latest in years with high discharge and colder water temperatures.
- Returning adults are attracted to high velocity flows. Delays in upstream migration can result from "false attraction" flows associated with hydropower and fish passage operations (Clarke et al. 2008). For adult salmonids in the Pacific Northwest, delays in relation to tailrace attraction have been well documented and have been related to reduced spawning success (e.g., Fleming and Reynolds 1991).
- In an experimental study, Fleming and Reynolds (1991) used net pens to intentionally delay adult Arctic grayling that were migrating upstream to spawn; fish were delayed for 3, 6, and 12 days. Compared to control group fish, which were held for only 12 hours, adults that were delayed for three days or longer did not travel as far upstream to spawn. The authors suggest that such delays in Arctic grayling spawning migrations may lead to the use of non-preferred spawning habitat and ultimately decrease recruitment.
- The swimming performance of fish is affected by flow, as well as other factors such as species, fish size, temperature, stock, ecology/behavior, and physiological status (Feist and Anderson 1991). See Appendix B6 for details.
- Alterations in flow inherently change the amount and quality of habitat that is accessible to fish. Fish exhibit preferences for habitats that are characterized by specific depth, velocity, and substrate combinations. See Appendix B4 for target species migratory characteristics.

- Juvenile Chinook salmon are capable of detecting and responding to constant velocities of less than 1 inch per second (Hanson and Jacobson 1985 cited in Feist and Anderson 1991).
- With regard to fish passage systems, velocity may be used as a barrier or an attractant (Bell 1991).
- In clearwater systems, salmonid smolts have been reported to exhibit active swimming, maneuvering, and avoidance of changes in water velocity and hydrostatic pressure (Seitz et al. 2011). For example, in an assessment of fine-scale behavioral responses of Pacific salmonid smolts to altering flows, Kemp et al. (2005) noted that smolts exhibited behavioral choices for alternative flow conditions in open and constricted flume channels. Most smolts passed through the open channel, yet after controlling for the effects of flow, the rate at which smolts initially selected and subsequently rejected the constricted channel was greater. The authors concluded that knowledge of how diversion structures alter local hydraulic conditions and thus influence fish behavior is essential for successful fish guidance. However, it is unknown if smolts exhibit similar behavioral responses in turbid, high-velocity rivers (Seitz et al. 2011).
- Low winter discharge can result in increased anchor ice, and if the anchor ice forms in preferred winter habitats, it can result in fish displacement to less suitable habitats (Brown et al. 1993). Surface ice can protect against the formation of anchor ice, but warm water releases during the winter can impede surface ice formation (Lehmkuhl 1972 cited in Clarke et al. 2008).
- Frazil ice, which could form from turbulent water releases in the winter, has been related to respiratory complications in trout, and at high enough densities, can even cause suffocation (Brown et al. 1993).
- Changes in total dissolved gasses and hydrostatic pressure can occur as the result of flows plunging over spillways. The height and angle of the spillway as well as the depth to which the water plunges can produce supersaturated conditions that are lethal to fish. Rapid temperature increases and high amounts of photosynthetic activity further contribute to the likelihood that supersaturated conditions will result. Fish may develop gas bubble disease as a result of supersaturated conditions. Acute and chronic symptoms of this disease include stress-response behaviors, a loss of equilibrium, diminished swimming ability, reduced growth, and loss of lateral line sensitivity. (Clarke et al. 2008)

3. TEMPERATURE CONDITIONS

3.1. Existing Conditions

Existing thermal conditions in the Susitna River and its tributaries are not currently well known (Susitna-Watana Hydroelectric Project Revised Study Plan Section 5.5). Available historic data are not spatially or temporally continuous, thus limiting the ability to identify and describe thermal regimes within the Susitna River drainage. In 2012, a continuous water quality monitoring program was initiated, and additional monitoring will continue throughout 2013 and 2014. Although the temperature data set at this time is too small to draw conclusions regarding the temperature profile of the river, data from 21 sites that were monitored from July through October 2012 revealed that water temperatures in the mainstem river and its sloughs ranged from approximately 0 to 18 ºC during this time period (URS Corporation and Tetra Tech Inc. 2013).

3.2. Effects on Fish Behavior and Movement

- Spawning migration timing has been correlated with riverine conditions, particularly flow and water temperature (e.g., Keefer et al. 2008). However, the degree to which temperature may affect migration and spawn timing is species-specific and may be a function of different life history strategies and optimal embryonic development and juvenile rearing conditions (Quinn and Adams 1996).
- Adversely warm temperature conditions may delay or obstruct the migration and spawning of adult salmonids (Bell 1991; McCullough 1999).
- Under adverse thermal conditions, adults may utilize thermal refugia in cooler tributaries (e.g., Fish and Hanavan 1948 cited in McCullough 1999), areas of groundwater upwelling (e.g., Berman and Quinn 1991 cited in McCullough 1999), or deep holding pools (e.g., Moyle 1976 cited in McCullough 1999).
- Torgersen et al. (1999) found that adult Chinook salmon distribution was positively correlated with stream temperature patterns at reach-level spatial scales, although the strength of this correlation was diminished in a cold water stream compared to a warmer stream. At smaller spatial scales, habitat use patterns may be distinguishable provided that local variation in water temperatures is large enough to elicit a biologically significant response (e.g., Ebersole et al. 2001 cited in USEPA 2001).
- Temperature has been found to be negatively correlated with juvenile salmonid densities in both the field (e.g., Bjornn 1978 cited in McCullough 1999) and in the lab (Hahn 1977 cited in McCullough 1999). The temperature effect on density may occur through a combination of survival effects, behavioral avoidance, and interspecific competition (McCullough 1999).
- In the Snake and Clearwater rivers, Connor et al. (2002) found statistically significant correlations between stream temperature and juvenile fall Chinook salmon life history characteristics (i.e., fry emergence, growth to parr size, and smolt emigration), and they observed that the percentage of parr that overwintered in freshwater and outmigrated the following spring increased when spring water temperatures decreased. The authors hypothesized that dam construction and the subsequent flooding of historic spawning habitat has altered the life history of this stock, by forcing adults to use cooler headwater streams for spawning.
- In an experiment to simulate the transport of fish from warm tributaries to cold tailwaters, Clarkson and Childs (2000) found that a sudden decrease in water temperature from 20 to 10 ºC caused a loss of equilibrium in young life stages of sucker, chub, and squawfish. Such losses of equilibrium could potentially increase mortality through involuntary drift.
- Because fish have the ability to sense a temperature differential of approximately 0.3 ºC, it is possible that they may avoid higher than optimal temperatures (Bell 1991). However, there is no direct evidence suggesting that freshwater fish actively and immediately avoid higher than optimal temperatures (Bell 1991). In some instances, it is

possible that brief forays into physiological stressful habitats may provide a net benefit (e.g., food consumption, predator avoidance; USEPA 2001). Fish may remain in habitats with temperatures near their upper tolerance limits for long periods of time before moving to cooler waters, and acclimation to warmer water temperatures may be an important factor in triggering a movement response (Bell 1991). Fish do not necessarily move away from high temperature areas until temperatures are greater than their upper tolerance levels (Bell 1991). Fish may seek cooler waters based on indirect factors (e.g., innate responses to conserving body fat) or other potentially unrelated factors (e.g., light conditions, instream cover; Bell 1991). Alternatively, relatively warmer areas (e.g., upwellings) may be utilized during periods of critically low temperatures (Bell 1991).

- Indirect effects associated with increased water temperatures (e.g., decreased dissolved oxygen concentrations, habitat productivity/food availability, intraspecific competition) may also elicit behavioral responses in fishes. Behavioral responses to limited oxygen availability include changes in activity (e.g., ventilation frequency, feeding, less predator avoidance), increased use of air breathing or aquatic surface respiration, and vertical or horizontal habitat movements (Kramer 1987). Ambient temperature and dissolved oxygen levels, among other factors such as fish length, species, and flow conditions, can affect fish swimming ability (Bell 1991). Although the authors did not specifically address temperature conditions, Näslund et al. (1993) found that some individuals of a land-locked Arctic char population residing in an oligotrophic lake in Sweden migrated to distant productive lake habitats for summer foraging when food conditions in the primary lake were limited.

4. TURBIDITY/LIGHT CONDITIONS

4.1. Existing Conditions

The Susitna River is characterized by naturally occurring turbid waters, as a result of glacial inputs. Available turbidity data for the Susitna River has been compiled from historic USGS stations and the 1980s study program (Susitna-Watana Hydroelectric Project Pre-Application Document Appendix 4.4-1). As expected, turbidity measurements varied seasonally, with the greatest turbidity measurements observed in the summer months. During the summer, maximum turbidity measurement at each mainstem site ranged from 200 to 1,056 nephelometric turbidity units (NTUs). Observed winter values ranged from 0 to 3 NTUs. Spring and fall measurements were generally moderate to high and ranged from 0.01 to 590 NTUs. During the 2013 and 2014 Baseline Water Quality Study (Susitna-Watana Hydroelectric Project Revised Study Plan Section 5.5), turbidity will be monitored at several main channel and slough sites along the length of the Susitna River.

Clear-water inputs (e.g., tributaries) to Susitna River have the ability to attenuate the turbidity of mainstem waters. However, given the large width of the mainstem river, the spatial extent of such attenuation is limited. Clear-water plumes from tributaries are typically limited to the mainstem bank downstream of the tributary confluence, and the spatial extent of a clear-water plume is expected to fluctuate with discharge, as well as natural changes in turbidity throughout the seasons. Clear-water areas can also be found in slough and tributary habitats. Relative to the mainstem, sloughs and tributaries may be less turbid, because they are fed by different source flows (e.g., upwellings and non-glacial headwaters). In addition, the relatively low velocities of slough habitats allow suspended sediments to settle out of the water column, thereby reducing turbidity.

4.2. Effects on Fish Behavior and Movement

- Overall, the effects of turbidity on fish behavior and movement are quite variable. This variation appears to be related to differences in species, life stage, naturally occurring turbidity levels, acclimation to altered conditions, the magnitude of turbidity increases/exceedances, and other ambient conditions (Feist and Anderson 1991).
- Some observed behavioral responses of fish to acutely altered turbidity conditions include: 1. alarm-type responses (e.g., hiding in gravel, sporadic swimming); 2. decreased reaction distance to prey, as observed in juvenile coho salmon (Berg and Northcote 1985 cited in Feist and Anderson 1991); 3. decreased use of overhead cover; 4. increased activity; and 5. reduced substrate associations for brook trout and creek chubs (Gradall and Swenson 1982 cited in Feist and Anderson 1991).
- Juvenile salmonids typically avoid chronically turbid streams (Lloyd et al. 1987 cited in Bjornn and Reiser 1991), except for migratory purposes.
- Daily periods of outmigration for Pacific salmon have been found to be extended during turbid water conditions (e.g., McDonald 1960 cited in Feist and Anderson 1991; Noggle 1978 cited in Feist and Anderson 1991; Bell 1991). In the Susitna River, Hale (1987, cited in Feist and Anderson 1991) found that the outmigrations of Chinook and sockeye salmon peaked along with river flow and sediment discharge peaks. However, the effects of increased turbidity from increased flow were indistinguishable (Bell 1991).
- The distribution of downstream migrants across a stream channel is typically non-uniform with most fish located along the shoreline, although this pattern is likely to vary among species. Shorelines naturally guide migrating fish, presumably because they provide a visual reference. Other factors, such as light intensity, instream cover, and velocity, may also be important in understanding why the lateral distribution of fish is often greatest along the shoreline. (Bell 1991)
- The vertical distribution of downstream migrants is typically characterized by a greater number of fish in the top half of the water column, yet this distribution may be influenced by light intensity and time of day as well as water temperature, fish size, and species (Bell 1991).
- Ephemerally high concentrations of suspended sediments, such as those associated with storms and snow melt, appear to have little effect on larger juvenile and adult salmonids (Cordone and Kelley 1961 cited in Bjornn and Reiser 1991; Sorenson et al. 1977 cited in Bjornn and Reiser 1991). However, increased straying of adult fall Chinook and coho salmon from the Toutle River was observed in response to extremely elevated sediment concentrations as a result of the 1980 eruption of Mount St. Helens (Martin et al. 1984).
- Breeser et al. (1988) studied burbot movement in the upper Tanana River, a glacial tributary of the Yukon River. Radio-tagged burbot were most commonly detected in the main river channel, even when peak summer flows resulted in increased turbidity.

- Turbidity offers a measure of protection from piscivorous fish species (Bell 1991; Gregory and Levings 1998). Gregory and Levings (1998) found that predation rates of juvenile Chinook salmon were significantly less in the naturally turbid Fraser River (27-108 NTU) than in the clear-water Harrison River (1 NTU).
- Because fish often rely on visual cues for movement, turbidity can affect movement by obscuring targets and other visual references (Bell 1991; Brett and Groot 1963).
- Light levels, as well as other factors, play a role in the feeding, shelter seeking, and movement patterns of fish (Feist and Anderson 1991). Fish respond to shadow and light patterns and generally favor cover (Bell 1991), although specific responses to light and shadow tend to vary by species, developmental stage, and adaptation to ambient light levels (Feist and Anderson 1991).
- Sensitivity to light was found to increase during smolting in both coho and sockeye salmon, as evidenced by their seeking cover or deeper water (Hoar et al. 1957).
- Both natural and artificial light conditions, among other factors such as velocity, channel shape, depth, sound, odor, and temperature, play a role in fish guidance and passage at dams and diversions (Bell 1991). Depending on ambient stream conditions and light intensity, light can be used for fish guidance as both a deterrent and attractant (Bell 1991). Artificial lighting generally repels fish at higher intensities and attracts them at lower intensities (Fields et al. 1958). The effectiveness of artificial lighting as a deterrent may be diminished in more turbid water (Fields et al. 1958). During night time hours, artificial lighting can reduce the hours of normal darkness and thus impede movement (Bell 1991).

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