9.8. River Productivity Study

9.8.1. General Description of the Proposed Study

The production of freshwater fishes in a given habitat is constrained both by the suitability of the abiotic environment and by the availability of food resources (Wipfli and Baxter 2010). Algae are an important base component in the lotic food web, being responsible for the majority of photosynthesis in a river or stream and serving as an important food source to many benthic macroinvertebrates. In turn, benthic macroinvertebrates are an essential component in the processes of an aquatic ecosystem, due to their position as consumers at the intermediate trophic level of lotic food webs (Hynes 1970; Wallace and Webster 1996; Hershey and Lamberti 2001). Macroinvertebrates are involved in the recycling of nutrients and the decomposition of terrestrial organic materials in the aquatic environment, serving as a conduit for the energy flow from organic matter resources to vertebrate populations, namely fish (Hershey and Lamberti 2001; Hauer and Resh 1996; Reice and Wohlenberg 1993; Klemm et al. 1990). In turn, nutrients and energy provided by spawning salmon have the potential to increase freshwater and terrestrial ecosystem productivity (Wipfli et al. 1998; Cederholm et al. 1999; Chaloner and Wipfli 2002; Bilby et al. 2003; Hicks et al. 2005), and may subsidize otherwise nutrient-poor ecosystems (Cederholm et al. 1999).

The significant functional roles that macroinvertebrates and algae play in food webs and energy flow in the freshwater ecosystem make these communities important elements in the study of a stream's ecology. The operations of the proposed Project would likely affect one or more of the factors that can affect the abundance and distribution of benthic algae and benthic macroinvertebrate populations, which could ultimately affect fish growth and productivity in the system. The degree of impact on the benthic communities and fish resulting from hydropower operations will necessarily vary depending on the magnitude, frequency, duration, and timing of flows, as well as potential Project-related changes in geomorphology, ice processes, temperature, and turbidity. By investigating the current populations of algae, benthic macroinvertebrates, and fish in the Susitna River and the trophic relationships between them, this study will generate information about the current health and status of these populations throughout the varied habitats in the Susitna River, and provide a better understanding on the availability and utilization of food resources in the system. In addition, by applying what is known about the effects of river regulation and hydropower operation on these populations in riverine ecoysystems, we can begin to assess the potential impacts of Project operations on river productivity in the Susitna River, as well as provide information to inform development of any necessary protection, mitigation, and enhancement (PM&E) measures.

9.8.1.1. *Study Goals and Objectives*

The overarching goal of this study is to collect baseline data to assist in evaluating the effects of Project-induced changes in flow and the interrelated environmental factors (temperature, substrate, water quality) upon the benthic macroinvertebrate and algal communities in the middle and upper Susitna River. Individual objectives that will accomplish this are listed below.

1. Synthesize existing literature on the impacts of hydropower development and operations (including temperature and turbidity) on benthic macroinvertebrate and algal communities.
2. Characterize the pre-Project benthic macroinvertebrate and algal communities with regard to species composition and abundance in the middle and upper Susitna River.
3. Estimate drift of benthic macroinvertebrates in selected habitats within the middle and upper Susitna River to assess food availability to juvenile and resident fishes.
4. Conduct a feasibility study in 2013 to evaluate the suitability of using reference sites on the Talkeetna River to monitor long-term Project-related change in benthic productivity.
5. Conduct a trophic analysis to describe the food web relationships within the current riverine community within the middle and upper Susitna River.
6. Develop habitat suitability criteria for Susitna benthic macroinvertebrate and algal habitats to predict potential change in these habitats downstream of the proposed dam site.
7. Characterize the invertebrate compositions in the diets of representative fish species in relationship to their source (benthic or drift component).
8. Characterize organic matter resources (e.g., available for macroinvertebrate consumers) including coarse particulate organic matter, fine particulate organic matter, and suspended organic matter in the middle and upper Susitna River.
9. Estimate benthic macroinvertebrate colonization rates in the Middle Susitna Reach to monitor baseline conditions and evaluate future changes to productivity in the Susitna River.

9.8.2. Existing Information and Need for Additional Information

A number of evaluations of the benthic macroinvertebrate community were conducted on the Susitna River in the 1970s and in the 1980s for the original Alaska Power Authority (APA) Susitna Hydroelectric Project (Friese 1975; Riis 1975, 1977; ADF&G 1983; Hansen and Richards 1985; Van Nieuwenhuyse 1985; Trihey and Associates 1986). ADF&G studies in the 1970s included sampling of macroinvertebrates using artificial substrates (rock baskets) deployed for a set period of time to allow for colonization. Friese (1975) and Riis (1975) set a total of eight rock baskets in Waterfall Creek, Indian River, and the mainstem middle Susitna River for 30 days during summer (July – September). Riis (1977) also deployed rock baskets in the Susitna River near the mouth of Gold Creek for a colonization period of 75 days; however, only two of seven baskets were retrieved. Results were limited to low numbers of invertebrates per basket, identified to taxonomic family.

Studies conducted in the 1980s for the original APA Susitna Hydroelectric Project focused on benthic macroinvertebrate communities in the sloughs, side channels, and tributaries of the middle reach of the Susitna River from river mile (RM) 125 to RM 142 during the period from May through October. Efforts included direct benthic sampling with a Hess bottom sampler and drift sampling. Alaska Department of Fish and Game (ADF&G) efforts in 1982 and 1984 also involved collection of juvenile salmon in these side channels and sloughs, and an analysis was conducted to compare gut contents with the drift and benthic sampling results (ADF&G 1983;

Hansen and Richards 1985). In addition, Hansen and Richards (1985) collected water velocity, depth, and substrate-type data to develop habitat suitability criteria (HSC), which were used to estimate weighted usable areas for different invertebrate community guilds, based on their behavioral type (swimmers, burrowers, clingers) in slough and side channel habitats. Efforts in 1985 (Trihey and Associates 1986) expanded to include sampling at nine sites in the Middle Susitna River Reach: three side channels, two sloughs, two tributaries, and two mainstem sites.

Algal communities were periodically sampled and analyzed for chlorophyll-a at Susitna Station from 1978 to 1980. In the 1980s, algae samples were collected as part of the APA Susitna Hydroelectric Project water quality studies, with sampling conducted at Denali, Cantwell (Vee Canyon), Gold Creek, Sunshine, and Susitna Station on the Susitna River, as well as on the Chulitna and Talkeetna rivers (Harza-Ebasco 1985 as cited in AEA 2011). Analysis showed low productivity (less than 1.25 mg/m^3 chlorophyll-a) and indicated algal abundance was most likely limited by high concentrations of turbidity (AEA 2011).

Baseline field data for benthic primary and secondary production was also collected in 1985, as part of the Primary Production Monitoring Effort (Van Nieuwenhuyse 1985). Chlorophyll-a (*chl-a*), and macroinvertebrates were collected from early April to late October 1985 from a variety of off-channel and mainstem habitat sites. Early April sampling took place in an open-water lead in Slough 8A, and revealed high macroinvertebrate densities (average 17,600 individuals/m^2) comprised almost entirely of chironomid larvae, and chlorophyll-a densities averaging 34.4 mg/m^2. Sampling in early May in Slough 8A revealed macroinvertebrate densities averaging 2,950 individuals/m^2, again almost entirely chironomids, and *chl-a* densities averaging 37mg/m^2. Results from five mainstem habitat sites showed similar macroinvertebrate numbers, with densities ranging from 393 to 8,820 individuals/m^2 in May 1985, but with considerably more diversity; chironomids accounted for an average of 53 percent of the density, and only 8 percent of the macroinvertebrate biomass. Algae samples beyond May 1985 had not been analyzed; therefore, no data were available for summer or fall. No sampling results were given for summer macroinvertebrate sampling (June and July). August and September 1985 sampling showed low average densities at mainstem sites (44 – 164 individuals/m^2), with large increases occurring in October 1985 (1,729 – 7,109 individuals/m^2). Average densities in Slough 8A in August 1985 remained similar to spring levels, at 2,851 individuals/m^2, with a surge in September 1985 (13,964 individuals/m^2); again, chironomids represented over 80 percent of the numbers. No further information or reports were available concerning the Primary Production Monitoring Effort task.

Benthic macroinvertebrate information from the 1980s is focused on a limited number of mainstem, side channel, and slough habitats located within a 17-mile reach of the middle Susitna River. Additional information is needed on mainstem benthic communities, as well as those in side channel and slough habitats, within both the Middle and Upper Susitna River reaches. Benthic algae information needs to be collected in conjunction with the macroinvertebrates to define their relationship in the river's trophic system. To assess the impact of future hydropower operations on the benthic communities within the Susitna River, additional information must be collected through an increased sampling effort, including more sampling sites along the river in relation to the distance both downstream from the proposed dam site and upstream from the proposed Project reservoir area.

9.8.3. Study Area

The River Productivity Study will entail field sampling throughout the upper and middle study reaches on the Susitna River (Table 9.8-1; Figures 9.8-1 through 9.8-2). The Upper Susitna River Reach is defined as the section of river above the proposed Watana Dam site at RM 184 (Figure 9.8-1). Sampling in the upper portions of this reach above the proposed reservoir (RM 233 – 260) will investigate the benthic communities that will be unaffected by the Project. The Middle Susitna River Reach encompasses the 86-mile section of river between the proposed Watana Dam site and the Chulitna River confluence, located at RM 98 (Figure 9.8-2). Sampling activities within this reach will investigate the benthic communities that may be affected by the Project and its regulated flows. Sampling will be conducted at various distances from the proposed dam site to document longitudinal variability, and estimate the effects that the proposed Project will have on benthos in the river system downstream. The Lower Susitna River Reach, defined as the approximate 98-mile section of river between the Chulitna and Talkeetna rivers confluence and Cook Inlet, will not be sampled in this study because the larger influences of the Chulitna and Talkeetna rivers will attenuate Project operation effects, if any, that would affect benthic communities on the mainstem Susitna River below the confluence of the three rivers. If the hydrology and geomorphic studies indicate a likely potential for Project effects in the lower river, the decision not to sample the lower reach will be revisited with the agencies and stakeholders through the Technical Workgroup process in fall/winter 2013.

9.8.4. Study Methods

To evaluate the effects of Project-induced changes in flow and the interrelated environmental factors (temperature, substrate, water quality) on the benthic macroinvertebrate and algal communities in the Susitna River, the following nine study components have been proposed:

9.8.4.1. *Synthesize existing information on the impacts of hydropower development and operations (including temperature and turbidity) on benthic macroinvertebrate and algal communities.*

Several reviews have been written on the effects that modified flows have on the benthic communities residing below dams (Ward 1976; Ward and Stanford 1979; Armitage 1984; Petts 1984; Cushman 1985; Saltveit et al. 1987; Brittain and Saltveit 1989). A majority of these reviews indicate that temperature and flow regimes are often the most important factors affecting benthic macroinvertebrates below dams. The type of dam and its mode of operation will have a large influence over the type and magnitude of effects on the receiving stream below. General information on the effects of hydropower on riverine habitats, especially glacially-fed river systems, as well as Project-specific information, will be reviewed and synthesized. Specifically, the literature review will summarize relevant literature on macroinvertebrate and algal community information in Alaska, including 1980s Susitna River data; review and summarize literature on general influences of changes in flow, temperature, substrates, nutrients, turbidity, light penetration, and riparian habitat on benthic communities; and review and summarize the potential effects of dams and hydropower operations, including flushing flows and load following, on benthic communities and their habitats.

9.8.4.2. *Characterize the pre-Project benthic macroinvertebrate and algal communities with regard to species composition and abundance in the middle and upper Susitna River.*

9.8.4.2.1. Benthic macroinvertebrate sampling

Macroinvertebrate sampling will be stratified by reach and mainstem habitat type defined in the Project-specific habitat classification scheme (mainstem, tributary confluences, side channels, and sloughs). To accomplish this objective, sampling will occur at six stations, each with three sites (one mainstem site and two off-channel sites associated with the mainstem site), for a total of 18 sites. Two stations will be located in the upper reach, above the proposed dam and reservoir area (upstream of RM 223), and four stations will be located below the dam site in the middle reach (Table 9.8-1; Figures 9.8.1-9.8.2). Efforts will be made to locate sampling sites at Focus Areas established by the Instream Flow Study team (Section 8.5), in an attempt to correlate macroinvertebrate data with additional environmental data (flow, substrates, temperature, water quality, riparian habitat, etc.) for statistical analyses, and HSC development. Station and site locations will be determined during the first quarter of 2013.

Three sampling periods will occur from April through October in both study years (2013–2014) to capture seasonal variation in community structure and productivity. Sampling will be conducted in riffle habitats within mainstem and off-channel habitat types (i.e., tributary confluences, side channels, and sloughs). Benthic macroinvertebrate sampling will be conducted using a stream-type sampler (Hess, Surber, Slack) commonly used for other Alaskan benthic macroinvertebrate studies to allow for comparable results; state and federal protocols, as well as methods used in the Susitna River studies in the 1980s, will be considered when designing the sampling approach (Hansen and Richards 1985; Carter and Resh 2001; Klemm et al. 1990; Klemm et al. 2000; Moulton et al. 2002; Peck et al. 2006). Replicate samples (n=5) will be collected to allow for statistical testing of results for short- and long-term monitoring. Measurements of depth, mean water column velocity, and substrate composition will be taken concurrently with benthic macroinvertebrate sampling at the sample location for use in HSC/HSI development in the instream flow studies. Water temperatures will be monitored hourly at sites with submerged temperature loggers deployed at all sampling sites throughout the ice-free season. Fine-scale (1 m vertical and horizontal resolution) measurements of flow will be recorded within a 5-m radius of selected sampling sites. Temperature and flow monitoring will be coordinated with the Baseline Water Quality Study (Section 5.5) and the Instream Flow Study (Section 8.5), and supplemental temperature loggers will be deployed if necessary to cover all River Productivity Study sites.

In addition, floating emergence traps will be deployed at each site to determine both the timing and the amount of adult insect emergence from the Susitna River (Cushman 1983). Adult aquatic insect emergence mass is a product of aquatic insect production from the stream, and is therefore a good surrogate for actual production (minus predation), and will be especially useful for relative comparisons between river sections and years (personal communication, M. Wipfli, University of Alaska-Fairbanks). Emergence traps will be checked and reset every month. Trapped adults will be identified, enumerated, and weighed. Exact trap design will be determined according to methods compatible with those used for other studies in comparable streams/basins in Alaska.

Due to the prevalence of large woody debris in the Susitna River, woody snags, if present at a sampling site, also will be sampled as a substrate strata for benthic macroinvertebrates, as requested by the U.S. Fish and Wildlife Service (USFWS) (USFWS River Productivity Study Request; May 31, 2012). Sampling methods for woody snags will be semi-quantitative (Moulton et al. 2002). Suitable woody snags will have been submerged for an extended period of time so as to be clearly colonized. Sections of woody snags to be sampled will be removed from the water by using a saw and placed over a plastic bin or in a bucket, and all benthic macroinvertebrates will be removed by handpicking, brushing, and rinsing. The snags will be allowed to dry for a period of time so that missed organisms will crawl out of the crevices and can then be collected. Snag sections sampled will be measured for length and average diameter to determine surface area sampled. Each snag section will count as a separate, replicate sample.

Benthic macroinvertebrate samples will be processed in a laboratory using methods compatible with those used for other studies in comparable streams/basins in Alaska. State and federal protocols (Barbour et al. 1999; Major and Barbour 2001; Moulton et al. 2002) will be considered when making decisions about the sample processing protocols, including subsampling protocols and the taxonomic resolution of specimen identifications.

Results generated from the collections will include several descriptive metrics commonly used in aquatic ecological studies, such as density (individuals per unit of area), taxa richness (both mean and total), EPT taxa (i.e., *Ephemeroptera*, *Plecoptera*, *Trichoptera*) richness, diversity (H'), evenness (J'), percent dominant taxa, the relative abundance of major taxonomic groups, and the relative abundance of the functional feeding groups. In conjunction with the bioenergetics modeling (Section 9.8.4.5.1), biomass estimates will be taken for primary invertebrate taxa collected for benthic and emergence sampling. The fresh blotted wet mass of invertebrate taxa in samples will be recorded, the samples will be oven dried at 60˚C until reaching constant mass, and the dry mass will be recorded. For a select subsample of the collection, energy density (J / g wet weight) will be estimated from the percent dry mass (dry mass / wet mass) of each sample (Ciancio et al. 2007; James et al. 2012). Energy density will be determined separately for the aquatic and terrestrial (adult) life-stages of each primary invertebrate taxon. For two selected stations, benthic macroinvertebrates and organic matter in samples will then be utilized for stable isotope analysis (Objective 5, Section 9.8.4.5.2).

Data collected during this study will be compared to the results of 1980s studies (ADF&G 1983; Hansen and Richards 1985; Van Nieuwenhuyse 1985; Trihey and Associates 1986) to evaluate any differences between the historic and current community structure. In addition, any invasive benthic macroinvertebrates identified in the sample collections will be identified and their collection locations will be recorded using the Geographic Information System (GIS) (NAD 83).

9.8.4.2.2. Benthic algae sampling

Benthic algae sampling will be collected concurrently with benthic macroinvertebrate sampling to allow for correlation between the two collections (Table 9.8-1). Benthic algae sampling will be conducted using methods compatible with other Alaska benthic algal studies, to allow for comparison of results. State and federal protocols will be considered when designing the sampling approach (Eaton et al. 1998; Barbour et al. 1999; Moulton et al. 2002; Peck et al. 2006). Measurements of depth, mean water column velocity, turbidity, and substrate composition will be taken concurrently with algae sampling at the sample location for use in HSC development in the instream flow studies. Light availability will be measured at each sample location with an underwater light sensor, to measure the photosynthetically active radiation (PAR) available to the algal community. Turbidity measurements will also be taken at the site to determine water clarity.

Benthic algae samples will be processed in a laboratory, using methods compatible with those used for other studies in comparable streams/basins in Alaska, considering state and federal protocols (Eaton et al. 1998; Barbour et al. 1999; Moulton et al. 2002; Peck et al. 2006) to determine sample processing protocols, including subsampling protocols.

Results generated from the collections would include both dry weight and chlorophyll-a, and several descriptive metrics to describe the algal community. For two selected stations, portions of algal material will then be utilized for stable isotope analysis (Objective 5, Section 9.8.4.5.2). In addition, any invasive algae taxa identified in the sample collections will be identified and their locations will be recorded using GIS (NAD 83).

9.8.4.3. *Estimate drift of invertebrates in selected habitats within the middle and upper Susitna River to assess food availability to juvenile and resident fishes.*

Invertebrate drift sampling will be conducted concurrently with benthic macroinvertebrate sampling at the six established benthic stations to allow for comparisons between the drift component and the benthic macroinvertebrate community, as well as revealing the availability of terrestrial invertebrates to fish predation. Sampling will be conducted in riffle habitats within the mainstem sites, and their associated off-channel habitat sites (Table 9.8-1).

Invertebrate drift sampling will be conducted using a drift net similar to those used for other drift studies in Alaska to allow for comparison of results; state and federal protocols will be considered (Keup 1988; Klemm et al. 2000). Drift sampling will be conducted during daytime hours, as a measure of background drift that is available to feeding fish (Waters 1972; Brittain and Eikeland 1988; Keup 1988). Sampling methods will involve collecting duplicate samples to allow for statistical testing of results for short- and long-term monitoring. Water velocity directly in front of the net will be recorded both upon deployment and upon retrieval of the net. Invertebrate drift samples will be processed in a laboratory, using methods compatible with other studies conducted in comparable streams/basins in Alaska. State and federal protocols (Barbour et al. 1999; Major and Barbour 2001; Moulton et al. 2002) will be considered when making decisions about the sample processing protocols, including subsampling protocols, taxonomic resolution of specimen identifications, and length measurements for individual specimens. Samples at two selected stations (one each in upper and middle reaches) will be tested for the stable isotope analysis task (Section 9.8.4.5.2). Organic matter (OM) content will be retained and analyzed by size (coarse and fine particulate OM) as discussed in Section 9.8.4.8.

Results generated from these collections will include drift density, drift rate, and drift composition. In conjunction with the bioenergetics modeling (Section 9.8.4.5.1), biomass estimates will be taken for primary invertebrate taxa collected for drift sampling. The fresh blotted wet mass of invertebrate taxa in samples will be recorded, the samples will be oven-dried at 60˚C until reaching constant mass, and the dry mass will be recorded. For a select subsample of the collection, energy density (J / g wet weight) will be estimated from the percent dry mass (dry mass / wet mass) of each sample (Ciancio et al. 2007; James et al. 2012). Energy density will be determined separately for the aquatic and terrestrial life stages of each primary invertebrate taxon. For two selected stations, portions of terrestrial invertebrate composition and organic matter in samples will then be utilized for stable isotope analysis (Objective 5, Section 9.8.4.5.2).

Data collected as part of this study will be compared to data from the benthic macroinvertebrate collections (Section 9.8.4.2.1) and the fish dietary analysis (Section 9.8.4.7). In addition, drift results will be compared to the results of 1980s drift studies (ADF&G 1983; Hansen and Richards 1985; Trihey and Associates 1986) to evaluate any differences between the historic and current drift components of the macroinvertebrate communities.

9.8.4.4. *Conduct a feasibility study in 2013 to evaluate the suitability of using reference sites on the Talkeetna River to monitor long-term Project-related change in benthic productivity.*

Sampling sites will be established in the Talkeetna River in areas that are physically similar to those sampled in the middle Susitna River, to ensure comparability. Sampling will be conducted in riffle habitats within the mainstem, side channels, and sloughs. One station will be established, with a mainstem site and two off-channel habitat sites associated with the mainstem site. Benthic and drift sampling will occur during approximately the same periods as sampling in the Middle Susitna River Reach (Objectives 2 and 3, Sections 9.8.4.2 and 9.8.4.3), with seasonal sampling during 2013. Benthic macroinvertebrate, benthic algal, and drift sampling methods and processing protocols will be identical to those used in sampling the Middle Susitna River Reach (Objective 2, Section 9.8.4.2). In the first quarter of 2014, sampling results from Talkeetna sites will be compared to results from similar sites in the Middle Susitna River Reach to determine whether the Talkeetna River would serve as a suitable reference site. If so, sites on the Talkeetna River can be used in a long-term monitoring program with Susitna River sites to help differentiate potential long-term changes that are Project-related versus those occurring for other reasons outside Project influence. Such a monitoring program would ideally collect multiple years of both pre-Project and post-Project data.

9.8.4.5. *Conduct a trophic analysis, using trophic modeling and stable isotope analysis, to describe the food web relationships in the current riverine community within the middle and upper Susitna River.*

9.8.4.5.1. Develop a trophic model to estimate how environmental factors and food availability affect the growth rate potential of focal fish species under current and future conditions.

To complement the fish habitat suitability analysis (Section 9.8.4.6), which focuses on physical habitat features, a trophic model will be developed to incorporate the density and quality of prey into an estimate of habitat quality. Growth rate potential models integrate knowledge of the foraging capabilities and bioenergetic physiology of a consumer with field data on its physical environment and prey base to quantify the values of different habitats (Brandt et al. 1992; Nislow et al. 2000; Jensen et al. 2006; Farley and Trudel 2009). The currency of these models, growth rate potential (GRP), is the expected growth rate of a consumer occupying a given habitat. For salmon, juvenile growth is strongly correlated with early marine survival and overall stock dynamics (Pearcy 1992; Beamish and Mahnken 2001; Moss et al. 2005; Duffy and Beauchamp 2011), making GRP a particularly valuable metric of freshwater habitat quality.

One drawback of typical GRP models is that modeled fish are often assumed to occupy a single uniform habitat (e.g., Brandt and Kirsch 1993). However, real fish may be able to exceed the growth rate predicted by these models by moving among nearby habitats to feed, rest, and digest. For example, by regularly moving between habitats of differing temperatures, some sculpin can increase their growth rates by as much as three-fold, relative to a strategy of using a single habitat (Wurtsbaugh and Neverman 1988; Neverman and Wurtsbaugh 1994). The growth of juvenile Chinook and coho salmon is relatively insensitive to the range of temperatures typically found in Alaskan streams, suggesting that small temperature differences among habitats may not substantially affect growth (Beauchamp 2009). However, thermal heterogeneity has a strong influence on the growth of juvenile coho salmon in the Bristol Bay region, due to the short growing season and the potential for faster-growing individuals to consume energy-rich salmon eggs (Armstrong et al. 2010). Further, resident fishes such as rainbow trout can exploit thermal variation patterns by moving from colder to warmer streams to prolong their access to pulsed resource subsidies during the summer (Ruff et al. 2011). Thus, the local movement patterns of both juvenile salmon and non-anadromous resident fishes among habitat types within the Susitna River study area could have important consequences for their growth rates.

Growth rate potential models will be developed to quantify the effects of environmental conditions and food availability on fish growth at each sampling location, while allowing for local movement among habitats. Due to the relatively data-intensive nature of GRP models, this analysis will focus on three species: coho salmon, northern pike, and rainbow trout. Coho salmon will be included due to their high ecological and economic value in the Susitna basin and Cook Inlet. Northern pike will be included as an invasive predator with the potential to expand their range and ecological impacts with future changes in the basin. Rainbow trout will be included as a representative resident salmonid and a potentially important competitor and predator of juvenile salmon. Importantly, detailed foraging parameters are available for these species (e.g., Nilsson and Brönmark 2000; Turesson and Bronmark 2004; Piccolo et al. 2007; Piccolo et al. 2008a, 2008b; Nilsson et al. 2009; Baktoft et al. 2012; Ranaker et al. 2012), enabling the development of well-supported foraging models. The necessary bioenergetics model parameters are also available for all three species (Bevelhimer et al. 1985; Stewart and Ibarra 1991; Rand et al. 1993).

Each species-specific GRP model will couple a foraging model (Fausch 1984; Hughes and Grand 2000; Hayes et al. 2007; Turesson and Bronmark 2007) with a Wisconsin bioenergetics model (Kitchell et al. 1977; Hanson et al. 1997), coded in the R programming language (A. G. Hansen, University of Washington, unpublished). The foraging models will take inputs of flow, turbidity, and prey density and predict a consumption rate. The bioenergetics models will take inputs of consumption, body size, temperature, diet composition, and the energy density of prey and predict a growth rate. Each GRP model will allow for the potential of local movement among habitats within a sampling location to enhance growth rates. Optimal simulated movement patterns will be estimated and compared with the observed movements documented by the radiotelemetry and passive integrated transponder (PIT) tagging components of the Fish Distribution and Abundance Study. GRP model simulations will be run using a Monte Carlo framework, with model inputs and outputs specified as probability distributions of values, rather than as point estimates (Bartell et al. 1986; Bolker 2008).

Preliminary GRP models for each species will be developed using data from the 2013 field season as well as from prior Susitna basin studies. Initial model predictions of the growth potential of particular sites will be tested by comparison with the observed growth and distribution of fish captured in those sites. A sensitivity analysis will be conducted to identify the most important parameters for further refinement (Beaudreau and Essington 2009). Field sampling during 2014 will focus on improving estimates for these parameters.

9.8.4.5.2. Conduct stable isotope analysis of food web components to help determine energy sources and pathways in the riverine communities.

Stable isotope analysis is a method which examines the naturally-occurring stable isotopes of elements (typically carbon and nitrogen) stored in organic materials. The analysis is frequently used to answer questions related to trophic structure and energy pathways within freshwater ecosystems and the interfaces with marine and terrestrial ecosystems (Chaloner et al. 2002; Finlay and Kendall 2007). Carbon isotope ratios ($\delta^{13}C$) are indicators of an organism's diet because consumers tend to reflect the carbon isotope values of the food they consume, whereas nitrogen isotopes ($\delta^{15}N$) indicate an organism's trophic level because the heavier nitrogen isotope accumulates in the consumer with each successive trophic transfer (approximately 3–4‰, according to DeNiro and Epstein 1981) (Chaloner et al. 2002). If food resources move in a predictable manner through the food chains, these stable isotopes can be used to trace the sources of productivity within aquatic food webs and the trophic position of consumers, which can be essential information for understanding the food web dynamics or for detecting responses to environmental and human-driven change (Chaloner et al. 2002; Finlay and Kendall 2007).

Several recent studies have used stable isotopes to investigate the contribution of marine-derived nutrients (MDN) from spawning salmon to freshwater ecosystems, and have estimated that salmon can contribute 17–30 percent (Bilby et al. 1996) to > 50 percent (Kline et al. 1990) of the nitrogen, and 23–40 percent (Bilby et al. 1996) of the carbon present in freshwater organisms. Adult salmon incorporate rich marine nutrients during their time in the ocean and are thereby enriched with the heavier isotopes of nitrogen and carbon, which they retain after entering fresh water to spawn, as they do not feed in fresh waters, and therefore remain isotopically distinct from terrestrially-derived organic material (Kline et al. 1990). Stable isotope analysis can be used to trace MDN through freshwater ecosystems, and ultimately can be used to quantify the contribution of marine-derived nitrogen or carbon to freshwater food webs (Kline et al. 1990; Hicks et al. 2005).

To better understand the trophic relationships in the upper and middle Susitna River, a stable isotope analysis will be conducted at two selected stations (with three sampling sites each), with one in the upper reach, and one in the middle river reach. Selection of these two stations will be made in the intial sampling efforts in the second quarter, based on how representative the site is in respect to the reach, and its suitability to provide ample materials for testing. Tissue samples from multiple study components (benthic macroinvertebrates, benthic algae, benthic organic matter, terrestrial invertebrates and organic matter in drift samples, and muscle tissue samples from the fish diet analysis collections) at sites within these two stations will be collected for stable isotope analysis. Results will be used in conjunction with the bioenergetics model (Section 9.8.4.5.1) to further explain the energy source pathways and trophic relationships in the Susitna River food web.

9.8.4.6. *Generate habitat suitability criteria for Susitna benthic macroinvertebrate and algal habitats to predict potential change in these habitats downstream of the proposed dam site.*

Habitat Suitability Index (HSI) models provide a quantitative relationship between numerous environmental variables and habitat suitability. An HSI model describes how well each habitat variable individually and collectively meets the habitat requirements of the target species and lifestage under the structure of Habitat Evaluation Procedures (USFWS 1980). Alternatively, Habitat Suitability Criteria (HSC) curves are designed for use in the Instream Flow Incremental Methodology to quantify changes in habitat under various flow regimes (Bovee et al. 1998). HSC describes the instream suitability of habitat variables related only to stream hydraulics and channel structure. Both models and habitat index curves are hypotheses of species–habitat relationships and are intended to provide indicators of habitat change, not to directly quantify or predict the abundance of target organisms. For the Susitna-Watana Hydroelectric Project aquatic habitat studies, HSC (i.e., depth, velocity, and substrate/cover) and HSI (i.e., turbidity, duration of inundation, and dewatering) models will be integrated to analyze the effects of alternate operational scenarios.

Literature-based draft HSC/HSI curves will be developed for benthic macroinvertebrate and algae communities. Potential sources of information include the Internet, university libraries, peer-reviewed periodicals, and government and industry technical reports. Special emphasis will be given to the existing 1980s study (Hansen and Richards 1985) for applicable information and methodology. Because benthic macroinvertebrate (BMI) and periphyton communities are comprised of numerous taxa, the HSC/HSI curves will be developed for commonly used benthic metrics (e.g., biomass, chlorophyll-a [algae], density, diversity, or dominant taxa) selected to summarize and describe the communities. The review will also examine macroinvertebrate life histories, behavior, and functional feeding groups to assist in grouping taxa into guilds as possible metrics. Habitat suitability information will address BMI and algal responses to changes in depth, velocity, substrate, turbidity, and frequency of inundation and dewatering.

Next, a histogram (i.e., bar chart) will be developed for each of the habitat parameters (e.g., depth, velocity, substrate, frequency of dewatering) using site-specific field observations (from Objectives 2, Section 9.8.4.2, and Objective 9, Section 9.8.4.9). The histogram developed using field observations from 2013 will then be compared to the literature-based HSI curve to validate applicability of the literature-based HSI curve for aquatic habitat modeling. This stage will be conducted by the third quarter of 2014.

As a final step, a panel of licensing participants and, if desired, regional experts (agency, Alaska Native entity, industry, and university researchers) will be selected to confirm HSC/HSI curves for each benthic metric. Using a roundtable discussion format, the panel members will review literature-based benthic community information and site-specific data to develop a final set of HSC/HSI curves. These curves will be used in the Instream Flow Study (Section 8.5) to define the relationship between habitat quantity and quality for each of the selected benthic metrics under various operational scenarios. Analysis and modeling efforts will be coordinated with the Instream Flow Study team.

9.8.4.7. *Characterize the invertebrate compositions in the diets of representative fish species in relationship to their source (benthic or drift component).*

In order to investigate and understand the trophic relationships within a river system and how they ultimately relate to fish, it is critical to examine not only the food source (Objective 2, Section 9.8.4.2) and its availability to fish via drift (Objective 3, Section 9.8.4.3), but also the consumption by fish predators. Because both benthic macroinvertebrates and terrestrial invertebrates are a primary food source for fish and other organisms (Wipfli 1997; Hershey and Lamberti 2001; Allan et al. 2003), any significant disturbance to the benthic community and the shoreline riparian vegetation has the possibility of affecting their predators. Therefore, it is important to investigate the trophic relationship between fish and these food sources by conducting a fish gut analysis and comparing results to drift and benthic macroinvertebrate data. In support of the bioenergetics modeling (Objective 5, Section 9.8.4.5.1), fish species targeted for dietary analysis will include juvenile coho salmon, juvenile and adult rainbow trout, and juvenile and adult northern pike, as identified in consultation with agencies and other licensing participants. Fish collection sites will correspond to benthic macroinvertebrate collection sites (both benthic, Section 9.8.4.2.1, and drift sampling, Section 9.8.4.) to allow for comparison with the benthic macroinvertebrate community and drift compositions.

A total of five fish per species/age class per sampling site collection will be sampled for fish stomach contents, using non-lethal methods (Meehan and Miller 1978; Hyslop 1980; Bowen 1996; Kamler and Pope 2001). All fish will have fork length and weight recorded with the stomach sample. In addition, scales will be collected from the preferred area of the fish, below and posterior to the dorsal fin, for age and growth analysis (DeVries and Frie 1996). At two selected sample collection locations (one each in upper and middle reaches), punch samples of muscle tissue will be obtained from each fish for use in the stable isotope analysis (Section 9.8.4.5.2). A subset of captured northern pike will be sacrificed for collection of otoliths and/or cleithra to improve age estimates for older fish. The collection efforts will be coordinated with the appropriate fish study team (Fish Distribution and Abundance in the Middle and Lower Susitna River Study, Fish Distribution and Abundance in the Upper Susitna River Study, and/or Salmon Escapement Study teams).

Fish gut content samples will be processed in a laboratory using methods compatible with studies conducted in other comparable streams/basins in Alaska. State and federal protocols (Hyslop 1980; Bowen 1996; Barbour et al. 1999; Major and Barbour 2001; Moulton et al. 2002) will be considered in determining the sample processing protocols, including subsampling protocols, the taxonomic resolution of specimen identifications, and data analysis approach. Data collected during this study will be compared to the results of 1980s fish diet studies (ADF&G 1983; Hansen and Richards 1985) to evaluate any differences between the historic and current fish diets.

9.8.4.8. *Characterize organic matter resources (e.g., available for macroinvertebrate consumers) including coarse particulate organic matter, fine particulate organic matter, and suspended organic matter in the middle and upper Susitna River.*

Organic matter materials serve as an important food resource to benthic macroinvertebrates, serving as a conduit for the energy flow from organic matter resources to vertebrate populations, such as fish (Hershey and Lamberti 2001; Hauer and Resh 1996; Reice and Wohlenberg 1993; Klemm et al. 1990). Given the dominant characteristics of the Susitna River system (large, cold, and turbid during the growing season), secondary productivity is not likely to be driven by primary production or from the algal community within the system, but rather by allocthanous inputs of organic material from the terrestrial environment. Benthic organic material is one of the most important “interrelated environmental factors” influencing the macroinvertebrate community, and damming the river will have significant consequences for the transport of organic matter from the upper watershed. Therefore, to address the importance of organic matter to productivity in this type of system, quantifying benthic organic matter as part of this study is essential.

This organic matter exists as both fine particulate organic matter (FPOM) and coarse particulate organic matter (CPOM). FPOM includes particles ranging from 0.45 to 1000 µm in size, and can occur in the water column as seston, or deposited in lotic habitats as fine benthic organic matter (FBOM) (Wallace and Grubaugh 1996). CPOM is defined as any organic particle larger than 1 mm in size (Cummins 1974). In order to quantify the amounts of organic matter available in the Susitna River for river productivity, CPOM and FPOM (specifically FBOM) will be collected concurrently with all benthic macroinvertebrate sampling (Objective 2, Section 9.8.4.2.1). Organic debris collected within each sample will be retained after processing for organisms. In order to streamline the collection efforts, a net mesh size of 250 µm for sampling devices will retain FPOM in the 250–1,000 µm size range for analysis, as well as CPOM particles. Suspended FPOM (seston) will be collected from material in invertebrate drift samples, utilizing the 250-µm mesh size for drift nets, as well (Objective 3, Section 9.8.4.3). Organic matter retained after organism sorting and processing will be separated from inorganic material, rinsed through sieves to separate particles into size classes, oven-dried (60°C), and weighed. Results will be calculated as amounts of CPOM and FPOM per unit area (g/m^2 and g/m^3, respectively). For the two selected stations, portions of the material will then be utilized for stable isotope analysis (Objective 5, Section 9.8.4.5.2).

9.8.4.9. *Estimate benthic macroinvertebrate colonization rates in the Middle Susitna River Reach to monitor baseline conditions and evaluate future changes to productivity in the Susitna River.*

Colonization is a process in which organisms move into and become established in new areas or habitats (Smock 1996). In disturbed habitats, this process is more accurately called recolonization. Numerous studies have shown that macroinvertebrates can rapidly colonize new or disturbed substrates (Shaw and Minshall 1980; Ciborowski and Clifford 1984; Williams and Hynes 1977; Townsend and Hildrew 1976; Miyake et al. 2003). The rate of recolonization is dependent on several factors, including time of the year, substratum particle size, the structure of the macroinvertebrate assemblages available to colonize at the time, and the distance of the colonist assemblages from the new or disturbed area (Robinson et al. 1990; Smock 1996; Mackay 1992).

Using a stratified sampling approach, a field study will be conducted to estimate potential benthic macroinvertebrate colonization rates for different seasons in the Susitna River. Sets of three to five preconditioned artificial substrates will be deployed incrementally for set periods of colonization time (e.g., 12, 8, 6, 4, 2, and 1 weeks) and then pulled simultaneously at the conclusion of the colonization period. One study site will be located in the middle reach of the

Susitna River, preferably at a study location within the reach established for regular benthic macroinvertebrate sampling (Objective 2, Section 9.8.4.2.1). Artificial substrates will be deployed at two depths at fixed sites along the channel bed. Benthic macroinvertebrate colonization rates will be conducted in a mainstem habitat that is representative of the majority of the Middle Susitna River Reach to reflect the typical colonization conditions present in the river. Benthic macroinvertebrate processing protocols will be identical to those used in Objective 2 (Section 9.8.4.2.1). State and federal protocols for both sampling and processing will be considered as the details of this study component are refined for implementation, in consultation with resource agencies.

Colonization information will be compared with colonization results from similar river systems and with post-Project colonization results. In addition, results will be utilized in HSC/HSI development (Objective 6, Section 9.8.4.6), and in the varial zone modeling task in the Instream Flow Study to assist in determining the potential Project effect of short-term flow fluctuations, most commonly the result of hydroelectric power generation, on benthic macroinvertebrates.

9.8.5. Consistency with Generally Accepted Scientific Practices

The methods described above have been developed in consultation with agency and Technical Workgroup (TWG) participants. All data collection and processing efforts will follow state (ADF&G) or federal (EPA, USGS) guidelines referenced throughout the study methods discussion (Agradi 2006; Barbour et al. 1999; Bovee et al. 1998; Eaton et al. 1998; Keup 1988; Klemm et al. 1990, 2000; Major and Barbour 2001; Moulton et al. 2002; Peck et al. 2006; USFWS 1980. In addition, any laboratory analysis will be conducted by a state- or federally-certified facility.

9.8.6. Schedule

The preliminary schedule for the river productivity study elements is presented in Table 9.8-2. During 2013, the literature review summarizing the impacts of hydropower development and operations on benthic macroinvertebrate and algal communities will be prepared and presented to the TWG. Research, field sampling, and sample processing and analysis will begin in the latter half of the first quarter of 2013, following FERC's approval of the study plan, and continue throughout the remainder of 2013. The Initial Study Report summarizing 2013 activities will be issued within one year of FERC's Study Plan Determination (i.e., February 1, 2013). Field sampling efforts will resume in the latter half of the first quarter of 2014, with analysis and research continuing through the fourth quarter. The Updated Study Report will be produced within two years of FERC's Study Plan Determination.

9.8.7. Interdependency with Other Studies

The River Productivity Study is interrelated to several AEA studies (Figure 9.8-3). The Instream Flow (Section 8.5), Aquatic Habitat Characterization (Section 9.9), and the Geomorphology studies (Section 6) will provide useful inputs on site selection and for evaluating Project effects on river productivity under various operating regimes. The Water Quality Studies (Section 5) will provide useful input information for analysis of river productivity. The Upper (Section 9.5) and Middle and Lower River (Section 9.6) Fish Distribution and Abundance studies will coordinate with the collection of samples for gut content analysis and stable isotope analysis.

Output information from the multiple objectives of the River Productivity Study will provide additional input information to the trophic analysis, Objective 5, Section 9.8.4.5, of the River Productivity Study as well as to the Water Quality Study (Section 5) and Instream Flow Study (Section 8.5).

9.8.8. Level of Effort and Cost

The initial cost estimate for completion of the nine study objectives described above is $1,200,000. Efforts such as the literature review, trophic analysis (bioenergetics model and stable isotope analysis), and HSC criteria development will be office-based studies. Collection of benthic macroinvertebrates, algae, and organic matter, drift samples, and the analysis of fish diets will require three extensive field efforts per year for the two study years. Adult emergence sampling will require monthly to bi-weekly site visits from April through October to collect samples and reset the traps. The colonization study will require frequent site visits each month to deploy additional sets of samplers over the course of the study. A majority of the work effort will take place in the laboratory to subsample, sort, and identify the macroinvertebrate and algae samples, as well as to conduct the stable isotope analyses on the numerous sample components. After sample processing, the remainder of the study effort will be office-based, consisting of data entry, analysis, and synthesis and report writing.

9.8.9. Literature Cited

AEA (Alaska Energy Authority). 2011. Pre-application Document: Susitna-Watana Hydroelectric Project FERC Project No. 14241. December 2011. Prepared for the Federal Energy Regulatory Commission, Washington, DC.

ADF&G (Alaska Department of Fish and Game). 1983. Volume 3. Resident and juvenile anadromous fish studies on the Susitna River below Devil Canyon, 1982. Susitna Hydro Aquatic Studies, Phase II Basic Data Report. Prepared for Alaska Power Authority. Alaska Department of Fish and Game, Anchorage, Alaska. APA Document 486.

Allan, J.D., M.S. Wipfli, J.P. Caouette, A. Prussian, and J. Rodgers. 2003. Influence of streamside vegetation on inputs of terrestrial invertebrates to salmonid food webs. Canadian Journal of Fisheries and Aquatic Sciences 60:309–320.

Angradi, T.R. (editor). 2006. Environmental Monitoring and Assessment Program: Great River Ecosystems, Field Operations Manual. EPA/620/R-06/002. U.S. Environmental Protection Agency, Washington, D.C.

Armitage, P.D. 1984. Environmental changes induced by stream regulation and their effect on lotic macroinvertebrate communities. Pages 139-164 *in* A. Lillehammer and S.J. Saltveit, editors. Regulated Rivers. Universitetsforlaget AS, Norway.

Armstrong, J.B., D.E. Schindler, K.L. Omori, C.P. Ruff, and T.P. Quinn. 2010. Thermal heterogeneity mediates the effects of pulsed subsidies across a landscape. Ecology 91(5):1445-1454.

Baktoft, H., K. Aarestrup, S. Berg, M. Boel, L. Jacobsen, N. Jepsen, A. Koed, J.C. Svendsen, and C. Skov. 2012. Seasonal and diel effects on the activity of northern pike studied by high-resolution positional telemetry. Ecology of Freshwater Fish 21(3):386-394.

Barbour, M.T., J. Gerritsen, B.D. Snyder, and J.B. Stribling. 1999. Rapid bioassessment protocols for use in streams and wadeable rivers: Periphyton, benthic macroinvertebrates and fish. Second Edition. EPA 841-B-99-002. U.S. Environmental Protection Agency; Office of Water; Washington D.C.

Bartell, S.,J. Breck, R. Gardner, and A. Brenkert. 1986. Individual parameter perturbation and error analysis of fish bioenergetics models. Canadian Journal of Fisheries and Aquatic Sciences 43(1):160-168.

Beamish, R. J., and C. Mahnken. 2001. A critical size and period hypothesis to explain natural regulation of salmon abundance and the linkage to climate and climate change. Progress in Oceanography 49(1-4):423-437.

Beauchamp, D. 2009. Bioenergetic ontogeny: linking climate and mass-specific feeding to life-cycle growth and survival of salmon. Pages 53–72 in.

Beaudreau, A.H., and T.E. Essington. 2009. Development of a new field-based approach for estimating consumption rates of fishes and comparison with a bioenergetics model for lingcod (Ophiodon elongatus). Canadian Journal of Fisheries and Aquatic Sciences 66(4):565-578.

Bevelhimer, M.S., R.A. Stein, and R.F. Carline. 1985. Assessing significance of physiological differences among 3 esocids with a bioenergetics model. Canadian Journal of Fisheries and Aquatic Sciences 42(1):57-69.

Bilby R.E., E.W. Beach, B.R. Fransen, J.K. Walter, and P.A. Bisson. 2003. Transfer of nutrients from spawning salmon to riparian vegetation in western Washington. Transactions of the American Fisheries Society 132:733–745.

Bilby, R.E., B.R. Fransen, and P.A. Bisson. 1996. Incorporation of nitrogen and carbon from spawning coho salmon into the trophic system of small streams: evidence from stable isotopes. Canadian Journal of Fisheries and Aquatic Sciences 53: 164–173.

Bolker, B.M. 2008. Ecological models and data in R. Princeton University Press, Princeton, NJ.

Bovee, K.D., B.L. Lamb, J.M. Bartholow, C.B. Stalnaker, J. Taylor, and J. Henriksen. 1998. Stream habitat analysis using the instream flow incremental methodology. U.S. Geological Survey, Biological Resources Division Information and Technology Report USGS/BRD-1998-0004. viii + 131 pp

Bowen, S.H. 1996. Quantitative description of the diet. Pages 513-529 *in* B. R. Murphy and D. W. Willis, eds., Fisheries Techniques (Second Edition). American Fisheries Society, Bethesda, Maryland, USA.

Brandt, S. B., and J. Kirsch. 1993. Spatially explicit models of striped bass growth potential in Chesapeake Bay. Transactions of the American Fisheries Society 122(5):845-869.

Brandt, S.B., D.M. Mason, and E.V. Patrick. 1992. Spatialy explicit models of fish growth rate. Fisheries 17(2):23-&.

Brittain, J.E. and S.J. Saltveit. 1989. A review of the effect of river regulation on mayflies (Ephemeroptera). Regulated Rivers: Research and Management 3: 191-204.

Brittain, J.E. and T.J. Eikeland. 1988. Invertebrate drift – A review. Hydrobiologia 166: 77-93.

Carter, J.L. and V.H. Resh. 2001. After site selection and before data analysis: sampling, sorting, and laboratory procedures used in stream benthic macroinvertebrate monitoring programs by USA state agencies. Journal of the North American Benthological Society 20(4): 658-682.

Cederholm, C.J., Kunze, M.D., Murota, T., and Sibatani, A. 1999. Pacific salmon carcasses: essential contributions of nutrients and energy for aquatic and terrestrial ecosystems. Fisheries 24: 6–15.

Chaloner, D.T., K.M. Martin, M.S. Wipfli, P.H. Ostrom, and G.A. Lamberti. 2002. Marine carbon and nitrogen in southeastern Alaska stream food webs: evidence from artificial and natural streams. Canadian Journal of Fisheries and Aquatic Sciences 59: 1257-1265.

Chaloner D.T., and M.S. Wipfli. 2002. Influence of decomposing Pacific salmon carcasses on macroinvertebrate growth and standing stock in southeastern Alaska streams. Journal of the North American Benthological Society 21:430–442.

Ciancio, J.E., M.A. Pascual, and D.A. Beauchamp. 2007. Energy density of patagonian aquatic organisms and empirical predictions based on water content. Transactions of the American Fisheries Society 136(5):1415-1422.

Ciborowski, J.J.H. and H.F. Clifford. 1984. Short-term colonization patterns of lotic macroinvertebrates. Canadian Journal of Fisheries and Aquatic Sciences 41: 1626-1633.

Cummins, K.W. 1974. Structure and function of stream ecosystems. Bioscience 24: 631-641.

Cushman, R.M. 1983. An inexpensive, floating, insect-emergence trap. Bulletin of Environmental Contamination and Toxicology 3(5): 547-550.

Cushman, R.M. 1985. Review of ecological effects of rapidly varying flows downstream from hydroelectric facilities. North American Journal of Fisheries Management 5: 330-339.

DeNiro, M.J., and S. Epstein. 1981. Influence of diet on the distribution of nitrogen isotopes in animals. Geochim. Cosmochim.Acta, 45: 341–351.

DeVries, D.R., and R.V. Frie. 1996. Determination of age and growth. Pages 483–512 in B. R. Murphy, and D. W. Willis, editors. Fisheries Techniques, 2nd edition. American Fisheries Society, Bethesda, Maryland.

Duffy, E.J., and D.A. Beauchamp. 2011. Rapid growth in the early marine period improves the marine survival of Chinook salmon (Oncorhynchus tshawytscha) in Puget Sound, Washington. Canadian Journal of Fisheries and Aquatic Sciences 68:232-240.

Eaton, A., L. Clesceri, A. Greenberg. 1998. Standard Methods for the Examination of Water and Wastewater. American Public Health Association, American Water Works Association, Water Environment Federation, Washington, D.C.

Farley, E., and M. Trudel. 2009. Growth rate potential of juvenile sockeye salmon in warmer and cooler years on the eastern Bering Sea shelf. Journal of Marine Biology 2009.

Fausch, K.D. 1984. Profitable stream positions for salmonids: relating specific growth rate to net energy gain. Canadian Journal of Zoology 62(3):441-451.

Finlay, J.C., and C. Kendall. 2007. Stable isotope tracing of temporal and spatial variability in organic matter sources to freshwater ecosystems. Pages 283-333 *in* Michener, R.H., and K. Lajtha, eds. Stable Isotopes in Ecology and Environmental Science, 2nd ed. Blackwell Publishing.

Friese, N.Y. 1975. Pre-authorization assessment of anadromous fish populations of the Upper Susitna River watershed in the vicinity of the proposed Devil Canyon Hydroelectric Project. Prepared for the U.S. Fish and Wildlife Service, Anchorage, Alaska. Alaska Department of Fish and Game. APA Document 1611

Hansen, T.F. and J.C. Richards. 1985. Availability of invertebrate food sources for rearing juvenile Chinook salmon in turbid Susitna River habitats. Susitna Hydro Aquatic Studies, Report No. 8. Prepared for Alaska Power Authority. Alaska Department of Fish and Game, Anchorage, Alaska. APA Document No. 2846.

Hanson, P.C., T.B. Johnson, D.E. Schindler, and J.F. Kitchell. 1997. Fish Bioenergetics 3.0. University of Wisconsin Sea Grant Inst., Madison, Wis.

Hauer, F.R. and V.H. Resh. 1996. Benthic macroinvertebrates. Pages 339-369 *in* F.R. Hauer and G.A. Lamberti, editors. Methods in stream ecology. Academic Press, San Diego, California.

Hayes, J.W., N.F. Hughes, and L.H. Kelly. 2007. Process-based modelling of invertebrate drift transport, net energy intake and reach carrying capacity for drift-feeding salmonids. Ecological Modelling 207(2-4):171-188.

Hershey, A.E. and G.A. Lamberti. 2001. Aquatic insect ecology. Pages 733-775 *in* J.H. Thorp and A.P. Covich, editors. Ecology and classification of North American freshwater invertebrates. Academic Press, San Diego, California.

Hicks, B.J., M.S. Wipfli, D.W. Lang, and M.E. Lang. 2005. Marine-derived nitrogen and carbon in freshwater-riparian food webs of the Copper River Delta, southcentral Alaska. Oecologia 144: 558-569.

Hughes, N.F., and T.C. Grand. 2000. Physiological ecology meets the ideal-free distribution: Predicting the distribution of size-structured fish populations across temperature gradients. Environmental Biology Of Fishes 59(3):285-298.

Hynes, H.B.N. 1970. The ecology of running waters. University of Toronto Press, Toronto, Ontario. 555 p.

Hyslop, E.J. 1980. Stomach content analysis: a review of methods and their applications. Journal of Fish Biology 17(4):411-429.

James, D.A., I.J. Csargo, A. Von Eschen, M.D. Thul, J.M. Baker, C.A. Hayer, J. Howell, J. Krause, A. Letvin, and S.R. Chipps. 2012. A generalized model for estimating the energy density of invertebrates. Freshwater Science 31(1):69-77.

Jensen, O.P., T.R. Hrabik, S.J. D. Martell, C.J. Walters, and J.F. Kitchell. 2006. Diel vertical migration in the Lake Superior pelagic community II. Modeling trade-offs at an intermediate trophic level. Canadian Journal of Fisheries and Aquatic Sciences 63(10):2296-2307.

Kamler, J. F. and K.L. Pope. 2001. Nonlethal methods of examining fish stomach contents. Nebraska Cooperative Fish & Wildlife Research Unit -- Staff Publications. Paper 55. http://digitalcommons.unl.edu/ncfwrustaff/55

Keup, L.E. 1988. Invertebrate fish food resources of lotic environments. Instream Flow Information Paper No. 24. U.S. Fish and Wildlife Service Biological Report 88(13). 96 pp.

Kitchell, J., D. Stewart, and D. Weininger. 1977. Applications of a bioenergetics model to yellow perch (Perca flavescens) and walleye (Stizostedion vitreum vitreum). Journal of the Fisheries Research Board of Canada 34(10):1922–1935.

Klemm, D.J., J.M. Lazorchak, and D.V. Peck. 2000. Section 9. Benthic Macroinvertebrates *in* J.M. Lazorchak, B.H. Hill, D.K. Averill, D.V. Peck, and D.J. Klemm, editors. Environmental monitoring and assessment program – surface waters: Field operations and methods for measuring the ecological condition of non-wadable rivers and streams. EPA/620/R-00/007, U.S. Environmental Protection Agency, Cincinnati, Ohio.

Klemm, D.J., P.A. Lewis, F. Fulk, and J.M. Lazorchak. 1990. Macroinvertebrate field and laboratory methods for evaluating the biological integrity of surface waters. EPA/600/4-90/030, Environmental Monitoring Systems Laboratory, U.S. Environmental Protection Agency, Cincinnati, Ohio.

Kline, T.C., J.J. Goering, O.A. Mathisen, P.H. Poe, and P.L. Parker. 1990. Recycling of elements transported upstream by runs of Pacific salmon: I. δ^{15}N and δ^{13}C evidence in Sashin Creek, southeastern Alaska. Canadian Journal of Fisheries and Aquatic Sciences 47: 136–144.

Mackay, R.J. 1992. Colonization by lotic macroinvertebrates: a review of processes and patterns. Canadian Journal of Fisheries and Aquatic Sciences 49: 617-628.

Major, E.B., and M.T. Barbour. 2001. Standard operating procedures for the Alaska Stream Condition Index: A modification of the U.S. EPA rapid bioassessment protocols, 5th edition. Prepared for the Alaska Department of Environmental Conservation, Anchorage, Alaska.

Meehan, W.R., and R.A. Miller. 1978. Stomach flushing: effectiveness and influence on survival and condition of juvenile salmonids. Journal of the Fisheries Research Board of Canada. 35(10): 1359-1363.

Miyake, Y., T. Hiura, N. Kuhara, and S. Nakano. 2003. Succession in a stream invertebrate community: A transition in species dominance through colonization. Ecological Research 18: 493-501.

Moss, J.H., D.A. Beauchamp, A.D. Cross, K.W. Myers, E.V. Farley, J.M. Murphy, and J.H. Helle. 2005. Evidence for size-selective mortality after the first summer of ocean growth by pink salmon. Transactions of the American Fisheries Society 134(5):1313-1322.

Moulton, S. R. II, J. G. Kennen, R. M. Goldstein, and J. A. Hambrook. 2002. Revised protocols for sampling algal, invertebrate, and fish communities as part of the national water-quality assessment program. USGS Open-File Report 02-150. U.S. Geological Survey, Reston, Virginia.

Neverman, D., and W.A. Wurtsbaugh. 1994. The thermoregulatory function of diel vertical migration for a juvenile fish, Cottus extensus. Oecologia 98(3):247-256.

Nilsson, P.A., and C. Brönmark. 2000. Prey vulnerability to a gape-size limited predator: behavioural and morphological impacts on northern pike piscivory. Oikos 88(3):539-546.

Nilsson, P. A., L. Jacobsen, S. Berg, and C. Skov. 2009. Environmental Conditions and Intraspecific Interference: Unexpected Effects of Turbidity on Pike (Esox lucius) Foraging. Ethology 115(1):33-38.

Nislow, K.H., C.L. Folt, and D.L. Parrish. 2000. Spatially Explicit Bioenergetic Analysis of Habitat Quality for Age-0 Atlantic Salmon. Transactions of the American Fisheries Society 129(5):1067-1081.

Pearcy, W.G. 1992. Ocean ecology of North Pacific salmonids. Washington Sea Grant Program, University of Washington Press, Seattle.

Peck, D.V., A.T. Herlihy, B.H. Hill, R.M. Hughes, P.R. Kaufmann, D.J. Klemm, J.M. Lazorchak, F.H. McCormick, S.A. Peterson, P.L. Ringold, T. Magee, and M. Cappaert. 2006. Environmental Monitoring and Assessment Program – Surface Waters Western Pilot Study: Field Operations Manual for Wadeable Streams. EPA/620/R-06/003. U.S. Environmental Protection Agency, Office of Research and Development, Washington, D.C.

Petts, G.E. 1984. Impounded rivers: perspectives for ecological management. John Wiley & Sons, New York.

Piccolo, J.J., H.F. Hughes, and M.Y. Bryant. 2007. The effects of water depth on prey detection and capture by juvenile coho salmon and steelhead. Ecology of Freshwater Fish 16(3):432-441.

Piccolo, J.J., N.F. Hughes, and M.D. Bryant. 2008a. Development of net energy intake models for drift-feeding juvenile coho salmon and steelhead. Environmental Biology Of Fishes 83(3):259-267.

Piccolo, J.J., N.F. Hughes, and M.D. Bryant. 2008b. Water velocity influences prey detection and capture by drift-feeding juvenile coho salmon (Oncorhynchus kisutch) and steelhead (Oncorhynchus mykiss irideus). Canadian Journal of Fisheries and Aquatic Sciences 65(2):266-275.

Ranaker, L., M. Jonsson, P. A. Nilsson, and C. Bronmark. 2012. Effects of brown and turbid water on piscivore–prey fish interactions along a visibility gradient. Freshwater Biology 57(9):1761-1768.

Rand, P.S., D.J. Stewart, P.W. Seelbach, M.L. Jones, and L.R. Wedge. 1993. Modeling steelhead population energetics in Lakes Michigan and Ontario. Transactions of the American Fisheries Society 122(5):977-1001.

Reice, S.R. and M. Wohlenberg. 1993. Monitoring freshwater benthic invertebrates and benthic processes: Measures for assessment of ecosystem health. Pages 287-305 *in* D.M. Rosenberg and V.H. Resh, editors. Freshwater biomonitoring and benthic macroinvertebrates. Routledge, Chapman and Hall, Inc., New York, New York.

Riis, J. 1975. Pre-authorization assessment of the proposed Susitna River Hydroelectric Projects: Preliminary investigations of water quality and aquatic species composition. Prepared for the U.S. Fish and Wildlife Service, Anchorage, Alaska. Alaska Department of Fish and Game. APA Document 1611.

Riis, J.C. 1977. Pre-authorization assessment of the proposed Susitna River Hydroelectric Projects: Preliminary investigations of water quality and aquatic species composition. Prepared for the U.S. Fish and Wildlife Service, Anchorage, Alaska. Alaska Department of Fish and Game. APA Document 1610

Robinson, C.T., G.W. Minshall, and S.R. Rushforth. 1990. Seasonal colonization dynamics of macroinvertebrates in an Idaho stream. Journal of the North American Benthological Society 9(3): 240-248.

Ruff, C. P., D.E. Schindler, J.B. Armstrong, K.T. Bentley, G.T. Brooks, G.W. Holtgrieve, M.T. McGlauflin, C.E. Torgersen, and J.E. Seeb. 2011. Temperature-associated population diversity in salmon confers benefits to mobile consumers. Ecology 92(11):2073-2084.

Saltveit, S.J., J.E. Brittain, and A. Lillehammer. 1987. Stoneflies and river regulation – a review. Pages 117-129, *in* J.F. Craig and J.B. Kemper, editors. Regulated Streams: Advances in Ecology. Plenum Press, New York.

Shaw, D.W. and G.W. Minshall. 1980. Colonization of an introduced substrate by stream macroinvertebrates. Oikos 34: 259-271.

Smock, L.A. 1996. Macroinvertebrate movements: Drift, colonization, and emergence. Pages 371-390 *in* F.H. Hauer and G.A. Lamberti, editors. Methods in stream ecology. Academic Press, San Diego, California.

Stewart, D. J., and M. Ibarra. 1991. Predation and production by salmonine fishes in Lake Michigan, 1978-88. Canadian Journal of Fisheries and Aquatic Sciences 48(5):909-922.

Townsend, C.R. and A.G. Hildrew. 1976. Field experiments on the drifting, colonization and continuous redistribution of stream benthos. Journal of Animal Ecology 45(31): 759-772.

Trihey and Associates. 1986. Close-out status report for invertebrate analysis. Prepared for Alaska Power Authority. APA Document 3404

Turesson, H., and C. Bronmark. 2004. Foraging behaviour and capture success in perch, pikeperch and pike and the effects of prey density. Journal of Fish Biology 65(2):363-375.

Turesson, H., and C. Bronmark. 2007. Predator-prey encounter rates in freshwater piscivores: effects of prey density and water transparency. Oecologia 153(2):281-290.

USFWS (U.S. Fish and Wildlife Service). 1980. Habitat evaluation procedures (HEP). ESM 102. U.S. Fish and Wildlife Service, Division of Ecological Services, Washington, D.C., March 31, 1980.

USFWS (U.S. Fish and Wildlife Service). 2012. Letter to the Federal Energy Regulatory Commission, subject: Scoping Comments, Recommendations and Study Requests Notice of Intent to File License Applications; Filing of Pre-Application Document; Commencement of Licenseing Proceeding and Scopeing; Request for Comments on the Pre-Application Docment and Scoping Document 1, and Identifcation of Issues of Associated Study Requests for the Susitna-Watana Hydoelectric Projects 14241-000. Enclosure 11 River Productivity Study Request, dated May 31, 2012

Van Nieuwenhuyse, E.E. 1985. Summary of Results: Task 71, Primary production monitoring effort. Technical Memorandum prepared for Harza-Ebasco Susitna Joint Venture. Arctic Environmental Information and Data Center, University of Alaska-Fairbanks, Anchorage, Alaska. December 1985. SUS Document 597.

Wallace, J.B. and J.W. Grubaugh. 1996. Transport and Storage of FPOM. Pages 191-215 *in* F.H. Hauer and G.A. Lamberti, editors. Methods in stream ecology. Academic Press, San Diego, California.

Wallace, J.B. and J.R. Webster. 1996. The role of macroinvertebrates in stream ecosystem function. Annual Review of Entomology 41: 115-139.

Ward, J.V. 1976. Effects of flow patterns below large dams on stream benthos: a review. Pages 235-253 *in* J.F. Orsborn and C.H. Allman, editors. Instream flow needs symposium, volume II. American Fisheries Society, Bethesda, Maryland.

Ward, J.V. and J.A. Stanford. 1979. Ecological factors controlling stream zoobenthos with emphasis on thermal modification of regulated streams. Pages 215-236 *in* J. V. Ward, and J. A. Stanford, editors. The Ecology of Regulated Streams. Plenum Press, New York, New York.

Waters, T.F. 1972. The drift of stream insects. Annual Review of Entomology 17: 253-272.

Williams, D.D. and H.B.N. Hynes. 1977. Benthic community development in a new stream. Canadian Journal of Zoology 55: 1071-1077.

Wipfli, M.S. 1997. Terrestrial invertebrates as salmonid prey and nitrogen sources in streams: contrasting old-growth and young-growth riparian forests in southeastern Alaska, USA. Canadian Journal of Fisheries and Aquatic Sciences 54:1259–1269

Wipfli, M.S., and C.V. Baxter. 2010. Linking Ecosystems, Food Webs, and Fish Production: Subsidies in Salmonid Watersheds. Fisheries 35(8):373-387.

Wipfli, M.S., J. Hudson, and J. Caouette. 1998. Influence of salmon carcasses on stream productivity: response of biofilm and benthic macroinvertebrates in southeastern Alaska, U.S.A. Canadian Journal of Fisheries and Aquatic Sciences 55: 1503–1511.

Wurtsbaugh, W.A., and D. Neverman. 1988. Post-feeding thermotaxis and daily vertical migration in a larval fish. Nature 333(6176):846-848.

9.8.10. Tables

Table 9.8-1. Preliminary macroinvertebrate and algae sampling sites, stratified by reach and habitats. Refer to Figures 9.8-1 – 9.8-2 for locations of the preliminary sampling reaches.

Sampling Reach	Reach Description	Number of Mainstem Sites	Number of Associated Off-channel Sites[1]
Upper Reach			
UR-1, -2, -3	Reference upstream of reservoir	2	4
Middle Reach			
MR-1	Immediately below dam site	1	2
MR-2	Upstream of Devils Canyon	1	2
MR-6	Downstream of Devils Canyon	2	4
Susitna River Totals		**6**	**12**

Notes: 1 Side-channels, sloughs, tributary confluences associated with a mainstem sampling site.

Table 9.8-2. Preliminary schedule for River Productivity Study.

Activity	2013				2014				2015
	1Q	2Q	3Q	4Q	1Q	2Q	3Q	4Q	1Q
Literature Review on Hydropower Impacts		—	—	—					
Sampling benthic macroinvertebrate communities, algal communities, and organic matter.		—	—			—	—		
Invertebrate drift sampling		—	—			—	—		
Sampling Talkeetna for Reference Site Feasibility Study		—	—						
Trophic analysis with bioenergetics and stable isotope analysis		—	—	—	—	—	—	—	
Generate habitat suitability criteria					—	—	—	—	
Conduct a fish gut analysis		—	—			—	—		
Establish baseline colonization rates		—	—			—	—		
Data Analysis and Reporting			—	—	—	—	—	—	—
Initial Study Report				—	Δ				
Updated Study Report								—	▲

Legend:

—— Planned Activity
----- Follow up activity (as needed)
Δ Initial Study Report
▲ Updated Study Report

9.8.11. Figures

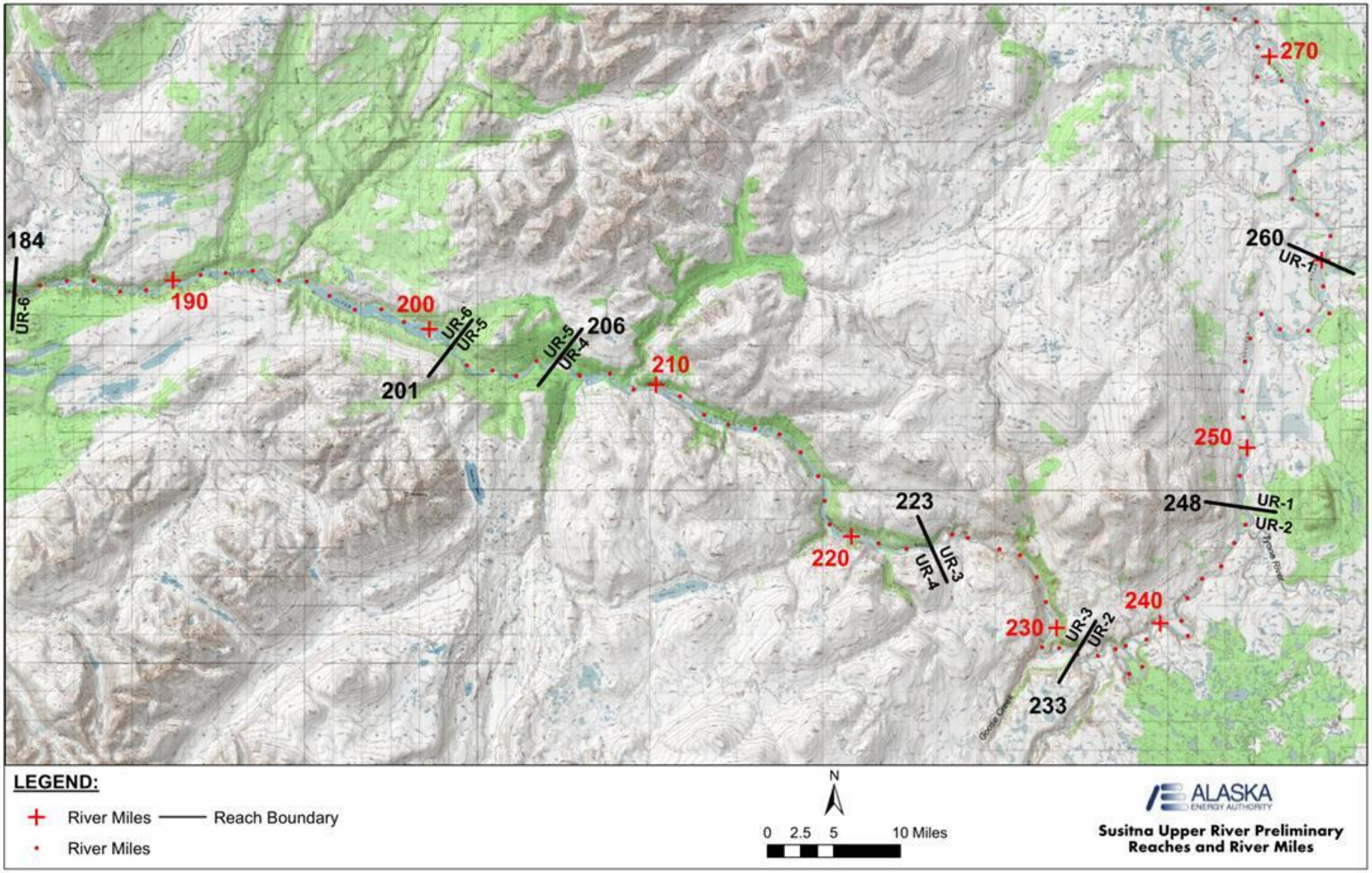

Figure 9.8-1. Upper Susitna River Reach, Preliminary Reaches and River Miles.

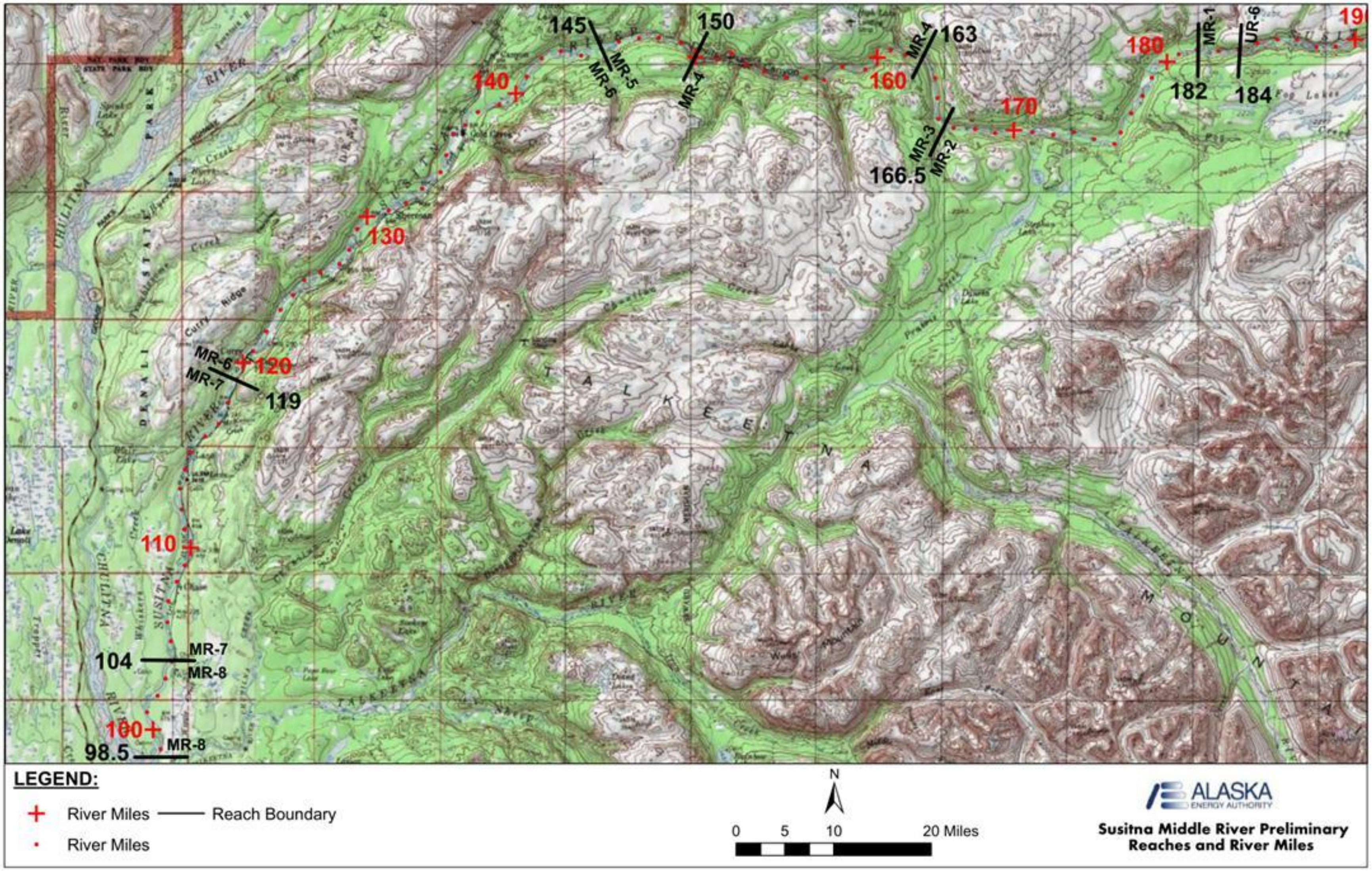

Figure 9.8-2. Middle Susitna River Reach, Preliminary Reaches and River Miles.

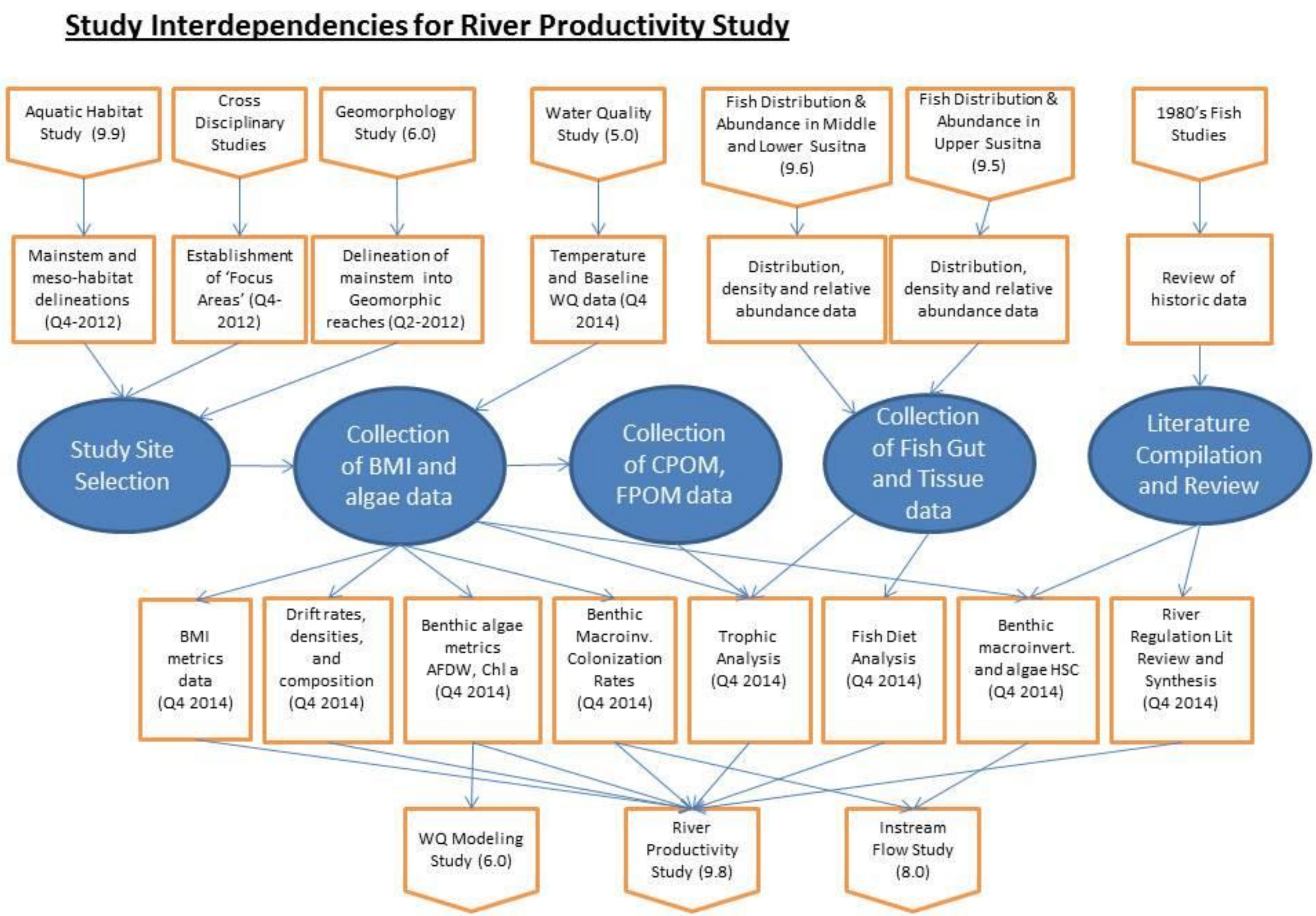

Figure 9.8-3. Study Interdependencies for River Productivity Study .