DEVELOPMENT OF A DREDGED MATERIAL MANAGEMENT PLAN FOR THE LOWER SNAKE RIVER

APPENDIX L
AQUATIC RESOURCES
ALTERNATIVE RANKING MATRIX

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EXECUTIVE SUMMARY

Construction of dams on the lower Snake River has altered the character of the natural river flow from running to standing water and created over 200 km of standing water. The result has been deposition of material in lower velocity areas. This deposition has created a number of habitat and management problems including changes in aquatic biota, interference with navigation and flood control. Development of a Dredged Material Management Plan (DMMP) for Lower Granite Reservoir and the other lower Snake River and McNary reservoirs is intended to maintain the Federally authorized 14-feet deep navigation channel. The DMMP will direct a course of action for managing the dredge removal and disposal material across the next 20 years in a means directed toward providing increased habitat quantity and quality for species listed under the Endangered Species Act (ESA).

The purpose of this report is to provide an ecological analysis of 12 management alternatives proposed to address the sedimentation problems. A ranking matrix was developed for the 12 proposed sediment management alternatives. Criteria used to evaluate the proposed alternatives included aspects of the life cycle of migrating salmonids and resident fishes, their food production, and maintaining the biological integrity of the Lower Granite ecosystem. Effects of implementation of each of these alternatives on each criterion was evaluated relative to a possible benefit (+), deleterious or neutral effect. Scores were obtained for each of the alternatives and those with the highest scores (i.e. positives exceeded negatives) were considered to be biologically acceptable alternatives.

Six land disposal alternatives are being examined in the selection process for the preferred alternative. Alternatives 1b, 2b, and 3b provide for direct land disposal whereas alternatives 4b, 5b and 6b provide for construction of a temporary in-water storage area (Alpowa Creek site) followed by later removal and land disposal.

Effects of alternatives that employ temporary in-water storage for rehandling to upland disposal sites were deemed deleterious to the aquatic habitat. Several factors contributed to the undesirable aspects of these alternatives including potential blockage to Alpowa Creek to upstream migrating steelhead *Oncorhynchus mykiss* to elimination of potential rearing habitat for subyearling chinook salmon *O. tshawytscha*. Therefore, all alternatives that remove larger volumes of dredged material that require temporary in-water storage were deemed unacceptable. Alternatives 4a, 4b, 5a, 5b, 6a, and 6b are alternatives that are considered unacceptable for these reasons.

Six in-water alternatives have been identified, ranging in volume of disposal from less than 300,000 yd^3 (CU) to approximately 2,000,000 CU (6a & 6b). Selectively placed in-water disposal is considered beneficial and could

ultimately enhance habitat conditions in the Lower Granite Reservoir ecosystem. The degree of benefit to the Lower Granite ecosystem is based upon the type of in-water disposal used. Maximum benefit to all aquatic fauna would accrue from shallow water disposal, such as island construction and shallow shoreline construction, whereas the least benefit would accrue from deepwater disposal. This conclusion was based on results from studies of experimental in-water disposal of dredged material in Lower Granite Reservoir where subyearling chinook salmon utilized shallow water habitat surrounding Centennial Island and several introduced fishes, considered game fishes, benefited from the increase in shallow water habitat. Experimental deepwater disposal was not considered deleterious to the Lower Granite ecosystem but not beneficial either for fishes. One possible benefit of deepwater disposal, although not tested, appears to be associated with the potential to increase the availability of benthic macroinvertebrates to downstream migrating salmonids in areas near Lower Granite Dam and possibly other lower Snake River dams. Some data indicate this means of sediment disposal could provide increased food abundance and availability in forebays. Although theoretically valid, deepwater disposal would unlikely alter the channel significantly to increase water velocities and therefore, decrease travel time of downstream migrating salmonids through Lower Granite and other lower Snake River reservoirs.

Based on a thorough analysis of potential benefits, negative or neutral effects, the most biologically acceptable alternatives would be 1a, 2a, and 3a with less support for alternatives 1b, 2b, and 3b. The Corps should select a preferred alternative from the screened alternative list and formulate a Recommended Plan for long-term management of dredging. Alternative 4 – Maintenance Dredging With RDT Recommended Beneficial Use of Dredged Material and a 3-Foot Levee Raise would best meet environmental criteria based upon restoration of juvenile salmonid habitat including opposing sandbars used by Snake River fall chinook salmon that outmigrate as subyearlings. Alternative 4 incorporates mitigation features that act to restore valuable shallow water sand bar habitat to the Lower Granite ecosystem.

Suitable shallow water habitat preferred by juvenile fall chinook is represented by natural shallow sloping shoreline beaches. Criteria would include a slope of 3-5% going from zero depth at the water edge down to 15 feet deep at the deepest edge within the river channel. An average of 6-9 feet deep built into a shallow water bench would be acceptable. Substrate surface should be predominately open sand that is relatively smooth throughout its distribution without the hummocking resulting from simple split-bottom barge load dumping. This requires some smoothing method of dragging a beam subsurface from a small to medium size tug at an horizontally oriented angle referenced to the shoreline edge from riverward depth toward the shoreline, thus establishing that 3-5% slope to zero along the waterline. This barge dumping/smoothing sequencing would need to be done in phases working riverward from zero depth to the maximum 15 foot depth.

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1.0 Alternatives

1.1 Background

Construction of dams on the lower Snake River has altered the character of the natural river flow from running to standing water. A characteristic of running waters, like the pre-impounded lower Snake River, is its capacity to transport suspended material; waters with higher velocities transport larger material while non-moving waters transport little and very small materials. Closure of Lower Granite Dam and other lower Snake River dams have altered the natural flow regimen and created over 200 km of standing water. The result has been deposition of material in lower velocity areas such as at the upstream reaches of reservoirs, stream/river confluences, and directional changes in the channel. In Lower Granite Reservoir, sediment deposition has occurred around the confluence of the Snake and Clearwater rivers, and downstream to Silcott Island. This deposition has created a number of habitat and management problems including changes in aquatic biota, interference with navigation and flood control. The purpose of this report is to provide an analysis of 12 alternatives proposed by personnel of the US Army Corps of Engineers to alleviate the sedimentation problem in the lower Snake River reservoirs.

A number of management alternatives to alleviate the sediment problem in Lower Granite Reservoir has been examined in the past (Meyers and Sasser-Blair 1988). Most have involved removal of sediment through dredging and either in-water or land disposal. Dredging and either in-water or land disposal would alter the physical habitat. Changes in the physical habitat can alter the habitat suitability for different species, both invertebrate and vertebrate. Habitat changes can be beneficial and increase the suitability and availability of habitat for a given species or habitat changes can be detrimental and result in less suitable habitat. Improved suitability can result in increased abundance and overall increased biological production and conversely, decreased suitability can result in decreased abundance or even extirpation of a species from a given area. Dredging and disposal of dredged material can afford a substantial opportunity for habitat changes. Some of these changes are beneficial for some species, neutral or even detrimental to other species (Bennett et al. 1998).

In the late-1980s the Corps organized a regional Interagency Working Group for technical review of dredge management proposals for the Snake and Clearwater rivers confluence area and a proposal to use in-water disposal of dredged material for beneficial use within the Lower Granite reservoir. The Interagency Working Group determined that not enough technical information was available to accept the assumptions generated for estimating benefits of creating aquatic habitat with in-water disposal of dredged material, or which design of habitat components would be most suitable for salmonid and resident species. The Group directed that an experimental pairwise comparison study was required where long-term monitoring for species composition, utilization, and habitat parameter quality would be compared between established reference sites and created habitat sites composed of shallow water versus mid-depth versus deep water. The study would prioritize beneficial use based upon suitability for salmonid species first, then unsuitablility for predator piscine species on juvenile salmonids.

Dredging began in 1986 with land disposal. Experimental in-water disposal was initiated in 1988. A total of over 20 reference sites representative of existing shallow water, mid-depth benches, and deep water habitat were established for comparison to two in-water disposal sites. Approximately 900 million cubic yards of sediment per year was used in 1988 to raise a mid-depth bench originally 20-40 feet (6.1-12.1 meters) deep to a depth of 6-12 (1.8-3.6 meters), thereby creating a shallow water underwater plateau. In 1989 a linear island referred to as Centennial Island was created immediately atop of the downriver segment of the underwater plateau. A mid-channel site at River Mile 120 offshore and slightly downriver of Centennial island was utilized as the comparable deep water disposal experimental site. Monitoring of the fish and benthic macroinvertebrate communities began in 1988 and continued through 1994, spawning ancillary studies up through 1997 to supplement components and variables in the database.

An adaptive management framework guided annual study objectives, which evolved as the study years progressed. The primary objectives included:

1. Assess age-0 chinook salmon *Oncorhynchus tshwaytscha* abundance in Lower Granite reservoir, identify critical habitat components and function, then assess the potential suitability of the experimental disposal sites for rearing of age-0 chinook salmon.
2. Compare benthic community structure and abundance at experimental disposal sites and reference sites.
3. Monitor abundance of larval, juvenile, and adult resident fish species that are predators upon juvenile salmonids (both native and introduced/exotic) with emphasis on the native Northern pikeminnow *Ptychocheilus oregonensis* and the non-native smallmouth bass *Micropterus dolomieui* at experimental in-water disposal sites compared with those estimates at reference sites.
4. Estimate juvenile salmonid consumption by Northern pikeminnow and other predators, such as smallmouth bass, in Lower Granite reservoir.
5. Assess white sturgeon, *Acipenser transmontanus* abundance and habitat components associated with their abundance in Lower Granite reservoir.

Adult Snake River fall chinook salmon enter the Columbia River in August, September, and early October (Bjornn 1960). Redds are constructed in the mainstem Snake River from October until December (Waples et al. 1991, A. Garcia annual reports), with a majority of redds annually appearing clustered in specific areas, such as river kilometer (Rkm) 260.8 in 1991 (William Connors, U.S. Fish and Wildlife Service, Ahsahka, Idaho, personal communication).

Little is known about timing of emergence for Snake River fall chinook salmon (Howell et al. 1985). Bennett and Shrier (1986) and Bennett et al. (1988, 1990a, 1991, 1993a, 1993b) have captured small (<50 mm) subyearling chinook salmon in Lower Granite reservoir in April which suggests emergence can occur in March to early April. Most juvenile fall chinook salmon from the Snake River migrate to the ocean as subyearlings (Bjornn 1960).

After emergence and initial dispersal, fall chinook salmon exhibit a high fidelity for lower velocity backwater areas for rearing. Bennett and Shrier (1986) and Bennett et al. (1988, 1990a, 1991, 1993a, 1993b) captured subyearling chinook salmon over low gradient, low velocity, sandy substrates in Lower Granite reservoir, likely an antipredation strategy at locations that produce suitable macroinvertebrate prey abundance. Becker (1970) showed earlier that subyearling chinook salmon utilize relatively slow moving waters near the shorelines or immediately downriver of islands of the central Columbia River for resting and feeding. Subyearling salmon migrate through reservoirs more slowly than yearling chinook salmon and spend more time in reservoir habitats for rearing (Rondorf et al. 1990, Curet 1993) since they are not afforded the additional YR1 rearing and overwintering in the subbasins that yearling chinook salmon are allowed.

A majority of subyearling fall chinook salmon that occur along the shorelines of the lower Snake River reservoirs are believed to be progeny of adult fall chinook salmon which spawn in the free flowing portion of the Snake and Clearwater rivers or possibly in tailwaters of impoundments on the lower Snake River. Bennett et al. (1987-1998) and Curet (1993) sampled subyearling fall chinook salmon primarily by beach seining and open water trawling. Subyearling chinook salmon appear to be distributed primarily along the shoreline of the reservoir over sand substrate during their early rearing period in the reservoirs and pelagically oriented once shoreline temperatures exceed 18-20 degrees C. Temperature appears to regulate the duration of shoreline residence and downriver movement by increasing the metabolic activity of the fish beyond tolerant physiological levels.

Food habits and the caloric importance of prey were assessed for four length groups (40-50 mm, 56-70 mm, 71-85 mm, and >86 mm) of subyearling chinook salmon collected in Lower Granite and Little Goose reservoirs, Washington, during 1991-1992 (Curet 1993). Ephemeropterans and Cladocerans were the most important prey item for the 40-50 mm size class. Ephemeropterans and Dipterans were the most important prey items for the 56-70 and 71-85 mm size classes and larval fish were the most important prey item (72%) in the diet of fish >86 mm. Application of a bioenergetics model estimated that subyearling chinook salmon were feeding at 27% of their maximum ration during the time interval modeled (April-July). The observed proportion of maximum ration was only 7% greater than the estimated maintenance ration (zero growth) modeled for the same time interval suggesting either forage limitations, competition or other abiotic and biotic factors may be influencing subyearling growth in the reservoir (Curet 1993) such as the cold water releases augmented from Dworshak reservoir during the summer to assist spring chinook smolt outmigration.

Smallmouth bass and northern pikeminnow are both predators of subyearling fall chinook salmon. Smallmouth bass appear to be the most serious predator along the shorelines of Lower Granite reservoir. These predators may consume up to 6% of the wild subyearling chinook salmon juvenile population as they rear and migrate through Lower Granite reservoir (Curet 1993). Curet (1993) estimated mean daily consumption rates of subyearling chinook salmon for three groups of smallmouth bass (<250 mm, 250-389 mm, and >389 mm) collected in May 1992 (<1 month following the Corps experimental reservoir drawdown of Lower Granite and Little Goose reservoirs to spillway crest) and two length groups of northern pikeminnow (250-349 mm and >349 mm) collected during the smolt outmigration period (April through June) in 1987-1991. Daily consumption rates of subyearling chinook salmon by smallmouth bass were similar between the <250 mm and 250-389 mm length groups at 0.06 and 0.09 prey/predator/day, respectively. No consumption was noted by the >389 mm length group although low numbers of smallmouth bass at this size were sampled. Consumption of subyearling chinook salmon by northern pikeminnow was detected only in April. Daily consumption rates of subyearling chinook salmon by norther pikeminnow ranged from 0.01 to 0.06 prey/ predator/ day for the 250-349 mm and >349 mm length groups, respectively.

The estimated population size of subyearling chinook salmon along the shoreline of Lower Granite reservoir peaks between mid-May and the first week of June. The duration of subyearling chinook salmon rearing along the shoreline of the reservoir differs between years. In 1987 and 1992 subyearlings disappeared from the shoreline by late May whereas in 1990 and 1991 subyearlings remained along the shoreline until late June.

In Little Goose reservoir, the estimated peak population size of subyearling chinook salmon occurs along the shoreline in mid-May to early-June. No subyearling chinook salmon are collected along the shoreline typically after mid-July. Population estimates by river reach indicate that the highest numbers of subyearling chinook salmon rear mid-reservoir between Rkm 134.4-166.5 followed by Rkm 113.1-134.3 and Rkm 166.6-172.1.

The most likely beneficial effect of shallow water habitat creation identified through 10 years of monitoring data was the effect of creating more refuge habitat suitable to juvenile fall chinook for rearing during their subyearling migratory lifestage.

Depending upon growth and subsequent degree of smoltification subyearling chinook do not pass quickly through a reservoir, but utilize the shoreline and open water areas of Lower Granite and Little Goose reservoirs as rearing areas before migrating downriver. Curet (1993) found that the overall rearing period for subyearling chinook in Lower Granite reservoir was 75 days in 1992 and 112 days in 1991, in both cases less than in John Day reservoir on the Columbia River (>160 days) (Sims and Miller 1981). Based on results from 1987, 1990, 1991, and 1992, duration of littoral rearing was longer in the cooler years (ie, producing higher runoff flows, Curet 1993). Littoral rearing differed from 48 days in 1992 to 84 days in 1991. The open water rearing period was most similar between the two years at 27 and 28 days, for 1992 and 1991 respectively. Mid-water and bottom trawl collections in Lower Granite reservoir during June 1992 indicated that after the subyearlings migrate from the shoreline of the reservoir in late spring the fish appeared to be pelagically oriented in mid to deep water areas before beginning their downriver migration. In 1990 and 1991, when shoreline temperatures remained below 18 degrees C until mid to late June, subyearlings remained along the shoreline of the reservoir until late June and peak abundance along the shoreline of the reservoir occurred in late May to early June, two weeks later than in 1987 and 1992, lower flow years of more rapid warmer shoreline temperatures. The 27 to 28 day open water rearing period observed for subyearlings in Lower Granite closely coincided to results from subyearling collections in the unimpounded lower Snake River between Lower Granite reservoir and Hells Canyon Dam. Connor et al. (1992) noted an approximate 30 day difference between peak shoreline abundance and peak arrivals of subyearlings at Lower Granite Dam. Duration of open water rearing appeared to be related to temperature and was similar for both 1991 and 1992.

Subyearling chinook salmon in both Lower Granite and Little Goose reservoirs are consistently collected over sand substrate and in areas of reduced velocity (Curet 1993). Beach seine haul sampling by Curet (1993) suggest that subyearling chinook salmon distribution is clumped. Subyearling chinook salmon were concentrated over suitable micro-habitats where conditions such as temperature and dissolved oxygen levels remain at levels conducive for rearing. Subyearling chinook salmon rearing along the shoreline of Lower Granite reservoir during the spring exhibit a strong selection for substrata consisting of primarily sand and a moderate avoidance of cobble/sand and talus/sand (Curet 1993). Curet (1993) also found a strong avoidance of rip-rap habitat consistent for all years analyzed (years 1990-1992). These findings are consistent with subyearling collections in the Hanford Reach of the Columbia River where subyearlings utilize shoreline areas of reduced current velocity for resting and feeding (Dauble et al. 1989). The reason for the higher abundance of subyearling chinook salmon over sand substrate is not clear. Low velocities may be important in influencing rearing potential than the prevailing substrate (Bennett et al. 1992b).

Habitat selection studies, conducted for many salmonid species, generally suggest that larger fish inhabit deeper and faster water (Dauble et al. 1989). As increasing water temperatures result in water too warm for shoreline rearing, subyearlings may move offshore into deeper, faster areas where they rear until commencing their downriver migration. The fidelity exhibited by subyearlings for shoreline rearing in the reservoir and the unimpounded lower Snake River above Lower Granite reservoir may compromise survival since these areas are shared with a number of predators (Curet 1993, Connor et al. 1992; Bennett et al. 1988).

The application of a bioenergetics model, used in analysis of stomach contents of subyearling chinook salmon (Curet 1993), suggests temperatures may dictate shoreline distribution and timing of downriver migration. Both specific growth rates (calories/gram predator/day) and daily weight increments for subyearling chinook salmon declined once water temperatures exceeded 13 degrees C. At temperatures exceeding the preferred range of 12 to 14 degrees C (Brett 1952), the metabolic demands of subyearling chinook begin to exceed the fish's ability to consume adequate forage to maintain optimal growth. Migration from the shoreline of Lower Granite reservoir occurred once water temperature exceeded 18 degrees C coinciding with the model predicted cessation and reduction of weight gain and growth rates (Curet 1993). Curet (1993) results suggest reservoir and shoreline temperature greatly influence the duration of shoreline and open water rearing period of subyearling chinook salmon, and hence their fitness to survive downriver migration. Based on data from John Day reservoir (Sims and Miller 1981), neither rate of downriver movement or residence time of subyearling fall chinook is influenced by river velocities.

The primary difference between suitable juvenile fall chinook salmon rearing habitat and juvenile predator species (Northern pikeminnow and smallmouth bass) is the preference for some cover structure by pikeminnow and bass. Thus open sand substrate without cover provides refuge for juvenile fall chinook since juvenile predator species tend to avoid areas without cover, although they prefer shallow water sand or cobble substrate for feeding during the warming periods of the reservoirs (similar to warming periods in the unimpounded lower Snake River (Petersen et al. 1999) and reaches of the Columbia River). During the active monitoring phase of the Lower Granite reservoir habitat utilization studies, the discussions of predator population dynamics, predation on juvenile salmonids, and the links relating fish to habitat focused much more closely on the critical importance of the shallow water habitat overlapping utilization by juvenile fall chinook and those juvenile Northern pikeminnow and smallmouth bass typically too young or small to directly consume the juvenile salmon. Whereas in earlier discussions of the results collected from the first few years of Bennett's studies in Lower Granite reservoir, a much wider range of fish to habitat linkages were considered likely. It readily appeared that some of these more complex linkages were unlikely in importance as critical indicators and not worth concentrating due to their decreased priority in ecological significance. The focus readily highlighted the need to pay greater attention to larval fish and associated macroinvetebrate and limnologic surveys in very shallow water around the created island as compared to the reference sites. It appeared less important to carefully examine for complex habitat distribution throughout the reservoir.

As expected based upon the relatively young age of the reservoir, zooplankton densities in Lower Granite reservoir were low (1-46 organisms/liter) in the late 1970s (Funk et al. 1985). The highest abundances were in protected or quiescent areas.

As reservoirs age, the invertebrate species composition and abundance convert from lotic flowing riverine macroinvertebrate species found in the shallower and higher velocity environments of the pre-dam river to lentic or pelagic reservoir microinvertebrate species found drifting in the photic zone of the deeper and slower velocity environments of the post-dam pool. Species abundance and composition for benthic macroinvertebrates sampled in the early 1980s (5-7 years following refill) were related to habitat differences including substrate type and size, depth, flow, and season of year (Bennett and Shrier 1986, Dorband 1980). By the early-to-mid 1980s, the dominant benthic invertebrate taxa in Lower Granite reservoir had already converted to dipteran chironomid midges and annelid oligochaete blood worms (Bennett and Shrier 1986, Bennett et al. 1988). Within a few years after reservoir filling, Dorband (1980) already found a shift in dominant benthic taxa at RM 135, approximately 4/5th the distance upreservoir from Lower Granite Dam near the Port of Wilma. The Port of Wilma is about 4-5 RMs above Silcott Island at RM 131 where the hydraulic influence of the unimpounded flow input becomes dominated by the backwater effect of the reservoir volume and lower water velocities. Upriver of RM 135 there were more lotic species (larvae of tricopteran caddisflies, ephemeropteran mayflies, and plecopteran black flies), while below RM 135 lentic taxa were common (dipteran chironomid midges and annelid oligochaete blood worms). The transition zone between the lentic and lotic habitats had the lowest density of benthic macroinvertebrates possibly attributable to deposition from sediment input where the average water velocity across the channel slows. Species diversity of macroinvertebrate communities at shallow sites increases with downstream movement or colonization of drifting organisms scoured from upriver habitats, provided that like substrate and associated habitat components are available and suitable.

In the early 1980s, shoreline distributed littoral areas (< 15.5 feet deep) generally had the highest invertebrate abundance, species diversity, and species evenness. Sites of similar depth within the reservoir appeared different based upon location in the reservoir (as defined by river mile) with regard to benthic invertebrate numbers within and across species (Bennett and Shrier 1986, Bennett et al. 1988). Annual and seasonal population abundance variations occurred, with increased variation evident for species exhibiting seasonal emergence (eg. chrinomids as they pupated into adults) than species that are aquatic through all lifestages (eg. oligochaetes). Oligochaetes are ubiquitous throughout the lower Snake River reservoir sediments. Oligochaete biomass does not appear to vary with depth of water. While the numerical densities can fluctuate widely with a pattern similar to chironomids, the average biomass density appears to remain relatively constant around 5 g/m2. Oligochaetes prefer fine sediments with a high percent of organic content.

Chironomids can make up a substantial portion of the diets of certain fishes. If food is a limiting resource to fall chinook salmon rearing and migrating through Lower Granite reservoir, then it is necessary to estimate chironomid densities as a function of depth and substrate type. As early as Bennett et al. (1988) sampling showed a statistically weak pattern of biomass and abundance when measured by season and depth. The shallow water biomass peaks in summer at about 20 g/m2, and drops off to around 5 g/m2 in the winter. Measured by depth, the biomass appears to be constant from 5-20 feet deep, but begins to decrease as depth increases below 20 feet. Chironomids are most likely located in sand-silt sediments, and decrease in both finer and coarser sediment type environments. The chironomid community within the lower Snake River reservoirs are composed of several different species, thus resulting in chironomids being readily susceptible to predation by rearing salmonid smolts across the duration of the smolt migration seasons during each of the overlapping pupation and emergence episodes of the various chironomid species.

The role of crayfish in resident and predatory fish diets is extensively reported for every year of sampling in both Lower Granite reservoir since Bennett (1988) and in the unimpounded Snake River upriver of Lower Granite reservoir (Nelle 1999, Petersen et al. 1999), especially for sustaining Northern pikeminnow and smallmouth bass. Crayfish predominantly inhabit shallow water riprap areas from which they forage from riverward for primarily oligochaetes and other soft substrate inhabitants. In the Oxbow reservoir above Hells Canyon (Bennett, pers. comm.), in Lower Granite reservoir during the physical drawdown test in 1992 (Bennett et al. 1995, Curet 1994), and in the unimpounded Snake River between Lower Granite reservoir and Hells canyon dam (Nelle 1999), crayfish have been found at all depths. To demonstrate the importance of crayfish in sustaining predator productivity in both Lower Granite reservoir and the unimpounded Snake River between lower Granite reservoir and Hells Canyon Dam, Bennett et al. (1995) observed a vertical migration of smallmouth with the 2 feet per day receding water during the physical drawdown test of Lower Granite reservoir in March 1992. Crayfish were left desiccated as they searched wetted shelter in the sediment cracks of the 30 feet deep zone that was dewatered for several weeks. When the pool refilled in late-March and early-April, the majority of the smallmouth bass survived and vertically migrated back up to the shallow water zones that had cover via riprap when spring chinook smolts began migrating. Smallmouth bass consumption rates on juvenile salmonids increased in 1992 compared to previous smolt migration years as a consequence of interception by predators that were occupying a littoral zone that was temporarily devoid of crayfish. Crayfish recruited back to the littoral zone with the year, and smallmouth bass consumption rates decreased in 1993 to similar rates estimated for previous and post years of sampling (Bennett et al. 1995, Bennett et al. 1997).

Studies on the Columbia River have shown the importance of benthic invertebrates, particularly *Corophium salmonis*, in diets of juvenile white sturgeon (McCabe et al. 1992a; McCabe et al. 1992b). More extensive research is needed to determine significant links between sturgeon distribution, growth, and invertebrate abundance. Sprague et al. (1992) indicated that white sturgeon may be feeding on organisms in the water column rather than exclusively on organisms associated with the substrate. *Corophium* species, river drift organisms, were the predominant prey item eaten by young-of-the-year and juvenile white sturgeon in two Columbia River impoundments and the lower Columbia River (Sprague et al. 1992; McCabe et al. 1992a; Muir et al. 1988). *Corophium* species abundance in Lower Granite reservoir appear low (Bennett et al. 1991), however, crayfish were abundant near the upper end of Lower Granite reservoir. Cochnauer (1981) reported crayfish and chironomid species were dominant food items identified from white sturgeon stomachs in the middle Snake River. This may explain the high density of juvenile white sturgeon in the upper section of Lower Granite reservoir relative to lower areas of the reservoir. Highest densities of crayfish in Lower Granite reservoir, a prey item of white sturgeon >45 centimeters long (Scott and Crossman 1973), occurrednear the upper end of the reservoir which coincided with the highest densities of juvenile white sturgeon. Bennett et al. (1990) reported high abundance of larval fishes above Rkm 204.8 which also may contribute to food resources available to white sturgeon. Lepla’s (1994) sampling in 1990-1991 show that the upriver portion of Lower Granite reservoir is the most critical portion of the reservoir for juvenile white sturgeon rearing.

Development and operation of the Columbia and Snake river hydrosystem have altered the natural riverine habitat suitable for white sturgeon by modifying historic flow regimes and sedimentation, temperature, dissolved oxygen, and accessibility and diversity of food supplies (Coon et al. 1977; Haynes and Gray 1981; Lukens 1981; Ebel et al. 1989; Parsley and Beckman 1992). The watershed has further been impacted by logging, agriculture, mining, stream channelization, water pollution, and harvest allowing some species of fish to flourish while others decline.

Historically, diadromus white sturgeon in the Columbia and Snake river system ranged freely and made extensive seasonal migrations to optimize changing habitats (Bajkov 1951). Dams and resulting impoundments have isolated white sturgeon populations (North et al. 1992) and reduced habitat diversity by replacing riverine habitats with lentic environments. Populations of fish species adapted to riverine conditions typically decline at the highest rate

(Parsley et al. 1992). Landlocked populations of white sturgeon in the Snake River in Idaho are classified as a species of special concern (Mosley and Groves 1990; 1992) for the states of Washington and Idaho.

White sturgeon remain relatively abundant in the Snake River between Lower Granite dam (Rkm 173) and Hells Canyon dam (Rkm 398) (Lepla 1994, Cochnauer 1983; Cochnauer et al. 1985; Lukens 1985). White sturgeon studies conducted prior to Lepla (1994) between Lower Granite and Hells Canyon dams mainly described the population status above Lower Granite reservoir with little data on fish residing in the reservoir environment proper. Coon et al. (1977) estimated 8,000-12,000 white sturgeon (>46 cm TL) in the Snake River between Hells Canyon and Lower Granite dams during 1972-1975 with 44 fish sampled in the reservoir near Blyton Landing. Lukens (1984) reported an estimate of 4,000 white sturgeon between the confluence of the Snake and Clearwater rivers and Hells Canyon Dam. Luken's (1984) efforts at collecting white sturgeon in Lower Granite reservoir were unsuccessful. Monitoring of fish stocks in 1992 and 1993 by Bennett at al. (1994) sampled 320 white sturgeon yielding an estimate of 1,804 (95% Confidence Interval (CI) of 816-7,219. This estimate (1,804) is similar to Lepla's (1994) estimate of 1,372 indicating abundance of white sturgeon in Lower Granite reservoir remained similar or assumed relatively stable following Lepla's (1994) surveys during 1991 and 1992. Density of white sturgeon in Lower Granite reservoir is also similar to densities reported above Lower Granite reservoir from past surveys. Although direct comparisons were not possible, density of white sturgeon in Lower Granite reservoir (28 fish/Rkm) was similar to 24 fish/Rkm reported above Lower Granite reservoir by Lukens (1985) but lower than estimates by Coon et al. (1977). Coon et al. (1977) estimated white sturgeon densities ranged from 35-53 fish/Rkm between Lower Granite and Hells Canyon dams while Lepla's (1994) estimate for Lower Granite reservoir alone was 12-45 fish/Rkm (average of 28 fish/Rkm). White sturgeon are generally considered less abundant in each upriver impoundment in the Columbia and Snake river system. Comparison of fish density in Lower Granite reservoir with Columbia River impoundments concluded density of white sturgeon in Lower Granite reservoir (0.38 fish/hectare) was lower than reported in Bonneville reservoir (6.12 fish/hectare) and The Dalles reservoir (2.51 fish/hectare) but slightly higher than John Day reservoir (0.30 fish/hectare) (Beamesderfer and Rien 1992). The lower Columbia River below Bonneville Dam supported the highest density (14.6 fish/hectare) of white sturgeon in the Pacific Northwest which was attributed to abundant food resources available with access to migration to the ocean (Devore 1992).

Gillnet and setline sampling was used by Lepla (1994) to estimate population structure. Setline hooks were primarily baited with Pacific lamprey *Lampreta tridentata*, rainbow trout *Oncorhynchus mykiss*, and largescale sucker *Catostomus macrocheilus*. White sturgeon collected with gill nets ranged in length from 10.3 to 203 cm tail fork length (FL) with a mean of 62.3 cm FL. White sturgeon collected with setlines ranged from 69 to 236 cm FL with a mean of

127.3 cm FL. The corrected length frequency distribution indicated juvenile white sturgeon measuring <112 cm FL (125 cm TL) comprised 94% of the length distribution indicating juvenile and young-of-the-year (YOY) fish. Mature adult white sturgeon (>125 cm TL) were not utilizing Lower Granite reservoir with the same frequency as juveniles. A sample of 504 white sturgeon were aged from 0 to 29 years. Juvenile white sturgeon from ages 0-8 comprised 84% of the entire sample with 1986-87 aged fish indicating weak year-classes. A plot of length at age data indicated growth was relatively consistent up to age $\geq$ 8.

Presence of YOY and high abundance of juvenile white sturgeon in Lower Granite reservoir indicated recruitment has been occurring in the Lower Granite-Hells Canyon population. The high abundance of juvenile and YOY fish near the upper end of Lower Granite reservoir also suggests that the reservoir primarily serves as rearing habitat. McCabe and Tracy (1993) suggested wide dispersal of white sturgeon larvae allowed more use of feeding and rearing habitats while minimizing competition. Lepla (1994) assumed no spawning occurred in Lower Granite reservoir since velocities measured in the reservoir (0.0-0.60 meters/second) are below threshold levels perceived to elicit spawning (1.0 m/sec; Anders and Beckman 1993).

Mean length at age has increased significantly for white sturgeon compared to previous surveys in the Lower Granite to Hells Canyon dam reach. Mean lengths of white sturgeon for ages 5-18 years in Lower Granite reservoir were longer than lengths of similarly aged fish during 1972-1975 (Coon et al. 1977) and 1982-1983 (Lukens 1984). This increase in growth over past surveys in the Lower Granite to Hells Canyon dam reach may in part be related to sampling a juvenile population from an impoundment. White sturgeon from 1972-1975 and 1982-1983 surveys were primarily sampled in riverine sections above Lower Granite reservoir which may have accounted for slower growth rates. Miller and Beckman (1992) reported faster growth of juvenile white sturgeon in the Columbia River occurred in impoundments rather than in the lower Columbia River, suggesting faster growth was related to increased food availability. General principle of reservoir aging suggests possible factor of less prey diversity with increased aging of reservoir where only 2-3 species remain, but each of these 2-3 species produce significantly higher abundance equalling a net increase in availability of a suitable (although not particularly the most preferred) or catchable food base.

Comparison of length at age data with white sturgeon in the Bliss-C.J. Strike reach of the middle Snake River indicated growth was similar for ages 4-14 years. Growth rates in the C.J. Strike reach appeared higher than in Lower Granite reservoir for ages <3 and >14 years. Cochnauer (1983) reported white sturgeon in the middle Snake River exhibited higher growth rates due to warmer water. The more recent operations under the Hydrosystem BiOp where cold Dworshak water and cooler Hells Canyon water is used to augment lower Snake River flows for either meeting passage flow targets or for cooling the lower Snake

River (principally only affecting Lower Granite reservoir effectively) could result in lower number of adequately warm degree days for white sturgeon growth compared to historical condition.

Comparison of mean lengths of juvenile white sturgeon from Lower Granite reservoir and Columbia River impoundments (Miller and Beckman 1992) indicated mean lengths were longer in Lower Granite reservoir. Higher growth rates for Snake River white sturgeon relative to Columbia River populations may result from warmer water, lower densities, and less competition for food resources. Similar studies comparing Columbia River impoundments and the lower Columbia River determined juvenile white sturgeon from Columbia River impoundments had greater length-at-age and condition than fish from the lower Columbia River citing increased food availability and lower densities (Miller and Beckman 1992). An additive factor of less turbidity in reservoir environment than in riverine environment, hence better search and capture efficiency on the 2-3 over abundant species left in the decreasing diversity of prey.

Low frequency of white sturgeon from the 1986-1987 year classes suggested potential low recruitment to the population during those years. Year class failures have been observed in white sturgeon populations (Miller and Beckman 1992) with implications that the environment affects white sturgeon reproduction more than stock-recruitment relations during some years and in some areas (Parsley et al. 1992) which lends support to environmental perturbations influencing white sturgeon recruitment in the Snake River, Idaho since harvest was prohibited following 1970. Numerous environmental conditions can potentially impact white sturgeon recruitment over several years and life stages with water flow receiving recent attention. Spring flows in the Hells Canyon reach associated with 1986-1987 year classes were relatively high compared to the following lower water years associated with the onset of the drought in the middle Snake River Basin. Suction dredging conducted near the Port of Wilma during 1987 may have also contributed to mortality of YOY and juvenile white sturgeon rearing in this area. Buell (1992) reported suction dredging in the Columbia River seriously injured and killed juvenile white sturgeon and speculated that dredging operations attracted feeding white sturgeon which compounded mortality.

White sturgeon abundance was not distributed uniformly throughout Lower Granite reservoir. Approximately 56% of white sturgeon sampled with gill nets were captured near the Port of Wilma and Red Wolf Crossing Bridge (Rkm 215.6-221.1) coinciding with locations of highest-catch-per-unit-effort (CPUE = 0.32 fish/hr). Catch rates for white sturgeon decreased considerably with downstream sampling from Rkm 215.6 during both sampling years of Lepla (1994). Comparison of CPUE among transects determined catch rates at transects above Rkm 204.8 (Nisqually John Landing on right/north bank and Centennial Island on left/south bank) statistically higher ($P<0.001$) than transects below Rkm 204.8 with exception of Rkm 187.9 (2.5 Rkm upriver Knoxway

Canyon Bay (Figure 10). White sturgeon <35 cm FL were sampled primarily at transects upriver of Rkm 212 while fish >35 cm FL were collected throughout Lower Granite reservoir.

Seasonal changes in distribution occur in Lower Granite reservoir (Lepla 1994). Relative numbers of white sturgeon in the upper section of the reservoir increased from May through November implying upriver redistribution/movement as the summer to fall season progressed. However, multiple comparison tests indicated seasonal use of mid and lower reservoir transects was not significant with exception to Rkm 187.9 (2.5 Rkm upriver of Knoxway Bay). Number of white sturgeon sampled at Rkm 187.9 was highest (0.31 fish/hr) only during April-July 1991 and declined sharply as summer progressed. Catch rates at Rkm 187.9 in 1990 were low and were also similar in 1992 (Bennett et al. 1994, 1995). Catch rates at remaining mid and lower reservoir locations were low regardless of season.

Movements from 0 to 25 river kilometers were observed from recaptured white sturgeon with the majority of fish travelling 1-5 river kilometers. Differences in fish size did not appear to affect distance traveled in the reservoir. Approximately 65% of the fish recovered were collected within the upper 10 river kilometers of Lower Granite reservoir where densities of white sturgeon were highest.

Evaluation of habitat components associated with white sturgeon in Lower Granite reservoir provide information on reservoir habitat use and impacts to white sturgeon by altering existing reservoir habitat components through carefully planned in-water disposal of dredged material in Lower Granite reservoir (Lepla 1994).

Lepla (1994) determined physical habitat use by white sturgeon by measuring water, temperature, dissolved oxygen, depth, and water velocity at each gill net or hook line set. Evaluation of habitat use by white sturgeon also included sampling for crayfish with sets of “minnow” traps. Water depth, mean water velocity, and near substrate water velocity data were used by Lepla (1994) to develop habitat suitability criteria (HSC) for white sturgeon. Habitat use curves describe relative suitability of use independent of habitat availability. Habitat suitability criteria for each habitat descriptor range from 0 to 1 with 0 = unsuitable and 1 = suitable. These curves were fit to habitat data based upon catch-per-unit-effort (CPUE) computed by Lepla (1994) for each habitat type.

White sturgeon use depths from 6.1 meters to 39.6 meters in Lower Granite reservoir with a mean depth of 20.3 meters. Catch rates (0.19 fish/hr) and suitability indices (1.0) were highest at intermediate depths of 18-22 meters. No white sturgeon were sampled from depths <6 meters and >40 meters. White sturgeon used water velocities from 0.0-0.58 meters/second. Highest velocities were typically recorded in the main channel near the upper end of Lower Granite reservoir during spring (Rkm 215.6-221.1). Catch rates (0.15-0.17 fish/hr) and suitability indices (1.0) for mean and near substrate velocities were highest at 0.38 meters/second. The majority (73%) of water velocity observations ranged from 0.0-0.15 meters/second.

A wide range of temperatures were measured with highest catch rates (0.18 fish/hr) occurring at 20-22 degrees C. Near substrate dissolved oxygen ranged from 1.71 to 1.3 milligrams/liter (mg/l) with no white sturgeon sampled at locations <5.0 mg/l. Sufficient concentrations of dissolved oxygen (>5.6 mg/l) were generally maintained in Lower Granite reservoir throughout 1990-1991 with exception to low oxygen readings (<5.0 mg/l) at water substrate interface <Rkm 192.9 on 06 August 1990. Concentrations returned $\geq$ 6.0 mg/l by 20 August 1990 throughout the reservoir.

Substrate from mid and lower reservoir transects (<208 Rkm) was predominantly silt, while sand was dominant at upper main channel transects >208-221 Rkm. Catch rates were highest (0.31 fish/hr) over sand substrate.

Number of crayfish ranged from 0-1 animals collected at lower reservoir (174 Rkm) transects to 267 animals collected at 215 Rkm. The majority (81%) of crayfish were sampled at upper reservoir transects. A Spearman's rank correlation indicated high correlation between crayfish and white sturgeon distribution (rs = 0.81).

Stepwise discriminant analysis of nine variables indicated that maximum depth, substrate, near substrate water velocity, and near substrate dissolved oxygen concentrations provided the best separation between presence and absence of white sturgeon.

Catch and depth information from 909 white sturgeon were used by Lepla (1994) to evaluate depth use in Lower Granite reservoir. Maximum depths at transects ranged from 13.3-48.7 meters in the main channel thalweg while areas sampled adjacent to the thalweg were 11-26.2 meters. Approximately 77% of the white sturgeon were collected in the thalweg with higher catch rates (0.13 fish/hr) than areas adjacent to the thalweg (0.04 fish/hr). Highest catch rates (0.23-0.32 fish/hr) of whie sturgeon occurred in the thalweg at upper reservoir transects (Rkm 215.6 and Rkm 221.1) where maximum depths were <23 meters. Catch rates at transects below Rkm 208.3 were significantly lower where main channel depths ranged from 23.4-48.7 meters.

Use of thalweg and areas adjacent to the thalweg by white sturgeon were similar between day and night sampling. Multiple comparison tests indicated catch rates were significantly higher in the tha;weg at transects sampled upriver of Rkm 208.3. No significant difference (P>0.05) in catch rates occurred between thalweg and adjacent areas below Rkm 208.3, with exception of Rkm 187.9. Catch rates were relatively high in the thalweg 2.5 rkm upriver of

Knoxway Canyon at Rkm 187.9 during spring sampling in 1991 and decreased as summer progressed. Distribution of white sturgeon in Lower Granite reservoir did not appear to be influenced by seasonal periods. No significant difference in use of deep water locations between seasons was apparent at most locations <Rkm 204.8, with exception of Rkm 187.9 near Knoxway Canyon. Catch rates at Rkm 187.9 were relatively high during spring sampling in 1991, otherwise numbers of white sturgeon sampled from mid and lower reservoir transects were generally low throughout seasonal intervals.

Catch rates and suitability indices indicated white sturgeon used habitat at the upper end of Lower Granite reservoir with greater frequency than mid and lower reservoir transects. These upper areas coincided with higher velocity, larger substrate, and shallower depths relative to transects sampled downriver. White sturgeon in Lower Granite reservoir have indicated a wide tolerance of habitat conditions as identified by the range of Lepla's (1994) observations. White sturgeon were captured at temperatures spanning the range observed in Lower Granite reservoir. Scott and Crossman (1973) reported white sturgeon were captured at temperatures from 0 to 23 degrees C which was similar to Lepla's (1994) collections in Lower Granite reservoir. Dissolved oxygen concentrations were <5.0 mg/l at lower reservoir transects during a brief period in 1990 but did not appear to affect the few white sturgeon sampled at those locations during 1990-1991. Suitability curves indicated velocity >0.45 meters/second was becoming less suitable for white sturgeon in Lower Granite reservoir which is lower than reported for juvenile white sturgeon (0.1-1.3 meters/second) in the Columbia River (Parsley and Beckman 1992). Parsley and Beckman (1992) concluded that juvenile white sturgeon used a wide range of habitat conditions and that one physical habitat variable was probably no more important than another for these life stages. This conclusion lends support to habitat use in Lower Granite reservoir since physical habitat variables selected by discriminant analysis explained only 26% of the variation indicating other criteria were responsible for white sturgeon distribution in Lower Granite reservoir. Based on similarities between crayfish and white sturgeon distribution, Lepla (1994) concluded that prey abundance and availability are dominant factors in determining white sturgeon distribution.

Deep water areas at mid and lower sections of Lower Granite reservoir were not considered significant since use of these areas by white sturgeon was markedly lower than at upriver locations. Catch rates of white sturgeon decreased considerably as sampling progressed downriver into Lower Granite reservoir during both 1990 and 1991 sampling (Lepla 1994). Lepla's (1994) fishing efforts adjacent to the thalweg in shallower water captured fewer sturgeon, so no direct impact to white sturgeon for disposition of dredged sand to form fall chinook rearing habitat in the shallow or mid-depth bench habitats. Haynes and Gray (1981) suggested that white sturgeon make feeding forays into shallow water during hours of darkness. Lepla's (1994) comparison of catch rates between the thalweg and areas adjacent to the thalweg during hours of daylight and darkness in Lower Granite reservoir were similar indicating no increased movement of white sturgeon into shallow areas during night sampling. Enhancing mid-depth shoreline benches into sandy, shallow water habitat would increase crayfish, chironomid midge, and possibly *Corophium* amphipod production, thus increasing availability to rearing juvenile sturgeon and fall chinook salmon in the more prey and habitat depauperate lower reaches of Lower Granite reservoir.

Lepla (1994) and other study data indicate that white sturgeon in Lower Granite reservoir use thalweg and upper reservoir locations with water depths <23 meters. Mid and lower reservoir locations were not used with the same frequency as upper reservoir transects regardless of season. Sediment dredged near the confluence and deposited at lower and mid reservoir locations may alter the physical habitat in these areas by decreasing water depth, increasing water velocity, and establishing substrate sizes larger than silt and fine sand. These physical habitat changes will probably have no negative effect and limited positive effect on white sturgeon productivity since physical habitat variables explained a low percentage of the variation for juvenile white sturgeon distribution in Lower Granite reservoir (Lepla 1994). However, enhancement of submerged shoreline for sandy, shallow habitat at disposal sites may attract foraging white sturgeon if prey availability increases as a result of disturbance and exposure of the existing benthic community and enhancement of the habitat suitable for increasing crayfish and *Corophium* amphipod populations. Lepla’s (1994) study strongly suggests that negative impacts from deep-water sediment disposal would be minimal to white sturgeon if conducted at lower reservoir locations (<RKm 193.3).

1.2 Dredged Material Removal

Dredging in Lower Granite Reservoir has the potential to make substantial changes in the physical habitat, especially by altering the substrate, velocity, and depth characteristics. Two proposals for dredging are being examined; dredging to the extent of the current footprint – removing “naturally” deposited materials from the bottom, down to the original river channel bed. The proposed dredging associated with the current footprint would extend the anticipated dredging over a relatively large water surface area-the confluence of the Snake and Clearwater rivers to Silcott Island-although depth of sediment removal would be limited to the original channel.

Ecologically, a number of benefits would accrue from dredging to the original river channel including maintenance of “original” riverine like habitat for white sturgeon *Acipenser transmontanus* and production of riverine like benthic macroinvertebrates. Lepla (1994) convincingly demonstrated the importance of the habitat in upstream area of Lower Granite Reservoir for white sturgeon. Approximately 56 % of his total white sturgeon captures were made in the original river channel of Lower Granite Reservoir from Red Wolf Bridge to the confluence of the Snake and Clearwater rivers. His distribution of spatial abundance of white sturgeon was also nearly identical to that for crayfish, an important food item for white sturgeon (Lepla 1994) and predatory game fishes in Lower Granite Reservoir. Anglea (1997) and Naughton (1998) have both demonstrated that crayfish constitute a significant dietary item for smallmouth bass *Micropterus dolomieu*, and others (Bennett and Shrier 1987; Bennett et al. 1988; Chandler 1993) have reported on their significance for food for northern pikeminnow *Ptychocheilus oregonensis* and channel catfish *Ictalurus punctatus.* To date one species of crayfish, the signal crayfish *Pacifastacus leniusculus* is found in Lower Granite Reservoir (Lepla 1994 and Anglea 1997) and its habitat seems to be linked with substrate, as it is a hiding form and not burrowing. This species of crayfish is aggressive, mobile and grows and reproduces rapidly (Lowery and Holdich 1988). Numbers of signal crayfish collected from upstream areas, having more riverine habitat type, were considerably higher than in downstream areas (Lepla 1994; Anglea 1997). The two habitat factors likely associated with this change are higher velocities and larger substrate. Therefore, dredging to the depth of the natural channel would be beneficial for maintenance of suitable habitat for white sturgeon and crayfish

Benthic macroinvertebrates that are commonly consumed by salmonids in Lower Granite Reservoir also seem to be largely taxa that are commonly associated with hard substrates (Bennett Unpublished data). Nightengale (1999) reported differences in the macroinvertebrate fauna of hard versus soft substrates in the lower Snake River reservoirs. Several taxa of aquatic organisms commonly found in the stomachs of juvenile anadromous salmonids in Lower Granite Reservoir were from organisms produced on firm substrates (Karchesky 1996). Hard substrata in lower Granite Reservoir occur along riprap (Nightengale 1999) and the original river channel. Some of these organisms “drift” in the upstream portion of Lower Granite Reservoir primarily in the seasons of higher flow that increases their availability to rearing and downstream migrating juvenile salmonids and resident fishes. Therefore, dredging that could improve the “natural” integrity of the bottom of the river channel in the upstream portion of Lower Granite Reservoir and would be beneficial to the production and potential availability of macroinvertebrates to fishes.

Dredging alternatives that expand the current footprint, however, have the potential to substantially alter this important aquatic habitat in Lower Granite Reservoir. Under various alternatives that include use of the expanded dredging footprint, the natural river bottom would be removed to create a large, localized “sump” for sediment collection. The most biologically appealing aspect of the expanded footprint is that the dredging activity would be localized into one area as proposed by the US Fish and Wildlife Service (Meyer and Saser-Blair 1988). However, biologically, the area identified for the expanded footprint would be continuously changing and the suitability of the habitat probably would be decreased for numerous fishes and macroinvertebrates. Loss of the original river channel in the upstream area of Lower Granite Reservoir is considered a substantial loss to maintaining the integrity of the Lower Granite ecosystem. Effects could include loss of benthic macroinvertebrate production and loss of fish rearing habitat for juvenile anadromous and resident fishes. For these reasons, heightened dredging associated with the proposed expanded footprint was deemed unacceptable. The upstream area of Lower Granite Reservoir is probably the ecologically most important habitat for both resident fishes and fish food items for juvenile anadromous salmonid fishes (Curet 1994; Lepla 1994). Alternatives that could potentially be deleterious to this area in Lower Granite Reservoir are considered ecologically unacceptable.

1.3 Disposal Activities

1.3.1 Land Disposal.

Land disposal alternatives 4b, 5b, and 6b include dike construction and filling of aquatic habitats in the Alpowa Creek area south of Silcott Island. In contrast, alternatives 1b, 2b, and 3b provide for direct land disposal with no in-water storage. All alternatives that include levee construction were considered unacceptable because of the loss of habitat and potential blockage to upstream migrating adult steelhead *Oncorhynchus mykiss* that may spawn in Alpowa Creek (Glen Mendel, WA. Department of Fish & Wildlife, Personal Communication). At the present time, little information exists on the ecological importance of the aquatic habitat south of Silcott Island. Fall chinook salmon O. *tshawytscha* rear along shorelines of Lower Granite Reservoir in surrounding areas to Silcott Island (Bennett et al. 1999) but too little sampling has been conducted in this specific area to assess its rearing habitat potential for fall chinook salmon. Also, backwaters in the Lower Snake River reservoirs provide important and often limited habitat for rearing of larval, juvenile and adult fishes (Bennett et al. 1983). These backwaters often warm faster, temperatures are often higher and closer to optimum temperatures during the growing period of resident fishes, and provide low velocity habitat alternatives to the main channel reservoir habitat. Bratovich (1985) demonstrated that backwaters in Little Goose Reservoir were the habitats most commonly used for rearing by larval resident fishes and Bennett et al. (1988) reported the importance of low velocity areas in Lower Granite Reservoir for larval fish rearing habitat. Lower Granite Reservoir currently has very limited backwater habitat and further loss is considered detrimental to the system. Therefore, alternatives that would alter aquatic habitats for temporary in-water disposal are considered unacceptable.

1.3.2 In-Water Disposal.

Chipps et al. (1997) showed that construction of shallow water habitat with dredged material has increased habitat complexity in Lower Granite Reservoir and proper placement has potential as an enhancement technique. Six fishes were sampled in an area prior to shallow in-water disposal in Lower Granite Reservoir compared to 11 species of fish at the same area following in-water disposal. Chipps et al. (1997) concluded that islands constructed from dredged material altered the “natural” reservoir habitat by decreasing depth and therefore, improved rearing habitat for several resident fishes.

Differences in habitat suitability also exist for habitat created by dredged material depending upon substrate size. For example, at the island site in Lower Granite Reservoir, the shoreward station with sandy substrate often supported a different fish community structure (station 1) than that from the channel side (station 2) that was armored with cobble/boulders to secure the shoreline. Species that prefer larger substrate, as smallmouth bass, were consistently collected in higher abundance along the larger substrate than in the area with finer substrate, without armoring of larger substrate. Therefore, data suggest that fish community structure can also be “fine tuned” with manipulation of the size of substrate as well as changes in depth.

Bennett et al. (1998) showed that fall chinook salmon utilized the shallow waters surrounding Centennial Island in Lower Granite Reservoir. In some years, as many as 10% of the total sample of subyearling chinook salmon from Lower Granite Reservoir originated from the habitat created by in-water disposal. Bennett et al. (1998) reported that fall chinook were most commonly collected over lower gradient shorelines having low velocities and sandy substrate. Habitat having these physical characteristics can be effectively constructed in any of the lower Snake River reservoirs with appropriate placement of dredged material.

The third potential benefit of in-water disposal in the lower Snake River reservoirs could be in increasing the availability and possible abundance of benthic macroinvertebrates. Although some investigators have reported that abundance of macroinvertebrates is higher in shallow water than in deep waters, Bennett et al. (1988, 1990, 1991, 1993) consistently have reported no differences in benthic macroinvertebrate abundance between shallow and deep water habitats in Lower Granite Reservoir. Therefore, theoretically, macroinvertebrate abundance could be enhanced in many areas of the lower Snake River as > 90% of the habitat in Lower Granite Reservoir and likely other lower Snake River reservoirs is considered either mid-depth (20-60 ft) or deep water (>60 ft). Probably one significant potential benefit of using dredged material would be to enhance the availability of macroinvertebrates to downstream migrating salmonids. Bennett and Shrier (1987), Bennett et al. (1988) and Karchesky (1996) clearly demonstrated the importance of benthic macroinvertebrates in Lower Granite Reservoir to downstream migrating salmonids. Dipterans and ephemeropterans were highly abundant in the stomachs of juvenile anadromous steelhead and spring/summer chinook salmon in Lower Granite Reservoir. However, the abundance and availability of benthic macroinvertebrates to downstream migrating salmonids seems to differ throughout the reservoir. Muir and Coley (1996) showed that stomachs from a large proportion of juvenile salmonids collected at Lower Granite Dam were empty suggesting either low food abundance near the dam or the lack of feeding. Since others have demonstrated food in the stomachs of juvenile salmonids throughout their downstream migration, the data indicate that low food availability may be a factor in the feeding of salmonids near Lower Granite Dam and possibly other lower Snake River dams. The morphometry of the area surrounding the forebay may be one reason for the low presence of food in stomachs of juvenile salmonids collected at Lower Granite Dam. The shoreline in the forebay is steep and water depth is great (>100 ft) and food abundance seems to be limited to pupating and terrestrial insects (Muir and Coley 1996). Although not known, downstream migrating juvenile salmonids probably do not forage at those extreme depths. Therefore, dredged material might be effectively deposited to enhance the abundance and availability of benthic macroinvertebrates for food to juvenile salmonids in the forebay of Lower Granite Dam and possibly other lower Snake River dams.

Several water quality attributes could be changed by in-water disposal of dredged material. Creating more shallow water could increase the availability of warmer waters in all of the lower Snake River reservoirs. Currently, water temperatures are below optimum throughout the growing season for all resident game fish. Higher water temperatures could enhance annual growth increments and possibly result in higher survival and higher standing crops. Effects of higher water temperatures in shallow waters on anadromous salmonids are unknown. Curet (1994) reported that subyearling chinook salmon migrate from shallow shoreline areas to deeper waters in the spring/summer when shoreline temperatures attain 18° C. These data indicate that if water temperatures warmed earlier in the spring up to 18°C, growth rates of subyearling chinook and possibly their survival might be enhanced.

Also, in-water disposal could theoretically decrease reservoir depth; decreased depth may enhance the water velocity through the reservoirs. Higher water velocities might decrease the migration period of juvenile salmonids through Lower Granite and possibly other lower Snake River reservoirs. However, although this may be an important fish management goal, very large quantities of dredged material would be required to significantly alter the migration rates of juvenile salmonids through the reservoir.

2.0 General Analysis of Alternatives

Six land disposal options are being examined in the selection process for the preferred alternative. Alternatives 1b, 2b, and 3b provide for direct land disposal whereas alternatives 4b, 5b, and 6b provide for construction of a temporary storage area (Alpowa Creek site) followed by later removal and land disposal.

Effects of alternatives that employ temporary storage are deemed deleterious to the aquatic habitat. Several factors contribute to the undesirable aspects of these alternatives including potential blockage to Alpowa Creek to upstream migrating steelhead to elimination of potential rearing habitat for subyearling chinook salmon. Therefore, all alternatives that remove larger volumes of dredged material and require temporary in-water storage are deemed unacceptable. Alternatives 4b and 6b are two alternatives that are considered unacceptable for these reasons.

Six in-water alternatives have been identified, ranging in volume of disposal from less than 300,000 yd^{3} (CU) to approximately 2,000,000 CU. In-water disposal could be beneficial and could ultimately enhance habitat conditions in the Lower Granite Reservoir ecosystem.

The degree of benefit to the Lower Granite system is based on the type of in-water disposal used. Maximum benefit would accrue from shallow water disposal, such as island construction and shallow shoreline construction, whereas the least benefit would accrue from deepwater disposal. As indicated earlier, subyearling chinook salmon utilize shallow water habitat surrounding Centennial Island, the number of fishes has been about doubled, and several introduced fishes, considered game fishes, benefit from the increase in shallow water habitat. Experimental deepwater disposal was not considered deleterious to the Lower Granite ecosystem (Bennett et al. 1997) but not beneficial either for fishes. The principal benefit of deepwater disposal appears to be associated with the potential to increase the availability of benthic macroinvertebrates to downstream migrating salmonids in downstream areas near Lower Granite and possibly other lower Snake River dams. Although theoretically valid, deepwater disposal would unlikely significantly increase water velocities and therefore, decrease travel time of downstream migrating salmonids through Lower Granite and other lower Snake River reservoirs.

2.1 Overview of Alternatives

1a. Navigational Maintenance – In-water Disposal. This alternative provides one of the highest potential benefits to the lower Snake River reservoirs (see Criteria evaluation). Dredging would be similar of that done experimentally from 1986 – 1992 and its effects along with shallow water disposal were considered positive on the lower Snake River reservoirs. Both anadromous and resident fishes could benefit from this alternative, if in-water disposal were conducted to enhance shallow water habitat. Based on these reasons, this alternative should be considered one of the **Acceptable** alternatives.

1b. Navigational Maintenance- Up-land Disposal. This alternative provides for one potential benefit to the lower Snake River reservoirs: dredging would be of similar magnitude of that done experimentally since 1986. Based on the various criteria, dredging could have a positive effect although no aquatic ecological benefits would accrue from up-land disposal. Negative impacts were associated with anadromous fishes and food abundance. However, total ecosystem impact of this alternative would be minor and this alternative could be considered **Satisfactory**. Alternative 1b should be considered as a **Satisfactory** alternative as long as up-land disposal did not require temporary in-water disposal.

2a. 12 ft Levee Raise-Navigational Maintenance-In-water Disposal. Alternative 2a from an aquatic ecological standpoint would have overall similar effects to Alternative 1a. Based on the criteria, this alternative provides for one of the highest potential benefits to anadromous fishes the lower Snake River reservoirs. Dredging would be similar to that done experimentally since 1986 and was therefore considered positive to the lower Snake River ecosystem. If in-water disposal were conducted to enhance shallow water habitat, this alternative could also have positive effects to both anadromous and resident fishes and should be considered as one of the **Acceptable** alternatives.

2b. 12 ft Levee Raise-Navigational Maintenance- Up-land Disposal. Alternative 2b from an aquatic ecological standpoint would have similar overall effects as Alternative 1b as the summary scores were similar. Dredging would be similar to that conducted experimentally since 1986 and that aspect of this alternative was considered positive. Because the benefits of shallow in-water disposal did not occur, the up-land disposal did not score positively to the lower Snake River ecosystem. As with Alternative 1b, anadromous fishes and food abundance were considered to be affected negatively. However, Alternative 2b should be considered as a **Satisfactory** alternative as long as up-land disposal did not require temporary in-water disposal.

3a. 8 ft Levee Raise-Dredge 300,000 CU -In-water Disposal. Alternative 3a was evaluated as having a similar effect on both anadromous and resident fishes as alternatives 1a and 2a. Dredging was evaluated to have similar benefits to others that provided for dredging to the original channel depth and the benefits of shallow in-water disposal have been indicated. For these reasons, Alternative 3a was considered as an **Acceptable** alternative.

3b. 8 ft Levee Raise-Dredge 300,000 CU - Up-land Disposal. Alternative 3b was another alternative that rated in the ranking similarly as the previous alternatives. Effects of the limited dredging were considered beneficial although with up-land disposal, no in-water benefits to either resident or anadromous fishes were seen. As with alternatives 1b and 2b, the most negative effects were associated with anadromous fishes and food abundance. Alternative 3b Alternative 3b should be considered a viable alternative as long as up-land disposal did not require temporary in-water disposal. Therefore this alternative was considered **Satisfactory**.

4a. 4 ft Levee Raise-Dredge 1,000,000 CU -In-water Disposal. Alternative 4a from an aquatic ecological standpoint was found to potentially have more deleterious effects than beneficial effects. Effects of dredging were highly negative because the large quantity was considered to require an expanded dredging footprint beyond that of dredging to the original channel depth. As considered this alternative should be considered as an **Unacceptable** alternative. However, if dredging were to be completed without the expanded footprint, and with shallow water disposal, this alternative could be considered **Satisfactory**.

4b. 4 ft Levee Raise-Dredge 1,000,000 CU - Up-land Disposal. Alternative 4b from an aquatic ecological standpoint would have similar deleterious effects as other proposed alternatives that require an expanded footprint and because of the large volume of material temporary in-water disposal. Up-land disposal would not provide any in-water disposal benefits, and the temporary in-water storage would result in a permanent habitat loss. This alternative scored negative for dredging and with loss of associated habitat, should be considered **Unacceptable**.

5a. 3 ft Levee Raise-Dredge 1,000,000 CU -In-water Disposal. Alternative 5a like that of Alternative 4a from an aquatic ecological standpoint was found to potentially have more deleterious effects than beneficial effects. Effects of dredging were highly negative because the large quantity of dredged material was considered to require an expanded dredging footprint beyond that of dredging to the original channel depth. As considered this alternative should be considered as an **Unacceptable** alternative. However, if dredging were to be completed without the expanded footprint, and with shallow water disposal, this alternative could be considered **Satisfactory**. This alternative provides for some potential benefits to the lower Snake River reservoirs with shallow in-water disposal and thus scored positive for the in-water disposal but the positive scores were off-set by the large-scale dredging effort.

5b. 3 ft Levee Raise-Dredge 1,000,000 CU -Up-land Disposal. This alternative provides nearly total negative scores to the lower Snake River reservoirs. The proposed large-scale dredging footprint and along with required temporary in-water disposal scored negative. As a result, this alternative should be considered **Unacceptable**.

6a. No Levee Raise-Dredge 2,000,000 CU -In-water Disposal. Alternative 6a from an aquatic ecological standpoint was not considered beneficial. The large volume of dredging required to satisfy the volume necessitated the expanded footprint that scored highly negative. The negative scores off-set the potential positive benefits from in-water disposal and therefore this alternative was considered **Unacceptable**.

6b. No Levee Raise-Dredge 2,000,000 CU - Up-land Disposal. Alternative 6b from an aquatic ecological standpoint would have overall deleterious effects from the expanded dredging footprint and required temporary in-water storage and habitat loss. The large volume of dredging combined with the temporary in-water disposal make this alternative **Unacceptable**.

2.2 Critical Habitat Considerations

The project area of the Snake River is designated to be critical habitat for all three Snake River salmon ESU stocks (December 28, 1993; 58 FR 68543) and for Snake River Basin steelhead (February 16, 2000; 65 FR 7764) and Middle Columbia River Basin steelhead (February 5, 1999; 64, Number 24). In designating critical habitat, NMFS considers the following requirements of the species: (1) space for individual and population growth, and for normal behavior; (2) food, water, air, light, minerals, or other nutritional or physiological requirements; (3) cover or shelter; (4) sites for breeding, reproduction, or rearing of offspring; and, generally, (5) habitats that are protected from disturbance or are representative of historical geographical and ecological distributions of the species.

In addition to these factors, NMFS also focuses on the known physical and biological features (primary constituent elements) within the designated area that are essential to the conservation of the species and that may require special management considerations or protection, termed Essential Fish Habitat (EFH) pursuant to the Magnuson-Stevens Fishery Conservation and Management Act, 16 U.S.C. 1801 *et seq*. These essential features may include, but are not limited to, spawning sites, food resources, water quality and quantity, and riparian vegetation (50 CFR 424.12(b)), and can be generally described to include the following: (1) juvenile rearing areas; (2) juvenile migration corridors; (3) areas for growth and development to adulthood; (4) adult migration corridors; and (5) spawning areas. Within these areas, essential features of critical habitat include adequate: (1) substrate, (2) water quality, (3) water quantity, (4) water temperature, (5) water velocity, (6) cover/shelter, (7) food, (8) riparian vegetation, (9) space, and (10) safe passage conditions. Adjacent riparian area is defined by NMFS as the area adjacent to a stream (river) that provides the following functions (components of Properly Functioning Habitat (PFH) or Properly Functioning Condition (PFC)): shade, sediment transport, nutrient or chemical regulation, streambank stability, and input of large woody debris or organic matter.

Section 9 of the ESA makes it illegal to “take” a threatened or endangered species of fish. The definition of “take” is to “harass, harm, pursue, hunt, shoot, wound, kill, trap, capture, or collect, or to attempt to engage in any such conduct” (16 U.S.C. 1532(19)). NMFS interprets the term “harm” in the context of habitat destruction through modification or degradation as an act that actually kills or injures fish.

Table 1 and visual surveys of 1934 sounding data used to recreate the pre-dam lower Snake River channel (Lower Snake River Juvenile Salmon Migration Feasibility Study, Fluvial Geomorphology Appendix H and Snake River Maps Appendix S, USACE 1999) demonstrate that an unimpounded large class river is primarily composed of greater than 70% shallow water habitat in the form of opposing deposition bars of sand for most flow years, and at least 50-60% shallow water habitat for very high flow years where possibly 10% of the lower Snake River could constitute deep water. The pooling of Lower Granite reservoir in 1975 inudated the historical shallow water habitat, thus converting approximately 40-60% of the shallow water sand bar habitat used by juvenile fall chinook salmon into mid-depth bench habitat more suitable for white sturgeon (if no additional structural cover is provided in the substrate) or adults of resident predator species (if additional structural cover is provided in the substrate) or deep water habitat utilized by few species (eg. channel catfish). An analysis of limiting conditions for reservoir wide habitat readily indicates that shallow water habitat composed of low gradient, open sand with no additional cover structure (eg. opposing sand bars) suitable for and replicative of fall chinook salmon rearing habitat should be the objective target for maximizing beneficial use of in-water disposal of dredged material.

Table 1. Quantification of three water depth habitats in Lower Granite reservoir, Snake River (SR) and Clearwater River (CR) during the early- to mid-1980s. estimates calculated from U.S. Army Corps of Engineers cross section profiles. SR120.46 is the mid-reservoir section where the majority of the fine silt and sand material settles out due to increased rate of depth affecting the slowing rate of water velocity.

Reservoir Reach (River Mile)	Shallow (<20 ft) Acres (percent)	Mid-depth (20-60 ft) acres (percent)	Deep (>60 ft) Acres (percent)	Total acres (percent of total reservoir or reach)
SR107.4-SR120.46	281 (8%)	1241 (34%)	2147 (57%)	3669 (43%)
SR120.46-SR146.33	983 (8%)	2795 (58%)	1017 (21%)	4795 (57%)
SR107.4-SR146.33	1264 (15%)	4036 (48%)	3164 (37%)	8464 (94%)
CR0.0-CR4.4	349 (71%)	141 (29%)	0 (0%)	489 (6%)
SR107.4-SR146.33 and CR0.0-CR4.4	1612 (18%)	4177 (47%)	3164 (35%)	8953 (100%)

Apart from this comparison between the abundance and suitability of historical versus existing shallow water sandbar habitat, very few of the EFH components that existed along the shoreline of the lower Snake River reservoirs have been modified or eliminated in the recent past due to previous maintenance dredging, where other associated human activities and economic growth along the shorelines have resulted in some modification of habitat that introduced additional needs for dredging. The two EFH components that may have been potentially influenced by confluence dredging in the past are (2) juvenile migration corridor and (4) adult migration corridor, specifically the essential features of (1) substrate, (2) water quality, (7) food, as in macroinvertebrate production, and (10) safe passage conditions. Adjacent to the footprint boundary for dredging in the confluence is a critically important (1) juvenile rearing area for fall chinook salmon in the embayment of Wilma. The existing open, sandy, shallow water rearing habitat within Wilma remains protected from modification of any bathymetric feature that would be due to proposed dredging, therefore not affected by the dredging proposed to occur in the mainstem channel. Dredging activities will be confined to the in-water work window when no or very few salmonids would be migrating or requiring premigration rearing, so exposure to short-term increases in turbidity should not exist. Dredging is not allowed at elevations below the existing channel bottom contours because removal of input sand and silt is the target, hence native substrate classes of cobble and gravel suitable for spawning should not be affected. It has been routinely shown that macroinvertebrates displaced by dredged material removal aid in colonizing or supplementing existing populations at the in-water disposal sites and that the populations at the removal site become recolonized relatively rapid depending upon season (Bennett et al. 1990, 1991, 1993a, 1993b, 1995a, 1995b; Bennett and Nightengale 1996), both influenced through the mechanism of drift.

The EFH components that may be potentially influenced by dredging in the boat basins or their approaches from the main channel are (1) juvenile rearing areas, (2) juvenile migration corridors, and (4) adult migration corridors; specifically the essential features of (1) substrate, (2) water quality, (5) water velocity, (7) food, as in macroinvertebrate production, and (10) safe passage conditions. Boat basins and HMU water intake basins fill with fine substrate dominated by silt that is not suitable substrate preferred by salmonids. High use by recreational boat traffic can limit their suitability for salmonid rearing. Dredging activities will be confined to the in-water work window when no or very few salmonids would be migrating or requiring premigration rearing, so exposure to short-term increases in turbidity should not exist and removal of unsuitable size classes of substrate should not have a negative effect. These areas will be dredged by mechanical means to virtually eliminate the possibility of entrainment of any juvenile salmonid that may be present. Water velocities will not be affected since these areas are functionally shallow water back eddies more suitable for resident fish. Macroinvertebrates displaced by dredged material removal can aid in colonizing or supplementing existing populations at the in-water disposal sites and that the populations at the removal site become recolonized relatively rapid depending upon season. An additional concern with the substrate quality removed from boat basins that have not been dredged in a number of years, such as the Hells Canyon Resort Marina, is the potential for the accumulation of bound contaminants in the silt as a result of spillage from fueling or other activities, or brought downriver to settle in the lower velocities of the backwater eddy environment. Recent sampling in these basins indicate that concentrations of contaminant indicators are below the level that would preclude their disposal in-water. In the event that a pocket of visually contaminated sediments is hauled up in the clamshell or bucket, the Corps would direct that such an area would be classified and investigated as Hazardous Waste and deposited in a truck for removal to an appropriated established waste disposal site.

The EFH component that may be potentially influenced by dredging in the lock approaches of Lower Granite and Lower Monumental dams are (5) spawning areas, specifically the essential features of (1) substrate, (5) water velocity, (6) cover/shelter, and possibly (7) food, as in macroinvertebrate production. Prior to dredging, these areas will be surveyed for redds according to established protocol (Dauble et al. 1995) to determine if modifications to velocity and substrate could cause salmon to avoid these areas for spawning. If redds are found and verified, then location and duration of dredging will be modified to accommodate avoidance and protection of any verified redds.

The Corps believes that periodic maintenance dredging performed on a schedule of every 4-5 years and contained entirely within the previously disturbed footprint would not degrade the suitability of that habitat for Snake River spring/summer and/or fall chinook salmon, and/or Snake or Middle Columbia River Basin steelhead, thus not adversely modifying Critical Habitat or EFH components of that Critical Habitat. This is because the area is used primarily as a migration corridor for all lifestages of these stocks and migration of each lifestage of each stock has terminated for the brood years, with the exception of potential for utilization of the submerged shallow water for rearing and feeding by fall chinook and some adult migration by B-run steelhead to upriver tributaries to hold for spawning in the following spring. None of the known or potential areas used by fall chinook for rearing will be disturbed by any dredged material removal action.

3.0 SUMMARY

1. Inflow of sediment into Lower Granite Reservoir and other lower Snake River reservoirs has created reservoir management problems including loss of depth for unrestricted navigation.
2. Twelve sediment reservoir management alternatives are being examined to alleviate these problems: six examine the potential for in-water disposal while six examine land disposal. Six alternatives provide for increasing the height of the levees in the Lewiston – Clarkston areas along with either in-water or land disposal.
3. Biological criteria were established that examine aspects of the life cycle of salmonids that rear (i.e. subyearling chinook salmon) and migrate through Lower Granite Reservoir, for selected resident fishes (i.e. white sturgeon, salmonid predators, and game fishes), their food items and the ecological integrity of the Lower Granite ecosystem.

4. Analysis of the effects of these management alternatives on these organisms revealed a number of alternatives could have significant adverse biological effects. Those that included an expanded dredging footprint and those alternatives that provided for temporary in-water ‘storage” of dredged material for later land disposal were considered biologically unacceptable.
5. Maximum biological benefits of in-water disposal in the lower Granite ecosystem have accrued from shallow water disposal. Although shallow water was biologically (i.e. maximum light penetration) defined as water < 20 ft in depth, maximum biological benefits accrued from creating shoreline habitat with nearly proportional decreases in benefits with increasing depth.
6. Biological benefits from shallow water disposal ranged from increasing rearing habitat for sub-yearling chinook salmon, increasing food abundance and increasing habitat for resident fishes.
7. Three alternatives were found to be biologically **Acceptable** (1a, 2a, 3a), three were considered **Satisfactory** (1b, 2b, 3b) six were found to be **Unacceptable** (4b,5b, 6a, and 6b).

4.0 RECOMMENDATIONS

Based on an in-depth review of a variety of biological criteria, selection of a preferred alternative should be made from alternatives 1a, 2a, and 3a with less support for alternatives 1b, 2b, and 3b. Alternatives that require loss of habitat associated with increased dredging below the current river channel or temporary in-water disposal are not recommended.

4.1 Screening of Alternatives

Four alternatives should be screened from the list above by the Corps and structured around those activities (clamshell dredging and in-water disposal) that have been performed in the recent past to maintain the authorized depths in the navigation channels of the Lower Snake River and McNary reservoirs (Table 2). The areas include Lake Wallula behind McNary Lock and Dam on the Columbia River and the reservoirs behind the four lock and dam projects on the Lower Snake River: Ice Harbor, Lower Monumental, Little Goose, and Lower Granite. This navigation project provides for a 14-foot channel with at least 14 feet over the sills at each of the locks and 14-foot by 250-foot channels providing access to port and barge loading facilities in each reservoir. Sediment has been deposited over time reducing the navigation clearances in places in each reservoir and reducing the flood flow conveyance capacity of the upper reservoir behind Lower Granite Dam.

Table 2. Final alternatives proposed in the DMMP/EIS following screening.

Comparison of Alternatives				
Alternative	**Dredging Requirement**	**Dredged Material Disposal**	**Levee Modification**	**Relocation/ Acquisition Requirements**
1 – "No Change" – Navigation Maintenance Dredging With In-Water Disposal	Maintenance of navigation	In-Water	None	None
2 – Navigation Maintenance Dredging With Strategic In-Water Disposal and a 3-Foot Levee Raise	Maintenance of navigation	In-Water to Create Shallow Water Fishery Habitat	Raise levees up to 3 feet to provide enhanced flood conveyance	Limited raising of roadways; acquisition/ Relocation of commercial buildings
3 – Navigation Maintenance Dredging With Upland Disposal and a 3-Foot Levee Raise	Maintenance of navigation	Upland at "Joso" site in Lower Monumental Reservoir	Raise levees up to 3 feet to provide enhanced flood conveyance	Limited raising of roadways; acquisition/ Relocation of commercial buildings
4 – Navigation Maintenance Dredging With RDT Recommended Beneficial Use of Dredged Material and a 3-Foot Levee Raise	Maintenance of navigation	Upland/In-Water or as Designated by Local Sponsor	Raise levees up to 3 feet to provide enhanced flood conveyance	Limited raising of roadways; acquisition/ Relocation of commercial bldgs.; disposal sites provided by sponsor

4.2 Preferred Alternative

The Corps should select a preferred alternative from the screened alternative list and formulate a Recommended Plan for long-term management of dredging. Alternative 4 – Maintenance Dredging With RDT Recommended Beneficial Use of Dredged Material and a 3-Foot Levee Raise would best meet environmental criteria based upon restoration of juvenile salmonid habitat including opposing sandbars used by Snake River fall chinook salmon that outmigrate as subyearlings. Alternative 4 incorporates mitigation features that act to restore valuable shallow water sand bar habitat to the Lower Granite ecosystem. Other proposed non in-water beneficial uses of dredged material may be adopted on a case-by-case basis under this plan as opportunities become available and when local sponsors agree to fulfill sponsorship requirements. To insure that the plan continues to optimize the use of dredged material, the RDT has review responsibilities for the disposal practices for each dredging season and direct modification of the plan if appropriate as new information and opportunities for beneficial use become available.

The 3-foot levee raise feature is the preferred plan for maintaining the flow conveyance capacity in the Snake and Clearwater Rivers confluence area of Lower Granite reservoir. Raising the levee was found to reduce the need for dredging in the confluence area of Lower Granite reservoir and, therefore, is considered as a part of this DMMP.

4.2.1 Dredging Areas and Quantities

Dredge templates were designed for the Federal navigation channel in each pool to achieve the maintenance dredge requirements. For the Lower Granite pool, the areas which require dredging for navigation are located on the Clearwater River between the Snake River confluence and the Port of Lewiston, located between Clearwater River Miles 0.00 and 1.56 and on the Snake River from the vicinity of Silcott Island near Snake River Mile 131 upstream to the U.S. 12 bridge located near Snake River Mile 139.5. A range of dredge volumes between 16,000 and 300,000 cubic yards would be required on a 2-year cycle to develop and maintain the designed navigation channels in the Lower Granite reservoir. An estimated 4,000 cubic yards would be dredged from behind Little Goose, and 2,000 cubic yards from behind Lower Monumental and Ice Harbor dams at 2-year intervals. The areas to be dredged in each case are located at the upstream end of each pool. The maintenance dredging for the McNary Reservoir is estimated to be approximately 32,000 cubic yards every 2 years.

Dredging should be accomplished using a clam shell dredge of approximately 15 cubic yard capacity discharging to a barge with a capacity of 3,000 cubic yards. The barges should have a maximum size of 240 feet long by 42 feet wide with a maximum draft of 14 feet. The expected rate of dredging is 5,000 cubic yards per 8-hour shift. Dredging should be performed in the Snake River during the period of December 15 through March 1 and for a longer period from December 1 to March 30 in the Columbia River. Multiple shift dredging work days should be used when necessary to ensure that dredging was completed within these windows.

All material dredged in the Lower Granite Pool should be disposed of downstream of Centennial Island located near Snake River Mile 120.5. Proposed disposal areas are along opposing submerged sand and silt composed bars several hundred feet in length, primarily in Lower Granite reservoir (seven sites identified for restoration of shallow water rearing habitat, Table 3).

Table 3. Proposed in-water disposal sites within Lower Granite reservoir for restoration of shallow water rearing habitat for juvenile Snake River fall chinook salmon.

Site Number	Location (RM)	Description (Landmark)	Final Disposal Depth Range	Acres	Site Capacity (MCY)
1	119.5-120.5	Kelly Bar/ Centennial Island – Left Bank	Shallow and Mid – Completed in	48.6	0.3 Shallow; ? Mid

			1998		
2	117.5-119.0	Blyton Landing/ Yakawawa Canyon – Right Bank	Shallow and Mid	114.6	2.5 Shallow; ? Mid
3	115.7-117.0	Knoxway Canyon – Left Bank	Shallow and Mid	110.8	10.5 Shallow; ? Mid
4	114.0-115.0	Upriver Granite Point – Right Bank	Shallow and Mid	144.2	3.8 Shallow; ? Mid
5	112.5-113.5	Downriver Granite Point – Left Bank	Shallow and Mid	30.7	0.6 Shallow; ? Mid
6	110.0-112.0	Wawawai – Right Bank	Shallow and Mid	354.8	12.0 Shallow; ? Mid
7	108.0-109.8	Offield Landing – Left Bank	Shallow and Mid	218.4	5.3 Shallow; ? Mid
Total				1022.1	35.0 Shallow

Beginning in year 1, in-water disposal should be proposed upon the underwater bench at RM 116, immediately upriver of Knoxway Canyon in Lower Granite reservoir for sand and silt composite substrate materials, and at the northshore between RM 22.5 to 23 in Ice Harbor reservoir for cobble and gravel composite substrate materials. This site has a capacity of 10.5 MCY to achieve the design components for shallow water habitat. Assuming 300,000 to 400,000 CY of dredging removal per year or every 2 years, it could take 20 years just to achieve the capacity allowed by the Knoxway Canyon site.

An alternate disposal option could include sand deposition initiated at the downriver end of Lower Granite reservoir at the Offield Landing site and proceed upriver from Lower Granite Dam towards the Knoxway Canyon site. Materials would be deposited in shallow and mid-range water disposal areas to restore shallow water habitat wherever possible. The entire channel below elevation 670 feet msl is available to be used for material disposal as required. Sands, gravels and cobbles, expected to comprise 85 percent of the total material, would be dumped in the shallow to mid-range depths from 15 feet to 35 feet to form shallow water habitat. Approximately 15,000 cubic yards of dredge material would be deposited per acre. A beam drag would be used to flatten and level the tops of the piles to form a flat shallow area of between 10 feet and 15 feet in depth that is suitable for fish habitat. The remaining 15 percent of material that is silt or finer would be mixed in the load with sand to be deposited as base material for which shallow water habitat will be built upon. Deep water disposal provides no beneficial use to aquatic organism productivity, thus deep water disposal is not proposed or planned to occur.

5.0 REFERENCES

Anders, P.J. and L.G. Beckman. 1992. Location and timing of white sturgeon spawning in three Columbia River impoundments. In: R.C. Beamesderfer and A.A. Nigro, editors. Status and habitat requirements of white sturgeon populations in the Columbia River downstream from McNary Dam, volume 1. Final Report (Contract DE-AI79-86BP63584) to Bonneville Power Administration, Portland, Oregon.

Anglea, S.M. 1997. Abundance, food habits and salmonid fish consumption of smallmouth bass and distribution of crayfish in Lower Granite Reservoir, Idaho-Washington. Master's thesis. University of Idaho, Moscow.

Bajkov, A.D. 1951. Migration of white sturgeon (*Acipenser transmontanus*) in the Columbia River. Fish Commission of Oregon, Department of Research 3(2):8-21. Portland, Oregon.

Beamesderfer, R.C. and T.A. Rien. 1992. Dynamics aand potential production of white sturgeon populations in three Columbia River reservoirs. In: R.C. Beamesderfer and A.A. Nigro, editors. Status and habitat requirements of white sturgeon populations in the Columbia River downstream from McNary Dam, volume 1. Final Report (Contract DE-AI79-86BP63584) to Bonneville Power Administration, Portland, Oregon.

Becker, C.D. 1970. Feeding bionomics of juvenile chinook salmon in the Central Columbia River. Northwest Science, Volume 44, No. 2.

Bennett, D.H., and F.C. Shrier. 1987. Monitoring sediment dredging and overflow from land disposal activities on water quality, fish and benthos in Lower Granite Reservoir, Washington. Completion Report. U.S. Army Corps of Engineers, Walla Walla, Washington.

Bennett, D.H. and G.C. Shrier. 1986. Effects of sediment dredging and in-water disposal on fishes in Lower Granite Reservoir. Completion Report. U.S. Army Corps of Engineers, Walla Walla, Washington.

Bennett, D.H., L.K. Dunsmoor, and J.A. Chandler. 1988. Fish and benthic community abundance at proposed in-water disposal sites, Lower Granite Reservoir. Completion Report. U.S. Army Corps of Engineers, Walla Walla, Washington.

Bennett, D.H., L.K. Dunsmoor, J.A. Chandler, and T. Barila. 1989. Use of dredged material to enhance fish habitat in Lower Granite Reservoir, Idaho-Washington. U.S. Army Corps of Engineers, Walla Walla, Washington.

Bennett, D.H., L.K. Dunsmoor, and J.A. Chandler. 1990. Lower Granite Reservoir in-water disposal test: Results of the fishery, benthic and habitat monitoring program-Year 1 (1988). Completion Report. U.S. Army Corps of Engineers, Walla Walla, Washington.

Bennett, D.H., J.A. Chandler, and G. Chandler. 1991. Lower Granite Reservoir in-water disposal test: Results of the fishery, benthic and habitat monitoring program-Year 2 (1989). Completion Report. U.S. Army Corps of Engineers, Walla Walla, Washington.

Bennett, D.H., T.J. Dresser, Jr., and K.B. Lepla. 1992. Monitoring fish community activity at disposal and reference sites in Lower Granite Reservoir, Washington (Year-4). Department of Fish and Wildlife Resources, College of Forestry, Wildlife and Range Sciences. Univerisity of Idaho, Moscow, Idaho.

Bennett, D.H., T.J. Dresser Jr., and T.S. Curet. 1992b. Abundance of subyearling chinook salmon in Little Goose Reservoir Washington, spring, 1991. Completion Report. U.S. Army Corps of Engineers, Walla Walla, Washington.

Bennett, D.H., T.J. Dresser, T.S. Curet, K.B. Lepla, and M.A. Madsen. 1993a. Lower Granite Reservoir in-water disposal test: Results of the fishery, benthic and habitat monitoring program Year-3 (1990). U.S. Army Corps of Engineers, Walla Walla, Washington.

Bennett, D.H., T.J. Dresser, T.S. Curet, K.B. Lepla, and M.A. Madsen. 1993b. Lower Granite Reservoir in-water disposal test: Results of the fishery, benthic and habitat monitoring program-Year 4 (1991). Completion Report. U.S. Army Corps of Engineers, Walla Walla, Washington.

Bennett, D.H., T.J. Dresser, Jr., and M.A. Madsen. 1994. Lower Granite Reservoir in-water disposal test: Results of the fishery, benthic and habitat monitoring program Year-5 (1992). Completion Report. U.S. Army Corps of Engineers, Walla Walla, Washington.

Bennett, D.H., M.A. Madsen, T.J. Dresser, Jr., and T.S. Curet. 1995. Monitoring fish community activity at disposal and reference sites in Lower Granite Reservoir, Idaho-Washington Year 5 (1992). Completion Report. U.S. Army Corps of Engineers, Walla Walla, Washington.

Bennett, D.H. and T.J. Dresser Jr. 1996. Larval fish abundance associated with in-water disposal of dredged material in Lower Granite Reservoir, Idaho-Washington. Pages 333-337 in Water Quality '96: Proceedings of the 11th Seminar, U.S. Army Corps of Engineers, Seattle, Washington.

Bennett, D.H., T.J. Dresser, Jr., S.R. Chipps, and M.A. Madsen. 1997. Monitoring fish community activity at disposal and reference sites in Lower Granite Reservoir, Idaho-Washington Year 6 (1993). Completion Report U.S. Army Corps of Engineers, Walla Walla, Washington.

Bennett, D.H., T. Barila, and C. Pinney. 1996. Effects of in-water disposal of dredged material on fishes in Lower Granite Reservoir, Snake River. Pages 328-332 in Water Quality '96: Proceedings of the 11th Seminar, U.S. Army Corps of Engineers, Seattle, Washington.

Bennett, D.H., T.J. Dresser, Jr., and M.A. Madsen. 1998. Habitat use, abundance, timing and factors related to the abundance of subyearling chinook salmon rearing along shorelines of lower Snake River reservoirs. Completion Report U.S. Army Corps of Engineers, Walla Walla, Washington.

Bjornn, T.C. 1960. The salmon and steelhead stocks of Idaho. Idaho Department of Fish and Game.

Bratovich, P.M. 1985. Reproduction and early life histories of selected resident fishes in Lower Snake River reservoirs. Master's thesis. University of Idaho, Moscow.

Brett, J.R. 1952. Temperature tolerance in young Pacific Salmon, genus Oncorhynchus. Journal, Fisheries Research Board of Canada, vol. 9 no. 6, p. 265-323.

Buell, J.W. 1992. Fish entrainment monitoring of the Western-Pacific dredge R W Lofgren during operations outside the preferred work period. Buell and Associates, Inc., Portland, Oregon.

Chandler, J.A. 1993. Consumption rates and estimated total loss of juvenile salmonids by northern squawfish in Lower Granite Reservoir, Washington. Master's thesis. University of Idaho, Moscow.

Chipps, S.R., D.H. Bennett, and T.J. Dresser Jr. 1996. Trends in resident fish abundance associated with use of dredged material for fish habitat enhancement. Pages 338-341 in Water Quality '96: Proceedings of the 11th Seminar, U.S. Army Corps of Engineers, Seattle, Washington.

Chipps, S.R., D.H. Bennett, and T.J. Dresser Jr. 1997. Patterns of fish abundance associated with a dredge dispoal island: Implications for fish habitat enhancement in a large reservoir. North American Journal of Fisheries Management 17:378-386.

Cochnauer, T.G. 1981. Survey status of white sturgeon populations in the Snake River, Bliss Dam to C.J. Strike Dam. Idaho Department of Fish and Game, River and Stream Investigations, Job Performance Report, Project F-73-R-3, Job I-b. Boise, Idaho.

Cochnauer, T.G. 1983. Abundance, distribution, growth and management of white sturgeon (Acipenser transmontanus) in the middle Snake River, Idaho. Doctoral dissertation. University of Idaho, Moscow, Idaho.

Cochnauer, T.G., J.R. Lukens, and F.E. Partridge. 1985. Status of white sturgeon, *Acipener transmontanus*, in Idaho. In: P.P. Binkowski, and S.I. Doroshov, editors. North American sturgeons. Dr. W. Junk Publishers, Dordrecht, Netherlands.

Connor, W.P., H. Burge, and R. Bugert. 1992. Migration timing of natural and hatchery fall chinook in the Snake River Basin. Proceedings of a technical workshop. University of Idaho, 1992. Passage and survival of chinook salmon from the Snake River Basin. Bennett, D.H., L.K. Dunsmoor, and J.A. Chandler. 1988. Fish and benthic community abundance at proposed in-water disposal stations, Lower Granite Reservoir. Completion Report. U.S. Army Corps of Engineers, Walla Walla, Washington.

Connor, W. P, H.L. Burge, and D.H. Bennett. 1998. Detection of PIT-tagged subyearling chinook salmon at a Snake River dam: implications for summer flow augmentatiion. North American Journal of Fisheries Management 18:530-536.

Conte, F.S., S.I. Doroshov, P.B. Lutes, and E.M. Strange. 1988. Hatchery manual for white sturgeon *Acipenser transmontanus* with application to other North American Acipenseridae. Cooperative Extension, University of California, Division of Agriculture and Natural Resources, Publication 3322. Davis, Cailifornia.

Coon, J.C., R.R. Ringe, and T.C. Bjornn. 1977. Abundance, growth, distribution and movements of white sturgeon in the mid-Snake River. Idaho Water Resources Research Institute, Contribution 97 Forest, Wildlife and Range Experiment Station. University of Idaho. Moscow, Idaho.

Curet, T. 1993. Habitat use, food habits, and the influence of predation on subyearling chinook salmon in Lower Granite and Little Goose reservoirs. Master's thesis. University of Idaho, Moscow.

Dauble, D.D., T.L. Page, and W. Hanf, Jr. 1989. Spatial distribution of juvenile salmonids in the Hanford Reach, Columbia River. Fishery Bulletin, U.S. 87:775-790).

Devore,J.D., B.W. James, C.A. Tracy, and D.H. Hale. 1992. Dynamics and potential production of white sturgeon in the Columbia River downstream from Bonneville Dam. In: R.C. Beamesderfer and A.A. Nigro, editors. Status and habitat requirements of white sturgeon populations in the Columbia River downstream from McNary Dam, Volume 1. Final Report

(Contract DE-AI79-86BP63584) to Bonneville Power Administration, Portland, Oregon.

Dresser, T.J. 1996. Nocturnal fish-habitat associations in Lower Granite Reservoir, Washington. Master's thesis. University of Idaho, Moscow.

Ebel, W.J., C.D. Becker, J.W. Mullan, and H.L. Raymond. 1989. The Columbia River-toward a holistic understanding. Pages 205-219 in: D.P. Dodge, editor. Proceedings of the International Large River Symposium. Canadian Special Publication of Fisheries and Aquatic Sciences.

Hanson, D.L., T.G. Cochnauer, J.D. Devore, H.E. Forner, Jr., T.T. Kisanuki, D.W. Kolhorst, P. Lumley, G. McCabe, A.A. Nigro, S. Parker, D. Swartz, and A. Van Vooren. 1992. White sturgeon management framework plan. Pacific States Marine Fisheries Commission, Portland, Oregon.

Haynes, J.M., and R.H. Gray. 1981. Diel and seasonal movements of white sturgeon, Acipenser transmontanus, in the mid-Columbia River. Fish Bull. 79:367-370.

Howell, P., K. Jones, D. Scarnecchia, L. LaVoy, W. Kendra, and D. Ortmann. 1985. Stock assessment of Columbia River anadromous salmonids. (Contract No. DE-A179-84BP12737, Project No. 83-335). U.S. Department of Energy, Bonneville Power Administration, Division of Fish and Wildlife, Portland, Oregon.

Karchesky, C. 1996. Food habits and dietary overlap of anadrmous and resident fishes in Lower Granite Reservoir, Idaho-Washington. Bachelor of Science Thesis, University of Idaho, Moscow.

Kohlhorst, D.W. 1980. Recent trends in the white sturgeon populations in California’s Sacramento-San Joaquin Estuary. California Fish and Game 66: 210-219.

Kohlhorst, D.W., L.W. Botsford, J.S. Brennan, and G.M. Caillet. 1991. Aspects of the structure and dynamics of an exploited central California population of white sturgeon (*Acipenser transmontanus*). Pages 277-293 In: P. Williot, edotor. Proceedings of the First International Symposium on the Sturgeon. October 3-6, 1989. CEMAGREF, Bordeaux, France.

Lepla, K.B. 1994. White sturgeon abundance and associated habitat in Lower Granite Reservoir, Washington. Master's thesis. University of Idaho, Moscow.

Lukens, J.R. 1981. Snake River sturgeon investigations (Bliss Dam upstream to Shoshone Falls). Idaho Department of Fish and Game Report to Idaho Power Company, Boise, Idaho.

Lukens, J.R. 1985. Hells Canyon White Sturgeon Investigations. Idaho Department of Fish and Game, River and Stream Investigations, Job Performance Report, Federal Aid Project No. F-73-R-7. Idaho Department of Fish and Game, Boise, Idaho.

Lukens, J.R. 1984. Hells Canyon White Sturgeon Investigations. Idaho Department of Fish and Game, River and Stream Investigations, JobPerformance Report, Project No. F-73-R-B. Idaho Department of Fish and Game, Boise, Idaho.

McCabe, G.T. and C.A. Tracy. 1992. Spawning characteristics and early life history of white sturgeon Acipenser transmontanus in the lower Columbia River. In: R.C. Beamesderfer and A.A. Nigro, editors. Status and habitat requirements of white sturgeon populations in the Columbia River downstream from McNary Dam, volume II. Final Report (Contract DE-AI79-86BP63584) to Bonneville Power Administration, Portland, Oregon.

McCabe, G.T., Jr., R.L. Emmett, and S.A. Hinton. 1992a. Feeding ecology of juvenile white sturgeon (*Acipenser transmontanus*) in the lower Columbia River. In: R.C. Beamesderfer and A.A. Nigro, editors. Status and habitat requirements of white sturgeon populations in the Columbia River downstream from McNary Dam, volume II. Final Report (Contract DE-AI79-86BP63584) to Bonneville Power Administration, Portland, Oregon.

McCabe, G.T., Jr., S.A. Hinton, and R.L. Emmett. 1992b. Distribution, abundance and community structure of benthic invertebrates in the lower Columbia River. In: R.C. Beamesderfer and A.A. Nigro, editors. Status and habitat requirements of white sturgeon populations in the Columbia River downstream from McNary Dam, volume II. Final Report (Contract DE-AI79-86BP63584) to Bonneville Power Administration, Portland, Oregon.

Miller, A.I. and L.G. Beckman. 1992. Age and growth of juvenile white sturgeon in the Columbia River downstream from McNary Dam. In: R.C. Beamesderfer and A.A. Nigro, editors. Status and habitat requirements of white sturgeon populations in the Columbia River downstream from McNary Dam, volume 1. Final Report (Contract DE-AI79-86BP63584) to Bonneville Power Administration, Portland, Oregon.

Mosley, R. and C. Groves. 1990. Rare, threatened, and endangered plants and animals of Idaho. National Heritage Section. Idaho Department of Fish and Game, Boise, Idaho.

Mosley, R. and C. Groves. 1992. Rare, threatened, and endangered plants and animals of Idaho. National Heritage Section. Idaho Department of Fish and Game, Boise, Idaho.

Muir, W. D. and T. C. Coley. 1996. Diet oif yearling chinook salmon and feeding success during downstream migration in the Snake and Columbia rivers. Northwest Science 70 (4):298-305.

Muir, W.D., R.L. Emmett, and R.J. McConnell. 1988. Diet of juvenile and subadult white sturgeon in the lower Columbia River and its estuary. California Fish and Game 74:49-54.

Myers, R. and S. Sather-Blair. 1988. Lower Granite Reservoir dredging alternatives-Snake River-Washington-Idaho. U.S. Fish and Wildlife Service Evaluation Report. Boise, Idaho.

Naughton, G.P. 1998. Predator abundance and salmonid prey consumption in the tailrace and forebay of Lower Granite Dam and upper arms of Lower Granite reservoir. Masters Thesis, University of Idaho, Moscow.

Nelle, R.D. 1999. Smallmouth bass predation on juvenile fall chinook salmon in the Hells Canyon Reach of the Snake River, Idaho. Master's Thesis. University of Idaho, Moscow.

Newcombe, C.P. and J.O.T. Jensen. 1996. Channel suspended sediment and fishereis: a synthesis for quantitative assessment of risk and impact. North American Journal of Fisheries Management 16:693-727.

Nightengale, T. 1999. Benthic macroinvertebrates on hard substrates in Lower Granite, Little Goose and Lower Monumental reservoirs, Snake River, Washington. Masters Thesis, University of Idaho, Moscow.

North, J.A., R.C. Beamesderfer, and T.A. Rien. 1992. Distribution and movements of white sturgeon in three lower Columbia River reservoirs. In: R.C. Beamesderfer and A.A. Nigro, editors. Status and habitat requirements of white sturgeon populations in the Columbia River downstream from McNary Dam, volume 1. Final Report (Contract DE-AI79-86BP63584) to Bonneville Power Administration, Portland, Oregon.

Parsley, M.J., and L.G. Beckman. 1992. An evaluation of spawning and rearing habitat for white sturgeon in the lower Columbia River. In: R.C. Beamesderfer and A.A. Nigro, editors. Status and habitat requirements of white sturgeon populations in the Columbia River downstream from McNary Dam, volume 1. Final Report (Contract DE-AI79-86BP63584) to Bonneville Power Administration, Portland, Oregon.

Parsley, M.J., L.G. Beckman, and G.T. McCabe, Jr. 1992. Habitat use by spawning and rearing white sturgeon in the Columbia River downstream from McNary Dam. In: R.C. Beamesderfer and A.A. Nigro, editors. Status and habitat requirements of white sturgeon populations in the Columbia River downstream from McNary Dam, volume 1. Final Report (Contract DE-AI79-86BP63584) to Bonneville Power Administration, Portland, Oregon.

Petersen, J., C. Barfoot, S. Sauter, D. Gadomski, P. Connolly, and T. Poe. 1999. Predicting the effects of dam breaching in the lower Snake River on predators of juvenile salmon. Prepared for U.S. Army Corps of Engineers, Walla Walla District.

Rondorf, D.W., G.A. Gray, and R.B. Fairley. 1990. Feeding ecology of subyearling chinook salmon in riverine and reservoir habitat of the Columbia River. Transaction of the American Fisheries Society 119:16-24.

Semakula, S.N. 1963. The age and growth of white sturgeon (*Acipenser transmontanus* Richardson) of the Fraser Riveer, British Columbia, Canada. Master's Thesis. Department of Zoology, University of British Columbia.

Scott, W.B., and E.J. Crossman. 1973. Freshwater Fishes of Canada, Bulletin 184. Fisheries Research Board of Canada, Ottawa, Canada.

Sims, C.W. and D.R. Miller. 1981. Effects of flow on the migratory behavior and survival of juvenile fall and summer chinook salmon in John Day Reservoir. Annual Report of Research financed by Bonneville Power Administration (Contract DE-A179-81BP-27602) and Coastal Zone and estuary Studies Division, Northwest and Alaska Fisheries Center, National Marine Fisheries Service, National Oceanic and Atmospheric Administration.

Sprague, C.R., L.G. Beckman, and S.D. Duke. 1992. Prey selection by juvenile white sturgeon in reservoirs of the Columbia River. In: R.C. Beamesderfer and A.A. Nigro, editors. Status and habitat requirements of white sturgeon populations in the Columbia River downstream from McNary Dam, volume II. Final Report (Contract DE-AI79-86BP63584) to

Bonneville Power Administration, Portland, Oregon.

U.S.A.C.E. (Corps). 1991, and other years. Annual Fish Passage Report. U.S. Army Corps of Engineers, Walla Walla District, Walla Walla, Washington.

Waples, R.S., R.P. Jones, B.R. Beckman, and G.A. Swan. 1991. Status review for Snake River Fall Chinook Salmon. NOAA Technical Memorandum, NMFS F/NWC-201.