SKAGIT FISHERIES INVESTIGATION FEASIBILITY STUDY

Prepared by the
U.S. Army Corps of Engineers
Seattle District
Seattle, Washington

Jeffrey Dillon
Therese Littleton
Jeffrey Laufle

TABLE OF CONTENTS

1.0 INTRODUCTION

1.1 Study Purpose

The Seattle District Corps of Engineers is currently exploring the feasibility of a cost shared project agreement with Skagit County, Washington to assess possible solutions to alleviate flooding in the Skagit Basin. As part of the reconnaissance study, a recommendation has been made to proceed with the feasibility study. In the feasibility study, there will be a need to assess the potential impacts to fish due to channel modifications such as the placement of additional riprap, overtopping levee segments and increasing flood protection by raising levee heights.

Agency coordination to date has identified an extensive sampling program to assess impacts to fish of adding additional riprap to already protected surfaces. The purpose of this report is to examine the feasibility of assessing the impacts of the addition of riprap to levee by using information from existing studies.

The basic research question being asked is,

"Is there enough information available to assess impacts of placing additional riprap on the lower Skagit River?"

1.2 Individual Objectives to Assess

To answer the basic research question, the following objectives were developed.

- Compare riprap habitats to each other and to natural habitats
- What are the habitat values of riprap and natural areas (by species)?
- What techniques exist to reduce riprap impacts?
- Describe and quantify riprap impacts
- What is the distribution and behavior of salmonid species in the lower Skagit River?

2.0 PROJECT AREA DESCRIPTION

2.1 General- The Skagit River valley has a long history of flooding since the area was settled in the mid-1800's. In the valley below Sedro Woolley, the maximum safe channel capacity varies from 100,000 cfs to 146,000 cfs. Since 1908, flows have frequently exceeded 100,000 during the winter floods, which normally occur from October through March. Some flood protection is currently provided by a combination of upstream storage at hydroelectric projects and downstream local flood protection works. The floods of November 1990 caused $39,800,000 in price-updated damages in the lower basin with extensive damage to flood protective works, residential structures and agricultural lands and crops (USACE, 1993).

2.2 Project Area- The watershed of the Skagit River encompasses over 3,000 square miles. The upper Skagit basin is in the Cascade Mountain range and has elevations of over 8,000 feet with narrow precipitous canyons. Much of the upper basin above Marblemount is publicly owned land contained in North Cascades National Park, Ross Lake National Recreation Area, Glacier Peak Wilderness and the Mount Baker-Snoqualmie National Forest. In the mid to lower reaches of the basin, forest harvesting is practiced extensively. The lower Skagit valley, below Sedro Woolley, is a broad, generally flat flood plain with extensive agricultural development. The majority of the population in the Skagit basin lives in the low-lying flood plain.

The Skagit River is rich in natural resources. The upper to mid slopes are heavily forested with conifers and are prime habitat for many varieties of large mammals, birds and smaller mammals. Some natural wildlife habitat areas remain in the lower agricultural areas of the valley. The delta, with its marshes and sloughs, as well as large, open agricultural fields, is very important for migratory waterfowl and other birds. A wildlife recreation area located on Fir Island is operated by the Washington State Department of Fish and Wildlife (WDFW).

The Skagit divides into two distributaries just below the town of Mount Vernon; the North and South Forks. Much of the river below Sedro Woolley has been extensively channelized, leveed and armored with riprap. The remaining habitat areas have become increasingly more important as they become more scarce. The river itself is a vital migration route and spawning area for anadromous fish, such as chinook, coho, chum and pink salmon, steelhead and other trout species.

Agriculture, urbanization, channel modification and forest practices have significantly changed the Lower Skagit valley as well as the upper watershed.

2.3 Fish Resources- All five species of Pacific salmon use the Skagit River system; spring and summer/fall chinook (*Oncorhynchus tshawytscha*), coho (*O. kisutch*), pink (*O. gorbuscha*), chum (*O. keta*) and sockeye (*O. nerka*). Steelhead trout (*O. mykiss*), cutthroat trout (*O. clarkii*), Dolly Varden char (*Salvelinus malma*), bull trout (*Salvelinus confluentus*), and white sturgeon (*Acipenser transmontanus*) are also present. Most of these populations are maintained by natural production; however, hatchery production augments the chinook, coho and steelhead runs. Sockeye returning to Baker lake are also intensively managed by WDFW. See Table 1 for additional information.

Table 1. Selected anadromous fish species in the Skagit River basin.

SPECIES		PRODUCTION [1]	SPAWNING PERIOD	JUVENILE OUTMIGRATION
Spring Chinook		5,300	July-September	March-July
Summer/Fall Chinook		49,800	September	March-June
Coho		149,900	December	March-June
Pink [2]		1,350,000	September-October	March-May
Chum	Even Year	258,900	December	March-May
	Odd Year	68,000		
Steelhead	Summer	16,800 [3]	February-	April-May
	Winter		March - June	

1. Production includes total catch and escapement from recent year catches, generally mid-1980's to 1990. From U.S. Fish and Wildlife Service Planning Aid letter 1993.
2. Odd-year returns only.
3. Includes hatchery and natural production for both runs.

Chinook salmon enter the system as two discrete races, the spring and summer/fall runs. Spring chinook enter the system from May to about August, spawning from July to early September in the upper Cascade River, the upper Sauk River, and the tributaries of the Suiattle River. Juvenile spring chinook rear in freshwater for a few months and outmigrate from March to July. Summer/fall chinook enter the system from late June to early August into September, spawning in September and October in the mainstem and the major tributaries. Juvenile summer/fall chinook outmigrate in their first spring from late March to June. Hatchery fish of both species are cultured at the Clark Creek Hatchery near Marblemount with outmigration usually coinciding with natural runs. The 1992 Salmon and Steelhead Stock Inventory (SASSI) has identified the Lower Skagit and Lower Sauk chinook stocks as being depressed. This categorization indicates that production is below expected levels, but that permanent damage to the stock is unlikely.

Coho salmon enter the system from late August to September, spawning in December in all accessible tributaries. Juvenile coho rear in freshwater for a year and outmigrate in their second spring from March to June. The natural run of coho has been significantly reduced over the last few years. Coho are cultured at both state and tribal hatcheries. The 1992 SASSI has identified Skagit coho stocks as being depressed.

Pink salmon enter the system in odd-numbered years from August to October. Spawning occurs from September to late October in the mainstem above Lyman, the Sauk River, Cascade River and other major tributaries except the Baker River. Juvenile pink salmon outmigrate immediately after emergence (March to May). A small amount of even-year spawning may occur in the Skagit River; however the Puget Sound region does not support even-year populations.

Chum salmon enter the system from October to late December. Spawning occurs in December in the mainstem, side channels and sloughs upstream of Rockpoint and the Sauk and Cascade Rivers. The juveniles outmigrate from March through May.

Sockeye salmon have been severely reduced in number, possibly due to the dams on the Baker River. They enter the system from July through August and spawn on specially constructed beaches in the Baker River system. Several agencies are trying to restore the sockeye run in the Skagit. The 1992 SASSI has identified this stock as being a critical stock that has declined to a point where it is in jeopardy of significant loss of within-stock diversity or extinction. The years 1995 and 1996 have seen improved returns of sockeye to the artificial spawning grounds.

Steelhead return in summer and winter runs, from both natural and hatchery production. The summer run enters from May to October and does not spawn until February or March in the upper headwaters and tributaries. Juvenile summer steelhead rear in freshwater for two or three years before outmigrating from April to late May. Winter steelhead enter the system from January to March, spawning from March to June in the mainstem and most tributaries. Hatchery winter run steelhead enter the river from December to February, spawning from January to March near the hatchery facilities.

Sea-run cutthroat trout and Dolly Varden/bull trout char run through much of the year in the Skagit River. Spawning peaks for the cutthroat in February and March. Spawning peaks for the Dolly Varden from September through November. The juveniles rear in freshwater for two to three years before outmigrating in the spring.

Most of the anadromous salmon and trout species outmigrate from March through June. The sloughs and side channels provide rearing habitat for juvenile chinook and coho. Some spawned-out steelhead and cutthroat trout return to the ocean between March and June.

White sturgeon are also present but sparsely distributed in the Skagit River. Several other resident fish species occur in the basin including: resident rainbow and cutthroat trout, resident Dolly Varden and bull trout, whitefish (*Prosopium williamsoni*), sculpins (*Cottus* spp.), and peamouth (*Mylocheilus caurinus*).

The Samish river also has runs of chinook (hatchery), coho and chum salmon. Small steelhead and cutthroat runs also occur in the Samish River. The 1992 SASSI has identified the Samish winter steelhead stocks as being depressed.

3.0. PROJECT SPECIFICS

3.1. Project Background- A multi-agency comprehensive study of water and related land resources published in 1971 provides the basis for specific flood control problems within Puget Sound and Adjacent Waters (PSAW, 1971). The need for additional Skagit River flood control is one project included in the PSAW report. The Flood Control Act of 1962 (Public Law 87-874, Section 209) is referenced in the body of this report as the specific congressional authority used in that study by the U.S. Army Corps of Engineers.

More recently, the U.S. Army Corps of Engineers entered into the feasibility phase of a flood control project in sponsorship with Skagit County. This effort is intended to follow up on the

1971 PSAW planning to reduce flood impacts to the Skagit River. The Flood Control Act of 1962 continues to serve as the authority for U.S. Army Corps of Engineers involvement.

3.2. Existing Flood Control Conditions- Flood control works on the Skagit River include levees, bank protection and stabilization works, and upstream storage. The levees and sea dikes along the Skagit River were constructed by 16 diking districts and a few private individuals. The diking districts maintain 55.8 miles of levees and 39 miles of sea dikes to protect 45,000 acres of land. Individual owners maintain 16 miles of levees to protect 1,000 acres of land. The levels of protection range from 3 to 14 year flood events. Overtopping of low areas occurs at flows of 84,000 cfs. By sandbagging and minor flood fighting, the levees can be held against 91,000 cfs (Mt. Vernon gage).

With financial aid from the Agricultural Stabilization and Conservation Service and the state of Washington, property owners and Skagit County constructed extensive bank stabilization works first half of this century along the river to reduce land loss to erosion. Most of these works consisted of riprap revetments. Since 1947, the U.S. Army Corps of Engineers has assisted in reconstruction of flood damaged levees and provided additional flood protection where public utilities were endangered.

Flood storage from upstream dams is capable of containing 220,000 acre feet of water during flood events. Rose Reservoir, owned by the City of Seattle, contributes 120,000 acre feet to flood storage. The upper Baker Reservoir provides 16,000 acre feet of storage as compensation for lost capacity during the time of dam construction. In addition, upper Baker Reservoir can store 84,000 acre feet of flood waters if compensated for lost revenues by the U.S. Army Corps of Engineers. Floodplain management by Skagit County has established a 15-year frequency floodway where development will be controlled by special building and health regulations.

The river banks along the project area are now extensively hydromodified with rural flood control levees. A recent investigation into current levee locations found that 49% of the levees are setback from the river and 29% are located on the river and require active levee vegetation management. The remaining 22% of levees are possibly setback with some amount of vegetation present between the bankslope and levee toe. Further information is needed to determine what percentage of the possible setback levees can remain free of vegetation management.

3.3. Location and Extent- The potential construction project involves improving the existing levee system on the lower Skagit River (Figure 1). The following project description sets the upper parameters of project scope to be considered in the flood damage reduction study. The scale of the study can be reduced with further scoping. t

Levees around Mt.Vernon and Burlington will receive between 100 year and standard project flood (SPF) protection. The locations of off-river (ring) dikes will be determined in part by the urban growth boundary. The remaining rural levees will provide protection from 25 to 50 year flood events. The levees will have the standard top width of 12 feet with 2:1 sideslopes. The footprint will be wider in cases where seepage berms are constructed on the landward sides. No levee will be placed across the mouth of the Nookachamps. However, a levee may be constructed to protect Clear Lake and Beaver Lake. This levee could cross Nookachamps Creek in the vicinity of the Highway 9 crossing. If this alternative is pursued, additional studies may be required.

Five to six overtopping segments will be constructed on the rural levees to alleviate the danger of catastrophic failure. The overtopping sections will attempt to distribute equal volumes of water to each overtopping area. Some widening of the channel will occur on the right bank adjacent to the Burlington Northern railroad bridge. Levees will not be extended into the bay. A cross dike may be built between Fisher Slough and the outlet of the Big Ditch to protect Stanwood. This levee segment will not impair any existing fish-bearing watercourses.

3.4. Purpose of Literature Review- The U.S. Army Corps of Engineers has entered into a cost sharing agreement with Skagit County, Washington, to study and construct flood control measures on the lower Skagit River. This report serves to identify current data and research information relevant to the likely impacts of this flood control plan.

The majority of project impacts will likely be from the placement or replacement of riprap (rock revetment) on the lower Skagit River during construction..

4.0. IMPACTS

4.1. Literature Search Results- Literature was acquired through many sources to document the impacts associated with various channelization and armoring projects. Reports gathered were summarized and ranged widely in subject, location and study design. We received reports on invertebrate, fish and vegetation impacts on many river systems including Alaska, Austria and Australia. Reports from the continental US include studies in the Mississippi drainage, Sacramento delta region, midwest, Rocky Mountains and the Pacific Northwest. Study designs took many forms but many focused on comparing natural river sections to recently modified sections. Some papers did not distinguish between revetment impacts and channelization impacts. Many references contributed to the impact analysis but were not directly impact related. Examples of such reports include restoration handbooks, fish ecology handbooks, and construction manuals.

In summarizing the literature, it was apparent that some impacts were documented on a reoccurring basis while others, like predation impacts, were not. Likewise, many studies outlined methods to reduce impacts from construction projects. We hope to describe clearly in the next two sections both physical and biological impacts as well as impact reduction measures documented in the literature.

4.2. Description of Physical Impacts- Revetment and channelization impacts can be categorized in three ways; immediate, near term or long term. Immediate impacts include those arising from petroleum spills, noise, turbidity and other very-short-duration occurrences associated with construction work in rivers. Near term impacts are those that can be moderated or removed with time such as loss of bankside vegetation, allochthonous food production, or in-water vegetation (algae). Long term impacts are those that are chronic in nature, and without mitigation, cannot be expected to improve over time. Such impacts include vegetation maintenance, loss of cover and woody debris, changes in flow characteristics, loss of habitat heterogeneity and underwater effects such as bed scour. Because of the long project life of riprap revetments and channelization, long term impacts appear to be most prevalent and significant. Impacts, especially near-term and long-term effects, are discussed in the sections below relative to project type, loss of cover and habitat features, and biological effects.

4.2.1 Physical Impacts- Riprap bank reinforcement- Impacts from this activity are primarily long-term in nature. The literature on riprap bank reinforcement impacts is often contained in analysis of channelization projects, and the impacts of riprap alone, or of riprap replacement, are not well quantified. An extensive literature review done by Washington Department of Fisheries (WDF, 1984) defines riprap revetment as channelization, because it constrains a river. Indeed, riprap can cause channelization by confining a river into reduced banks; however, our literature review was focused on the effects of rehabilitating riprap in an already channelized river. For that reason, we separated riprap placement impacts from those of channelization, which includes straightening and deepening activities.

The WDF (1984) report described riprap impacts to include loss of bank gravel sources for spawning areas, channel narrowing, and increased sediment transport resulting in coarser streambed materials. Stern and Stern (1980) state that bank stabilization causes reductions in channel migration and bank heterogeneity, and an increase in stream depth with correlated loss of riffle/pool configuration. Knudsen and Dilley (1987) showed that the negative impacts of riprap construction activities increase with the severity of habitat alteration, and that riprap bank protection can result in loss of fish production in small streams (discharge less than 10 ft^3/sec). In Montana trout streams, Hunter (1995) showed that using riprap bank protection can lock a stream into a preferred course, limiting its ability to create trout habitat.

Immediate impacts can include short-term turbidity events as soil is exposed and displaced into the river, especially if rain occurs before the soil is stabilized or protected.

4.2.2 Physical Impacts- Stream channelization- Impacts from this activity are generally long-term, but may include near-term effects as well. Of the types of habitat alteration included in our literature search, channelization of rivers and streams was identified as having the most severe impacts on fish populations. In Western Washington, channelization caused large decreases in salmonid production, increase in sediment contribution and scour, and decrease in desirable habitat characteristics (Cederholm and Koski, 1977; Chapman and Knudsen, 1980). Chapman and Knudsen (1980) observed exposure of raw soil and removal of canopy and streamside vegetation following channelization. In Big Beef Creek, channelization eliminated pools, riffles, bank vegetation and stream invertebrates; also, bank cover vegetation took four years to return to one-half the pre-channelized condition. Straightening and deepening not only caused substantial losses of biological productivity, but accelerated streambank erosion and streambed degradation (Cederholm, 1972). In the Beckler River, Wissmar and Beer (1994) observed that channel erosion reduced and degraded fish habitat.

In other regions, river channelization has been shown to cause a reduction in physical habitat heterogeneity (Shields and Hoover, 1991). A reduction of average size and number of trout and fish carrying capacity followed the loss of pools in a northern California stream (Moyle, 1976). A complete loss of suitable fish habitat was seen in Midwestern systems (Funk and Ruhr, 1971). Channelized rivers have been found unfavorable for supporting stable populations of larger game fish (Hansen, 1971), partly due to large daily fluctuations in summer water temperature and high turbidity resulting from channelization activities (Heneger and Harmon, 1971).

Immediate impacts can result from the excavation and placement of large amounts of soil as meanders are eliminated. Turbidity and siltation can result from erosion of exposed and loose soil, either by rain or by river flow, prior to final stabilization. A good summary of channelization impacts is offered by Simpson et. al. (1982) where they stated channelization activities affect individual organisms among the benthos and fish by affecting niches, food , reproduction , and behavior. At the population level, density and distribution of the populations are affected.

4.2.3 Physical Impacts- Habitat Removal- This is a near-term type of impact, though depending on land use practices adjacent to the site and upstream of it, natural correction of problems may not occur for some time, and thus might still require mitigation. In more arid regions, adequate recovery may slowed even more or never occur. Channelization and bank protection projects often result in removal of vegetative cover, riparian complexity and inwater habitat features. The Western Washington literature shows that removal of canopy and streamside vegetation over substantial reaches can cause low salmonid biomass (Chapman and Knudsen, 1980). Removal of large woody debris has been clearly shown to degrade habitat, reduce habitat diversity and reduce potential fish supporting capacity (Wissmar and Beer, 1994; Cederholm, 1972). This would also hold true for on-going snagging operations and instream debris removal. In their literature review, WDF (1984) identified several papers outlining the need for large woody debris in rivers in order to control water and sediment routing, define habitat by shaping pools and riffles, provide cover and serve as a substrate for biological activity.

In Montana trout streams, riparian vegetation in poor condition led to greatly accelerated erosion and dished-out banks that did not provide cover for fishes (Hunter, 1995). A creek in California lost fish carrying capacity with loss of overhanging bushes and other cover (Moyle, 1976), and in Iowa, removal of streambank cover was an important factor contributing to such conditions as higher water temperature and higher suspended sediment loads from channel erosion (Hansen, 1971).

Removal of vegetation can lead to immediate impacts involving turbidity and siltation if soil is eroded prior to revegetation or other stabilization.

4.3. Biological Impacts- Studies on the biological effect of placing riprap or channelizing streams show that although riprap and channelization share similar impacts, there are impacts specific to each, outlined below. In our literature search, we focused on impacts related to fish populations; impacts to invertebrates have not been investigated to the same extent. Studies that have been completed on invertebrate impacts related to channelization have been inconclusive.

4.3.1. Biological impacts and considerations--Riprap - In larger Northwest streams, coho and trout young-of-the-year suffer somewhat in newly riprapped sections; however, steelhead and cutthroat populations may increase under the same conditions (Knudsen and Dilley, 1987). In addition to direct species-specific population effects, biodiversity may be affected by riprapping. Revetted habitats in the Willamette River in Oregon contained high densities of a smaller number of species than comparable unrevetted areas (Li, et al., 1984). Species using riprap as habitat were small fishes hiding in interstitial spaces and those feeding on benthic invertebrates and algae (Hjort, et al., 1983). On the Thompson River, B.C., it was found that juvenile chinook and steelhead also used interstitial spaces in riprap and responded better to larger rock (Lister et. al., 1995). In Montana trout streams, twice as many brown trout were found in natural sections as in riprapped sections (Bianchi and Marcoux, 1975).

4.3.2. Biological impacts and considerations--Channelization- Channelization impacts on aquatic habitats in general, and salmonid habitat in particular, are significant. Knudsen and Dilly (1987) found notable decreases in salmonid populations in large channelized Western Washington streams. When Big Beef Creek, on the Olympic Peninsula, was channelized, resulting in the loss of chum salmon redds (Cederholm and Koski, 1977); also, many chum shifted their spawning activities upstream to compensate for channelization downstream. In smaller Western Washington streams, the smallest salmonids (coho at the time of sampling) were least affected by channelization, while the largest (cutthroat) were most affected (Chapman and Knudsen, 1980). The same study looked at a tributary of the Skagit River called Childs Creek where 25% more total salmonid biomass was found in a newly channelized section when compared to a control section. However, by October, the same channelized section had 95% less biomass than found in the control section. This could have profound implications on fish populations for which overwintering habitat is critical.

In Montana trout streams, channelized sections were found to have fewer, smaller fish (Whitney and Bailey, 1959; Elger, 1968; Cederholm, 1972). Channelization of Big Spring Creek in Montana has resulted in complete destruction of trout stream habitat (Cederholm, 1972).

The channelization of the Bunyip River in Australia had near term effects which included reduction in the numbers and biomass of resident stream fish populations (Hortle and Lake, 1983). The authors speculated that long term effects would depend on whether fish populations would recover by adapting to the new conditions. The channelization reduced trout populations by eliminating suitable physical habitat; trout in the river were less abundant and smaller (Hortle and Lake, 1983). In the Danube floodplain, in Europe, channelized tributaries had no backwaters or side channels. Fish could only use riprapped banks or rare shallow slope gravel shorelines to escape the main flow, and spawning and nursery sites were limited to the main channel shoreline (Jurajda, 1994).

Moyle's (1976) Modoc Creek, California, study showed fewer and smaller rainbow trout, brown trout and Modoc sucker, as well as lower biomass in channelized sections. Only riffle-dwelling fishes were able to use the scant cover and turbulent water in channelized areas (Moyle, 1976). Channelization has degraded and destroyed stream fish habitat in the midwest (Funk and Ruhr, 1971). In the Little Sioux River and other streams in Iowa, numbers of fish are greater in unchannelized sections, and channelized areas show a reduction in the number per acre of fish over 6 inches long. Fish populations in 23 channelized streams there showed no sign of returning to normal 40 years after channelization (Hansen, 1971). A related effect of channelization is that it reduces or eliminates suitable macroinvertebrate attachment areas (Heneger and Harmon, 1971), presumably affecting potential food sources for fish.

5.0. REDUCING IMPACT

5.1. Location Considerations- Impacts associated with riprap projects may be related to proximity of construction to the river. Construction of a riprap project away from the river's edge or outside the riparian corridor can greatly reduce impacts associated with vegetative regrowth, slope modification and habitat complexity. Therefore, levees constructed inland and away from natural river banks (setback levees) offer the greatest impact reduction from riprap projects.

If a riprap project must be placed on the river's edge, its relative position in the river can influence its impact on local fish populations. Knudsen and Dilley (1987) found that impacts from riprap placement were inversely proportional to stream size and fish size. Dardeau and his colleagues (1995) found that alluvial rivers dominated by soft substrates may be impacted less from riprap projects; in fact, riprap in such areas may provide increased invertebrate diversity and cover for fish.

5.2. Rock Considerations- Placement technique and rock size can affect the level of negative impact to fish populations from riprap placement. Likewise, efforts can be made to minimize rock related impacts by using appropriate sizes and placement methods.

5.2.1 Regional research- Construction guidelines currently used for riprap placement commonly require the rock to be keyed to each other, presenting a smooth, hydraulically efficient surface. Restoration guidelines, manuals and research have recently begun to describe and support placement techniques that allow more habitat. Providing habitat roughness through the use of larger rocks allows juvenile chinook and steelhead to more effectively use the rocks as cover during high flows (Lister, et al., 1995). The same report concludes that riprap embankments intended to provide habitat for juvenile salmonids should be constructed of coarser material than has commonly been used. The use of large rounded rock is considered superior to angular rock for providing maximum usage by juvenile fishes. Angular rock can cause low chinook usage due to the turbulent flow characteristics of the rock in heavy current (Schaffter et al., 1983; Michny and Diebel, 1986). The use of angular rock to minimize impact may be most beneficial in areas of less turbulent flow such as lower river or delta regions (DeHaven and Weinrich, 1988; Strait and Michney, 1989). Work on the Newaukum River has shown that using a "dirtier" riprap mixture (i.e., containing interstitial fines and gravel) can be economical and beneficial, both as a spawning gravel source and to speed establishment of overhanging bank vegetation (WDF, 1984).

Work in Idaho on concealment cover found large angular boulders (49 cm - 52 cm) from natural slopes were used by juvenile trout (Griffith and Smith, 1993). Knudsen and Dilley (1987) found that negative short term effects of construction appeared to increase with severity of habitat alteration, to decrease with increase in stream size , and to decrease with increasing fish size.

5.2.2. Research in other regions- Research in areas outside the Pacific Northwest region has shown similar results in relating rock size to habitat impacts. The non-keyed approach was documented by Dardeau, et al. (1995) to have direct habitat benefits to fishes of the Mississippi River by approximating natural situations in which velocity and substrate size are positively associated. Dardeau, et al. found these benefits to be most pronounced in alluvial river systems with soft substrates. On a Montana stream, Hunter (1995) found that large riprap provides breaks in flow, providing feeding stations and cover for trout.

Shields and Hoover (1991) found that eroding banks were greatly reduced by using riprap revetments on Twenty Mile Creek in Mississippi. They also found riprap to be effective in protecting habitat features when used immediately upstream or downstream. Riprap in Montana stream restoration was shown to provide trout cover and bank stabilization whether used as a continuous blanket or series of jetties (Hunter, 1995)

5.3. Using Constructed Habitat Features- The use of constructed habitat features is well documented. Their construction is designed to minimize impacts of both channelization and revetment. Habitat features can consist of any material; however, the use of natural material such as wood and rock seems most preferred.

5.3.1 Regional research- Use of wood and rocks for habitat features in the Northwest has become widespread. Various agencies have been placing habitat features into levee prisms and riprap bank stabilization projects for years in response to regulatory requirements by the Washington Department of Fish and Wildlife.

Specific research shows that additions to habitat complexity as a result of these constructed features may increase fish production in impacted streams (Knudsen and Dilley, 1987). On going work by the WDFW and USFWS also point to increased fish usage through the use of habitat features. The addition of habitat features can provide or replace refuge factors such as cover, depth and pool area, all considered to increase overwintering survival of trout (Cederholm, 1972).

Specific constructed habitat features described in the literature consist of the rock groins, woody debris placement, and large boulder placement. Rock groins are usually pyramidal jetty structures that protrude into the water column from a rock revetment. They serve to produce scour holes on the downstream edge of the groin and provide holding habitat downstream from the current. Li, et al., (1984) found that rock groins also accumulate woody debris. Debris accumulation provides habitat benefits beyond the hydraulic properties of groins by providing direct cover and three-dimensional complexity from woody debris. Constructed woody debris habitat features are usually placed below the water line and keyed into the riprap revetment. The debris often has a root structure attached which serves to provide direct cover for juvenile fish. Over time, woody debris can accumulate additional debris and multiply its effectiveness.

5.3.2. Research in other regions- Looking at research conducted throughout the world, we found that the use of constructed habitat features is widespread. In their work in Mississippi on Twenty Mile Creek, Shields and Hoover (1991) found that constructed habitat features can promote overall channel stability and serve as major habitat features. Specifically, they found that constructed weirs with stone protected stilling basins promoted biological recovery in channelized streams by providing coarse, stable substrate. They found that greater habitat heterogeneity created greater biological diversity and therefore an increase in stream fish communities. Refugia can also be provided for fishes experiencing reduced habitat, through the construction of channel modification projects with two-stage cross-sections that include low-flow channels (Shields and Hoover, 1991). The notion of substrate providing habitat is reiterated in work done in Montana. Hunter (1995) found that the placement of boulders along stream margins where overhanging grasses provide cover could provide rearing habitat for juvenile trout and break up long riffles. WDF (1984) cite several studies in which rock deflectors (usually in combination with replanting of overhanging bank vegetation) rendered revetted streams nearly comparable to unaltered streams.

5.4. Leaving Natural Features (LWD, meanders, etc.) in Place- The reduction of natural features as a result of channelization can have effects on fish communities and organisms. The loss of meanders through channelization greatly limits habitat diversity.

Construction techniques often call for complete removal of woody debris and rooted vegetation to protect the levee prism from damage caused by large trees. For instance the USCOE regulation 500-1-1 used nationwide requires that all vegetation over 4 inches be removed from levee prisms. Fortunately, levee plants can be planted or allowed to recover and be managed through a maintenance policy to have some benefits to fish. The productivity loss associated with removal of downed logs and channel meanders is much more difficult to mitigate.

5.4.1 Regional research- Regional studies have shown that large woody debris (LWD) contributes three-dimensional habitat features which fish can use for cover, shade, and relief from high flows. Presence of LWD increases surface area and roughness, which contribute to habitat complexity and potential fish carrying capacity. Desirable LWD recruitment occurs as channels shift and tree-bearing streambanks erode (Wissmar and Beer, 1994). Although current practice does not encourage leaving or planting trees and shrubs on revetments, a Sacramento study showed damage rates for revetments supporting woody vegetation tended to be lower than for unvegetated revetments of the same age located on banks of similar curvature. (Shields, 1991).

An ideal stream network should connect habitats required for 1) various fish life histories, 2) refugia from disturbances, 3) source areas that provide populations for recolonizing disturbed and restored habitats (Sedell, et al., 1990). In order to achieve these connections, features such as side channels and LWD should be preserved, or their functional equivalents should be included in construction projects to the greatest extent possible.

5.4.2. Research in other regions- On the Bunyip River in Australia, areas with tree snags present correlated with high fish abundance (Hortle and Lake, 1983). In the Baken Park reach of Rapid Creek, Montana, the U.S. Corps of Engineers restored a stream to improve trout habitat. In studying the project, it was determined that stabilizing the eroding banks on the outside of meander bends is a common mistake; this eroding process is natural and creates prime habitat (Hunter, 1995). In cases such as the Baken Park project, trees and brush could provide cover and stabilization but might have shorter life spans in restoration projects than well-placed rock habitat features.

5.5. Biological Community Impact Reduction- Impacts to biological communities from the activities of channelization and revetment construction are related to the life history and behavior patterns of individual organisms. Where some fishes are impacted severely, others may benefit from the placement of large rocky substrate. Impacts tend to dissipate with time and may see some recovery as vegetation growth, siltation and other factors act to restore the disturbed area (Knudsen and Dilly, 1987; Cederholm, 1972; Cederholm and Koski, 1977).

5.5.1. Regional research- The biological requirements of fish occurring in rivers and streams of the Pacific Northwest are diverse, reflecting many different habitat requirements, life histories and behaviors. Relating these factors to the impacts associated with either revetment construction or channelization is difficult, but some information is available. Overall, the impacts of channelization and revetment construction to fish species has been found to depend on the behavior and life history of the organism.

Several researchers found that depth of water used by salmonids is related to the size of the fish. Newly emerged fry were found to move towards shallow margins of their habitat (Chapman and Bjornn, 1969; Everest and Chapman, 1972; Cunjal and Power, 1986). More specifically, Li, et al. (1984) found that larval fishes avoided velocities greater than 11 cm/sec and were found at depths no greater than 30 cm. The shallow water preference of juvenile salmonids can put them in prolonged contact with revetment structures. The converse is true for adult salmonids. Orsborn (1990) found that as most species grow, a migration to deeper and faster water occurs. A reduction in the effect of revetment structures as salmonids grow would follow. The separation of juvenile and adult salmonids can act to reduce predator/prey relationships. Chapman and Knudsen (1980) found no predator/prey correlation between cutthroat and coho on riprap revetments because of the tolerance juvenile coho had towards revetment habitat. This study did not determine whether the juvenile coho's tolerance for revetments was due to the reduced risk of predator interactions with adult salmonids or because of the habitat provided by the rock substrate itself. However, Knudson and Dilly (1987) found that adult cutthroat were more abundant in riprapped sections of large streams indicating the possibility for predator interaction. Interspecies interaction may be limited. Moyle (1976) found juvenile salmonids used riprap habitats the most possibly due to a hierarchy causing smaller fish to use habitats of lesser quality.

Rock substrate use by salmonids for habitat has been well documented. The use of rock may be related to rock size and shape (ECOS, 1991). Lister, et al. (1995) found juvenile chinook and steelhead occupy stations that allow them to hold position in low or zero velocity, usually near bottom adjacent to high velocity flow, indicating that rock size influences juvenile fish usage. The same study also found that riprap interstices on the Thompson and Coldwater Rivers of British Columbia provided hiding places for fish. The authors further showed that large riprap supported higher juvenile chinook and steelhead densities than small riprap and cobble-boulder banks, although wild coho exhibited no preference. Li, et al. (1984) found that native larval fishes may use riprap for cover also, and that juvenile salmonids hide in riprap substrate during the day. Chinook and steelhead were shown to prefer larger riprap to smaller, reflecting a tendency to seek cover within a boulder or rubble substrate for rearing and overwintering. The use of rock for rearing and overwintering has been shown to be related to rock size, with larger rock better than smaller rock and rounded rock better than angular rock. However, rock alone cannot compensate for lost natural habitat. Vegetation plays an important role in habitat use and impact reduction to biological organisms.

The removal of vegetation in association with revetment and channelization projects is often significant. The result of this removal can be both positive and negative in the near term for salmonids; however, vegetation loss usually results in negative long term impacts to fish communities. Cederholm and Koski (1977) found that coho may avoid dense cover in summer and prefer open glides; conversely, steelhead may prefer dense shade. Chapman and Knudsen (1980) found larger salmonid biomass in streams with less vegetative cover. These studies may indicate that light can be an important limiting factor for salmonid biomass during summer in many streams. Even so, the negative impacts of vegetative removal are pronounced. Cederholm (1972) found steelhead recovery slow because of reduced streambank cover as a result of channelization of Big Beef Creek, Washington. Impacts from loss of cover are not limited to juvenile salmonids. Migrating adult chum salmon may recognize a lack of hiding cover in impacted spawning areas and move to more suitable areas upstream (Cederholm, 1972). Removal of vegetative cover impacts juvenile salmonids more than adult salmonids, and the recovery from these impacts seems related to the degree that vegetation is allowed to return after channelization or revetment construction.

Overwintering behavior by juvenile salmonids often requires the use of shallow water habitat. Juvenile salmonids display overwintering behavior in response to high flows, a mechanism that both protects them against displacement from the river and ensures their use of productive habitats during food limited periods. Orsborn (1990) shows that many species move to cover areas and cover objects when water temperatures decrease in fall and winter. Overwintering habitat is often limited in many northwest systems, particularly in association with channelization and riprap structure. Channelization and riprap placement replace existing overwintering habitat such as side channels, overhanging banks and woody structure with rock. However, not all habitat value is lost after rock placement. Interstitial spaces of riprap are used by juvenile rainbow, cutthroat and chinook although side channels and ponds are most preferred by coho (Orsborn, 1990). The reluctance of coho to use riprap as overwintering cover can expose them to a higher degree of flow-related impact than other juvenile salmonids; however, as mentioned earlier, Chapman and Knudsen (1980) observed juvenile coho preferentially using shallow riprapped areas, so species preference in this case is unclear. Loss of pool habitat as a result of channelization also plays a role in overwintering. Cederholm (1972) found that the preferred habitat of coho and steelhead is in association with pools; pools with permanent hiding cover resulted in greatest overwintering salmonid populations. Pool habitat is often removed entirely during channelization. Although reduction in pool habitat can occur with revetment construction, due to changes in river flow characteristics, it is not usually as profound as that associated with channelization.

5.5.2. Research in other regions- The literature provides evidence that constructed habitat features in regions outside the Northwest may also be effective in restoring fish habitat lost when a river or stream is channelized. Juvenile salmonids in a restored stream in Montana were found to be using habitat created by boulders placed along banks in riffles. Adults were using boulder berms for resting (Hunter, 1995). Channelization of rivers in Mississippi has often resulted in channel destabilization and increased erosion. Using coarse, stable material for bank protection and channel stabilization can improve fish habitat. In channelized Mississippi streams, species diversity and richness of fish communities were positively associated with structures, both natural and constructed. Such structures increase depth, decrease velocity and increase physical heterogeneity at low flow (Shields and Hoover, 1991). Other case studies in the Mississippi Valley show that riprap bank protection provides hard substrate for benthic invertebrates, especially important in channelized alluvial river systems where this material is scarce or absent (Dardeau, et al., 1995). In the lower Danube River, which is channelized, shoreline habitat was found to be important as nursery area for 0+ age fishes of all species studied. Fishes under these conditions were found to be more influenced by changes in their ability to reproduce successfully than by food source changes (Jurajda, 1994).

6.0 SUMMARY

6.1. Construction Impact Summary

6.1.1. Immediate Impacts- Rock is the material of choice for revetment construction. Placement of rock and other construction site activities often cause an increase in turbidity. Under normal circumstances, increased turbidity is the most significant immediate impact. A customary environmental permitting requirement is that all rock used during revetment construction be clean of contaminants and relatively clean of fines. The use of clean material, coupled with the ability of fishes to avoid areas of local turbidity, should render the impacts from turbidity insignificant.

Equipment required for the construction of revetment and channelization projects includes bulldozers, dump trucks, excavators and small vehicles. Some of this equipment works close to the river's edge, with potential spills of petroleum and other products from broken hydraulic hoses or oil leaks. Environmental permitting requirements and typical construction methods minimize in-water work and spills. Pollution containment standards used by contractors, including oil booms and equipment checks, reduce the probability and extent of petroleum contamination. Following approved spill contamination protocols minimizes the impacts petroleum spills.

Noise generated by construction equipment and rock dumping can temporarily disturb wildlife, especially native songbirds. Working within established biological windows for aquatic and terrestrial species should minimize noise related impacts.

6.1.2. Near term impacts- Loss of existing vegetation through the clearing and grubbing process of revetment construction is an important near term impact. Typical construction methods require that all vegetation be cleared prior to rock placement. This clearing results in total loss of the habitat value afforded by the vegetation. Replacement of this vegetation is slow due to the new rock covering and may never occur in arid conditions. To mitigate for habitat loss, willow shoots, grasses and other hardy native species are often planted. The plantings also help reduce post project turbidity, and noxious weeds.

Food production from terrestrial sources is often directly related to the vegetative cover along the project banks. The removal of vegetation and subsequent placement of rock greatly reduces this food source, which provides nourishment to both terrestrial and aquatic organisms. Replanting of revetment slopes can help mitigation for this food loss.

Leaf litter, and detritus comprise the majority of food production for invertebrates which in turn provide much of the food for juvenile fishes. These food sources are greatly reduced locally by the placement of new rock if only temporarily. Over time, this loss is reduced or eliminated as soft substrates begin to accumulate in the interstices of the rock, and as the rock is colonized by algae, and accumulates leaf litter and detritus important to invertebrate grazers. Where the natural substrate is cobble and rock, an appreciable loss of productivity is less likely. No mitigation is available for this impact however, detritus and invertebrates populations establish quickly and prolonged impacts are not considered significant.

6.1.3. Long term impacts- The near term impacts of vegetation removal can be persistent if vegetation maintenance standards fail to allow recovery of habitat values. Existing standards often fail to allow for overhanging vegetation or trees of adequate size to provide shade and cover for aquatic organisms. Terrestrial organisms that use the riparian corridor are also negatively affected. Vegetation maintenance is considered a significant impact with the existing vegetation standards. If future standards allow for more flexible management of riparian vegetation, this impact could be reduced but probably not eliminated.

Direct reduction of the amount and quality of aquatic habitat is likely to occur as a result of rock placement. Sand and gravel bankslopes common along Northwest rivers will be replaced by large rock, while river bottom substrates of gravel or mud will not be directly altered. As a result, scour may eliminate pool habitat as the river's energy is directed along the thalweg during higher flows. The significance of this habitat loss is directly related to pre-construction pool habitat availability along the project site and use of that habitat by aquatic organisms.

Instream cover afforded by downed logs, overhanging banks or overhanging vegetation is common along natural sections of Northwest rivers. Bank complexity from these features is nearly always lost through revetment construction. The replacement of natural bank with uniform rock requires that the bank be sloped and simplified. The pre-construction condition of these habitat features along the project site will determine the duration and extent of this long term impact. Also, the construction techniques used will determine the degree to which these features will return with time. Mitigation such as groin construction and/or placement of woody debris can reduce the overall impact. In cases where the habitat is already degraded, or where current natural conditions have little instream cover, the long term impact from loss of instream cover could be less significant.

Indirect habitat degradation by changes in flow characteristics across revetment rocks and through the channel can have long term impacts to habitat quality. Small angular rocks placed as armorment may not be adequate for use as hiding cover by adult or juvenile fishes. Altered flow patterns can remove pool habitat near the banks where most habitat complexity occurs. Larger changes in flow characteristics across the channel can also alter habitat. Scour and loss of habitat variability can follow revetment placement or channelization. The impacts depend on the size, location and type of project. If the river is large enough to present a uniform deep glide habitat condition with a soft substrate bottom, impacts should be reduced. Where meanders remain and where the river is naturally confined, the long term impact from altered stream energy will be reduced further.

6.2. Impact Reduction Summary- *In order of importance*- We can apply several ideas from the literature review to the Skagit River project. As mentioned earlier, the proposed project is located on the lower Skagit River mainstem in an area already characterized by flood control structures. Under the proposed plan, the old structures would be upgraded to provide better protection and be stronger. There is opportunity to avoid further degradation or improve the fish habitat situation if suggestions in the literature are used in project design.

6.2.1. Avoidance- From an environmental perspective, the most desirable action is to avoid potentially adverse impacts. Nonstructural alternatives, or those that protect individual structures, are best. Such actions might include creation of floodways that can take flooding pressure off developed areas while maintaining ecological integrity. Another example would be floodproofing individual structures or confined areas such as the central districts of small towns.

If larger-scale levees are needed, the use of setback levees could avoid the need to significantly alter bankslope characteristics including vegetation. Setback levees are built some distance off the bank; current riparian vegetation and habitat values are unaffected by construction. The floodplain between the river's edge and the levee becomes available for high flows and meandering, increasing flood capacity and wildlife habitat. If chronic erosion encroaches on the setback levee, further bank protection work might be necessary; however, setback levees should be explored wherever practical as they are the single most effective means to provide both flood protection and adequate habitat values.

Placement of revetments over existing overwintering areas such as sloughs, backwaters, and off-channel ponds has the potential to significantly affect fish, and should be avoided. Juvenile salmon, especially coho, require overwintering habitat. Not enough is known about the availability of overwintering habitat, or the potential suitability of revetments as overwintering habitat, to remove or degrade remaining natural areas. Serious effort should be directed toward avoiding further loss of overwintering habitat.

Limits on the size and scope of the project through proper engineering are essential to avoiding unnecessary impacts. Construction of levees only where needed will alleviate adverse impacts to off channel habitat, and to natural bankslope and instream habitat features.

6.2.2 Minimization- Unavoidable impacts can be made less significant; for instance, construction techniques can be employed to minimize potential impacts. From the literature, we have summarized several items that could be beneficial. In sections where revetment cross sections must be widened, landward construction allows existing channel capacity to remain unaltered. Landward construction also minimizes channel velocity changes and subsequent changes to habitat suitability through retention of channel capacity.

Operational maintenance (removal) of vegetation on the bankslopes of the rock revetments can have significant impacts to habitat quality. Allowing as much vegetation growth as possible will minimize impacts associated with cover loss and food production. To further minimize vegetation loss impacts over time, the planting of willows or other hardy native plants on the waterward face can jump-start regrowth and minimize productivity loss.

Blocking access to overwintering habitat such as sloughs and backwaters can have significant effects on fish, especially juvenile salmonids. Minimizing these impacts through design and construction of proper outlet gates to provide adequate fish passage is important. Engineering solutions should be developed to retain access for juvenile salmonids to these areas after construction.

6.2.3. Mitigation- Mitigation is commonly required by regulatory agencies when unavoidable losses of habitat or productivity are encountered as a result of construction projects. Construction of riprap revetments and channelization projects often have impacts requiring various degrees of mitigation. This following list of recommended mitigation actions for revetment and channelization projects represents the synthesis of literature reviewed herein. A similar list was compiled by the Washington Department of Fisheries (WDF, 1984) for their Newaukum River bank hardening research.

Revise levee vegetation standards- In the absence of levee maintenance, vegetation lost as a result of revetment projects will return to a pre-project condition after considerable lengths of time. Operation and management policies requiring removal of vegetation preclude this succession, necessitating mitigation. Changing policies governing long-term vegetation standards is indicated by the literature as having the greatest potential to mitigate for long term productivity losses. Small changes in allowable vegetation could have significant benefits.

Place rock groins into the design as frequently as practical for better habitat suitability- Lost habitat features and habitat heterogeneity as a result of revetment construction can be overcome in part by the construction of rock groins. Scour patterns and water flow disruptions have been shown to create productive salmonid habitat commonly lost during revetment and channelization construction. Flow disruptions can be maximized through revetment design by providing an irregular bankline.

Consider using larger rock in the design to allow better habitat suitability for salmonids- Mitigation for lost shallow water habitat can be partially overcome by the use of larger rocks, either as part of the armored cross section or individually within the channel. Sturdy, long-lasting large rock features used singularly or in clusters can increase the likelihood of use by juvenile salmonids during critical overwintering periods.

Consider using woody debris in the revetments- Woody debris placed in the levee cross section and partially buried within the toe provides habitat qualities similar to that of groin construction, but with the added advantages of three-dimensional complexity and detritus production. Woody debris provides mitigation for in-water physical habitat losses commonly found during revetment construction. Woody debris should be constructed at varying elevations to provide habitat value at high flood flows as well as low summer flows.

6.3. Project Specific Summary- The literature review of riprap and channelization impacts has provided several ideas and technical views applicable to the Skagit River Flood Control study. Not all impacts can be avoided in this case, but considering the current condition of the project area and nature of the proposed work, using currently accepted fish-friendly construction and mitigation features will likely result in minimal impacts or improved condition along the Skagit River.

Information gleaned from literature and knowledge of the biological conditions currently at the project area indicate that juvenile salmonids will be affected more than adult salmonids and that impacts to adult Pacific salmon will be negligible. We find that impacts to juvenile salmonids will likely be positively correlated with freshwater residency time. Chum and pink salmon will probably not be significantly impacted by this project, as they migrate to saltwater very quickly after emergence from the gravel. Impacts will be most pronounced during the winter months; therefore, coho and chinook, which overwinter in freshwater as part of their life histories, will likely be most affected by the project. Resident adult trout in the project area are common but probably not as abundant as in the middle and upper watershed. Bull trout can be expected to travel through the project area but are considered to have habitat preferences found outside project area. Cutthroat trout and rainbow trout tend to have less reliable reactions to revetment construction; these species have been found to exhibit both positive and negative responses to revetment construction. In almost all cases, impacts to resident trout have been less than to anadromous species.

The following measures have been found to have the best applicability to work proposed on the Skagit River. The measures are designed to avoid, minimize, and mitigate for impacts associated with this specific project. Without more information on specific project design parameters or specific background information on current habitat availability and relative suitability, an overall determination of impact is not possible.

1. Set back portions of the levee footprint wherever practical.
2. Construct levee improvements from the landward side in all cases.
3. Reestablish lost overwintering habitat along the project corridor or nearby where practical.
4. Include constructed habitat features such as rock groins to increase habitat complexity.

7.0 RECOMMENDATIONS

7.1. Identify Data Gaps and Ongoing/Related Research

7.1.1 Data gaps

We found little or no data quantifying habitat losses from replacing or rehabilitating old riprap with new riprap. No studies were found describing the benefits of incorporating some of the suggested mitigation features listed above, such as keyed-in LWD and replanting, in already riprapped banks. Also, there is little data on revisiting riprap impact study sites after construction. Most of the research quantifies initial impacts of bank stabilization projects.

7.1.2. Related research- The Washington Department of Fisheries conducted an extensive literature review on the effects of riprap bank hardening and associated channelization. The draft report on this work was completed in 1984 (WDF, 1984), and the agency (now the Washington Department of Fish and Wildlife) continues to work on assessing impacts of river habitat alteration and cumulative impacts of extensive bank hardening across the state.

The U.S. Fish and Wildlife Service in Olympia, Washington is currently investigating the impact of bank stabilization projects, including levee revetments, on aquatic organisms. They are looking at relative impacts found between various construction materials including rock. Evaluation of constructed habitat features may also be part of this effort.

Annual monitoring reports from California in relation the Sacramento River bank protection project have been written by the USFWS and California Department of Fish and Game (USFWS, 1992; Cal Fish and Game, 1983). Future monitoring reports should provide additional information.

7.2. Recommended Follow-on Work- The following list of recommended work has been prioritized by need or importance relative to the project. We recommend that the following work items be completed to obtain further information on the impacts associated with the proposed Skagit River Flood Damage Reduction project.

1. The amount and availability of habitat currently found along the project site is the baseline condition. The quantification of this condition either by GIS data or ground surveys will allow planners to develop an understanding of the type and quality of habitat to be modified. In addition, this information will help in the quantifying the habitat loss and avoidance or mitigation of impacts related to setback levees and constructed habitat features added to the project.

2. The environmental features described earlier in this report are general and not designed specifically for this project. Some work is necessary to identify any modifications or design challenges relevant to the Skagit River. In addition, some work could be completed to identify areas that might benefit most from placement of these features. Budget limitations and construction timeframes will reduce the practicality of placing either groins or woody debris along the entire project area. For example, areas not designated for setback levees and found to

have productive natural banks may warrant placement of more or larger groins than sections lower in the project area. Areas away from identified sewer outfalls or other urban degradation may also be more productive places for groin placement.

3. It has been inferred that the massive loss of slough habitat in the lower Skagit River has reduced overwintering productivity of the river and placed increasing pressure on the few remaining sloughs. A survey should be completed to quantify the amount of slough habitat currently open to fish passage along the project area and to quantify any further loss of slough habitat due to the proposed project. If losses occur beyond the current condition, engineering solutions to retain adequate fish passage should be devised.

4. Quantifying fish losses as a result of the Skagit River flood control project is difficult using existing literature. Estimated ranges of potential losses could be derived but are likely to include too wide a range of values to be useful. In addition, systems similar to the Skagit River are not well represented in the literature. There is a need to revisit a large river system previously documented as having revetment/channelization related impacts and describe its rehabilitation. The lower Deschutes River studied by Knudsen and Dilley (1984) might be a good opportunity to reevaluate natural vs. channelized sections under current regimes of flow, vegetation, siltation and channel changes. Many impact assessments occur immediately after construction, not taking into account their recovery from construction and near term impacts.

A small number of limited, well-focused studies should be designed to determine specific baseline conditions, and to provide information which can be used for any post-construction monitoring studies.

8.0. REFERENCES

8.1 Literature Cited.

Bianchi, D.R., and R. Marcoux. 1975. The physical and biological effects of physical alteration on Montana trout streams and their political implications. In: Proceedings: Symposium on Stream Channel Modification, August 15-17, 1975, Harrisonburg, Virginia.

California Fish and Game. 1983. Sacramento River and Tributaries, Bank Protection and Erosion Control Investigation - Evaluation of Impacts on Fisheries, August, 1983. State of California, The Resources Agency, Department of Fish and Game, Bay - Delta Fishery Project. Prepared for the U.S. Army Corps of Engineers, Sacramento District.

Cederholm, C.J. 1972. The near term physical and biological effects of stream channelization at Big Beef Creek, Kitsap County, Washington. M.S. Thesis, University of Washington, Seattle. 91pp.

Cederholm, C.J. and K.V. Koski. 1977. Effects of stream channelization on the salmonid habitat and populations of Lower Big Beef Creek, Kitsap County, Washington. Washington 1969-1973. Washington Cooperative Fisheries Research Unit, University of Washington Seattle, WA.

Chapman, D.W., and T.C. Bjornn. 1969. Distribution of salmonids in streams with special reference to food and feeding. Pages 153-176 in T.G. Northcote, editor. Symposium on salmon and trout in streams. H.R. MacMillan Lectures in Fisheries, University of British Columbia, Vancouver, B.C.

Chapman, D.W., and E.E. Knudsen. 1980. Channelization and livestock impacts on salmonid habitat and biomass in western Washington. Trans. Am. Fish. Soc. 109:357-363.

Dardeau, E.A., K.J. Killgore, and A.C. Miller. 1995. Using riprap to create or improve riverine habitat. In: River, Coastal and Shoreline Protection: Erosion Control Using Riprap and Armourstone. C.R. Thorne, S.R. Abt, F.B.J. Barends, S.T. Maynord, and K.W. Pilarczyk, eds. John Wiley and Sons, Ltd., New York.

DeHaven, R.W. and D.C. Weinrich. 1988. Inventory of heavily-shaded riverine aquatic cover for the Lower Sacramento-San Juoquin Delta, Part I, Sacramento River, American River to Natomas Cross Canal. U.S. Fish and Wildlife Service, Sacramento, California. Prepared for U.S. Army Corps of Engineers.

ECOS, Inc. 1991. Biological Data Report Regarding Sacramento Bank Protection Project Impacts on Winter-Run Chinook Salmon. Prepared for U.S. Army Corps of Engineers, Sacramento District.

Elger, A.A. 1968. Fish populations of a trout stream in relation to major habitat zones and channel alteration. Trans. Amer. Fish. Soc. 97(4):389-397.

Everest, F.H., and D.W. Chapman. 1972. Habitat selection and spatial interaction by juvenile chinook salmon and steelhead trout in two Idaho streams. Journal of the Fisheries Research Board of Canada 29:91-100.

Funk, J.L., and C.E. Ruhr. 1971. Stream channelization in the midwest. In: Stream Channelization: a Symposium. E. Schneberger and J.L. Funk, eds. American Fisheries Society, North Central Division, Special Publication No. 2. Omaha, Nebraska.

Griffith J.S., and R.W. Smith. 1993. Use of winter concealment cover by juvenile cutthroat and brown trout in the south fork of the Snake River, Idaho. N. Am. J. Fish Mgmt. 13:823-830.

Hansen, D.R. 1971. Stream channelization effects of fishes and bottom fauna in the Little Sioux River, Iowa. In: Stream Channelization: a Symposium. E. Schneberger and J.L. Funk, eds. American Fisheries Society, North Central Division, Special Publication No. 2. Omaha, Nebraska.

Henegar, D.L., and K.W. Harmon. 1971. A review of references to channelization and its environmental impact. In: Stream Channelization: a Symposium. E. Schneberger and J.L. Funk, eds. American Fisheries Society, North Central Division, Special Publication No. 2. Omaha, Nebraska.

Hjort, R.C. et al. 1983. Fish and invertebrates of revetments and other habitats in the Willamette River, Oregon. Final Report to Waterways Experiment Station, Army Corps of Engineers, Vicksburg, Mississippi.

Hortle, K.G., and P.S. Lake. 1983. Fish of Channelized and unchannelized sections of the Bunyip River, Victoria. Aust. J. Mar. Freshw. Res. 34:441-450.

Hunter, C.J. 1995. Better Trout Habitat: A Guide to Stream Restoration and Management. Montana Land Reliance, Island Press, Washington, D.C.

Jurajda, P. 1994. Effect of channelization and regulation on fish recruitment in a flood plain river. Regulated Rivers: Research and Management 10:207-215.

Knudsen, E.E., and S.J. Dilley. 1987. Effects of riprap bank reinforcement on juvenile salmonids in four western Washington streams. North Am. J. Fish. Mgmt. 7:351-356.

Li, H.W., C.B. Schreck, and R.A. Tubb. 1984. Comparison of habitats near spur dikes, continuous revetments, and natural banks for larval, juvenile, and adult fishes of the Willamette River. Water Resources Research Institute, Oregon State University. Final Technical Completion Report for Project No. 373905. Prepared for U.S. Department of the Interior, Geological Survey, Reston, Virginia.

Lister, D.B., R.J. Beniston, R. Kellerhals, and M. Miles. 1995. Rock size affects juvenile salmonid use of riprap. In: River, Coastal and Shoreline Protection: Erosion Control Using Riprap and Armourstone. C.R. Thorne, S.R. Abt, F.B.J. Barends, S.T. Maynord, and K.W. Pilarczyk, eds. John Wiley and Sons, Ltd., New York.

Michny, F. and R. Diebel. 1986. Sacramento River Chico Landing to Red Bluff 1985 juvenile salmon study. U.S. Fish and Wildlife Service, Division of Ecological Services. Sacramento, CA. 22 pp.

Moyle, P.B. 1976. Some effects of channelization on the fishes and invertebrates of Rush Creek, Modoc County, California. Cal. Fish and Game 62(3):179-186.

Orsborn, J.F. 1990. Pilot study on the condition of fisheries environments in river basins on the Olympic Peninsula. Prepared for the USDA Forest Service, Olympic National Forest. Olympia, Wa.

Schaffter, R.G., P.A. Jones and J.G. Karlton. 1983. Sacramento River and tributaries bank protection and environmental investigation- evaluation of impacts on fisheries. Final Report. California Department of Fish and Game. Sacramento, CA 93 pp.

Sedell, J.R. et. al. 1990. Role of refugia in recovery from disturbances: modern fragmented and disconnected river systems. Environ. Mgmt. 14:711-724.

Shields, F.D. 1991. Woody vegetation and riprap stability along the Sacramento River Mile 84.5-119. Water Resources Bulletin 27(3):527-536.

Shields, F.D., and J.J. Hoover. 1991. Effects of channel restabilization on habitat diversity, Twentymile Creek, Mississippi. Regulated Rivers: Research and Management 6:163-181.

Stern, D.H., and M.S. Stern. 1980. Effects of bank stabilization on the physical and chemical characteristics of streams and small rivers: An annotated bibliography. U.S. Fish and Wildlife Service, Missouri Institute of River Studies. Report No. FWS/OBS-80/12. Rolla, Missouri.

Strait, D. and F. Michny, 1989. Sacramento River Bank Protection Project. Contract 44. 1989 juvenile salmon study. U.S. Fish and Wildlife Service, Division of Ecological Services. Sacramento, CA.

USACE. 1993. Draft Reconnaissance Report: Skagit River, Washington flood damage reduction study. U.S. Army Corps of Engineers, Seattle District. Seattle, Washington.

USFWS. 1992. Final Report - Juvenile Salmon Study, Butte Basin Reach, Sacramento River Bank Protection Project, November 1992. Prepared for U.S. Army Corps of Engineers, Sacramento District. U.S. Fish and Wildlife Service, Fish and Wildlife Enhancement, Sacramento Field Office, Sacramento, California.

U.S. Army Corps of Engineers. 11 March 1991. Emergency Employment of Army and Other Resources Natural Disaster Procedures, ER500-1-1.

Washington Dept. of Fisheries. 1984. Draft Special Report - Newaukum River Bank Hardening Projects: Effects on Salmonid Habitat and Recommended Mitigation. Habitat Management Division.

Whitney, A.N., and J.E. Bailey. 1959. Detrimental effects of highway construction on a Montana stream. Trans. Amer. Fish. Soc. 88(1):72-73.

Wissmar, R.C., and W.N. Beer. 1994. Distribution of fish and stream habitats and influences of watershed conditions, Beckler River, Washington. Fisheries Research Institution, University of Washington School of Fisheries. No. FRI-UW-9418.

8.2 Bibliographies and Other Sources Not Currently Cited in Text.

Ayres Associates. 1996. Sacramento River Bank Protection Project, Sacramento River and tributaries, Lower American River, California: Supplement No. 8a to Design Memorandum No. 2. Prepared for U.S. Army Corps of Engineers, Sacramento District, Sacramento, CA.

Brittain J.E., J.E. Eie, A. Brabrand, S.J. Saltveit, and J. Heggenes. 1992. Improvement of fish habitat in a Norwegian River channelization scheme. Regulated Rivers: Research and Management 8:189-194.

Cobb D.G., T.D. Galloway, and J.F. Flannagan. 1992. Effects of discharge and substrate stability on density and species composition of stream insects. Can. J. Fish. Aquat. Sci. 49:1788-1795.

Duff, D.A. 1988. Indexed bibliography on stream habitat improvement. USDA Forest Service, Intermountain Region, Ogden, UT.

Faurot, M.W. 1989. Habitat utilization by juvenile pink and chum salmon in Upper Resurrection Bay, Alaska. Final Technical Report EL-89-17. U.S. Army Corps of Engineers, Waterways Experiment Station. Vicksburg, MS.

Groot, C., and L. Margolis. 1991. Pacific salmon life histories. Department of Fisheries and Oceans. Pacific Biological Station, Nanaimo B.C., Canada. UBC Press. 563 pgs.

Hayman, R.A., E.M. Beamer, and R.E. McClure. 1996. Skagit System Cooperative chinook restoration research progress report No. 1. Final Project Performance Report.

Hynson, J.R., P.R. Adamus, J.O. Elmer, T. DeWan and F.D. Shields. 1985. Environmental features for streamside levee projects. Technical Report E-85-7. U.S. Army Corps of Engineers, Waterways Experiment Station. Vicksburg, MS.

Jones & Stokes Assoc. 1996. Final Environmental Assessment and initial study of streambank protection at River Park- Lower American River. Prepared for U.S. Army Corps of Engineers, Sacramento District. Sacramento, CA.

Keown, M.P. 1983. Streambank protection guidelines for landowners and local governments. U.S. Army Corps of Engineers, Waterways Experiment Station. Vicksburg, MS.

King County, 1993. Guidelines for bank stabilization projects in the riverine environments of King County Department of Public Works, Surface Water Management. Seattle, WA.

Knight, S.S., and C.M. Cooper. 1991. Effects of bank protection on stream fishes. In: 5th Federal Interagency Sediment Conference. Las Vegas, NV. Pp. 118-124.

Marcus, M.D., M.K. Young, L.E. Noel and B.A Mullan. 1988. Salmonid-habitat relationships in the western United States: a review and indexed bibliography. USDA Forest Service, Rocky Mt. Forest and Range Experiment Station. Ft. Collins, CO.

Martin, V.J. 1971. The place of channel improvement in watershed development. In: Stream Channelization: a Symposium. E. Schneberger and J.L. Funk, eds. American Fisheries Society, North Central Division, Special Publication No. 2. Omaha, Nebraska.

Meehan, W.R. 1991. Influences of forest and rangeland management on salmonid fishes and their habitats. American Fisheries Society Special Publication 19. Bethesda, MD.

McMahon, T.E., and G.F. Hartman. 1989. Influence of cover complexity and current velocity on winter habitat use by juvenile coho salmon (*Oncorhynchus kisutch*). Can. J. Fish. Aquat. Sci. 46:1551-1557.

McMahon, T.E. 1983. Habitat suitability index models: Coho salmon. U.S. Fish and Wildlife Service, Habitat Evaluation Procedures Group. Report No. FWS/OBS-82/10.49. Ft Collins, CO.

Nunnally, N.R., and F.D. Shields. 1987. Incorporation of environmental features in flood control channel projects. Final Technical Report E-85-3. U.S. Army Corps of Engineers, Waterways Experiment Station. Vicksburg, MS.

Simpson, P.W., J.R. Newman, M.A. Keirn, R.M. Matter, and P.A. Guthrie. 1982. Manual of stream channelization impacts on fish and wildlife. U.S. Fish and Wildlife Service, Office of Biological Services. Report No. FWS/OBS- 82/24. Kearneysville, WV.

USACE. 1989. Environmental engineering for local flood control channels. Engineer manual-EM1110-2-1205. U.S. Army Corps of Engineers, Washington DC.

USACE. 1979. Final Environmental Impact Assessment- Skagit River, Washington. U.S. Army Corps of Engineers, Seattle District. Seattle, WA.

NFRC. 1988. A Study of the Effects of Riprap on Chinook Salmon in the Sacramento River, California, November 1988. National Fisheries Research Center - Seattle, Washington.

Von Guerard, P. 1991. Variation in streambed material, bedload and benthic invertebrates. In: 5th Federal Interagency Sediment Conference. Las Vegas, NV. Pp. 18-21.