Edmonds Shoreline
Habitat Assessment

PENTEC ENVIRONMENTAL

Prepared for
City of Edmonds

October 31, 2001
Pentec #1213012

Edmonds Shoreline Habitat Assessment

Prepared for
City of Edmonds
121 – 5th Avenue N
Edmonds, WA 98020

October 31, 2001
Pentec #1213012

Prepared by
Pentec Environmental

J. Eric Hagen
Fisheries Biologist

Jon Houghton
Senior Biologist

CONTENTS Page

EDMONDS SHORELINE HABITAT ASSESSMENT

INTRODUCTION

On behalf of the City of Edmonds (City), Pentec Environmental (Pentec) evaluated salmonid habitat of the shoreline and nearshore areas from Picnic Point to Edwards Point (Figure 1). Salmonid habitat quality was assessed using the Tidal Habitat Model (THM) developed through an interagency technical advisory committee working with the Snohomish Estuary Wetland Integration Plan (SEWIP) (Appendix A). The habitat assessment was based on review of aerial photographs of the shoreline and nearshore area and a field survey conducted from a boat at low tide. The survey also included assessments of the Edmonds (Union Oil) Marsh and the marsh at the mouth of Shell Creek.

In addition to providing information to assist the City in its shoreline planning efforts, this assessment extends the shoreline habitat inventories previously completed from Marysville to Mukilteo (Picnic Point), as reported in the SEWIP Salmon Overlay (City of Everett and Pentec 2001) and Mukilteo Shoreline Habitat studies (Pentec 2000).

METHODS

Aerial photos of the shoreline from Picnic Point to Edwards Point (dated May 17, 1993) were downloaded from the Washington State Department of Ecology Web site (www.ecy.wa.gov/apps/shorephotos). The individual photos were then lined up to produce a continuous shoreline mosaic. Using the THM protocols, discrete units of habitat were delineated based on physical changes in shoreline/nearshore habitat types. These habitat units are termed assessment units (AUs).

We conducted a shoreline survey during a low tide to verify the photo information (including updating landscape features) and to provide additional information on intertidal habitat (e.g., presence/extent of eelgrass beds). Additional site visits were made to the Edmonds Marsh and the marsh at the mouth of Shell Creek to assess the habitat potential of these two areas in providing important transitional habitat for juvenile salmonids.

The THM model asks a series of 34 "yes" or "no" questions about the hydrological, chemical, physical, geomorphological, biological, and landscape features (indicators) present within the AU. The model is focused only on indicators that are of direct or indirect relevance to anadromous salmonids,

Table 1 - Existing AU Scores for Edmonds* Shoreline by EMU and Assessment Species

Chinook Salmon					Coho Salmon/Bull Trout				
EMU.AU Number	Raw Score	Pos. Int. Score[1]	Neg. Mult.[2]	Final Score[3]	EMU.AU Number	Raw Score	Pos. Int. Score[1]	Neg. Mult.[2]	Final Score[3]
9.01	19.0	19.0	0.70	13.3	9.01	19.0	19.0	0.80	15.2
9.02	20.0	20.0	0.45	9.0	9.02	20.0	20.0	0.65	13.0
9.03	18.0	18.0	0.70	12.6	9.03	18.0	18.0	0.80	14.4
9.04	30.0	45.0	0.70	31.5	9.04	30.0	39.0	0.80	31.2
9.05	22.0	22.0	0.63	13.9	9.05	22.0	22.0	0.80	17.6
9.06	17.0	17.0	0.56	9.5	9.06	17.0	17.0	0.72	12.2
9.07	22.0	22.0	0.70	15.4	9.07	22.0	22.0	0.80	17.6
9.08	25.0	25.0	0.70	17.5	9.08	25.0	25.0	0.80	20.0
9.09	27.0	27.0	0.80	21.6	9.09	29.0	29.0	0.80	23.2
9.10	20.0	20.0	0.70	14.0	9.10	20.0	20.0	0.80	16.0
9.11	17.0	17.0	0.58	9.8	9.11	17.0	17.0	0.73	12.4
9.12	8.0	8.0	0.16	1.3	9.12	8.0	8.0	0.29	2.3
9.13	9.0	9.0	0.50	4.5	9.13	9.0	9.0	0.72	6.5
9.14	37.0	74.0	0.30	22.0	9.14	37.0	74.0	0.30	22.2
9.15	17.0	17.0	0.90	15.3	9.15	17.0	17.0	--	17.0

* Includes shoreline north of City limits.
[1] Positive Intermediate Score is the product of Raw Score and all positive multipiers (those >1)
[2] Negative multiplier is the product of all negative multipiers (those <1)
[3] Final Score is the product of Positive Intermeditate Score and all negative multipiers (those <1)

which covers the area north of the marina to the jetty at Brackett's Landing, is also affected by (non-railroad) shoreline development, including the ferry terminal (i.e., overwater coverage). In addition, the propeller wash from the ferries likely affects a portion of the littoral habitat within this AU.

Nearshore AUs north of Brackett's Landing (i.e., AUs 9.01 through 9.10, excluding AU 9.09; Shell Creek marsh) contain similar substrate types (mostly sand and gravel/cobble) and shoreline armoring for the railroad bed. Eelgrass is also present along much of the shoreline in this area. Most of the nearshore AUs scored between approximately 13 and 18 for chinook habitat (scores for coho/bull trout were slightly higher), although the individual scores varied from a low of 9.0 (AU 9.06) to a high of 31.5 (AU 9.04). The considerably higher value for AU 9.04 is primarily due to presence of a stream (i.e., Lunds Gulch) and a natural tidal channel that remains wetted at MLLW. The latter feature results in a positive multiplier (x1.5 for chinook, and x1.3 for coho/bull trout).

Of the two marsh habitats addressed as part of this assessment, the Edmonds Marsh (AU 9.14) scored the highest. In fact, the raw score (i.e., no positive or negative multipliers applied) was the highest of any of the 15 AUs evaluated in this study. The Edmonds Marsh provides many of the habitat features that benefit juvenile salmonids during their transition to salt water (e.g., salinity gradients, epibenthic food production, off-channel refuge, etc.). However, much of this habitat value (in terms of the model score) is negated because of the restricted fish passage at the culvert connecting the marsh to the sound. Because access is severely limited by the 1,200-foot culvert, a negative multiplier of 0.3 (maximum restriction as defined by question 25c) is applied to the positive intermediate score (Table 1).

By comparison, the Shell Creek marsh (AU 9.09) is much smaller than the Edmonds Marsh and contains fewer of the estuarine habitat features that benefit juvenile salmon; thus, the intermediate positive score is lower. Because fish access to/from the marsh is somewhat limited by the culvert under the railroad (i.e., scores for question 25a), the net habitat score is reduced.

POTENTIAL FOR HABITAT IMPROVEMENTS

Marsh AUs

The model scoring suggests that improvements that result in increased fish passage through the culverts at the outlets at both marshes will substantially increase the habitat value especially for the Edmonds Marsh AU. Daylighting the marsh as has been proposed by several parties would make the marsh accessible to adults and even to juvenile salmonids moving along the shoreline from other streams of origin. These fish could enter the marsh on high tides and take advantage of the rich rearing conditions that exist there. Opening up access to Edmonds Marsh would also allow establishment of self-sustaining runs of coho and chum salmon, as well as sea-run cutthroat trout in lower Willow and Shellabarger creeks.

The elevation of the existing marsh at the mouth of Shell Creek is largely above the range of high tides; thus, this characteristic of this marsh would not be changed significantly by improving the culvert. Considerable excavation of the existing, productive freshwater marsh would be necessary to provide a significant area of salt or brackish marsh east of the railroad. At present, the culvert under the railroad does not constitute a significant barrier to upstream migration of chum or coho salmon which access this stream freely at high tide.

In summary, daylighting of the Edmonds Marsh outlet would offer a significant benefit in allowing establishment of new anadromous fish runs, whereas modifications of the marsh and culvert at the mouth of Shell Creek would not provide a reasonable ecological gain.

Nearshore AUs

In general, habitat quality of the nearshore environment north of Brackett's Landing is typical of central Puget Sound where a rail line parallels the shoreline. Without the riprap necessary to support and protect the railroad, the nearshore habitat conditions along much of the shoreline in this area may not be significantly different from what they were a century ago. Despite the isolation of the beaches from sediment sources on the adjacent bluffs, the shoreline remains dominated by sand and gravel with a broad sandy lower beach that supports abundant eelgrass. Over the coming centuries, it can be expected that the amount of this sand will decrease unless new sediment sources are provided to the beaches. At present, only streams such as that at Lunds Gulch provide significant sand to continue to nourish these beaches. Presence of the riprap for the railroad has likely eliminated some areas of upper beach that may have historically provided spawning habitat for forage fish spawning. Experimental additions of sediment waterward of the railroad tracks could be considered as a means of building more upper beach habitat restoring forage fish spawning areas. The large Woodway slide that crossed the tracks could warrant study as a prototype for such beach nourishment.

Lower habitat scores for AUs 9.11, 9.12, and 9.13 reflect the significant shoreline modifications resulting from the ferry terminal and the marina. These historic uses are a necessary part of the City's infrastructure and must be considered as a given. An evaluation of the actual effects of these structures on marine resource habitat could provide important data for use in determining if any modifications to the structures or operations would provide significant habitat benefit.

REFERENCES

City of Everett and Pentec, 2001. Salmon Overlay to the Snohomish Estuary Wetland Integration Plan. Prepared for the Port of Everett, Washington, by J.R. Carroll, Everett, Washington, and Pentec, Edmonds, Washington.

Pentec, 2000. Mukilteo Shoreline Habitat Assessment. Prepared for the City of Mukilteo. Prepared by Pentec, Edmonds, Washington.

00130\012\edmondshabitat_r.doc

MANUAL FOR USE AND APPLICATION OF SEWIP TIDAL HABITAT MODEL

INTRODUCTION

BACKGROUND

The Snohomish Estuary Wetland Integration Program (SEWIP) Tidal Habitat Model (the model) is the result of substantial modifications to the anadromous fish portion of the Mudflat Model developed originally by an interagency technical advisory committee (City of Everett et al. 1997). The technical basis and applicability of the Mudflat Model to anadromous fish has been reviewed and modified as a result of the 1999 listing of several Puget Sound anadromous salmonids stocks as threatened with endangerment under the Endangered Species Act. The model modifications were focused on more accurately describing the quality of habitats in the estuary and adjacent nearshore areas for salmonids, with emphasis on chinook salmon, coho salmon, and bull trout. Ecological functions provided by habitats in the SEWIP area include feeding, migration, predator avoidance, and saltwater adaptation. The model provides the tool for inventory and mapping of salmon habitat function, and planning of salmon habitat restoration that is described in the SEWIP Salmon Overlay (City of Everett and Pentec 2001).

Modifications to the Mudflat Model were developed in a series of workshops involving an interagency SEWIP Salmon Overlay Technical Advisory Committee (SSOTAC) composed of biologists from the City of Everett, Snohomish County, the Washington State Department of Ecology (Ecology), the Washington Department of Fish and Wildlife (WDFW), and The Tulalip Tribes. Pentec Environmental biologists provided meeting facilitation and technical input. Although consensus was reached on the great majority of the features of the model, not all aspects of the model were unanimously agreed to by all the SSOTAC participants.

GENERAL APPROACH

The model follows the indicator value assessment (IVA) method of the original SEWIP model and is patterned after the approach of Hruby et al. (1995). The model assesses discrete units of habitat that are delineated by physical changes in habitat types or hydrological boundaries between units of habitat. These discrete units are termed assessment units (AUs). The model asks a series of "yes" or "no" questions about the hydrological, chemical, physical, geomorphological, biological, and landscape features (indicators) present within the AU. The SSOTAC developed these questions and assigned relative values for a positive response to each. Values were based on the degree to which each indicator was judged to be associated with the positive aspects of each function: indicators strongly associated with the function being assessed were assigned a value of 3; those moderately associated were assigned a value of 2; those weakly associated with the function were assigned a value of 1. Aspects of some indicators were judged to be disproportionately beneficial (e.g., large areas of native marsh) or adverse (e.g., severe hydromodification or chemical contamination) to such a degree that they were assigned positive or negative multipliers that are applied to the sum of the values from all the other indicators. Both the indicator value rankings of specific landscape features and the overall value multipliers were assigned metrics based upon evidence from the literature where available, or where literature was lacking, by the collective agreement of the expert panelists.

APPLICABILITY AND GENERAL ASSUMPTIONS

Although developed for use as part of the overall SEWIP, the model is also considered to be fully applicable to other estuary and nearshore conditions around the greater Puget Sound area. The model is designed to be relevant to both tidal estuarine habitats and nearshore environments. Some model questions may not be applicable for both estuarine and nearshore habitats; if the model question is not relevant (or the indicator is not present), the question is simply left as a nonaffirmative answer. In the nearshore, for example, no AU is expected to have a native plant marsh over more than 25 percent of its area; hence this question (16d) likely will never be scored in EMU 6. This will not diminish the model's ability to rate the relative quality of an AU within EMU 6, however. The model is focused only on indicators that are of direct or indirect relevance to anadromous salmonids. Moreover, the model focuses on existing or presumed indicator condition, not on the processes necessary to maintain those conditions. Although the model is clearly focused on the several important functions provided by estuarine and nearshore areas to juvenile salmonids, certain features of the model also serve to rate quality for adult salmon.

DOCUMENT PURPOSE

This document sets forth the underlying rationale and assumptions for each question and provides the model user with background information and protocols to assist in model application. The model is composed of 34 questions. To refine the model sensitivity to complexities and gradients in the environment, several questions include multiple subquestions, with only one subquestion to be answered under each question. This manual lists and describes the main questions. All questions and subquestions can be found in the field inventory sheet, Appendix B.

MAPPING METHODOLOGY

The AUs were first delineated on a series of 1998 aerial photographs obtained by Snohomish County from the Washington State Department of Natural Resources (DNR). This photo series included the County's hydromodification layer, indicating major categories of shoreline modification such as bulkheads, riprap, and dikes. These features were used in conjunction with major transitions in riparian condition or shoreline morphology in the initial delineation (done in the office) of AUs. This photo series was taken to the field and used as the base map and a primary data source for field assessment of each AU using the model. Some AU boundaries were adjusted on the basis of field observations of transitional conditions that were not evident in the photos alone.

Final AU boundaries were transferred onto a second series of 1996 aerial photographs available in the City's GIS system so that the area of each AU could be calculated.

In defining the specific AU boundaries in the waterward and landward directions, the following conventions were used:

1. Waterward Boundary

   - For nearshore AUs in EMU 4 through 7, the waterward boundary was set at -30 ft mean lower low water (MLLW), the approximate limit of productive vegetative growth that directly forms habitat for salmonids (e.g., beds of bull kelp, *Nereocystis luetkeana*).

   - In the mainstem Snohomish River, waterward boundary was set at the edge of the dredged navigation channel or at the -10 ft MLLW contour, where bathymetric data were available.

   - In other distributary channels and in the mainstem above the upper turning basin, the waterward boundary was set at 50 ft waterward of the lowest line of vegetation visible in aerial photos except where more extensive shallow sand or mud bars were evident in aerial photos or from the field surveys; in those cases, the boundary was drawn 50 ft waterward of the lowest edge of the visible shallow-water area.

2. Landward Boundary

   - In AUs lacking riparian vegetation (e.g., riprapped or bulkheaded areas) the boundary was set at mean higher high water (MHHW).

   - In AUs scored as having a riparian buffer (either above or below ordinary high water [OHW]), the landward boundary was set at 25 ft landward of OHW or to the top of any adjacent dike, whichever was least.

In AUs meeting the criterion for large woody debris (LWD) contribution, the boundary was set at one site potential tree height (187 ft) from OHW or to the limit of the trees that could contribute LWD, whichever was least. An exception was made for Otter Island; because of the forested wetland nature of the island and the presence of tidal channels penetrating well into the island, the entire island was considered part of the AU.

Several questions in the model are scored on the basis of portions of the AU that lie within the littoral zone. The littoral zone is defined as that area between MHHW (about +11.2 ft MLLW) to -10 ft MLLW, the area typically considered to be important habitat for juvenile anadromous fish during their early marine life history (e.g., McDonald et al. 1987). In areas where the upper beach is vegetated with water-dependent vegetation, the OHW line will be used to define the upper limit of the AU.

Along the major distributary channels of the Snohomish River, shoreline AUs will be defined and rated down to extreme low water (ELW) in the adjacent channel. This is done to focus assessment of habitat function on those attributes most important to juvenile salmonids. It is assumed that, while moving downstream in the water column of the center portion of the mainstem channels, juvenile salmonids are not dependent on shoreline features that are scored in the model (e.g., McDonald et al. 1987).

ASSUMPTIONS AND FIELD PROTOCOL

INDICATOR GROUP - HYDROLOGY

Question 1: Does AU have a vernal or perennial freshwater stream or spring?

Assumptions: This indicator addresses the feeding and osmoregulatory (saltwater adaptation) functions. Fresh water entering a tidal littoral habitat is assumed to provide increased ecological function by providing a range of small-scale salinity gradients that allow juvenile salmonids to select a salinity compatible with their stage of osmoregulatory adaptation (Thorpe 1994, Healey 1991, Rich 1920). Contributions of fresh water at the saltwater interface can also add diversity of plant and prey assemblages. For example, saltmarshes with freshwater input are more likely to support sedge assemblages that produce prey used by juvenile chinook (Pomeroy and Wiegert 1981). Freshwater streams and springs are especially useful for ocean-type chinook fry that outmigrate to estuary environments shortly after emergence from the gravel (Healey 1982).

Protocol: Answer "yes" if the AU has a freshwater stream or spring during the spring outmigration period. Spring or stream must be of sufficient flow to either modify the vegetative assemblages present or maintain a channel with sufficient depth to provide juvenile salmonids refuge during low tides. Freshwater inflow should be sufficient that salinity in the stream is lower than the ambient tidal water flowing by the AU. Note that presence of a channel is scored separately in Questions 4 and 5; thus, additional value is assumed if the channel is formed by freshwater rather than tidal flow.

Scoring can be done from maps or aerial photographs but may require field survey to verify that the water flow has significant freshwater inflow and does not consist merely of tidal drainage.

Question 2: Is littoral area of AU depositional (slow currents, low wave action)?

Assumptions: This indicator addresses the feeding function. Depositional areas are where settling of fine-grained sediments and organic particles occurs. Depositional areas in estuarine habitats have been shown to be more productive for epibenthic zooplankton prey of juvenile salmonids than are nondepositional areas (e.g., Sibert et al. 1977, Houghton and Gilmour 1997, Houghton et al. 1998).

Protocol: Subquestions are scored based on the percentage of the littoral portion of the AU area that displays depositional characteristics, i.e., fine-grained sediments or accumulations of organic debris. Vegetated marsh areas will almost always be depositional; areas with coarse sand or gravel will seldom be depositional in an estuarine or nearshore environment.

Percentage of AU that is depositional can be determined from maps or aerial photographs, but in many cases will require field verification of breaks in habitat (e.g., sediment) type.

Question 3: Does AU have refuge from high velocities (e.g., during maximum ebb tide)?

Assumptions: This indicator addresses the migration function and is relevant to estuarine AUs only (i.e., it will not be scored for most nearshore areas). Refuge from high velocities during river flooding or during maximum ebb tides allows juvenile salmonids to remain in the estuarine environment longer, potentially increasing the opportunities for feeding and growth before continued migration into the marine environment (Maser and Sedell 1994, Levy and Northcote 1981).

Protocol: Determination that refuge from high velocities is present in an AU may be possible from high-quality aerial photography, but field verification is usually necessary. Features providing this refuge include, but may not be limited to: LWD, large boulders or bedrock features, deep channel areas connected to main distributary channels, blind sloughs, and off-channel mudflat/marsh complexes with low tide refuge. In some cases, artificially constructed features such as wing walls, bridge piers, or riprap may also provide refuge from high velocities (e.g., Maser and Sedell 1994, CDFG 1995).

Question 4: Does AU contain a tidal channel?

Assumptions: This indicator addresses the predation/protection and feeding functions. Shallow tidal channels in marsh/mudflats provide low-tide refuge and feeding opportunities for juvenile salmonids (e.g., Levy and Northcote 1982, Levings 1982, Ryall and Levings 1987, Healey 1991). These functions are especially important for chinook fry (Congleton et al. 1981, Levy and Northcote 1982), as movement by this species into deeper water appears to be controlled by size (Thorpe 1994), probably as a manifestation of predator avoidance. Presence of a channel within an AU allows fish to remain within the AU during low-tide periods (Healey 1982) and prolongs the opportunities for fish to exploit food resources within the AU. Deeper channels and those that remain flooded at tides equal to or lower than MLLW provide additional benefits as deepwater refuge from certain types of predators (e.g., Levy and Northcote 1982). The habitat benefits to chinook of a deep tidal channel are sufficient that a natural, deep tidal channel (or a channel constructed to simulate and function as a natural channel) are given a positive multiplier of 1.5. Channel benefits for bull trout and coho are less well documented but are given a positive multiplier of 1.3. Shallower drainages (i.e., those that do not retain sufficient water for juvenile salmonid residence when the tide falls below mean sea level [MSL]) are still valuable but provide those values for only a portion of the tidal cycle. Constructed navigation channels that bisect an AU were considered to provide many of the functions provided by natural channels.

Protocol: Unless photos taken at different tide stages are available, scoring this indicator will require a site survey. An AU that lies along the margin of one of the major distributary channels of the river does not receive a positive answer for this question unless it has side channels that enter the distributary. "Yes" is the appropriate answer to Question 4a, if the channel is either deep enough (e.g., deeper than 0 ft MLLW) or contains enough runoff flow to provide habitat for juvenile salmonids during low tides. If a natural channel is present but it does not provide habitat below mean tide level, or if a dredged navigation channel is present, answer "yes" to Question 4b.

Question 5: Is tidal channel dendritic or highly sinuous?

Assumptions: This indicator addresses the predation-protection and feeding functions. Most natural unconfined stream channels are sinuous, and channels through broad natural mudflats are often also dendritic, with first-, second-, and third-order channels (Congleton et al. 1981). Increased length provided by channels that are either dendritic or highly sinuous provides increased low-tide refuge area and increased access to more of the AU at more tidal elevations. Healey (1982) also notes that sinuous channels increase trapping of detritus, increasing prey productivity.

Protocol: Channel morphology can be determined using aerial photographs or by site survey. A highly sinuous channel is defined as one that has sinuosity of greater than 1.5; i.e., where the channel length between two points is 1.5 times the straight line distance between the two points. A dendritic channel system within an AU must have multiple secondary channels; the secondary channels can be shallower than the main channel.

INDICATOR GROUP – WATER QUALITY

Question 6: What range of salinity is present in AU?

Assumptions: This indicator addresses the feeding and osmoregulatory (saltwater adaptation) functions. Presence of a range of salinities within the estuarine environment provides staging opportunities for outmigrant and returning salmonids to adjust physiologically between fresh and salt water. The range of salinities available within the estuary transition zone also affects the juvenile salmonid forage base by providing niches unavailable in fresh water only, and thereby a more diverse assemblage of food organisms (e.g., insects and crustaceans) (Pentec 1992). For the function of physiological transition (i.e., up- or down-regulation of gill ATPase activation for adjustment to changing NaCl concentrations), AUs with polyhaline salinities (marine conditions with >18 parts per thousand [ppt] salinity) are considered less important to salmonids than AUs with typically oligohaline or mesohaline salinities (variable salinity often ranging between 0.5 and 5 ppt but occasionally ranging as high as 18 ppt). This difference in importance is a result of the fact that most physiological changes that occur during smoltification occur at the lower salinities (Healey 1982). However, species that spend a greater portion of their early life history rearing in fresh water (e.g., coho, bull trout) may engage in extended rearing in an AU that has predominantly fresh water (almost always <0.5 ppt).

Protocol: The range of salinities within an AU may be based on location within the planning area, ascertained from previous monitoring efforts, or can be evaluated during field survey using either a hydrometer or refractometer. For example, areas in EMU 1 are by definition fresh water, although a deep-channel salt wedge may be present (answer "yes" to Question 6a). AUs in EMUs 4 through 7 are polyhaline (answer "yes" to Question 6c). In EMUs 2 and 3 efforts should be made to characterize the salinities over the tidal range experienced within the AU. This characterization need not require empirical testing, but if modeled, uncertainties should be minimized.

Question 7: Do temperature and dissolved oxygen meet criteria for salmonid health?

Assumptions: This indicator addresses the health and growth efficiency of salmonids in the AU. An AU will provide no function for salmonid rearing or refuge during periods when dissolved oxygen (DO) and/or temperature exceed thresholds of tolerance for the species. Threshold for temperature is considered to be 18°C (64°F) as a 24-hr average. Threshold for DO is considered to be greater than 8 mg/l in fresh water (EMU 1); greater than 6 mg/l in marine areas (EMUs 4 through 7); and greater than 7 mg/l in EMUs 2 and 3. Maximum habitat function is provided when the majority of an AU meets the temperature/DO thresholds at all times. However, if the majority of an AU does not meet temperature and/or DO criteria for salmonids at some times, e.g., mid-day in midsummer, it can still provide suitable habitat at other times, when temperature and/or DO are not limiting.

Protocol: Range of temperature and DO within an AU should be determined from previous monitoring efforts to the extent practicable. Alternatively, or additionally, these data can be collected during field visits with portable field probes. Efforts should be made to characterize the temperature/DO over the tidal and seasonal range experienced within the AU. This characterization could be modeled and need not require field measurement. Measurement of acceptable temperature and DO in an AU in the late spring or summer suggests that these water quality factors would be unlikely to limit salmonid use in the fall through early spring, when temperatures are lower and DOs higher.

INDICATOR GROUP – PHYSICAL FEATURES

Question 8: Shoreline complexity: What is the ratio of the AU high-water shoreline length at MHHW to its linear width at MLLW?

Assumptions: This indicator addresses the migration, predation/protection, and feeding functions. Higher shoreline complexity increases the "edge effect" by increasing the length of shoreline in close proximity to vegetation and the opportunity for fish to feed and find refuge from certain predators along the upper tide line. Shoreline vegetation provides direct shade, cover, and insect fall for juvenile salmonids (e.g., Spence et al. 1996; Cordell et al. 1997, 1998; Hetrick et al. 1998a,b) as well as indirect benefits from contribution of leaves and twigs to the detrital food base within the AU.

Protocol: Waterward edge width is the straight-line distance (e.g., at MLLW) between the boundary lines between the AU in question and the two adjacent AUs, measured parallel to the flow of the adjacent river channel (or parallel to the beach contour, in nearshore AUs; EMUs 4 through 7; see Figure 1). The high-water shoreline at MHHW is approximately the distance a fish migrating in shallow water would follow at high tide in transiting through the AU. In the estuary, this line may coincide with the transition from unvegetated mudflat to vegetated marsh. In a modified AU, the line may be along a dike edge or bulkhead. In nearshore areas, this line may be the high tide wrack line and may or may not be vegetated, or it may follow the MHHW line along a modified (e.g., riprapped) shoreline. If an island is present wholly within the AU, the distance around that island at MHHW is added to the length of the MHHW shoreline around the perimeter of the AU. This question is best answered using aerial photographs taken at low tide.

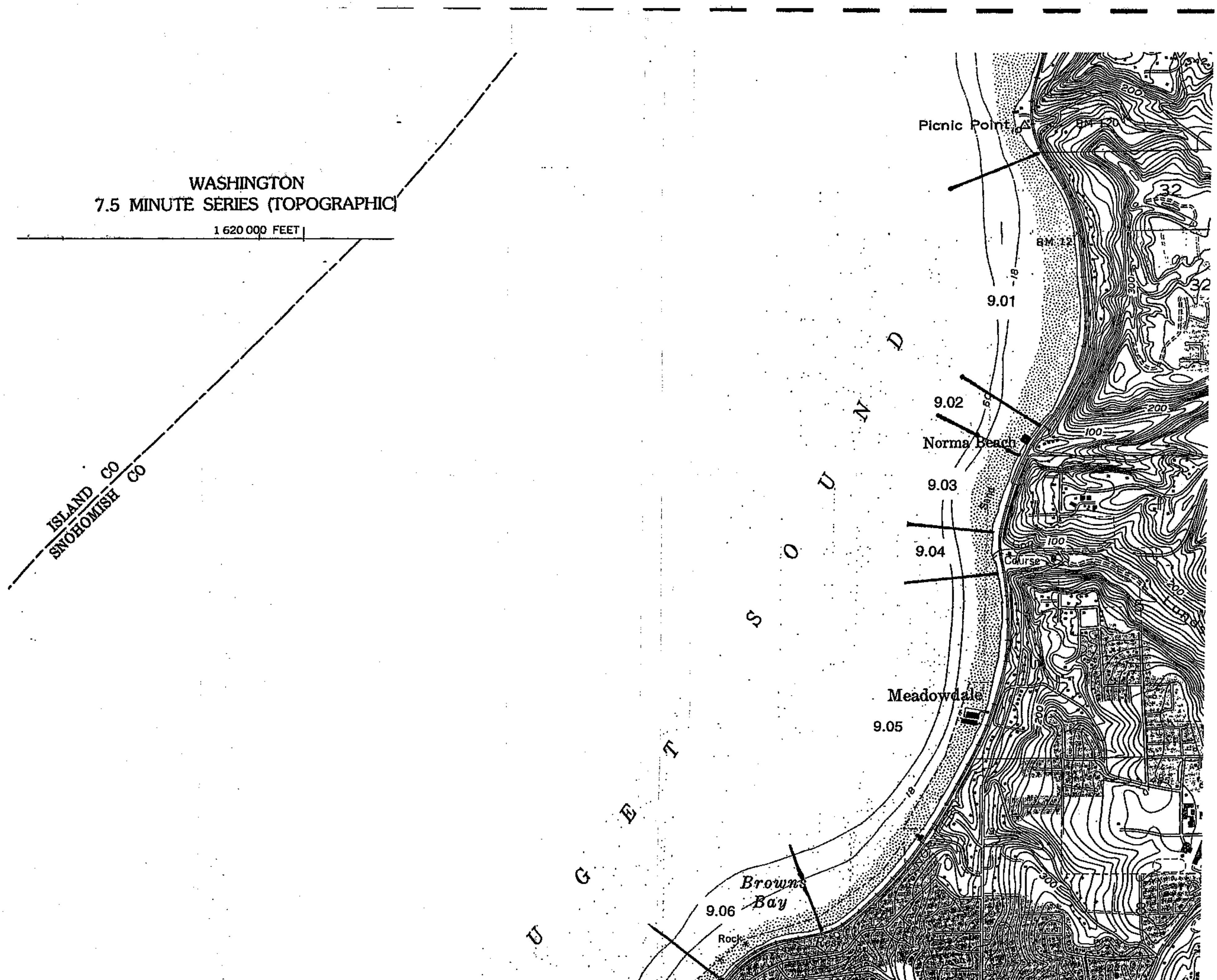
Question 9: Is AU sheltered from waves?

Assumptions: This indicator addresses the feeding and refuge functions. Shelter from wave action provides a stable sediment/water interface. This stability allows accumulation of fine organic detritus on the sediment surface and allows development of a productive microflora, primarily benthic diatoms. Both detritus and microflora are grazed by epibenthic zooplankters that are prey for juvenile salmonids (Healey 1982, 1991). Shelter from wave action also reduces suspension of sediment that can reduce feeding efficiency of juvenile salmonids For example, Bisson and Bilby (1982) showed that juvenile salmonid feeding efficiency was reduced in waters with turbidities greater than 70 to 100 NTU. (See Newcomb and Jensen 1996 for comprehensive review of suspended sediment effects.)

Protocol: This indicator is scored based on the geographic location and morphological configuration of the AU and surrounding uplands in relation to prevailing winds. Most AUs in EMUs 1 through 3 that are not along the main river channels are sheltered from waves. In some AUs, a portion of the area may be exposed to waves while the remainder is not; answer this question "yes" if more than 50 percent of the AU is sheltered.

Question 10: What is the predominant slope of the AU in the littoral zone?

Assumptions: This indicator addresses the feeding and predation/protection functions. Lower slopes in the littoral zone are presumed to provide small fish with shallow-water escape


WASHINGTON
7.5 MINUTE SERIES (TOPOGRAPHIC)
1 620 000 FEET
ISLAND CO
SNOHOMISH CO
Picnic Point
BM 12
9.01
9.02
Norma Beach
9.03
9.04
Course
Meadowdale
9.05
Browns Bay
9.06
Rock
PUGET SOUND

primarily juveniles, although certain features also rate habitat quality for adults. Values are based on the degree to which each indicator was judged to be associated with the positive aspects of each function. Indicators strongly associated with the function being assessed were assigned a value of 3; those moderately associated were assigned a value of 2; those weakly associated with the function were assigned a value of 1. Several questions include multiple subquestions, with only one subquestion to be answered under each question. Aspects of some indicators have been judged by the THM's developers to be disproportionately beneficial (e.g., presence of a natural tidal channel wetted at mean lower low water [MLLW]) or adverse (e.g., presence of riprap or bulkheads below mean higher high water [MHHW]) to such a degree that they are assigned positive or negative multipliers that are applied to the sum of the values from all the other indicators. Different multipliers for chinook salmon and coho salmon/bull trout for certain indicators reflect differences in habitat preference/requirements for these species. A discussion of the underlying rationale and assumptions for each question is provided in Appendix A.

The SEWIP Salmon Overlay report grouped the individual AUs into seven Ecological Management Units (EMUs). A portion of EMU 7 includes the nearshore AUs from the City of Everett south to the City of Mukilteo (Elliot Point). For the Mukilteo Shoreline Habitat Assessment, we designated the shoreline from Elliot Point to Picnic Point as EMU 8. To maintain consistency with these previous efforts, we designated the shoreline from Picnic Point to Edwards Point as EMU 9 (see Figure 1). Based on the physical habitat features visible in the photos (and our familiarity with the survey area), we divided this shoreline segment into 15 AUs (i.e., 9.01, 9.02,...9.15), including the Shell Creek and Edmonds marshes. Each AU was evaluated for existing habitat conditions using the THM score sheet (Appendix B).

RESULTS OF HABITAT ASSESSMENT

The existing AU scores, by assessment species, are presented in Table 1. The AU scores for the nearshore environment from Picnic Point to Edwards Point indicate a generally moderate level of habitat quality, with some AUs providing substantially greater habitat value as compared with others in this EMU. Assessment unit 9.04, which contains a pronounced stream delta (Lunds Gulch), scored the highest of all AUs included in this evaluation. In contrast (and not surprisingly), AU 9.12, defined as the area inside of the Edmonds Marina breakwater, scored the lowest of all the AUs. The next lowest score was recorded for AU 9.13—located outside of the marina breakwater—and is likewise attributed to the extensive shoreline modifications there. AU 9.11, from certain types of predators such as piscivorous fish (Thorpe 1994). Shallower slopes also tend to be composed of finer sediments and provide a stable sediment/water interface for development of epibenthic zooplankton prey (CDFG 1995).

Protocol: Simple field measurements using a hand-held clinometer or visual observations can be used to score this question. The answer is based on the average slope over the majority of the littoral zone of the AU. For example, an AU with a riprapped margin between OHW and MSL, but with a broad mudflat from the toe of the riprap to the channel edge, would merit a "yes" on Question 10a. (The adverse effects of the riprap would be accounted for in several other questions in the model.)

Most mudflats or marshes are flatter than 10h:1v. Shoreline areas that are modified with riprap are often steeper than 2h:1v and thus would receive no score under this question. Detailed surveying may be needed to score areas with intermediate slopes, such as an AU along a distributary channel with a moderately sloped, diked shoreline.

Question 11: What range of depths is present in the AU?

Assumptions: This indicator addresses the feeding and predation/protection functions. Littoral areas between MHHW and -10 ft MLLW are typically considered to constitute the depth range wherein juvenile salmonids prefer to feed and migrate during their early marine life history (Thorpe 1994, CDFG 1995). This range encompasses the depths at which smaller juvenile salmonids feed primarily on epibenthic prey (e.g., amphipods, harpacticoid copepods, decapod larvae—see Healey 1982); larger smolts transition to a more pelagic lifestyle and feed predominantly on prey such as fish larvae in the water column (Kask and Parker 1972, Healey 1991, Thorpe 1994). Also, availability of shallow water provides alternatives for predator avoidance. Thus, an AU that has more of its area within the littoral depth range is considered to provide better functions for juvenile salmonids than an AU where much of the area is deeper or seldom inundated.

Protocol: Percentage of the AU within the preferred littoral range can be determined in the field or from available bathymetric surveys. Where native marsh vegetation extends above MHHW, the littoral area should be extended to OHW, since the high marsh also contributes to salmonid habitat quality.

INDICATOR GROUP – SEDIMENT TYPE

Questions 12 through 15: What sediment types are found in the littoral portion of the AU?

Assumptions: This indicator addresses the feeding function. Presence of finer-grained sediments, either as a silt or mud bottom or in a matrix of coarser gravel or cobble, is indicative of a more productive littoral environment for salmonid prey, primarily epibenthic crustaceans (CDFG 1995, Pentec 1996, Angell and Balcomb 1982, Simenstad et al. 1991, Sanders 1959).

Protocol: Note that Questions 12 through 15 can each be answered in the affirmative independent of other responses. If the littoral zone of an AU has 75 to 100 percent mud or mixed fine substrates, "yes" is the correct answer to Questions 13 and 14.

Question 12: Answer "yes" if the littoral zone of the AU has more than 25 percent of its bottom covered with silty sand.

Question 13: Answer "yes" if the littoral zone of the AU has 25 to 50 percent of its bottom covered with mud or mixed fine sediments.

Question 14: Answer "yes" if the littoral zone of the AU has more than 50 percent of its bottom covered with mud or mixed fine sediments.

Note: An AU with 80 percent mud or mixed fine substrate would score a "yes" for both Questions 13 and 14, for a total value of 5. Also, an AU with 30 percent silty sand, 40 percent mud, and 30 percent coarse sand or cobble would answer "yes" to Question 12 and "yes" on Question 13, for a total value of 3.

Question 15: Answer "yes" if the AU has spawning habitat for surf smelt or sand lance in the upper intertidal zone.

Surf smelt spawn in a coarse mixture of sand, pea gravel, and shell fragments at high-tide swash lines (Bargmann 1998, Eschmeyer and Herald 1983). Sand lance spawn in sand-gravel substrate in the upper intertidal zone between mean high tide and approximately +5 ft

(Bargmann 1998). The WDFW baitfish unit in La Conner should be contacted regarding identified spawning areas in any particular AU.

INDICATOR GROUP – RIPARIAN ZONE

Two aspects of the nature of the riparian zone bordering estuarine and nearshore AUs are considered in the model: the extent of tidal marshes below OHW and the extent of riparian scrub-shrub and forest above OHW. It is recognized that the several functions of riparian buffers typically identified as applicable along streams higher in the watershed (e.g., Spence et al. 1996, Brosofske et al. 1997, Hetrick et al. 1998a,b) are not fully applicable in providing similar functions in the estuary and nearshore areas. Nonetheless, these riparian zones do affect the quality of these habitats for salmonids. Questions 16 through 19 address the feeding and refuge (predation/protection) functions.

Question 16: Is the vegetated edge below OHW?

Assumptions: Many tidal areas are bordered by intertidal marshes that serve several of the buffer functions typical in more fluvial systems. For example, the marsh may provide refuge (for juvenile salmonids that can swim in among the vegetation to avoid predators), food (e.g., insect production [Cordell et al. 1998]; amphipods [Levings 1990]), and a source of detrital energy to important food webs. Marshes are a principal foraging area for ocean-type chinook fry (Levings 1990, Thorpe 1994) and are extensively used by salmonids at night (CDFG 1995). The model assumes that juvenile salmonids utilize primarily the waterward edge of tidal marshes and do not penetrate more than a few feet into densely vegetated areas; thus, full functional value is given for an AU with saltmarsh around 50 percent of its shoreline that is greater than 10 ft in width. The additional indirect functions provided in AUs with a tidal marsh of native vegetation covering more than 25 percent of their area are recognized with a 2X multiplier in Question 16d.

Protocol: In most cases, width of the vegetated edge must be assessed from site survey of the AU, as aerial photography will not provide the accuracy to delineate the vegetated edge at the widths defined by the model. Also, assessment of species composition (i.e., non-native vs. native) is required to address the multiplier defined in 16d. Answer "yes" to Question 16d if native species occupy the vegetated edge over greater than 25 percent of the AU surface area below OHW.

Question 17: Is the vegetated edge above OHW?

Assumptions: If the marsh fringe is of sufficient width, the contribution of riparian forests at higher elevations (>OHW) is reduced, or, at the very least, effective only during the highest tides. For example, trees may provide shade along the edge of the high marsh that is seldom underwater; hence, shading will have little effect on water temperature. However, if the saltmarsh fringe is relatively narrow, riparian forests along the edge of the saltmarsh may provide highly effective shading over the water, and relatively increased contributions of organic components to support the detrital food web over that contributed by saltmarsh vegetation alone. Such conditions could be found particularly within the upper estuary. Riparian scrub-shrub and forests are assumed to begin providing significant functions in estuarine and nearshore areas at widths exceeding 25 ft or covering the waterward sides and tops of dikes. Credit is given under Question 17 even where the riparian vegetation is dominated by non-native species such as blackberry, on the assumption that this vegetation will still provide shading, insect fall, and litter fall to the aquatic environment. Additional credit is given under Question 18 if the vegetation is predominantly native species.

Protocol: Width and composition of the riparian forest is usually assessed from a site survey of the AU, as aerial photography may not provide the accuracy to delineate the riparian composition at the widths defined by the model. Answer "yes," as appropriate, among the three qualifiers (i.e., 17a,b,c) based upon field measurements or estimates of the width of the riparian zone above OHW and the extent of the AU high-water margin that has riparian scrub-shrub or forests greater than 25 ft in width. Credit can be given for vegetated widths less than 25 ft where the shoreline configuration supports riparian vegetation for the full width that may interact with the aquatic environment (e.g., the waterward slope and top of a dike).

Question 18: Is the riparian zone vegetation dominated by native species?

Assumptions: It is assumed that riparian vegetation that includes a mix of native species will provide a greater food resource to juvenile salmonids than will a riparian border of non-native species.

Protocol: If the riparian scrub-shrub or forest vegetation is dominated (>50 percent of the total cover) by native species, answer yes to Question 18.

Question 19: Does the riparian zone of the AU provide a significant source of LWD?

Assumptions: This indicator addresses the feeding and predator/protection functions. In general, the role of LWD in providing fish habitat within the estuary and nearshore is assumed to be of lesser importance than its role in freshwater fluvial conditions upstream. This is because of tidal water-level changes, which leave anchored wood submerged, or out of the water, a portion of the time, and because of the reduced importance of the pool-forming function of wood in estuaries where juvenile salmonid use is less than year-round. Late seral stands of riparian forest are necessary to recruit LWD into the active stream channel or marshes accessible to anadromous fish. Immature riparian forests do not provide LWD that will be retained for a long enough period of time in the channel to be considered important fish habitat elements. To be of direct habitat value to salmonids, LWD must be large enough to be retained in the channel and thereby provide hydraulic control, cover, and velocity refuge. Large wood also provides for organic contributions to the estuary and thereby supplements the detrital base (Maser and Sedell 1994).

Relatively smaller sizes of LWD can be retained in lower-energy, off-channel estuarine habitats and thus provide the same functions as larger LWD in more active channels. Mature trees considered for this purpose are those with diameter at breast height (dbh) of more than 0.3 m. Trees recruit to the estuary or nearshore from the adjacent riparian zone are assumed to have limbs and rootwads attached; thus, the criterion for recruitment is similar to that for inwater LWD with limbs or rootwads (Question 20).

Protocol: The state of maturity of a riparian stand can be evaluated from recent, high-quality, aerial photographs, or from field surveys. Answer "yes" to Question 19 if at least 50 percent of the riparian zone of the AU contains mature trees that meet the 0.3-m dbh size criterion, and if those trees have the potential to fall into areas accessible to juvenile salmonids, generally considered to be below MHHW. If the area between MHHW and OHW consists of a broad, vegetated marsh, trees that fall from the riparian forest will land in these vegetated areas and have little potential to provide the full function of LWD in stream or shoreline areas. Although such trees may still provide limited function, they would not be considered to be a significant source of LWD in the context of the model. Diameter at breast height should be considered from field measurements of at least six trees within the AU.

INDICATOR GROUP – LANDSCAPE/CONNECTIVITY

Question 20: Is AU connected to adjacent AU by low- to moderate-gradient littoral habitats?

Assumptions: This question addresses the migration and predator-avoidance functions. Free and safe movement of juvenile salmonids through the sequence of habitats available in the estuary is an important determinant of the overall functional quality of the estuary (Thorpe 1994). Therefore, availability of a safe migration pathway from one AU to the adjacent AU is considered to improve the function of both. A safe migration pathway is defined as a low-gradient, e.g., 5h:1v or flatter, transition from one AU to the next.

Protocol: The boundaries between AUs should be examined during field surveys to determine the nature of shorelines. Often, distinct breaks in shoreline type will be used to define the boundaries of adjacent AUs. If these breaks are the result of shoreline armoring, bulkheading, or deep water, then the two adjacent AUs would be judged to lack shallow-water connectivity. If one AU transitions into the next along a low- to moderate-gradient shoreline in one direction, answer "yes" to Question 20a. If it has low-gradient transitions into adjacent AU on both sides, answer "yes" to Question 20b.

INDICATOR GROUP – SPECIAL HABITAT FEATURES

Question 21: Does the AU contain significant densities of LWD?

Assumptions: This indicator addresses the feeding and predation/protection functions. The relative importance of LWD in providing physical habitat and hydraulic control in the estuary and marine nearshore areas is believed to be lower than in upstream reaches, but it is still important (e.g., Maser and Sedell 1994). Suitable criteria for wood-loading in estuaries and marine areas have not been established by quantitative research and likely would vary substantially over the gradient of conditions present.

The retention of wood in the channel is a function of channel width, wood size, and wood type, whereby wide channels retain proportionately less wood per unit channel length than narrower channels. Most of the wood recruited into estuaries and nearshore areas is derived from upstream sources, not from riparian stands immediately adjacent to AUs within the estuary. For purposes of this model, LWD is defined to include the following:

- logs with length >10 m and diameter >0.6 m
- logs/trees with rootwad and/or branches, length >10 m, and diameter >0.3 m
- stumps with diameter >1 m

Wood-loading densities proposed for the estuary and nearshore reflect a reduced ecological function of LWD in estuary and nearshore areas compared with densities suggested by DNR as needed to rank as "good" loading levels in streams. The inchannel densities assumed in the model to provide full ecological function would rate as "fair" under the Washington State Forest Practices Board (WFPB 1994) watershed analysis protocols for channel widths less than 20 m in streams. This rating is justified on the basis of the reduced functionality of LWD in the estuarine environment (for salmonid habitat), and the "channel widths" found in the estuary that often exceed 20 m. The suggested model LWD assessment values would be within the range considered "good" by Ralph et al. (1991) for Washington streams with channel widths less than 20 m in unmanaged forests (range reported: 0.46 to 3.95 pieces per channel width). LWD criteria have typically been based on number of pieces per linear distance of stream channel, reflecting the derivation of those values. LWD densities (number of pieces per 100 m^2) are also proposed for broader marsh and mudflat areas that are prevalent in estuarine areas, although no field measurements are available upon which to base these levels.

Protocol: Wood loadings within a channel edge or nearshore AU must be assessed by field survey of the AU. Number of pieces by size class along the edge of the MHHW line should be counted along with those visible at lower water levels. In a broader marsh or mudflat AU, the number of pieces of LWD visible between MLLW and MHHW is counted and divided by the area of the AU between the same boundaries.

Question 22: Does the AU support macroalgal coverage over more than 10 percent of the littoral area during the spring outmigration period?

Assumptions: This question addresses the feeding and predator-avoidance functions. Macroalgae, especially where represented by several species, provide a substrate for growth of diatoms and for grazing by epibenthic crustaceans that constitute an important prey of juvenile salmonids (Northcote et al. 1979, Healey 1982, Levings 1990). In nearshore areas, macroalgae such as rockweed (*Fucus gardneri*) and laminarians (e.g., *Laminaria saccharina*) also provide vertical structure above the bottom that can provide refuge for juvenile salmonids from piscivores.

Protocol: This question may be scored based on high-quality color or color-infrared photographs; if such photographs are not available, a springtime field survey will be required. Area of coverage within the littoral zone will be visually estimated.

Question 23: Does the AU support eelgrass along the lower intertidal edge?

Assumptions: This question addresses the feeding and predator-avoidance functions. Eelgrass (*Zostera marina*) has been demonstrated to provide high-quality feeding and refuge habitat for juvenile salmonids (e.g., Simenstad and Wissmar 1985, Levings 1990, Thorpe 1994). Harpacticoid copepods in particular may be highly abundant on eelgrass blades. Eelgrass also provides a substrate for spawning by herring and may also provide structure for predator avoidance (e.g., Thom et al. 1994). Eelgrass may be found between about +2 ft and -18 ft MLLW, depending on water clarity.

Note: While the importance of eelgrass in overall AU function for juvenile salmonids is reflected in the SEWIP Model, the model and SEWIP management policies cannot be used as the sole means of addressing eelgrass impacts and mitigation requirements from a development proposal. Actions that might affect eelgrass beds must also comply with WDFW policies and the state Hydraulic Code (WAC 220-110).

Protocol: This question may be scored based on high-quality color or color-infrared photographs; if such photographs are not available, field surveys will be required. Field surveys should be conducted between late spring and early fall by diver, underwater video, or by extreme low-tide foot or boat surveys.

Question 23a: Answer "yes" if eelgrass is present along 5 to 10 percent of the low-tide shoreline of the AU.

Question 23b: Answer "yes" if eelgrass is present along 10 to 25 percent of the low-tide shoreline of the AU.

Question 23c: Answer "yes" if eelgrass is present along more than 25 percent of the low-tide shoreline of the AU.

Question 23d: Answer "yes" if eelgrass is present over more than 25 percent of the entire area of the AU.

This question (23d) results in a multiplier of 2 times the entire score for the AU and reflects the high importance placed on eelgrass for juvenile salmonids and for overall nearshore ecosystem function. (Recall that only one of these four subquestions may be answered.)

Question 24: Do functioning feeder bluffs provide a significant source of sediment to the AU?

Assumptions: This question addresses the feeding function. Erosion of gravel feeder bluffs along the shorelines of Puget Sound is a major contributor to the maintenance of certain types of shoreline habitat (e.g., Canning and Shipman 1995), including areas that support spawning by important forage fish species (Bargmann 1998, Eschmeyer and Herald 1983). In many areas of Puget Sound, feeder bluffs have been isolated from erosion by shoreline hardening (see Question 30) increasing the relative importance of remaining bluffs.

Protocol: This question is best scored during a field visit. Answer "yes" if a feeder bluff is present that is not cut off at its base from wave erosion and longshore sediment transport, and if the bluff appears to provide a significant sediment source to the associated beach.

INDICATOR GROUP – STRESSORS

Question 25: Is access to the AU by anadromous fish limited?

Assumptions: Artificial (man-made) barriers to immigration and emigration limit habitat use by salmonids for rearing, and thereby may reduce the overall carrying capacity of the estuarine environment for salmonid production. Any AU with access restricted by an artificial barrier over 90 percent of the time is considered to provide no function for salmonids, and the model score for such an AU would be zero (i.e., no value). Many portions of estuarine habitats will be naturally restrictive at certain times of the year because of high water temperatures or tidal conditions; such natural restrictions to habitat use are not penalized under this protocol.

Freshwater and estuarine habitat restrictions may represent the singlemost important element to reducing the ability of a system to support salmonids. Variable stressor penalties recognize that not all barriers are complete; that is, some habitat may be accessible under some tidal conditions and not others. Stressor penalties increase with increasing access restrictions to habitat. Artificial barriers restricting estuarine use include diking, ditching, dredging, and impassable or restrictive tide-gated culverts (Beechie et al. 1994).

Protocol: To answer this question, the assessor must examine the AU for the presence/ absence of culverts and/or dikes. If these are present within the AU, they pose a potential restriction to tidal circulation and immigration/emigration for salmonids. Culverts should be evaluated for length, slope, presence/absence of tide gates, and tide-gate functionality (if present). If present, the assessor should address tide-gate functionality at both low and high tide. The assessor will determine if the potential exists to strand salmonids within the AU on the basis of the evaluation of the tide-gate function. Culvert slope and length will be evaluated for their ability to pass juvenile salmonids upstream on an ebb tide by virtue of the velocity and depth gradients established. Criteria for juvenile salmonid passage will follow those reported by Powers (1997). Dikes or storm berms that totally isolate an AU from salmon-accessible waters on all but flood or extreme tides (e.g., AU accessible less than 10 percent of the time) dictate that it is inappropriate to score the AU for salmon in its present state.

The lowest penalty (Question 25a) recognizes that an AU with partially restricted access (i.e., is inaccessible 25 to 50 percent of the time) may still provide important habitat for salmonids. A barrier restriction that exists 50 to 75 percent of the time (Question 25b) carries a greater risk of stranding or isolation of fish within the AU, thereby resulting in increased mortality. An AU that is only accessible between 10 and 25 percent of the time is considered to provide limited habitat for juvenile salmonids and is assigned the lowest decimal multiplier.

Question 26: Does the AU contain accumulations of wood debris (e.g., bark) over the bottom?

Assumptions: This question addresses the feeding function. Small to moderate accumulation of wood debris on the bottom (up to 40 percent by volume) can have a stimulatory effect on benthic assemblages (Kathman et al. 1984, Schaumberg and Walker 1973). However, dense accumulations of wood debris that smother the bottom (i.e., reach 100 percent cover of the bottom) have been shown to have a strongly negative effect on benthic infauna and to result in significant changes to epibenthos (e.g., Conlan and Ellis 1979, Jackson 1986, Freese and O'Clair 1987).

Protocol: Two levels of wood debris accumulation are reflected by Questions 26a and 26b. For AUs that are largely intertidal, this question can be answered by a field reconnaissance during low tide. Subtidal areas where wood debris accumulations can be expected must be surveyed by some combination of grab sampling, video observations, or diver observations.

Question 27: Does intertidal log raft storage occur in the AU?

Assumptions: This question addresses the feeding function. Grounding of log rafts at low tide can affect the benthic community by compacting sediments, smothering organisms, and precluding access to the underlying sediments. Zegers (1979) found an 88 to 95 percent reduction in benthic organism populations in Coos Bay, Oregon, due to grounding of logs. Smith (1977) found that the only benthic organism not affected by grounding of logs in the Snohomish River Estuary was the epibenthic amphipod *Anisogammarus*. (These animals, which are a preferred prey species of juvenile salmonids, may have been attracted to the log rafts.) This question is scored based on the percentage of the AU affected by log raft storage on a recurring basis (i.e., more than once a quarter), because the effects of log raft grounding on epibenthic prey of juvenile salmonids diminish rapidly with time since the last storage (e.g., Cheney 1989).

Protocol: Answer "yes" to Question 27a if log rafts have affected 10 to 50 percent of the AU in the last 3 months. Answer "yes" to Question 27b if log rafts have affected more than 50 percent of the AU in the same time period.

Question 28: Do water column contaminant concentrations exceed salmonid thresholds for health or survival?

Assumption: This question addresses the feeding and health functions. Toxicants within the water column could cause direct mortality, preclude the use of habitat, or cause sublethal toxicity to salmonids during periods of exposure within an AU. For example, outmigrant juvenile salmonids passing through a PCB- and PAH-contaminated portion of the Duwamish River Estuary were found to exhibit reduced disease resistance relative to unexposed control group fish (Arkoosh et al. 1998). The impact from such exposures to the overall salmonid population within a WRIA is assumed to be proportional to the relative percentage of the population exposed to those conditions when such thresholds are exceeded. Thus, if water column thresholds are exceeded during periods of high abundance, then the impact could be significant; if thresholds are exceeded during low abundance periods, the impact from the stressor would be less significant. The SEWIP stressor multipliers reflect this proportionality difference, by assigning multipliers of 0.3 and 0.7 to the total score during periods of high and low salmonid abundance, respectively. It is assumed that exceedance of existing water quality toxicant standards within an AU would equate to a potentially stressful condition for salmonids, and such exceedances, if present over a significant portion of the AU, would warrant the application of one of the above stressor multipliers; stressors present in a limited, permitted, mixing zone within the AU would not warrant a positive response to these questions. It is also assumed that these stressor multipliers would be assigned to anthropogenic toxicants only. Conventional water quality parameters (temperature and DO) are not evaluated under the stressor categories (see Question 7).

Protocol: Evaluation of water column pollutants within an AU can be conducted by review of relevant and applicable data from the site or from a nearby location that could be construed to exhibit similar conditions based upon site history. If there were no historical record of industrial activity on or near the site, it would be unlikely that toxicant exceedances in the water column would exist. Should field reconnaissance suggest that water quality is locally impaired within the AU, then field sampling should be conducted and samples submitted to a qualified laboratory to define the extent and significance of impairment. Field observations of odd color, odor, sheen, or unusual biological indicators (e.g., dead fish, dead algae, etc.) would be indicators to the assessor that water samples should be collected and submitted for analysis. If water samples are collected, site conditions will dictate whether simple grab samples or depth-integrated sampling is warranted. Standard water sampling protocols will be followed in accordance with laboratory procedures (APHA et al. 1995).

Question 29: Do AU sediments contain contamination at levels that may affect salmonid health or prey base?

Assumptions: This question addresses the feeding and health functions. Toxicants within sediment may serve as a source of bioavailable contaminants to which salmonids could be exposed within an AU. Contaminated sediments could preclude the use of habitat or cause sublethal toxicity to salmonids during periods of exposure within an AU. They could also affect the species abundance and distribution of critical salmonid food organisms. The direct impact from contaminated sediment exposures to the overall salmonid population within a WRIA is proportional to the total area affected, and the concentrations of the contaminants within the area contaminated as defined by the state sediment quality standards (SQS) or cleanup screening levels (CSLs). The SQS and CSLs are biological criteria based on benthic infaunal taxa not directly trophically linked to salmonids. Since salmonids do not depend heavily on food webs based on infauna, it is assumed that the adverse effects of sediment contamination on salmonids are less severe than those of water column contamination.

Protocol: Existing data will be used to evaluate sediment conditions within an AU, to the extent possible. Should there be no foreseeable source of contamination to the site (e.g., no on-site or adjacent industry, or recent history of such) then it will be assumed that the sediment would meet salmonid use thresholds. If review of the site history indicates otherwise and no sediment evaluations have been conducted, then sediment sampling will be considered. Existing sediment sampling protocols will be followed in accordance with local jurisdiction requirements. Thus, sampling may involve grab samples for surficial sediments or sediment coring. Site-specific protocols will be developed for each evaluation in conjunction with regulatory authorities.

Thus, if SQS thresholds are exceeded over more than 25 percent of the AU, a multiplier of 0.8 is applied to the total SEWIP score, whereas if the higher CSL levels are exceeded over the same aerial extent, a multiplier of 0.6 is applied. Similar to the water column evaluations of toxicants, it is also assumed that these sediment-stressor multipliers would be assigned to anthropogenic toxicants only; thus, conventional sediment quality parameters (e.g., grain size, total organic carbon) are evaluated.

Question 30: Does AU shoreline include riprap or vertical bulkheads extending below MHHW?

Assumptions: This question addresses the feeding, migration, and predator-avoidance functions, as well as shoreline sediment source and transport processes, and reflects the horizontal extent of shoreline hardening. It is widely assumed that juvenile salmonids encountering vertical bulkheads or steep riprap as they migrate along estuarine or marine shorelines are more vulnerable to predation than they are as they migrate along gradually sloping beaches (e.g., Heiser and Finn 1970, Thom et al. 1994). Smaller fish (e.g., pinks, chums, and ocean-type chinook) are considered to be more vulnerable to predation along a vertical bulkhead than larger fish such as stream-type chinook, coho, and bull trout. Limited observations of predation along bulkheads and riprap in the Everett Harbor area (Pentec 1997) found that larger salmonids (possibly bull or cutthroat trout) were the primary predators on smaller salmonids. Thus, vertical bulkheads result in a lesser reduction of habitat function (a higher decimal multiplier) for bull trout and coho than for chinook. Vertical bulkheads also provide less shallow-water surface area for generation of epibenthic prey favored by smaller juvenile salmonids and may force fish to switch to pelagic prey.

Riprapping or bulkheading of shorelines also interferes with normal shoreline sediment erosion and deposition processes (e.g., Canning and Shipman 1995). Thus, bulkheads or riprap at any slope that limits natural shoreline processes is scored under this question.

Protocol: This question can be answered either through site photographs of sufficient detail or through a site visit. Answer "yes" to Question 30a if the AU high-water shoreline has 10 to 50 percent riprap or vertical bulkheads, or "yes" to Question 30b if more than 50 percent of the shoreline is hardened.

Question 31: Do riprap or bulkheads extend below MSL over the majority of the hardened AU shoreline?

Assumptions: This question addresses the feeding, migration, and predator-avoidance functions and reflects the vertical extent of shoreline hardening. The tidal nature of littoral habitat is recognized along with the fact that riprap or bulkheading can eliminate a large proportion of the intertidal habitat that would normally be available to juvenile salmonids. AUs in which the majority of the shoreline hardening extends below MSL (about +6 ft MLLW) will lack essential natural features of upper intertidal habitat and will be reduced in overall area. Migrating fish will encounter the hardened shoreline over 50 percent of the time. Therefore, this condition is scored with an additional decimal multiplier.

Protocol: This question can be answered either through site photographs of sufficient detail or through a site visit. Answer "yes" to Question 31 if shoreline hardening extends below MSL over a major portion (e.g., more than 25 percent) of AU shoreline scored as hardened in Question 30.

Question 32: Does the AU have one or more finger piers or marginal wharfs?

Assumptions: This question addresses the predator-avoidance function. Limited studies and observations have shown that a portion of shoreline-migrating juvenile salmonids, upon encountering a large overwater structure in marine areas, may either delay further shoreline movement for a time or move waterward along the margin of the wharf (e.g., Pentec 1997, Heiser and Finn 1970). It is presumed that those fish that move into deeper water or farther from shore may become more vulnerable to certain types of predation than they would be had they not encountered the wharf, although there is little information in the literature to document this predation (Pentec 1997, Simenstad et al. 1999). The degree of light penetration under the structure is considered to be important in determining the degree of interruption of migration induced by a wharf, but Ratte and Salo (1985) found no significant difference in the numbers of juvenile salmonids captured under a wharf in Tacoma between periods when the under-wharf area was artificially lighted and when it was unlit.

Protocol: This question can be answered either through site photographs or through a site visit. Answer "yes" to Question 32a if the AU has one finger pier, dock, or wharf greater than

8 ft wide, or "yes" to Question 32b if the AU has either two or more docks that are 8 to 25 ft wide or a single structure that is more than 25 ft wide.

Question 33: Is more than 10 percent of the AU littoral area covered with overwater structures that are more than 8 ft wide?

Assumptions: This question addresses the feeding, migration, and predator-avoidance functions. Shading of littoral area bottoms can reduce or eliminate benthic primary productivity. The effect is seen between elevations of about +8 ft MLLW (on most substrates; OHW in a marsh area) and -10 to -25 ft MLLW (depending on water clarity). Above +8 ft MLLW, there is little primary production on most substrates and rates of production are more limited by high light and desiccation; reduced light levels (e.g., partial shading by a narrow dock) can actually increase primary productivity at higher elevations. Overwater structures such as marina floats, while they may produce substantial epibenthic prey (e.g., Kozloff 1987), can create a maze that surface-oriented juvenile salmonids can follow in random directions, potentially delaying their progress along a given reach of shoreline. Overwater structures, like finger piers, can also lead fish into deeper water where they may be more vulnerable to certain types of predation than they would be in shallower waters. However, Cardwell et al. (1980) found that abundance of chinook and coho salmon, as well as herring, were higher inside the Skyline Marina than outside, and they noted a scarcity of fish and avian predators on juvenile salmonids within the marina. They also reported that prey favored by chinook and coho juveniles were more abundant in the marina than in nearby Burrows Bay.

Protocol: This question can be answered by scale drawings, aerial photographs, or by on-site measurements. Areas with light-transmissive grating or other material should be subtracted from the area of coverage before scoring this question. Answer "yes" to Question 33a if the AU has a total overwater coverage of 10 to 30 percent of its total littoral area; "yes" to Question 33b if overwater coverage is between 30 and 50 percent; "yes" to Question 33c if overwater coverage is between 50 and 75 percent; and "yes" to Question 33d if overwater coverage is greater than 75 percent.

Question 34: Is littoral area in the AU routinely disturbed by propeller scour, oil spills, or dredging?

Assumptions: This question addresses the feeding and salmonid health functions. Routine or recurring disturbances of the benthic environment that reduce the productivity or health of epibenthic prey of salmonids degrade the quality of the habitat. Propeller scour can resuspend finer and more richly organic surficial sediments that provide habitat for epibenthic zooplankters. Chronic oil releases can leave the epibenthos in a constant state of early recovery from an oiling event and could result in increased bioaccumulation of PAHs in salmon via a sediment-to-epibenthos pathway (e.g., Arkoosh et al. 1998). Dredging will eliminate less mobile existing benthos from an area and may result in a postdredging bottom that is less rich in organic matter, and which serves as a basis for epibenthic food webs upon which juvenile salmonids are dependent (e.g., Healey 1982). However, recovery of benthos, and especially of epibenthos, is expected to be rapid (e.g., McCauley et al. 1977, Richardson et al. 1977, Romberg et al. 1995.)

Protocol: Answer "yes" to Question 34 if any one of the following is applicable:

1. AU is sufficiently shallow to be scoured by vessel propeller wash over 25 percent of the littoral portion of the AU on a recurring basis.

2. The nature of use of the AU or adjacent areas is such that oil sheens are frequently visible on the water surface along the shoreline and can be assumed to affect at least 25 percent of the AU on a recurring basis.

3. The AU contains areas that are dredged for maintenance of navigation depths on a recurring basis; e.g., more than once every 6 years.

REFERENCES

Angell, T., and K.C. Balcomb III. 1982. Marine birds and mammals of Puget Sound. University of Washington Press, Seattle.

APHA (American Public Health Association, American Water Works Association, and Water Environment Federation). 1995. Standard methods for the examination of water and wastewater. American Public Health Association, Washington, DC.

Arkoosh, M.R., E. Casillas, P. Huffman, E. Clemons, J. Evered, J.E. Stein, and U. Varanasi. 1998. Increased susceptibility of juvenile chinook salmon from a contaminated estuary to *Vibrio anguillarum*. Transactions of the American Fisheries Society, 127:360-374.

Bargmann, G. 1998. Forage fish management plan: a plan for managing the forage fish resources and fisheries of Washington. Washington Department of Fish and Wildlife, Olympia.

Beechie, T., E. Beamer, and L. Wasserman. 1994. Estimating coho salmon rearing habitat and smolt production losses in a large river basin, and implications for habitat restoration. North American Journal of Fisheries Management 14:797-811.

Bisson, P.A., and R.E. Bilby. 1982. Avoidance of suspended sediment by juvenile coho salmon. North American Journal of Fisheries Management 4:371-374.

Brosofske K.D., J. Chen, R.J. Naiman, and J.F. Franklin. 1997. Harvesting effects on microclimatic gradients from small streams to uplands in western Washington. Ecological Applications 7(4):1188-1200.

Canning, D.J., and H. Shipman. 1995. The cumulative effects of shoreline erosion control and associated land clearing practices, Puget Sound, Washington. Coastal Erosion Management Studies, Volume 10. Washington State Department of Ecology, Shorelands and Water Resources Program, Olympia.

Cardwell, R.D., S.J. Olsen, M.I. Carr, and E.W. Sanborn. 1980. Biotic, water quality, and hydrologic characteristics of Skyline Marina in 1978. Washington Department of Fisheries, Technical Report No. 54, Olympia.

CDFG (California Department of Fish and Game). 1995. Inland and anadromous sport fish management and research. Klamath River Basin juvenile salmonid investigation: habitat type utilization of juvenile salmonids in the Klamath River estuary, April 1991 through September 1994. California Department of Fish and Game, Final Performance Report, Federal Aid Project F-51-R, Sacramento.

Cheney, D.P. 1989. Mitigation and monitoring plan. Attachment C to City of Everett environmental checklist, proposed 12th Street marina. Report of BioAquatics International, Bellevue, Washington, for Hulbert Mill Company, Everett, Washington.

City of Everett and Pentec Environmental. 2001. Salmon overlay to the Snohomish Estuary wetland integration plan. Prepared by the City of Everett, Washington, and Pentec, Edmonds, Washington.

City of Everett, Washington State Department of Ecology, US Environmental Protection Agency, and Puget Sound Water Quality Authority. 1997. Snohomish Estuary wetland integration plan (SEWIP). Prepared by the City of Everett Project Team, Everett, Washington.

Congleton, J.L., S.K. Davis, and S.R. Foley. 1981. Distribution, abundance and outmigration timing of chum and chinook salmon fry in the Skagit salt marsh. Pages 153-163 *in* E.L. Brannon and E.O. Salo, editors. Proceedings of the Salmon and Trout Migratory Behavior Symposium, University of Washington, School of Fisheries, Seattle.

Conlan, K.E., and D.V. Ellis. 1979. Effects of wood waste on sand-bed benthos. Marine Pollution Bulletin 10:262-267.

Cordell, J.R., L.M. Tear, K. Jensen, and V. Luiting. 1997. Duwamish River Coastal America restoration and reference sites: results from 1995 monitoring studies. University of Washington, School of Fisheries, Fisheries Resource Institute, FRI-UW-9709, Seattle.

Cordell, J.R., L.M. Tear, K. Jensen, and H.H. Higgins. 1998. Duwamish River Coastal America restoration and reference sites: results from 1997 monitoring studies, draft. University of Washington, School of Fisheries, Fisheries Resource Institute, Seattle.

Eschmeyer, W.N., and E.S. Herald. 1983. A field guide to Pacific Coast fishes. Houghton-Mifflin, Boston.

Freese, J.L., and C.E. O'Clair. 1987. Reduced survival and condition of the bivalves *Protothaca staminea* and *Mytilus edulis* buried by decomposing bark. Marine Environmental Research 23:49-64.

Healey, M.C. 1982. Juvenile Pacific salmon in estuaries: the life support system. Pages 315-341 *in* V.S. Kennedy, editor. Estuarine Comparisons, Academic Press, New York.

Healey, M.C. 1991. Life history of chinook salmon (*Oncorhynchus tshawytscha*). Pages 311-394 *in* C. Groot and L. Margolis, editors. Pacific salmon life histories. UBC Press, Vancouver, BC, Canada.

Heiser, D.W., and E.L. Finn, Jr. 1970. Observations of juvenile chum and pink salmon in marina and bulkhead areas. Supplemental Progress Report, Puget Sound Studies, Washington Department of Fisheries, Management and Research Division, Olympia.

Hetrick, N.J., M.A. Brusven, T.C. Bjornn, R.M. Keith, and W.R. Meehan. 1998a. Effects of canopy removal on invertebrates and diet of juvenile coho salmon in a small stream in southeast Alaska. Transactions of the American Fisheries Society 127:876-888.

Hetrick N.J., and M.A. Brusven, W.R. Meehan, and T.C. Bjornn. 1998b. Changes in solar input, water temperature, periphyton accumulation, and allochthonous input and storage after canopy removal along two small salmon streams in southeast Alaska. Transactions of the American Fisheries Society 127:859-875.

Houghton, J.P., and R.H. Gilmour. 1997. Ecological functions of a saltmarsh/mudflat complex created using clean dredged material, Jetty Island, Washington. Pages 156-170 *in* K.B. Macdonald and F. Weinmann, editors. Wetland and riparian restoration: taking a broader view. United States Environmental Protection Agency, Region 10, Seattle, Washington.

Houghton, J.P., R.H. Gilmour, and D.L. Gregoire. 1998. Ecological functions of a saltmarsh/ mudflat complex created using dredged material at Jetty Island, Washington - the final verdict. Page 11 *in* Abstracts & Biographies, Poster Abstracts. Puget Sound Research '98.

Hruby, T., W.E. Cesanek, and K.E. Miller. 1995. Estimating relative wetland values for regional planning. Wetlands 15(2):93-107.

Jackson, R.G. 1986. Effects of bark accumulation on benthic infauna at a log transfer facility in Southeast Alaska. Marine Pollution Bulletin 17(6):258-262.

Kask, B.A., and R.R. Parker. 1972. Observations on juvenile chinook salmon in the Somass River Estuary, Port Alberni, British Columbia. Fisheries Research Board of Canada, Technical Report 308.

Kathman, R.D., S.F. Cross, and M. Waldichuk. 1984. Effects of wood waste on the recruitment potential of marine benthic communities. Canadian Technical Report of Fisheries and Aquatic Sciences No. 1284, Department of Fisheries and Oceans, West Vancouver, British Columbia.

Kozloff, E.N. 1987. Marine invertebrates of the Pacific Northwest. University of Washington Press, Seattle.

Levings, C.D. 1982. Short-term use of a low tide refuge in a sandflat by juvenile chinook, (*Onchorhynchus tshawytscha*), Fraser River estuary. Canadian Technical Report of Fisheries and Aquatic Sciences No. 1111, Department of Fisheries and Oceans, Fisheries Research Branch, West Vancouver, British Columbia.

Levings, C.D. 1990. Strategies for fish habitat management in estuaries: comparison of estuarine function and fish survival. Pages 582-593 *in* W.L.T. van Densen, B. Steinmetz, and R.H. Hughes, editors. Management of freshwater fisheries, Proceedings of a Symposium Organized by the European Inland Fisheries Advisory Committee, Göteborg, Sweden.

Levy, D.A., and T.G. Northcote. 1981. The distribution and abundance of juvenile salmon in marsh habitats of the Fraser River estuary. University of British Columbia, Westwater Research Center, Technical Report 25, Vancouver, British Columbia.

Levy, D.A., and T.G. Northcote. 1982. Juvenile salmon residency in a marsh area of the Fraser River estuary. Canadian Journal of Fisheries and Aquatic Sciences 39:270-276.

Maser, C., and J.R. Sedell. 1994. From the forest to the sea, the ecology of wood in streams, rivers, estuaries, and oceans. St. Lucie Press, Delray Beach, Florida.

McCauley, J.F., R.A. Parr, and D.R. Hancock. 1977. Benthic infauna and maintenance dredging—a case study. Pergamon Press, Water Research II:233-242.

MacDonald, J.S., C.D. Levings, C.D. McAllister, U.H.M. Fagerlund, and J.R. McBride. 1987. A field experiment to test the importance of estuaries for chinook salmon (*Onchorhynchus tshawytscha*) survival: short-term results. Canadian Journal of Fisheries and Aquatic Sciences 45:1366-1377.

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

Northcote, T.G., N.T. Johnston, and K. Tsumura. 1979. Feeding relationships and food web structure of lower Fraser River fishes. University of British Columbia, Westwater Research Center, Technical Report 16, Vancouver, British Columbia.

Pentec (Pentec Environmental, Inc.). 1992. Port of Everett Snohomish Estuary fish habitat study 1991-1992. Final report. Prepared for the Port of Everett, Washington, by Pentec, Edmonds, Washington.

Pentec Environmental, Inc. 1996. Beneficial use of dredged materials, Jetty Island habitat development demonstration project. Year 5 monitoring report. Prepared for the Port of Everett, Washington, by Pentec, Edmonds, Washington.

Pentec (Pentec Environmental, Inc.). 1997. Movement of juvenile salmon through industrialized areas of Everett Harbor. Prepared for the Port of Everett, Washington, by Pentec, Edmonds, Washington.

Pomeroy, L.R., and R.G. Wiegert, editors. 1981. The ecology of a saltmarsh. Springer-Verlag, New York.

Powers, P.D. 1997. Culvert hydraulics related to upstream juvenile salmon passage. Washington Department of Fish and Wildlife, Lands and Restoration Services Program (internal report), Olympia.

Ralph, S.C., T. Cardoso, G.C. Poole, L.L. Conquest, and R.J. Naiman. 1991. Status and trends of instream habitat in forested lands of Washington: The Timber-Fish-Wildlife Ambient Monitoring Project. 1989-1991 Biennial Progress Report, Center for Streamside Studies, University of Washington, Seattle.

Ratte, L.D., and E.O. Salo. 1985. Under-pier ecology of juvenile Pacific salmon (*Oncorhynchus* spp.) in Commencement Bay, Washington. University of Washington, Fisheries Research Institute, School of Fisheries, FRI-UW-8508, Seattle.

Rich, W.H. 1920. Early history and seaward migration of chinook salmon in the Columbia and Sacramento Rivers. Bulletin of the Bureau of Fisheries (US) 37:74.

Richardson, M.D., A.G. Carey, Jr., and W.A. Colgate. 1977. Aquatic disposal field investigations Columbia River Site, Oregon. Appendix C: The effects of dredged material disposal on benthic assemblages. US Army Corp of Engineers Waterways Experiment Station, Dredged Material Research Program Technical Report D-77-30, Vicksburg, Mississippi.

Romberg, P., C. Homan, and D. Wilson. 1995. Monitoring at two sediment caps in Elliott Bay. Pages 289-299 in Puget Sound Research '95: proceedings. Puget Sound Water Quality Authority, Olympia, Washington.

Ryall, R., and C.D. Levings. 1987. Juvenile salmon utilization of rejuvenated tidal channels in the Squamish Estuary, British Columbia. Canadian Manuscript Report of Fisheries and Aquatic Sciences 1904.

Sanders, H.L. 1959. Sediments and the structure of bottom communities. Pages 583-584 in M. Sears, editor. Intern. Oceanogr. Congress-reprints. American Association for the Advancement of Science, Washington, DC.

Schaumburg, F.D., and J. Walker. 1973. The influence of benthic bark deposits on the aquatic community and the quality of natural waters. Water Resources Research Institute, Oregon State University, Corvallis.

Sibert, J., T.J. Brown, M.C. Healy, B.A. Ask, and R.J. Naiman. 1977. Detritus-based food webs: exploitation by juvenile chum salmon (*Oncorhynchus keta*). Science 196:649-650.

Simenstad, C.A., and R.C. Wissmar. 1985. $S^{13}C$ evidence of the origins and fates of organic carbon in estuaries and nearshore marine food webs. Marine Ecology Program 22:141-152.

Simenstad, C.A., C.D. Tanner, R.M. Thom, and L.L. Conquest. 1991. Puget Sound Estuary Program: estuarine habitat assessment protocol. Prepared for the US Environmental Protection Agency, Region 10, EPA 910/9-91-037, Seattle, Washington.

Simenstad, C.A., B.J. Nightingale, R.M. Thom, and D.K. Shreffler. 1999. Impacts of ferry terminals on juvenile salmon migrating along Puget Sound shorelines, phase I: synthesis of state of knowledge. Prepared for the Washington State Department of Transportation, Olympia.

Smith, J.E. 1977. A baseline study of invertebrates and of the environmental impact of intertidal log rafting on the Snohomish River delta. University of Washington, Washington Cooperative Fishery Research Unit, College of Fisheries, Seattle.

Spence, B.C., G.A. Lomnicky, R.M. Hughes, and R.P. Novitzki. 1996. An ecosystem approach to salmonid conservation. ManTech (Management Technology) Environmental Research Services Corp., Corvallis, TR-4501-96-6057, Oregon.

Thom, R.M., D.K. Shreffler, and K. Macdonald. 1994. Shoreline armoring effects on coastal ecology and biological resources in Puget Sound, Washington. Coastal Erosion Management Studies Volume 7. Washington State Department of Ecology, Shorelands and Water Resources Program, Olympia.

Thorpe, J.E. 1994. Salmonid fishes and the estuarine environment. Estuaries 17(1A):76-93.

WFPB (Washington State Forest Practices Board). 1994. Standard methodology for conducting watershed analysis under chapter 222-22 WAC. Version 2.1. WFPB, Olympia.

Zegers, P. 1979. The effects of log raft grounding on the benthic invertebrates of the Coos Estuary. Oregon State Department of Environmental Quality, Coos Bay.

Field inventory sheet.

THM IVA for Estuarine or Marine Habitat					
(This model assumes source of water is tidal fresh, brackish, or marine)	* F-feeding; M-migration, O-osmoregulatory, P-predator avoidance, H-health/toxicity				
Date Surveyors On site or Off site? Circle					
AU # Supplement w/Aireals? Date and Type?	Y/N	CH	CO/BT	Functions Addressed*	Comments
Hydrology				F, M, O	
1 AU has vernal or perennial freshwater stream or spring		3	3	F, O	
2a AU is depositional (slow currents, low wave action) over 25% of littoral area		2	2	F	
2b AU is depositional (slow currents, low wave action) over 50% of littoral area		3	3	F	
3 AU has refuge from high velocities (e.g., during max. ebb)		3	3	M, P	
4a AU contains a natural tidal channel wetted at MLLW		X1.5	X1.3	F, P	
4b AU contains tidal channel wetted at MSL (i.e., shallow drainage)		2	2	F, P	
5 Tidal channel is dendritic or highly sinuous		3	3	F, P	
Water Quality					
6a Fresh water only (salinity < 0.5 ppt)		1	3	F	
6b Oligohaline to Mesohaline (sal. variable: often 0.5 to 5 ppt, but can range to 18 ppt)		3	3	F, O	
6c Polyhaline (sal. typically 18 to 30 ppt)		1	1	F, O	
7a Temp/DO meet criteria for salmonid health during major use periods		2	2	H	
7b Temp/DO meet criteria for salmonid health at all times		3	3	H	
Physical Features					
Vascular plant/mud (or sand) flat boundary (vegetated/unvegetated boundary)					
Shoreline complexity					
8a Ratio of length of MHHW boundary to width at MLLW > 3 (include islands)		3	3	F, P	
8b Ratio of length of MHHW boundary to width at MLLW 1.2 to 3 (include islands)		2	2	F, P	
8c Ratio of length of MHHW boundary to width at MLLW < 1.2 (include islands)		1	1	F, P	
Exposure					
9 AU is sheltered from waves		2	2	F	
Slope					
10a Slope of substrate in littoral zone > 10h:1v (i.e., low gradient)		3	3	F, P	
10b Slope of substrate in littoral zone < 10h:1v but > 5h:1v (i.e., moderate)		2	2	F, P	
10c Slope of substrate in littoral zone < 5h:1v but > 2h:1v (i.e., steeper)		1	1	F, P	

Field inventory sheet.

AU # Date Surveyors	Y/N	CH	CO/BT	Address	Comments
Range of Depths					
11a > 10% of AU is littoral (MHHW to -10 ft; use OHW if marsh veg. above MHHW)		1	1	F, P	
11b > 25% of AU is littoral (MHHW to -10 ft; use OHW where vegetation indicates)		2	2	F, P	
11c > 50% of AU is littoral (MHHW to -10 ft; use OHW where vegetation indicates)		3	3	F, P	
Sediments (surficial only)					
12 Substrate in littoral zone - silty sand > 25% of area		1	1	F	
13 Substrate in littoral zone - mud or mixed fine 25 - 50% of area		2	2	F	
14 Substrate in littoral zone - mud or mixed fine > 50% of area		3	3	F	
15 Upper intertidal zone contains potential forage fish spawning habitat		3	3	F	
Vegetated Edge					
Below OHW					
16a Buffer: marsh edge > 10 ft wide over 50% of shoreline		3	3	F, P	
16b Marsh edge > 5 ft wide over 50% of shoreline; or > 10 ft wide over 25-50% of shoreline		2	2	F, P	
16c Marsh edge exists but < 5 ft wide, or less than 25% (but > 5%) of shoreline		1	1	F, P	
16d Marsh of native species occupies more than 25% of total AU		X 2	X 2	F	
Above OHW (riparian zone)					
17a Riparian scrub-shrub and/or forested > 25 ft wide over 10 to 24% of shoreline		1	1	F, P	
17b Riparian scrub-shrub and/or forested > 25 ft wide over 25 to 50% of shoreline		2	2	F, P	
17c Riparian scrub-shrub and/or forested > 25 ft over 50% of shoreline		3	3	F, P	
18 Riparian vegetation is dominated by native species		1	1	F	
19 Riparian zone provides signif. source of LWD recruitment		X1.5	X1.5	F, P	
Landscape					
20a AU has low to moderate gradient intertidal continuity with adjacent AU (one side)		1	1	M, P	
20b AU has low to moderate gradient intertidal continuity with adjacent AUs (both sides)		3	3	M, P	
Special Habitat Features					
Large Woody Debris (LWD) density (LWD must be in the IT zone below MHHW)					
21a 1.0 piece/channel width, /30 m of shoreline, or /100 m² of AU whichever is greater		3	3	P	
21b 0.5 piece/channel width, /30 m of shoreline, or /100 m² of AU whichever is greater		2	2	P	
21c 0.2 piece/channel width, /30 m of shoreline, or /100 m² of AU whichever is greater		1	1	P	

Field inventory sheet.

AU # Date Surveyors	Y/N	CH	CO/BT	Address	Comments
Submerged Vegetation (note provisions with regard to impacts to macrovegetation)**					
22 Algal cover over 10% of littoral area (during springtime)		1	1	F, P	
23a Eelgrass is present along 5 - 10% of low tide line of AU		1	1	F, P	
23b Eelgrass is present along 10 - 25% of low tide line of AU		2	2	F, P	
23c Eelgrass is present along more than 25% of low tide line of AU		3	3	F, P	
23d Eelgrass occupies more than 25% of total AU		X 2	X 2	F, P	
24 Do functioning feeder bluffs provide a significant source of sediment to the AU?		X 2	X 2	F	
Stressors					
25a Immigration/emigration restricted 25 to 50% of the time		X 0.8	X 0.8	M	
25b Immigration/emigration restricted 50 to 75% of the time		X 0.5	X 0.5	M	
25c Immigration/emigration restricted 75 to 90% of the time		X 0.3	X 0.3	M	
26a Wood debris present on the bottom 25% to 75% cover over AU		X 0.7	X 0.7	F	
26b Wood debris present on the bottom > 75% over AU		X 0.5	X 0.5	F	
27a Log rafting affects 10 - 50% of AU on a recurring basis		X 0.7	X 0.7	F	
27b Log rafting affects over 50% of AU on a recurring basis		X 0.5	X 0.5	F	
28a Water col. conditions exceed salmonid thresholds during periods of high abundance		X 0.3	X 0.3	H	
28b Water col. conditions exceed salmonid thresholds during periods of low abundance		X 0.7	X 0.7	H	
29a Sediment chemical contam. present (> SQS over more than 25% of AU)		X 0.8	X 0.8	F, H	
29b Sediment chemical contam. present (>CSL over more than 25% of AU)		X 0.6	X 0.6	F, H	
30a Riprap or vertical bulkheads extend below MHHW for 10 - 50% of shore		X 0.8	X 0.9	P,M,F	
30b Riprap or vertical bulkheads extend below MHHW along > 50% of shore		X 0.7	X 0.8	P,M,F	
31 Majority of riprapped or bulkheaded shoreline extends below MSL (+6 ft MLLW)		X 0.8	X 0.9	P,M,F	
32a Finger pier or dock > 8 ft wide		X 0.9	- -	P	
32b Two or more finger piers or docks > 8 ft wide; or single pier or dock > 25 ft wide		X 0.8	X 0.9	P	
33a Overwater structures cover 10 to 30% of littoral area in AU		X 0.8	X 0.9	P,M,F	
33b Overwater structures cover 30 to 50% of littoral area in AU		X 0.7	X 0.8	P,M,F	
33c Overwater structures cover 50 to 75% of littoral area in AU		X 0.5	X 0.7	P,M,F	
33d Overwater structures cover > 75% of littoral area in AU		X 0.4	X 0.5	P,M,F	
34 Littoral benthic habitat routinely disturbed by prop wash, chronic oil spills, or dredging		X 0.9	X 0.9	H, F	

thm_iva_field.xls