# Section 4. Linkage of Hydrologic Modeling Results to Salmon Population and Habitat Quality Models

## 4.1 Introduction

Two approaches to the evaluation of flow-related effects on salmon production and population performance were used in this project. The first approach made use of the steady-state ecological model, Ecosystem Diagnosis and Treatment (EDT) developed by Mobrand Biometrics, Inc. EDT is a habitat rating model that has been used by the co-managers of the salmon resource in Washington State and elsewhere to evaluate current conditions, compare these with estimates of historical conditions, and to perform future scenario modeling. It has likewise been used by the Stillaguamish Technical Advisory Committee and the Stillaguamish Implementation Review Committee, among other basin stakeholders and technical advisory groups around Puget Sound, to evaluate the potential for future actions to recover Chinook salmon.

The second approach rated habitat and watershed conditions using criteria or relations found in two index methods: 1) the Matrix of Pathways and Indicators employed by NOAA Fisheries (formerly National Marine Fisheries Service; 1996) to evaluate habitat conditions encountered by Endangered Species Act-listed salmon species, and 2) Quality Indices used by May, et al. (1997) to evaluate the effects of urbanization on Puget Sound Lowland streams.

Inputs to the EDT model include 34 “Level-2 Attributes” that characterize habitat conditions on a reach-by-reach basis, 7 measures of relative habitat quantity, 3 morphometric measures, and 2 attributes that define usage. Attribute values range from 0.0 to 4.0 with lower values generally denoting more favorable conditions. EDT uses species-specific rules and life history information to quantify the survival of different life stages in each reach. Model outputs include a diagnostic report that shows 1) the portion of the population which uses the reach, by life stage, 2) the effect of current conditions on productivity, by life stage, and 3) the influence of individual level 3 attributes (combinations of level 2 attributes) on productivity in a reach, also by life stage. By examining these outputs of the model it can be ascertained which level 3 attributes have the largest effect on productivity of important life stages in important reaches for those life stages.

Both EDT and the index methods rely on estimates of historic conditions, field-measured quantity and quality data, GIS-measured morphometric data, classified land cover from Purser, et al. (2003) and outputs from hydrologic modeling performed with Hydrologic Simulation Program Fortran (HSPF) under four scenarios: Template (a.k.a. pristine or historic [~85% hydrologically mature forest]), Current, Future 1 (buildout according to current Snohomish County and Stanwood Comprehensive plans) and Future 2 (replacement of currently planned rural residential land use with urban land use in subbasins within the greater Stanwood area including the I-5 corridor and land between the corridor and the present City of Stanwood).

This section documents the selection of flow-related EDT attributes and how attribute values were derived. Likewise, it describes the flow-related variables and parameters selected for use in alternative index methods to analyze effects of land use and water withdrawal-related flow changes on salmon habitat and populations.

The four scenarios are distinguished by different land uses and consequent changes to land cover, water extraction and use patterns. These scenarios are as described in Section 3. Figure 4-1 shows the reaches and subbasins to be used in the modeling efforts.

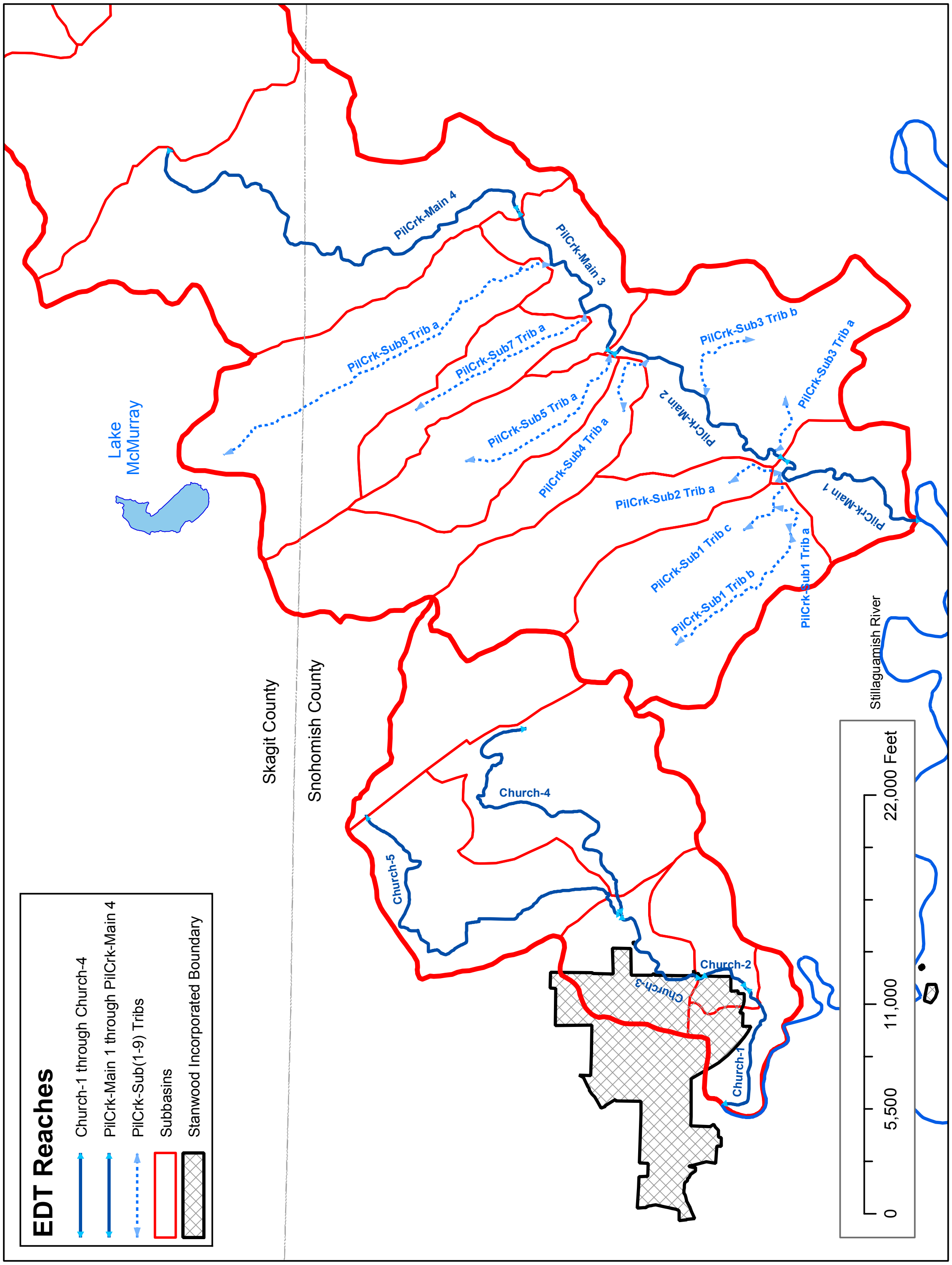

**Figure 4-1 EDT Model Reaches, View Zoomed to Church Creek and Lower Pilchuck Creek**

## 4.2 Ecological Modeling Strategy

A key question faced in this the project was how to represent the modeling scenarios and their associated hydrologic characteristics in terms of the inputs (Level 2 Attributes) to the EDT model.

### 4.2.1 Direct and Indirect Ecological Parameters

As shown in Table 4-1, there are 46 Level 2 attributes that describe habitat quantity and quality by reach in EDT. There are six EDT Level 2 attributes that are classified as "Direct", in that they can be determined from stream flow data with little interpretation. One of these (HydroRegimeNatural) can be assumed invariant across all scenarios in this study, barring impacts such as climate change that could theoretically shift a stream flow regime from “rain and snow-dominated” to “rain-dominated”. Another of the six, HydroRegimeReg is aimed at characterizing shifts in seasonal hydrographs caused by reservoirs for flood control, power, and water supply which are not present in our pilot watersheds. This leaves four relevant “Direct” EDT parameters that vary based on land use and water supply management actions that that were translated into distinct flow regimes for each study scenario by the hydrologic model.

The four "direct" or Tier-1 attributes for this pilot study are numbered 1-4 in Table 4-1. The remaining 39 EDT Level 2 attributes were reviewed to assess whether they would shift as a result of land use and water management actions within the pilot watersheds. Fourteen additional EDT parameters were identified as falling into this “Indirect” category. They are shown as attribute numbers 5 - 18 in Table 4-1. Of the 14, the first four can be expected to be modified as a result of both changes in watershed runoff processes and changes to discharge in the stream system. These four EDT attributes are used to characterize substrate conditions with respect to scour and fine sediment in stream habitat types as well as the richness of benthic macroinvertebrates as indicated by BIBI.

The next seven attributes (numbers 9-15) are expected to be influenced by changes in watershed runoff amounts and pathways that influence the water quality of flow entering the stream system. Four of these seven are classified as water chemistry indicators, and the other two are water temperature indicators. Finally, the remaining three attributes expected to vary from scenario to scenario are associated with stream processes and have stream discharge sensitivity. These include two describing wetted channel area in high and low flow period, and one describing bed scour depth in salmon spawning areas.

The remaining 28 EDT parameters are not expected to be affected by flow change associated with changes in watershed land use and water withdrawals. Attribute number 27 may be viewed as the single exception to this; it is used in EDT to characterize changes in seasonal hydrograph patterns caused by storage of stream flow in reservoirs. Such storages are not present in our pilot basins; consequently, this attribute value remains constant and has no impact in this study. Based on consultation with the Shared Strategy Water Quantity Subcommittee, attributes reflecting instream habitat structure, fish passage, and riparian condition were not varied across scenarios because they are distinct from the project focus which is an investigation of how changes in flow act as a driver for the focal species, coho salmon and Chinook salmon.

### 4.2.2 Options for Representation of Hydrologic Processes via EDT Level 2 Attributes

A limited number of options were considered for representing the four modeling scenarios in EDT. One option was to attempt to adjust all 18 EDT Attributes reflecting “direct” and “indirect” hydrologic impact. This would require tracking not only the influence of changes in stream flow regime caused by land and water management, but also instream processes potentially affected by changes in flow regime (sediment, scour, and habitat quantity), and also runoff quality. This approach recognizes that it is difficult to separate changes in flow from changes in quality and sediment regime. However, the assignment of “indirect” attribute values is likely to be speculative and require some strong assumptions.

A second approach considered was to restrict the analysis to the “direct” hydrologic attributes plus “indirect” attributes affected by runoff and that characterize instream processes. These include attribute numbers 6-8 and 16-18 for a total of 10 attributes when combined with the four “direct” stream flow regime attributes. This option would focus the analysis on stream flow regime change and its effects on sediment processes as well as habitat quantity.

A third option was to use only “direct” stream flow attributes. Its primary advantage was that hydrologic modeling provides a relatively well-documented and accepted vehicle to quantify the four EDT attributes involved compared to the more approximate approaches that are required to determine EDT inputs for the “indirect” attributes.

For the sake of completeness, the first approach that includes both “indirect” Level 2 EDT attributes associated with runoff-related water quality attributes, and those associated with flow regime effects in channels, was selected for this study It is important to keep in mind that in adopting this more inclusive approach, more and stronger assumptions were necessary in order to set “indirect” level 2 attribute values because of insufficient data or understanding about the correlation of some EDT attributes with runoff and stream flow.

## Table 4-1 EDT Level 2 Attributes and Association with Hydrologic Change and Scenario Modeling in this Study

| Number | EDT Attribute Code | EDT Attribute Name | Attribute Category | Attribute Sub-Category | Affected by flow change from land use, pumping, diversion? | Direct or Indirect | Runoff or Stream | Scenario Dependent? | Comment |
|---|---|---|---|---|---|---|---|---|---|
| 1 | FlwLow | Low Flow Change | Hydrology | Base Flow | Yes | Direct | NA | Yes | Based on 45-60 day low flow period averaged over 20 years of data. |
| 2 | FlwDielVar | Intra-day Stage Variation | Hydrology | Daily Stage | Yes | Direct | NA | Yes | Rated by typical maximum hourly ramping rate (in/hr) during month of maximum flow fluctuations |
| 3 | FlwHigh | Avg. Annual Peak | Hydrology | Peak | Yes | Direct | NA | Yes | Flashiness of flow compared to Template using Tqmean |
| 4 | FlwIntraAnn | Intra-Annual Flow Pattern | Hydrology | Peak | Yes | Direct | NA | Yes | Quantify based on change in Q2 per Lestelle et al, 2004. Record shows Pilchuck peaks>80% exceedance flow increased by approximately 1.3% per annum on average over a 47 year period- i.e. suggests a doubling of flood peaks over 35 years. |
| 5 | BenComRch | Benthos Diversity&Production | Biology | Macro-invert. | Yes | Indirect | Runoff and Stream Flow | Yes | BIBI changes as affected by runoff quality and flow. Riparian condition assumed equal to Template. |
| 6 | Emb | Embeddedness | Stream Corridor | Substrate | Yes | Indirect | Runoff and Stream Flow | Yes | linked to fine sediment load, fines filling surface gravel interstices or covering gravel only as applied to riffle and tailout habitats |
| 7 | FnSedi | Fine Sediment | Stream Corridor | Substrate | Yes | Indirect | Runoff and Stream Flow | Yes | Linked to fine sediment load, applies to fine sediment located in pool tailouts, glides, and small cobble riffles. |
| 8 | Turb | Turbidity | Water Quality | Sediment | Yes | Indirect | Runoff and Stream Flow | Yes | Actual EDT input is based on the SEV index for suspended sediment |

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| 9 | MetWatCol | Dissolved Metals and other pollutants | Water Quality | Chemistry | Yes | Indirect | Runoff | Yes | dissolved heavy metals and other pollutants compared to Template |
| 10 | MetSedSls | Sediment adsorbed metals and other pollutants | Water Quality | Chemistry | Yes | Indirect | Runoff | Yes | adsorbed heavy metals and other pollutants compared to Template |
| 11 | MscToxWat | Other Dissolved Toxicants | Water Quality | Chemistry | Yes | Indirect | Runoff | Yes | other toxic dissolved chemicals |
| 12 | NutEnrch | Nutrient Enrichment | Water Quality | Chemistry | Yes | Indirect | Runoff | Yes | Extent of nutrient enrichment using trophic classification |
| 13 | DisOxy | Dissolved Oxygen | Water Quality | Chemistry | Yes | Indirect | Runoff | Yes | Related to runoff temperature and nutrients concentration. |
| 14 | TmpMonMx | Maximum temp by month | Water Quality | Temperature | Yes | Indirect | Runoff | Yes | This is the maximum daily mean temperature for each month derived from averaging values for a number of years of data. Pathways and temperature of runoff will be considered. Riparian shading will be equal to Template for all scenarios. |
| 15 | TmpMonMn | Minimum temp by month | Water Quality | Temperature | Yes | Indirect | Runoff | Yes | This is the minimum daily mean temperature for each month derived from averaging values for a number of years of data. Pathways and temperature of runoff will be considered. Riparian shading will be equal to Template for all scenarios. |
| 16 | WidthMx | Monthly Maximum Width | Stream Corridor | Phys Hab | Yes | Indirect | Stream | Yes | Not a geomorphic parameter, rather this is a wetted width parameter. Should key to median flow during high flow month using Lestelle, 2004, p16. |
| 17 | WidthMin | Monthly Minimum Width | Stream Corridor | Phys Hab | Yes | Indirect | Stream | Yes | Not a geomorphic parameter, rather this is a wetted width parameter. Should key to median flow during low flow month using Lestelle, 2004, p16. |
| 18 | BdScour | Bed Scour | Stream Corridor | Substrate | Yes | Indirect | Stream | Yes | Bed scour in salmon spawning areas. Effects egg survival. |
| 19 | FshComRch | Fish Community | Biology | Fish | No | NA | NA | No | Some lit. suggests hydrologic change shifts fish community, but this is not documented by EDT manuals, and is likely a 2nd order effect. |

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| 20 | FshPath | Fish Pathogens | Biology | Fish | No | NA | NA | No | Presence of pathogenic organisms. Assumed constant at Template values for all scenarios |
| 21 | Fspintro | Fish Species Introduced | Biology | Fish | No | NA | NA | No | Introduced fish species. Assumed constant at Template values for all scenarios |
| 22 | PredRisk | Predation Risk | Biology | Fish | No | NA | NA | No | Relative abundance of predators compared to Template. Assumed invariant with scenarios. |
| 23 | Wdrwl | Water Withdrawals | Biology | Fish | No | NA | NA | No | Misnamed variable. Actually refers to degree of fish entrainment by improperly screen diversion structures. Not a flow parameter per se. |
| 24 | SalmCarcass | Salmon Carcass | Biology | Foodweb | No | NA | NA | No | Number of Carcasses per Mile. Assumed constant for all scenarios |
| 25 | Harass | Harassment | Biology | Social | No | NA | NA | No | Not flow associated. Assumed constant in this study. |
| 26 | HatFOutp | Hatchery Fish Outplants | Biology | Social | No | NA | NA | No | Not flow associated. Assumed constant in this study. |
| 27 | HydroRegimeReg | Regulated Hydrology Regime | Hydrology | Dam/Reservoir | Yes | Direct | NA | No | Purpose is to characterize seasonal effects of dams for flood, power, and water storage. None of significance exist in study basins currently or in scenarios. |
| 28 | HydroRegimeNat | Natural Hydrology Regime | Hydrology | Seasonal Pattern | No | NA | NA | No | Characterization of Natural Flow Regime as rain-on-snow, snow, rain, etc. |
| 29 | Confine | Confinement-natural | Stream Corridor | Morphology | No | NA | NA | No | Natural confinement |
| 30 | ConfineHydro | Confinement-Hydromodifications | Stream Corridor | Morphology | No | NA | NA | No | This parameter is used to quantify artificial intrusion from road fills, revetments, dikes, and levees. These management actions can be highly significant for populations, but they are excluded from the current project scope. |
| 31 | Grad | Gradient | Stream Corridor | Morphology | No | NA | NA | No | Avg. gradient of channel over reach, assumed constant with scenario |
| 32 | HbBckPls | Habitat Backwater Pools | Stream Corridor | Morphology | No | NA | NA | No | % Reach surface area in backwater pools, assumed constant with scenario |
| 33 | HbBvrPnds | Habitat Beaver Ponds | Stream Corridor | Morphology | No | NA | NA | No | % Reach surface area in beaver ponds, assumed constant with scenario |
| 34 | HbGlide | Habitat, Glides | Stream Corridor | Morphology | No | NA | NA | No | % Reach surface area in glides, assumed constant with scenario |

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| 35 | HbLrgCbl | Habitat, Large Cobbles/Boulder | Stream Corridor | Morphology | No | NA | NA | No | % Reach surface area in riffles with substrate sizes greater than 5". |
| 36 | HbOfChFctr | Habitat, Off Channel Factor | Stream Corridor | Morphology | No | NA | NA | No | Amount of off channel habitat as fraction of all "flow through" habitat. Assumed constant in all scenarios. |
| 37 | HbPlTails | Habitat, Pool Tailouts | Stream Corridor | Morphology | No | NA | NA | No | % Reach surface area in pool tailouts. Assumed constant in all scenarios. |
| 38 | HbSmlCbl | Habitat, Gravel/Small Cobble | Stream Corridor | Morphology | No | NA | NA | No | % Reach surface area in riffles with substrate sizes less than 5". |
| 39 | HbPls | Habitat Primary Pools | Stream Corridor | Morphology | No | NA | NA | No | % Reach surface area in primary pools, assumed constant with scenario |
| 40 | Icing | Icing | Stream Corridor | Morphology | No | NA | NA | No | Not an active process in pilot basins |
| 41 | Obstr | Fish Passage Obstruction | Stream Corridor | Morphology | No | NA | NA | No | Not flow associated. Assumed constant in this study. |
| 42 | ChLngth | Reach Length | Stream Corridor | Phys Hab | No | NA | NA | No | Channel length assumed equal to Template for all scenarios |
| 43 | WdDeb | Wood | Stream Corridor | Phys Hab | No | NA | NA | No | Assumed equal to Template for all scenarios. |
| 44 | RipFunc | Riparian Function | Stream Corridor | Riparian | No | NA | NA | No | Historically impaired by urbanization, but assumed equal to Template for all scenarios in this study. |
| 45 | TmpSptVar | Spatial Variation of Temp | Stream Corridor | Temperature | No | NA | NA | No | Characterizes frequency of groundwater inflow sites and tributary inputs to a reach that raise or lower temperature. Assumed constant for all scenarios |
| 46 | Alka | Alkalinity | Water Quality | Chemistry | No | NA | NA | No | Regional-Low Priority, West Side versus East Side |

## 4.3 Setting of EDT Level-2 Attribute Values

### 4.3.1 Direct Attribute Values

As a rule, direct Level 2 attribute values are derived from the hydrologic outputs of the HSPF model of Church Creek and Pilchuck Creek on a reach by reach basis for each of the four modeled scenarios following guidelines provided by Lestelle (2004). One exception to this is where EDT modeling reaches have been defined with finer resolution than HSPF modeling reaches. This situation occurs only in a few Pilchuck Creek tributary subbasins as follows. In Pilchuck Creek subbasin 1, three EDT tributary reaches (1a, 1b, and 1c) have been defined where as the HSPF model only simulates flows for the entire subbasin at the confluence of the tributary with the mainstem of Pilchuck Creek. For these EDT reaches, data from the HSPF model is assumed to be generally applicable to all reaches and Level 2 attribute values based on the HSPF model are assumed to be equal in all three reaches. The other exceptions are the two EDT reaches defined for small tributaries on the south side of Pilchuck Creek in subbasin 3. HSPF model-derived attribute values for these reaches are assumed to be equal values derived for the tributary in subbasin 2 because the drainage areas have similar land use patterns.

The remainder of this section describes the EDT attributes whose values are derived from the HSPF model outputs.

#### 4.3.1.1 FlwLow- Low Flow Change

As described in Section 3, Lestelle (2004) describes this parameter as the 45-60 day low flow period averaged over 20 years of data, but this definition was determined to provide a very poor indication of actual low base flow conditions in a basin affected both by urbanization and water withdrawals. Therefore, the average annual 7-day, minimum flow was substituted for the average annual 45-60 day low flow in computing ratios of scenario to template low base flow. The rating curve recommended by Lestelle was then applied using these ratios as shown in Figure 4-2. Table 4-2 displays the values corresponding to each reach and project scenario.

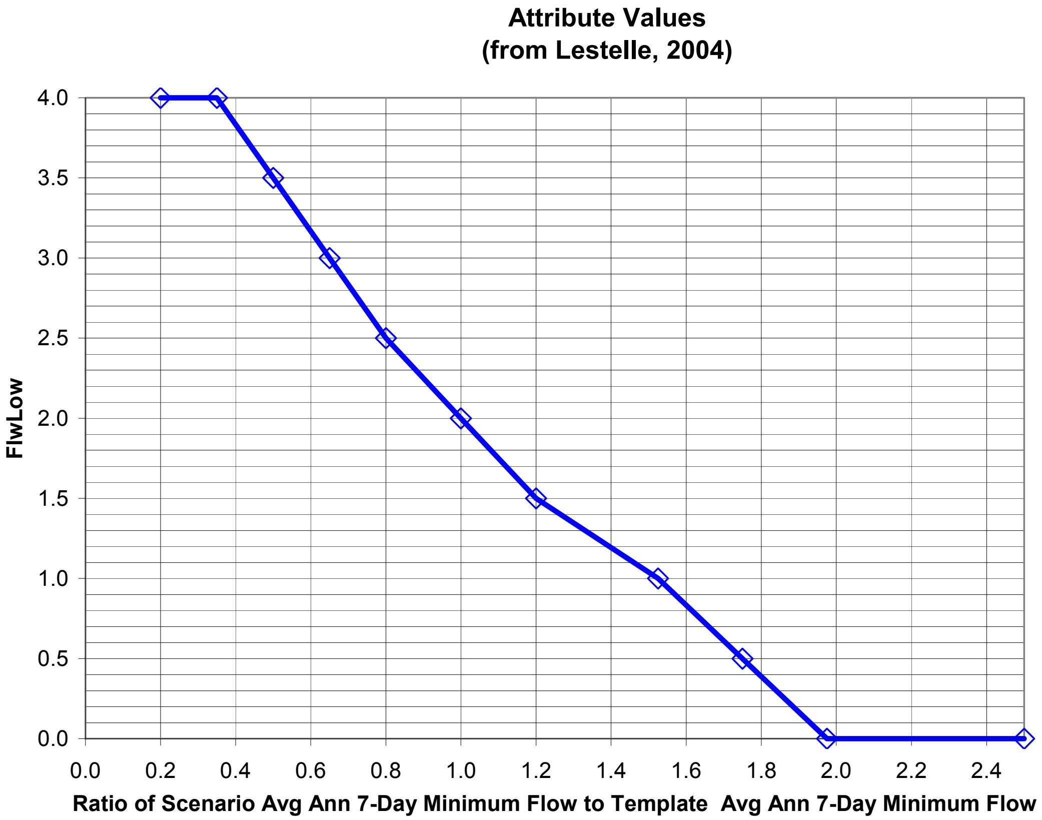

**Figure 4-2 FlwLow Attribute Values**

## Effect of FlwLow in EDT

Only qualitative information is available. EDT Level 2 values effect Level 3 attributes inside the model called "Flow" and "Predation". Values greater than 2 reduce productivity of certain life stages compared to template conditions while values less than 2 presumably increase predicted productivity.

**Table 4-2 FlwLow Level 2 Values**

| EDT Reach | Template | Current | Future 1 | Future 2 |
|---|---|---|---|---|
| Church-1 | 2.00 | 3.33 | 4.00 | 4.00 |
| Church-2 | 2.00 | 3.67 | 4.00 | 4.00 |
| Church-3 | 2.00 | 3.83 | 4.00 | 4.00 |
| Church-4 | 2.00 | 2.25 | 3.83 | 2.83 |
| Church-5 | 2.00 | 1.50 | 2.00 | 1.33 |
| PilCrk-Main 1 | 2.00 | 1.50 | 1.63 | 1.50 |
| PilCrk-Main 2 | 2.00 | 1.50 | 1.63 | 1.50 |
| PilCrk-Main 3 | 2.00 | 1.50 | 1.75 | 1.63 |
| PilCrk-Main 4 | 2.00 | 1.50 | 1.63 | 1.50 |
| PilCrk-Sub1 Trib a | 2.00 | 1.50 | 1.75 | 1.63 |
| PilCrk-Sub1 Trib b | 2.00 | 1.50 | 1.75 | 1.63 |

|  |  |  |  |  |
|---|---|---|---|---|
| PilCrk-Sub1 Trib c | 2.00 | 1.50 | 1.75 | 1.63 |
| PilCrk-Sub2 Trib a | 2.00 | 1.33 | 1.50 | 1.00 |
| PilCrk-Sub3 Trib a | 2.00 | 1.33 | 1.50 | 1.00 |
| PilCrk-Sub3 Trib b | 2.00 | 1.33 | 1.50 | 1.00 |
| PilCrk-Sub4 Trib a | 2.00 | 1.17 | 1.00 | 1.00 |
| PilCrk-Sub5 Trib a | 2.00 | 0.50 | 0.50 | 0.50 |
| PilCrk-Sub7 Trib a | 2.00 | 1.17 | 1.17 | 1.17 |
| PilCrk-Sub8 Trib a | 2.00 | 1.63 | 4.00 | 4.00 |

#### 4.3.1.2 FlwDielVar- Intra-day Stage Variation

This attribute is defined using the average of maximum daily stage ramping rates during the month with the most variable hydrographs. This attribute is designed to reflect both ramping rates caused by dam operations and by watershed urbanization and land cover change. For the pilot basins in this study, this attribute is determined using November simulated stage data because this month typically has the highest number of large precipitation events. Pristine basins (template conditions) are typically rated with a zero value for this attribute. The relationship of attribute values to hydrologic statistic is shown in Figure 4-3.

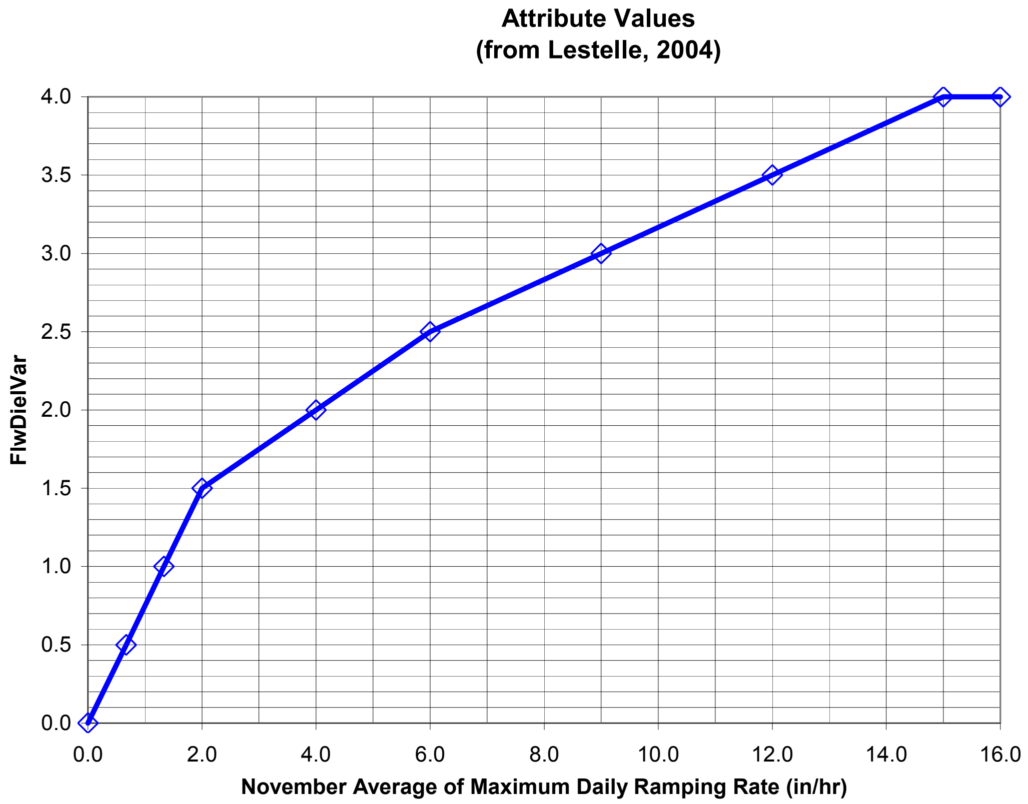

**Figure 4-3 FlwDielVar Attribute Relationship to HSPF Calculated Ramping Rate**

Effect of FlwDielVar in EDT

Only qualitative information was available prior to this study's sensitivity analysis of EDT "rules" as discussed in Section 5. According to Lestelle (2004), EDT Level 2 values affect Level 3 survival factors for "Flow" during free-swimming fish and egg incubation life stages that are susceptible to stranding because of water level fluctuations. Pristine conditions usually correspond to zero or near-zero values. As seen in Table 4-3, values of this attribute are all low, indicating favorable conditions and low sensitivity to the impacts associated with the analyzed scenarios in the study basins.

**Table 4-3 FlwDielVar Level 2 Values**

| EDT Reach | Template | Current | Future 1 | Future 2 |
|---|---|---|---|---|
| Church-1 | 0.1 | 0.4 | 0.6 | 0.9 |
| Church-2 | 0.0 | 0.1 | 0.2 | 0.4 |
| Church-3 | 0.1 | 0.2 | 0.4 | 0.6 |
| Church-4 | 0.0 | 0.1 | 0.2 | 0.3 |
| Church-5 | 0.0 | 0.1 | 0.2 | 0.3 |
| PilCrk-Main 1 | 0.3 | 0.3 | 0.3 | 0.4 |
| PilCrk-Main 2 | 0.2 | 0.2 | 0.3 | 0.3 |
| PilCrk-Main 3 | 0.2 | 0.2 | 0.2 | 0.2 |
| PilCrk-Main 4 | 0.2 | 0.2 | 0.2 | 0.2 |
| PilCrk-Sub1 Trib a | 0.0 | 0.2 | 0.4 | 0.5 |
| PilCrk-Sub1 Trib b | 0.0 | 0.2 | 0.4 | 0.5 |
| PilCrk-Sub1 Trib c | 0.0 | 0.2 | 0.4 | 0.5 |
| PilCrk-Sub2 Trib a | 0.0 | 0.1 | 0.1 | 0.1 |
| PilCrk-Sub3 Trib a | 0.0 | 0.1 | 0.2 | 0.2 |
| PilCrk-Sub3 Trib b | 0.0 | 0.1 | 0.2 | 0.2 |
| PilCrk-Sub4 Trib a | 0.0 | 0.1 | 0.1 | 0.1 |
| PilCrk-Sub5 Trib a | 0.0 | 0.1 | 0.1 | 0.1 |
| PilCrk-Sub7 Trib a | 0.0 | 0.0 | 0.0 | 0.0 |
| PilCrk-Sub8 Trib a | 0.0 | 0.1 | 0.1 | 0.1 |

#### 4.3.1.3 FlwHigh- Peak Flow Change

This attribute represents changes in peak annual flow- specifically the 2-year peak annual flow. Various estimation methods are described by Lestelle (2004) for this parameter. The most quantitatively rigorous relates attribute values to the ratio of 2-year peak annual flow for a scenario to the 2-year peak annual flow under template conditions. This type of data is often not available, but because of the availability of HSPF modeling results, the ratios are easily determined from frequency analysis of model outputs. The relationship between Level-2 values and the peak flow ratio is shown in Figure 4-4.

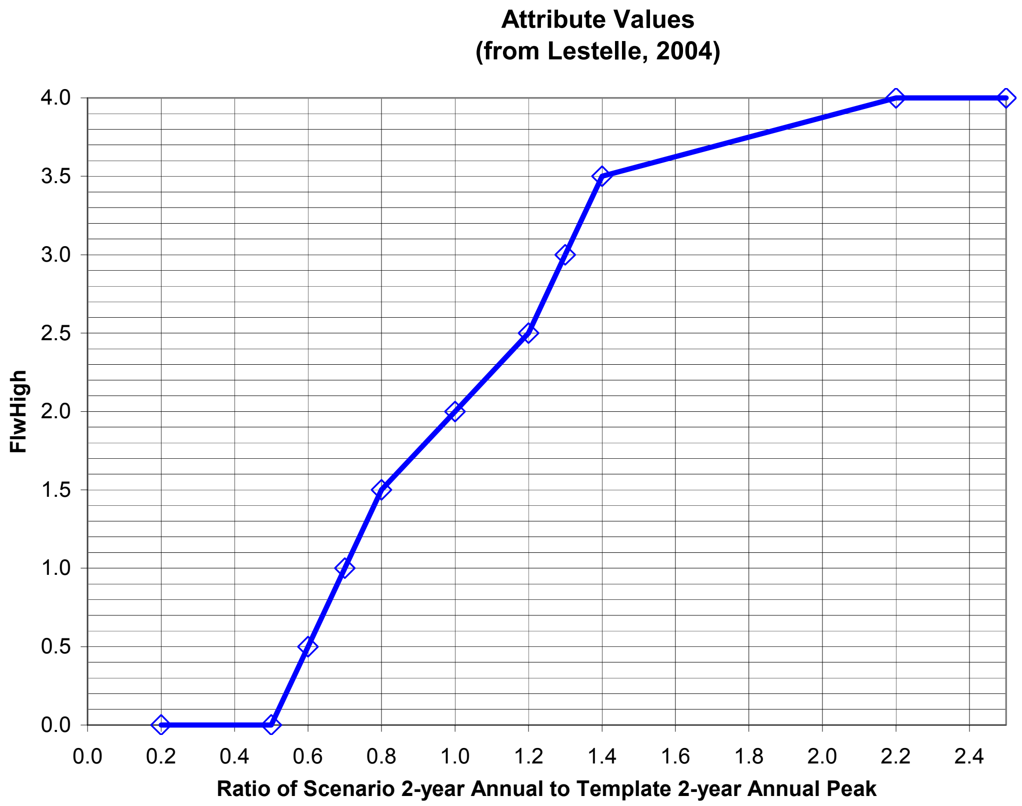

**Figure 4-4 FlwHigh Attribute Values in Relationship to 2-Year Flow Ratio**

Effect of FlwHigh in EDT

Only qualitative information is available. EDT Level 2 values affect Level 3 survival factor "Flow" inside the model. Lestelle (2004) states that several life stages are affected, notably fry colonization and inactive salmonid stages. Scour, though related, is treated by a separate Level 2 attribute. Values between 2 and 4 presumably reduce survival compared to template conditions. High values (>3.5 out of a maximum of 4.0) of this attribute are shaded for reference in Table 4-4.

**Table 4-4 FlwHigh Level 2 Values**

| | Template | Current | Future 1 | Future 2 |
|---|---|---|---|---|
| EDT Reach | | | | |
| Church-1 | 2.0 | 3.7 | 4.0 | 4.0 |
| Church-2 | 2.0 | 3.7 | 4.0 | 4.0 |
| Church-3 | 2.0 | 3.7 | 4.0 | 4.0 |
| Church-4 | 2.0 | 3.6 | 3.9 | 4.0 |
| Church-5 | 2.0 | 3.6 | 3.8 | 4.0 |
| PilCrk-Main 1 | 2.0 | 2.3 | 2.4 | 2.4 |
| PilCrk-Main 2 | 2.0 | 2.3 | 2.4 | 2.4 |
| PilCrk-Main 3 | 2.0 | 2.3 | 2.3 | 2.3 |

| | | | | |
|---|---|---|---|---|
| PilCrk-Main 4 | 2.0 | 2.3 | 2.3 | 2.3 |
| PilCrk-Sub1 Trib a | 2.0 | 3.9 | 4.0 | 4.0 |
| PilCrk-Sub1 Trib b | 2.0 | 3.9 | 4.0 | 4.0 |
| PilCrk-Sub1 Trib c | 2.0 | 3.9 | 4.0 | 4.0 |
| PilCrk-Sub2 Trib a | 2.0 | 3.4 | 3.7 | 3.7 |
| PilCrk-Sub3 Trib a | 2.0 | 3.4 | 3.7 | 3.7 |
| PilCrk-Sub3 Trib b | 2.0 | 3.4 | 3.7 | 3.7 |
| PilCrk-Sub4 Trib a | 2.0 | 2.9 | 3.6 | 3.6 |
| PilCrk-Sub5 Trib a | 2.0 | 3.2 | 3.6 | 3.6 |
| PilCrk-Sub7 Trib a | 2.0 | 2.4 | 2.7 | 2.7 |
| PilCrk-Sub8 Trib a | 2.0 | 2.8 | 3.5 | 3.5 |

#### 4.3.1.4 FlwIntraAnn- Intra-Annual Flow Variability

This attribute characterizes stream flashiness during storm flow. Values in this study are based on guidance provided by Lestelle (2004) that links attribute levels to the ratio of scenario long term average TQmean value to template long term average TQmean value. TQmean is an annual statistic that can be calculated from average daily flow data provided by the HSPF model. It is the ratio of the number of days in a year on which average discharge exceed mean annual discharge for the specific year. Figure 4-5 shows the relationship of attribute value to Tqmean ratio.

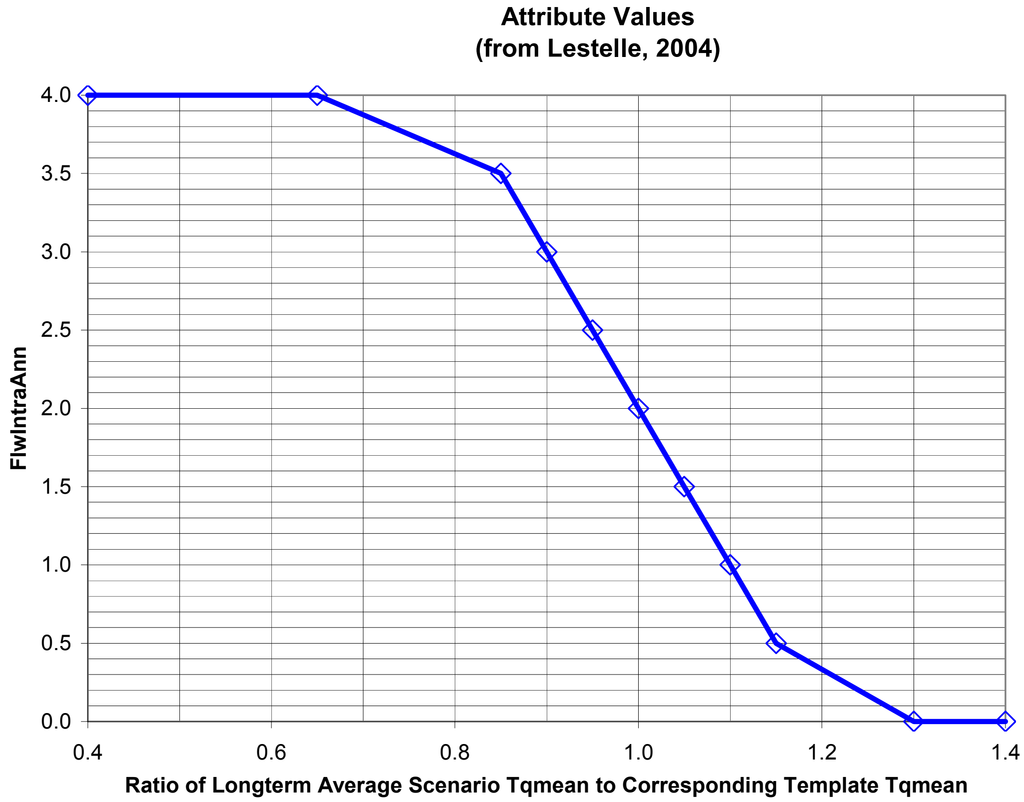

**Figure 4-5 FlwIntraAnn Attribute Values in Relationship to Tqmean Ratio**

Effect of FlwIntraAnn in EDT

Only qualitative information is available. EDT Level 2 values affect the Level 3 survival factor "Flow" inside the model. Lestelle (2004) states that this attribute "…principally affects survival of fingerlings during overwintering." Similar to FlwDielVar, it can also affect other free-swimming stages and reduce egg-to-fry survival due to stranding of redds. Very high values (>3.5) are highlighted by shading in Table 4-5.

**Table 4-5 FlwIntraAnn Level 2 Values**

| EDT Reach | Template | Current | Future 1 | Future 2 |
|---|---|---|---|---|
| Church-1 | 2.0 | 2.2 | 2.6 | 3.2 |
| Church-2 | 2.0 | 2.2 | 2.7 | 3.5 |
| Church-3 | 2.0 | 2.2 | 2.6 | 3.4 |
| Church-4 | 2.0 | 2.3 | 2.7 | 3.6 |
| Church-5 | 2.0 | 2.2 | 2.5 | 3.2 |
| PilCrk-Main 1 | 2.0 | 2.1 | 2.2 | 2.2 |
| PilCrk-Main 2 | 2.0 | 2.1 | 2.2 | 2.2 |
| PilCrk-Main 3 | 2.0 | 2.1 | 2.1 | 2.2 |
| PilCrk-Main 4 | 2.0 | 2.1 | 2.1 | 2.1 |
| PilCrk-Sub1 Trib a | 2.0 | 2.3 | 3.1 | 3.6 |
| PilCrk-Sub1 Trib b | 2.0 | 2.3 | 3.1 | 3.6 |
| PilCrk-Sub1 Trib c | 2.0 | 2.3 | 3.1 | 3.6 |
| PilCrk-Sub2 Trib a | 2.0 | 2.1 | 2.3 | 2.3 |
| PilCrk-Sub3 Trib a | 2.0 | 2.1 | 2.3 | 2.3 |
| PilCrk-Sub3 Trib b | 2.0 | 2.1 | 2.3 | 2.3 |
| PilCrk-Sub4 Trib a | 2.0 | 2.1 | 2.2 | 2.2 |
| PilCrk-Sub5 Trib a | 2.0 | 2.2 | 2.3 | 2.3 |
| PilCrk-Sub7 Trib a | 2.0 | 2.1 | 2.1 | 2.1 |
| PilCrk-Sub8 Trib a | 2.0 | 2.1 | 2.1 | 2.1 |

### 4.3.2 Setting of Indirect Attribute Values

Indirect attributes (those that are not derived directly from flow statistics, but rather are related to flow through well-known or hypothesized relationships) are either keyed to a flow parameter, such as relative stream power (see below), or are related to a watershed land cover descriptor, such as forest cover or imperviousness. Impervious area values (e.g., %TIA) and the means by which they were calculated were presented for each scenario in Section 3.

#### 4.3.2.1 BenComRch- Benthos Diversity & Production

Attribute values are linked to B-IBI scores by Lestelle (2004). B-IBI scores were predicted by May, et al. (1997) as a function of %TIA. May et al. (1997) reported B-IBI scores that ranged from 24 to 48 as total percent impervious area (TIA) approached zero. The King County Normative Flow study (Cassin, 2004) found that some of the scatter in the data would be attributed to differences in riparian condition at the B-IBI sampling points. On the assumption that B-IBI scores should be equal to 50 for pristine basin conditions (basin cover, riparian and in-channel conditions all in a pristine state) and that scores would decline to low B-IBI values at high TIA percentages (for example a value of 12 at TIA = 60% reported by May, 1997) *an approximation, in this study, to represent B-IBI score decline as influenced by basin cover change, but excluding riparian or in-channel degradation would be:*

$$\text{B-IBI} = 50 - \text{TIA}*0.625 \quad (4\text{-}1)$$

B-IBI scores were determined for each reach in each scenario using equation 4-1 and BenComRch values, in turn, were read from Figure 4-6 which is based on guidelines from Lestelle (2004).

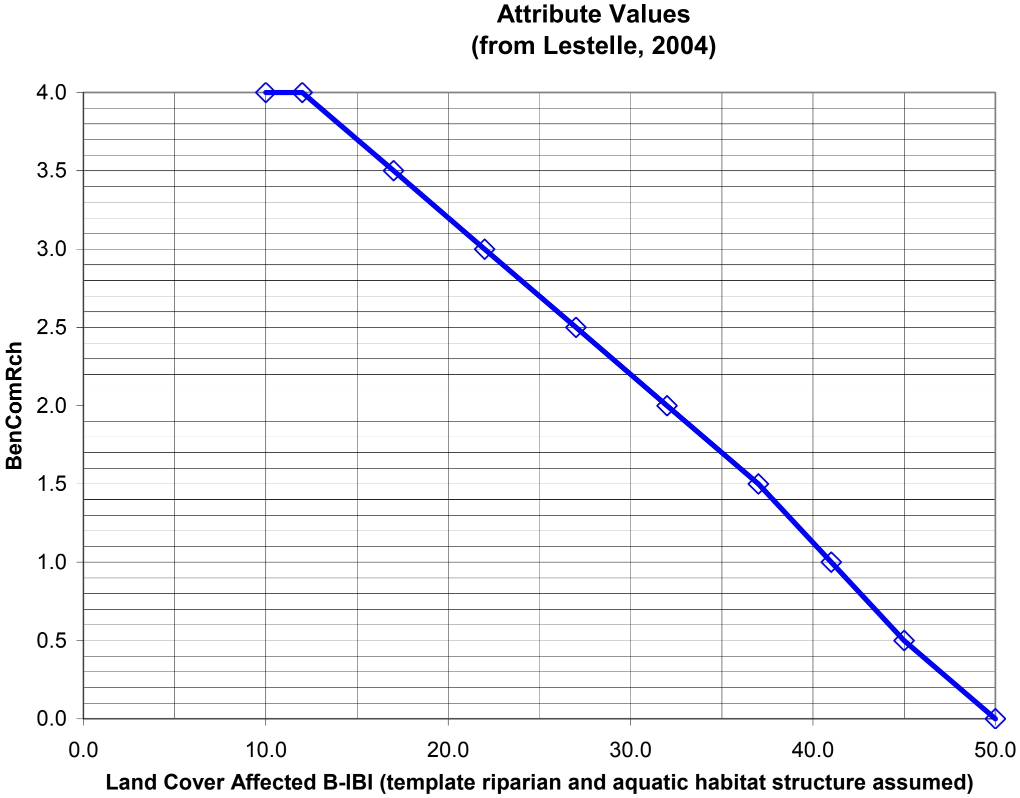

**Figure 4-6 BenComRch Attribute Values as a Function of B-IBI.**

Effect of BenComRch in EDT

This attribute affects the level 3 attribute “Food” in EDT and in turn influences maximum achievable density at the end of rearing life stages. This in turn affects productivity (Lestelle, 2004). Apparently, EDT uses this attribute to quantify the availability of food during rearing. Values of 1.0 or less suggest abundant and diverse food sources. Values closer to 2.0 reflect loss of diversity in food species, but are not expected to have a strong effect on survival in EDT.

**Table 4-6 BenComRch Level 2 Values**

| EDT Reach | Template | Current | Future 1 | Future 2 |
|---|---|---|---|---|
| Church-1 | 0.0 | 0.3 | 1.1 | 2.4 |
| Church-2 | 0.0 | 0.3 | 1.1 | 2.4 |
| Church-3 | 0.0 | 0.3 | 1.0 | 2.3 |
| Church-4 | 0.0 | 0.3 | 0.7 | 2.3 |
| Church-5 | 0.0 | 0.3 | 0.8 | 2.2 |
| PilCrk-Main 1 | 0.0 | 0.1 | 0.2 | 0.3 |
| PilCrk-Main 2 | 0.0 | 0.1 | 0.2 | 0.1 |
| PilCrk-Main 3 | 0.0 | 0.1 | 0.1 | 0.1 |
| PilCrk-Main 4 | 0.0 | 0.1 | 0.1 | 0.1 |
| PilCrk-Sub1 Trib a | 0.0 | 0.1 | 1.2 | 2.3 |
| PilCrk-Sub1 Trib b | 0.0 | 0.1 | 1.2 | 2.3 |
| PilCrk-Sub1 Trib c | 0.0 | 0.1 | 1.2 | 2.3 |
| PilCrk-Sub2 Trib a | 0.0 | 0.1 | 0.6 | 0.6 |
| PilCrk-Sub3 Trib a | 0.0 | 0.1 | 0.6 | 0.6 |
| PilCrk-Sub3 Trib b | 0.0 | 0.1 | 0.6 | 0.6 |
| PilCrk-Sub4 Trib a | 0.0 | 0.1 | 0.4 | 0.4 |
| PilCrk-Sub5 Trib a | 0.0 | 0.1 | 0.4 | 0.4 |
| PilCrk-Sub7 Trib a | 0.0 | 0.1 | 0.1 | 0.1 |
| PilCrk-Sub8 Trib a | 0.0 | 0.1 | 0.2 | 0.2 |

#### 4.3.2.2 Sediment Attributes: Fine Sediments (FnSedi), Embeddedness (Emb), and Turbidity (Turb)

Sediment attributes are generally related to the intensity of land use in a watershed. Resource use and development activities including agriculture, urbanization, and construction result in elevated levels of suspended sediment in streams. Sediment transported during higher flows is deposited in lower gradient reaches during the falling limb of the storm hydrograph. While spawning salmon will clean most or all of the fines from the substrate, fines eroded and transported from upstream subsequent to redd construction and then deposited within redds can have highly deleterious effects on juvenile salmon including mortality.

*Fine Sediments* (FnSedi) is defined as the percentage of fine sediment (criteria are explicit for both the <0.85 mm size fraction and the <6.3 mm size fraction to address suffocation and entombment, respectively) within salmonid spawning substrates. These substrates include tailouts, small cobble-gravel riffles, and glides. In this study, we have based the ratings for fine sediment on the small, 0.85 mm criteria, for the smaller tributary streams because of the limited availability of data linking substrate fine sediment below this threshold to basin impervious area (TIA).

May et al. (1997) cites studies that show intragravular fine sediment (<0.84 mm) can vary from less than 5% to greater than 25% as basin %TIA levels vary from 0% to 60%. However, all sites exhibiting fine sediment levels greater than 15% had local stream gradients less 0.7%. Lestelle (2004) also cites several studies related to the influence of forest practices on intragravular fine sediment. In one study, fine sediment varied between 1% on a stream draining an unlogged forest watershed and 29% for a site draining an actively logged watershed with heavily used logging roads. He also cites studies that suggest a correlation between fine sediment and two basin characteristics, percentage clearcut and road density. To this, we would add upstream landslide potential as indicated by steepness and geologic characteristics.

Clearly, the percentage of intragravular fine sediment is determined by a complex suite of conditions including the variable supply of upstream sediment, variable transport capacity at the site of interest, and pattern of sediment deposition among other factors. Available evidence suggests that in urbanizing basins of the Puget Lowland, intragravular sediment is correlated with total impervious area, probably reflecting the additional sediment supplied by eroding stream bed and banks subjected to longer durations of erosive flow levels. For forest practice areas, accelerated sediment delivery to channels has been correlated with clearcutting and associated loss of soil reinforcement by tree roots on steep, landslide prone slopes as well as with forest road density. This line of argument leads to two different approaches for pilot study reaches draining moderately slope lands subject to land development (all of Church Creek reaches and all tributary the EDT-modeled, tributaries in Pilchuck Creek. The Fine Sediment attribute, FnSedi is rated as 0 in low gradient channels where silts and sands dominate to a major extent under undisturbed conditions as they do in Church-1 which is not a gravel bed reach with a significant amount of spawning habitat. For the other Church Creek and Pilchuck Creek tributary reaches affected by urban and rural development, a simple power relationship using %TIA derived from data presented May et al (1997) was employed to estimate the percentage of fine sediments:

$$\%\text{Fines} = 4.1(\%\text{TIA})^{0.43} \qquad (4\text{-}2)$$

with the following results:

**Table 4-7 Percentage Fine Sediment from TIA% (Eq. 4-2)**

| EDT Reach | Template | Current | Future 1 | Future 2 |
|---|---|---|---|---|
| Church-1 | N/A | N/A | N/A | N/A |
| Church-2 | 0.0% | 7.4% | 13.5% | 18.7% |
| Church-3 | 0.0% | 6.6% | 13.1% | 18.7% |
| Church-4 | 0.0% | 5.5% | 11.9% | 18.7% |
| Church-5 | 0.0% | 6.6% | 12.4% | 18.7% |
| PilCrk-Main 1 | N/A | N/A | N/A | N/A |
| PilCrk-Main 2 | N/A | N/A | N/A | N/A |
| PilCrk-Main 3 | N/A | N/A | N/A | N/A |
| PilCrk-Main 4 | N/A | N/A | N/A | N/A |
| PilCrk-Sub1 Trib a | 0.0% | 9.5% | 14.2% | 18.7% |
| PilCrk-Sub1 Trib b | 0.0% | 9.5% | 14.2% | 18.7% |
| PilCrk-Sub1 Trib c | 0.0% | 9.5% | 14.2% | 18.7% |
| PilCrk-Sub2 Trib a | 0.0% | 4.1% | 10.5% | 10.5% |
| PilCrk-Sub3 Trib a | 0.0% | 5.5% | 10.5% | 10.5% |
| PilCrk-Sub3 Trib b | 0.0% | 5.5% | 10.5% | 10.5% |
| PilCrk-Sub4 Trib a | 0.0% | 4.1% | 9.5% | 9.5% |
| PilCrk-Sub5 Trib a | 0.0% | 4.1% | 9.5% | 9.5% |
| PilCrk-Sub7 Trib a | 0.0% | 0.0% | 5.5% | 5.5% |
| PilCrk-Sub8 Trib a | 0.0% | 0.0% | 6.6% | 6.6% |

For all study reaches except the Pilchuck Creek mainstem reaches, the values in Table 4-7 were converted to Level 2 attribute values using guidance provided by Lestelle. The relationship provided between fine sediment percentage and FnSedi values is represented by the curve shown in Figure 4-7.

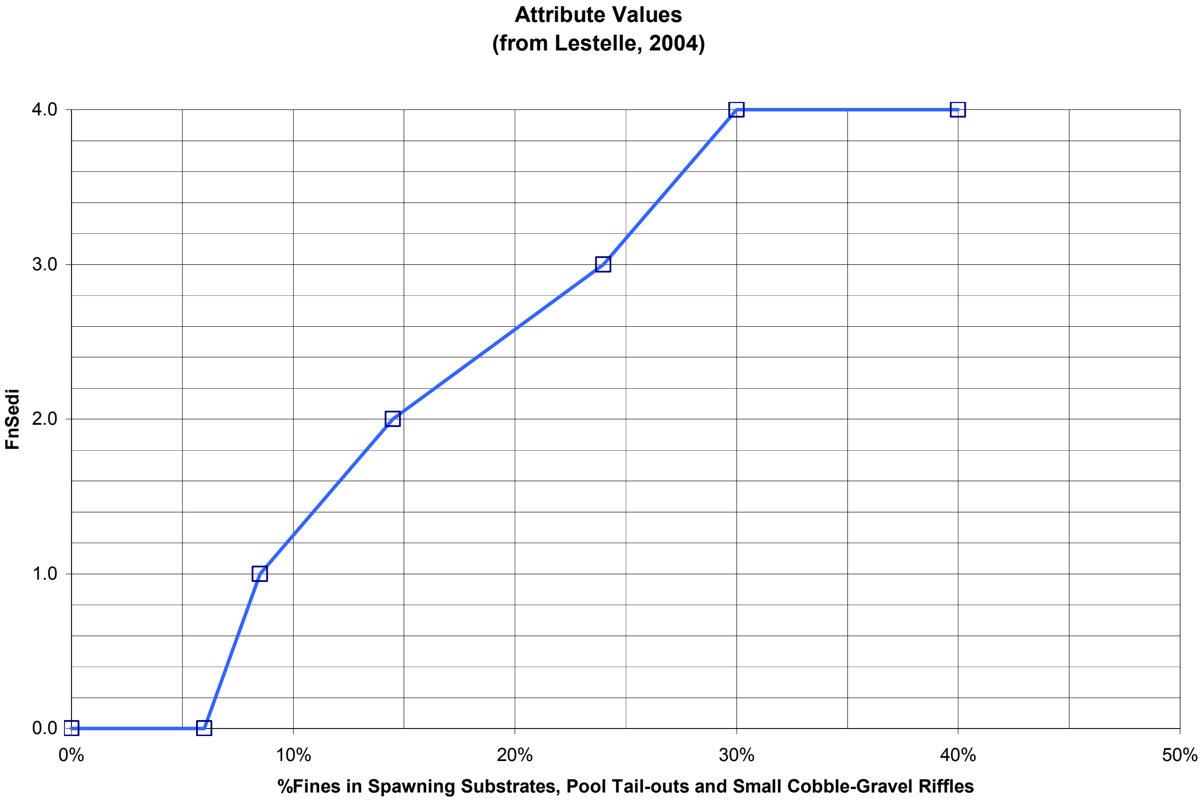

**Figure 4-7 Relationship between Fine Sediments and FnSedi Level 2 Rating**

The four mainstem reaches of Pilchuck Creek were treated in a different way. They are the only ones receiving runoff from steep industrial forest lands with the potential to deliver sediment to spawning beds. Of these reaches, only the lower 3 were considered susceptible to fine sediment intrusion as the uppermost reach is steep and considered likely to transport fines to the lower reaches.

Fine sediments percentages in the lower three reaches (Pilcrk_Main 1, 2, 3) were determined by a limited field survey conducted in August of 2005 during low flow conditions. Observation of surface fines were made using a grid method along transects in pool tailout habitat of spawning areas. These measurements were considered equivalent to percentage fines within the substrate based on previous observations correlating surface and subsurface measurements during the base flow period. Methods were similar to those used by Rhodes and Purser (1998) following those of Lisle and Eads (1991).

Observations at cross-sections within Pilchuck Creek modeling reaches were averaged to arrive at estimates of percentage of fine sediment in spawning gravel substrates. Results of these measurements and corresponding Level 2 attribute ratings for FnSedi are as follows:

| Table 4-8 Percentage Fines for Mainstem Pilchuck Creek | | |
|---|---|---|
| EDT Reach | %Fines (<6 mm) in Pool Tailout Habitat d.s. of adult hold pools. (Observed August 3, 2005) | Corresponding EDT Level-2 Rating for Fine Sediment FnSedi (after Lestelle, 2004) |
| PilCrk-Main 1 | 24.0[1] | 1.5 |
| PilCrk-Main 2 | 16.0 | 0.9 |
| PilCrk-Main 3 | 14.3 | 0.8 |
| PilCrk-Main 4 | Assumed to be < 10%, transport reach | 0.0 |

Note: No field measurements were made in the lowest reach of Pilchuck Creek. Projected estimate based on anecdotal observations that reach is often backwatered by the mainstem Stillaguamish River and has higher levels of both intragravular and surface fine sediment than upstream reaches.

As an approximation, FnSedi levels estimated from limited observations in the mainstem of Pilchuck Creek are assumed to be valid for all three non-template scenarios. Fine sediment ratings for template conditions were assumed to be zero. It is assumed that conditions in these mainstem reaches were controlled primarily by forest management of the forest production lands that predominate in upper Pilchuck Creek and that while disturbances within this area may shift from location to location, aggregate downstream impacts remain the same for all current and future scenarios.

The following table summarizes the fine sediment Level 2 ratings for all EDT-modeled reaches:

| Table 4-9 FiSedi Level 2 Values | | | | |
|---|---|---|---|---|
| EDT Reach | Template | Current | Future 1 | Future 2 |
| Church-1 | 0.0 | 0.0 | 0.0 | 0.0 |
| Church-2 | 0.0 | 0.6 | 1.8 | 2.4 |
| Church-3 | 0.0 | 0.2 | 1.8 | 2.4 |
| Church-4 | 0.0 | 0.0 | 1.6 | 2.4 |
| Church-5 | 0.0 | 0.2 | 1.6 | 2.4 |
| PilCrk-Main 1 | 0.0 | 1.5 | 1.5 | 1.5 |
| PilCrk-Main 2 | 0.0 | 0.9 | 0.9 | 0.9 |
| PilCrk-Main 3 | 0.0 | 0.8 | 0.8 | 0.8 |
| PilCrk-Main 4 | 0.0 | 0.0 | 0.0 | 0.0 |
| PilCrk-Sub1 Trib a | 0.0 | 1.2 | 2.0 | 2.4 |
| PilCrk-Sub1 Trib b | 0.0 | 1.2 | 2.0 | 2.4 |
| PilCrk-Sub1 Trib c | 0.0 | 1.2 | 2.0 | 2.4 |
| PilCrk-Sub2 Trib a | 0.0 | 0.0 | 1.3 | 1.3 |
| PilCrk-Sub3 Trib a | 0.0 | 0.0 | 1.3 | 1.3 |
| PilCrk-Sub3 Trib b | 0.0 | 0.0 | 1.3 | 1.3 |
| PilCrk-Sub4 Trib a | 0.0 | 0.0 | 1.2 | 1.2 |
| PilCrk-Sub5 Trib a | 0.0 | 0.0 | 1.2 | 1.2 |
| PilCrk-Sub7 Trib a | 0.0 | 0.0 | 0.0 | 0.0 |
| PilCrk-Sub8 Trib a | 0.0 | 0.0 | 0.2 | 0.2 |

Effect of Fine Sediment in EDT

This attribute affects the level 3 attribute "Sediment Load" in EDT and in turn influences the success rate of egg incubation. (Lestelle, 2004).

*Embeddedness* (Emb) is defined as the extent that cobbles or gravel are surrounded by or covered by sands, silts, and clays. As a first approximation, percentage embeddedness is assumed equal to percentage fine intragravular sediment as described and tabulated above. The curve for determining ratings from %Emb provided in the EDT input guidelines document (Lestelle, 2004) is shown in Figure 4-7.

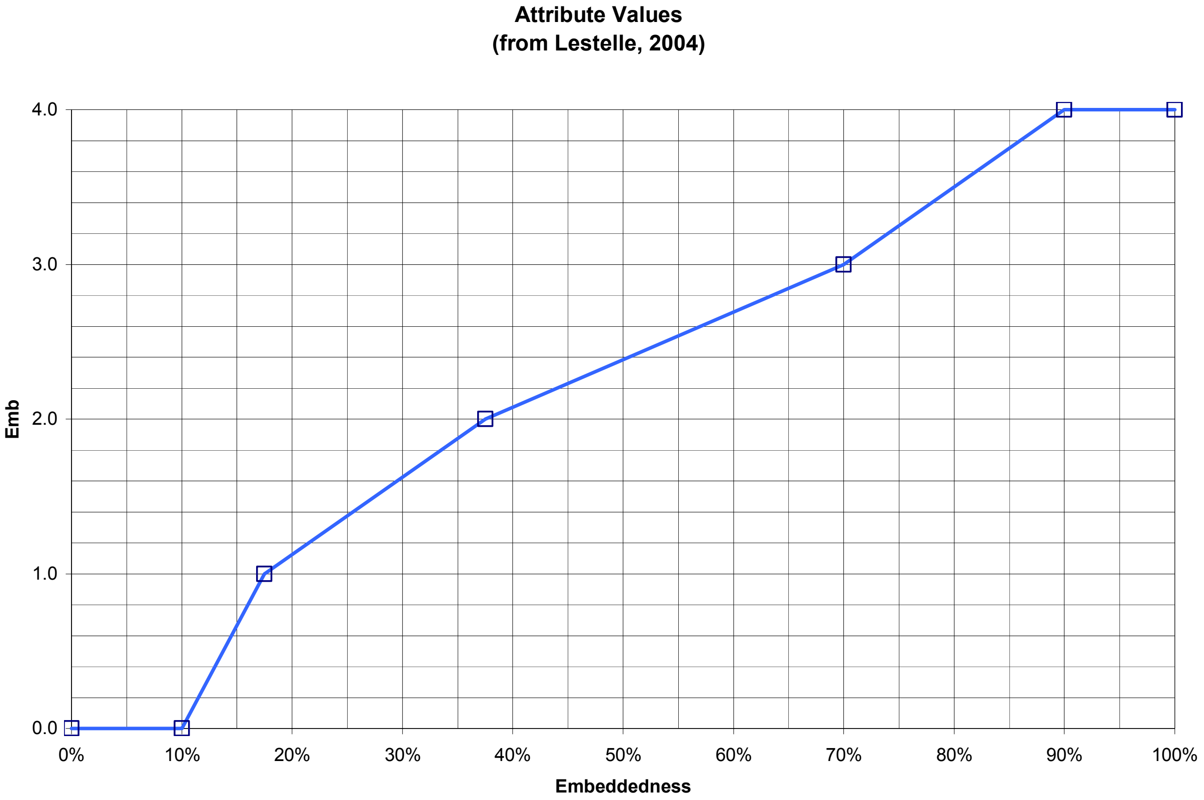

**Figure 4-8 Emb Attribute Values as a Function of %Embeddedness.**

Application of the fine sediment percentages shown in Tables 4-7 and 4-8 to this curve results in the ratings for Emb tabulated in Table 4-10. As before with fine sediment, embeddedness is rated as 0 in Church 1.

**Table 4-10 Emb Level 2 Values**

| EDT Reach | Template | Current | Future 1 | Future 2 |
|---|---|---|---|---|
| Church-1 | 0.0 | 0.0 | 0.0 | 0.0 |
| Church-2 | 0.0 | 0.0 | 0.4 | 1.1 |
| Church-3 | 0.0 | 0.0 | 0.4 | 1.1 |
| Church-4 | 0.0 | 0.0 | 0.3 | 1.1 |
| Church-5 | 0.0 | 0.0 | 0.3 | 1.1 |
| PilCrk-Main 1 | 0.0 | 3.0 | 3.0 | 3.0 |
| PilCrk-Main 2 | 0.0 | 2.1 | 2.1 | 2.1 |
| PilCrk-Main 3 | 0.0 | 2.0 | 2.0 | 2.0 |
| PilCrk-Main 4 | 0.0 | 0.0 | 0.0 | 0.0 |
| PilCrk-Sub1 Trib a | 0.0 | 0.0 | 0.6 | 1.1 |
| PilCrk-Sub1 Trib b | 0.0 | 0.0 | 0.6 | 1.1 |
| PilCrk-Sub1 Trib c | 0.0 | 0.0 | 0.6 | 1.1 |
| PilCrk-Sub2 Trib a | 0.0 | 0.0 | 0.1 | 0.1 |
| PilCrk-Sub3 Trib a | 0.0 | 0.0 | 0.1 | 0.1 |
| PilCrk-Sub3 Trib b | 0.0 | 0.0 | 0.1 | 0.1 |
| PilCrk-Sub4 Trib a | 0.0 | 0.0 | 0.0 | 0.0 |
| PilCrk-Sub5 Trib a | 0.0 | 0.0 | 0.0 | 0.0 |
| PilCrk-Sub7 Trib a | 0.0 | 0.0 | 0.0 | 0.0 |
| PilCrk-Sub8 Trib a | 0.0 | 0.0 | 0.0 | 0.0 |

*Turbidity* (Turb*)* is defined as the severity of suspended sediment episodes within the stream reach. Lestelle (2004) relates Turb levels to the Scale of Severity (SEV) Index (Newcombe and Jensen, 1996). This is calculated from the duration and concentration of suspended sediment in a reach during the month when highest concentrations typically occur using the following relationship:

$$SEV = 1.0642 + 0.6068(\ln[\text{duration in hours}]) + 0.7384(\ln[\text{concentration in mg/L}]) \qquad (4\text{-}3)$$

Although Turb can have a substantial effect on survival (>10% reduction for Turb>2.0) of several life stages within EDT, a calculation with data from the County's site on Church Creek at Church Creek Park suggest that an average grab sample concentration (12 mg/l) during March, the month with highest average, are approximately 1/10 tenth the concentration required to produce a rating of 2.0 for this attribute. This concentration level is assumed to represent conditions for the current scenario in all Church Creek reaches. For future scenarios on Church Creek and all scenarios on Pilchuck Creek tributaries, concentration was scaled by the ratio of % fine sediment values shown in Table 4-7. Effectively, this relates suspended sediment concentrations to %TIA raised to the 0.43 power. The SEV was calculated from the resultant concentrations based on a duration of 31 days (744 hours). This approach was taken for all Church Creek reaches and tributary reaches on Pilchuck Creek.

For the mainstem of Pilchuck Creek, an SEV value of between 5.2 and 5.6 was estimated from very limited suspended sediment grab sample data at Snohomish County's Jackson Gulch Road site near the mouth of Pilchuck Creek. This corresponds to a Turb rating of approximately 1.0. This was assumed to be valid in all mainstem Pilchuck reaches for all scenarios except template. Results of Turbidity rating approximations are shown in Table 4-11.

**Table 4-11 Turb Level 2 Values**

| EDT Reach | Template | Current | Future 1 | Future 2 |
|---|---|---|---|---|
| Church-1 | 0.0 | 1.3 | 1.4 | 1.6 |
| Church-2 | 0.0 | 1.3 | 1.4 | 1.6 |
| Church-3 | 0.0 | 1.3 | 1.5 | 1.6 |
| Church-4 | 0.0 | 1.3 | 1.5 | 1.6 |
| Church-5 | 0.0 | 1.3 | 1.5 | 1.6 |
| PilCrk-Main 1 | 0.0 | 1.0 | 1.0 | 1.0 |
| PilCrk-Main 2 | 0.0 | 1.0 | 1.0 | 1.0 |
| PilCrk-Main 3 | 0.0 | 1.0 | 1.0 | 1.0 |
| PilCrk-Main 4 | 0.0 | 1.0 | 1.0 | 1.0 |
| PilCrk-Sub1 Trib a | 0.0 | 1.4 | 1.5 | 1.6 |
| PilCrk-Sub1 Trib b | 0.0 | 1.4 | 1.5 | 1.6 |
| PilCrk-Sub1 Trib c | 0.0 | 1.4 | 1.5 | 1.6 |
| PilCrk-Sub2 Trib a | 0.0 | 1.4 | 1.4 | 1.4 |
| PilCrk-Sub3 Trib a | 0.0 | 1.2 | 1.4 | 1.4 |

| | | | | |
|---|---|---|---|---|
| PilCrk-Sub3 Trib b | 0.0 | 1.2 | 1.4 | 1.4 |
| PilCrk-Sub4 Trib a | 0.0 | 1.2 | 1.4 | 1.4 |
| PilCrk-Sub5 Trib a | 0.0 | 1.2 | 1.4 | 1.4 |
| PilCrk-Sub7 Trib a | 0.0 | 0.0 | 1.3 | 1.3 |
| PilCrk-Sub8 Trib a | 0.0 | 0.0 | 1.3 | 1.3 |

#### Summary of Effects of Sediment Attributes in EDT

Sediment attributes Fine Sediments and Embeddedness affect survival in the incubation (Fine Sediments), fry colonization and inactive fry (Embeddedness) life stages primarily through the potential to increase mortality through suffocation or entombment of eggs and/or juveniles. Turbidity, or more appropriately, Suspended Sediment, affects survival of all free swimming life stages through reduction in feeding rates and success, physiological stress, impaired homing, reduced growth rate, increased predation and resulting mortality. All sediment attributes affect the Level 3 survival factor Sediment Load during various life stages.

### 4.3.2.3 MetWatCol, MetSedSls, MscToxWat- Dissolved Metals, Adsorbed Metals, and Other Toxicants

The purpose of these three related attributes is to quantify toxicity related to dissolved and adsorbed metals and other substances. Toxicity levels in streams vary widely with land uses and other factors such as alkalinity. Generally, higher rates of metals and other pollutants are associated with higher levels of urbanization (Minton, 2002). Extreme levels can be associated with chemically intensive agriculture, mining, or industrial pollution.

Lestelle (2004) recommends ratings of zero when no toxicity is present, 1 for low level chronic toxicity, 2 for consistently chronic toxicity, 3 for acute toxicity during a whole month of the year, and 4 for consistent acute toxicity. May (1997) noted that metals levels were typically "insignificant" at TIA levels of less than 45%, but Lestelle points out the sporadic nature of metals loading and the difficulty of effectively sampling toxic conditions.

Absent any specific data citing problems with acute toxicity associated with land use and management practices in our pilot basins, the approach was to linearly scale attribute ratings between 0 and 2 based on TIA levels ranging from 0 to 45%. In effect, this limits the sensitivity of EDT results to the strong assumptions that must be taken to set level-2 input values. Level-2 attribute values for this parameter are given by:

$$\text{MetWatCol} = \%\text{TIA}*2/45\% \qquad (4\text{-}4)$$

The same attribute values were be used for MetSedSls and MscToxWat as well.

Effect of MetWatCol (MetSedSls, MscToxWat) in EDT

Only qualitative information is available. These attributes all affect the value of the Level 3 EDT model attribute "Toxic Substances" which, in turn, affects productivity of various life stages. Given the range of values for our reaches and scenarios, we do not expect these attributes to be strong drivers of EDT results.

**Table 4-12 MetWatCol (MetSedSls, MscToxWat)**

| EDT Reach | Template | Current | Future 1 | Future 2 |
|---|---|---|---|---|
| Church-1 | 0.0 | 0.2 | 0.7 | 1.5 |
| Church-2 | 0.0 | 0.2 | 0.7 | 1.5 |
| Church-3 | 0.0 | 0.1 | 0.7 | 1.5 |
| Church-4 | 0.0 | 0.1 | 0.5 | 1.5 |
| Church-5 | 0.0 | 0.1 | 0.6 | 1.5 |
| PilCrk-Main 1 | 0.0 | 0.0 | 0.2 | 0.2 |
| PilCrk-Main 2 | 0.0 | 0.0 | 0.1 | 0.1 |
| PilCrk-Main 3 | 0.0 | 0.0 | 0.0 | 0.0 |
| PilCrk-Main 4 | 0.0 | 0.0 | 0.0 | 0.0 |
| PilCrk-Sub1 Trib a | 0.0 | 0.3 | 0.8 | 1.5 |
| PilCrk-Sub1 Trib b | 0.0 | 0.3 | 0.8 | 1.5 |
| PilCrk-Sub1 Trib c | 0.0 | 0.3 | 0.8 | 1.5 |
| PilCrk-Sub2 Trib a | 0.0 | 0.0 | 0.4 | 0.4 |
| PilCrk-Sub3 Trib a | 0.0 | 0.1 | 0.4 | 0.4 |
| PilCrk-Sub3 Trib b | 0.0 | 0.1 | 0.4 | 0.4 |
| PilCrk-Sub4 Trib a | 0.0 | 0.0 | 0.3 | 0.3 |
| PilCrk-Sub5 Trib a | 0.0 | 0.0 | 0.3 | 0.3 |
| PilCrk-Sub7 Trib a | 0.0 | 0.0 | 0.1 | 0.1 |
| PilCrk-Sub8 Trib a | 0.0 | 0.0 | 0.1 | 0.1 |

#### 4.3.2.4 TmpMonMx- Maximum Temperature

This attribute characterizes the incidence of lethal and sub-lethal temperature events during the warmest month of the year. The severity of temperature events (as reflected in level-2 values) is defined in terms of both temperature threshold and duration above a threshold. The base data from which events are determined appears to be daily temperature. Although the documentation for this attribute is confusing and somewhat contradictory, our interpretation is that durations of temperature exceedances would be determined as annual averages from a long time series of data.

The HSPF model developed for this study computes stream temperature on an hourly basis for several decades in each reach for each scenario. Temperatures vary from scenario to scenario depending on differing runoff pathways associated with land cover and companion assumptions of the scenario related to water withdrawal and use. In all scenarios, riparian shading was held constant at template conditions.

The relationship to attribute ratings of different event durations for various temperature thresholds is shown in Figure 4-9. Note that in the figure, durations refer to consecutive days in the month. In addition to these rating curves, the EDT documentation lists these additional guidelines that do not lend themselves to graphical portrayal:

1. Greater than four non-consecutive days in the maximum temperature month exceeding 72 deg. F. is rated as a 3.0. Our interpretation of this guidance is to rate four non-consecutive days as 2.5 and to increase the rating by 0.5 for each additional non-consecutive day greater than the threshold.

2. If it is typical to have one day or more per year with a water temperature greater than 89.5, the rating is maximized at 4.0. This condition is extremely unlikely to occur in our climate given the air temperatures that are typically experienced in the lower Puget Sound region and the assumption of shaded reach conditions in all scenarios.

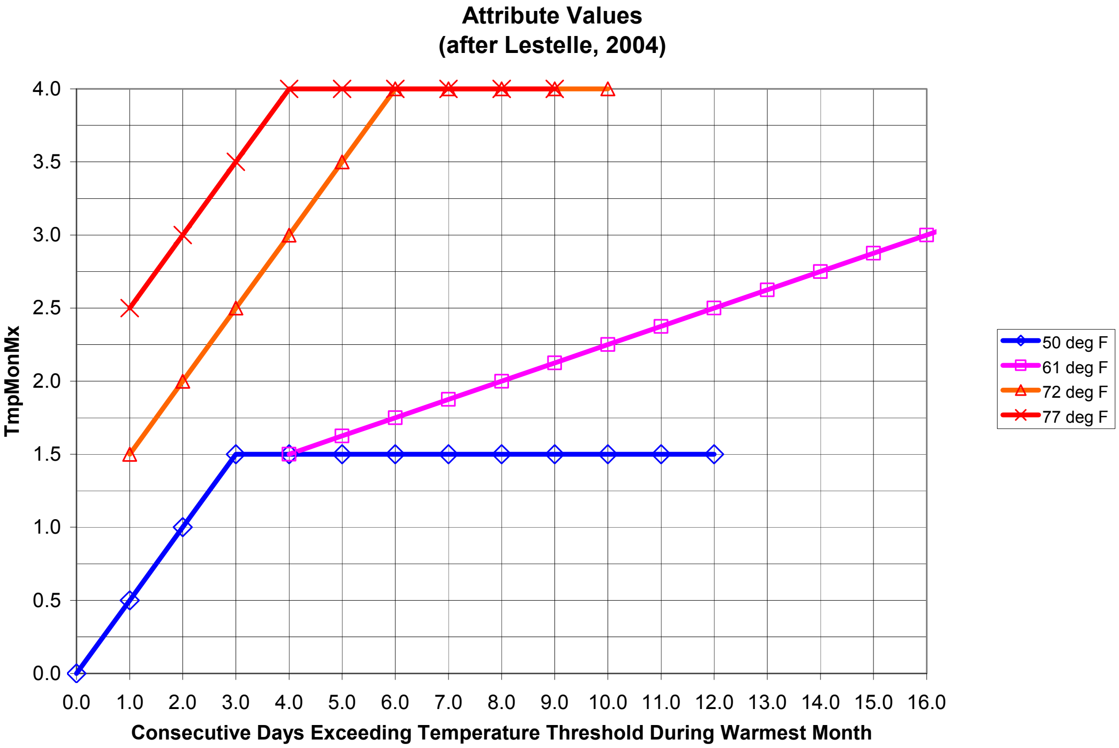

**Figure 4-9 Relation between Days Exceeding Threshold and TmpMonMx Level 2 Rating**.

Effect of TmpMonMx in EDT

Lestelle (2004) notes that this attribute is "a high priority for rating," suggesting potential strong influence on population predictions by EDT. TmpMonMx affects the Level 3 attribute "Temperature" which impacts productivity in most life stages. "Temperature" also influences several other Level 3 attributes during some life stages, which reinforces its influence on species productivity. Although no extremely unfavorable ratings are shown in Table 4-13, the effect on reach dewatering in Church Creek reaches and in subbasin 8 of Pilchuck Creek (Tributary 80) is evident in the trend of increasing values with scenarios reflecting increasing levels of urbanization.

| Table 4-13 TmpMonMx | | | | |
|---|---|---|---|---|
| EDT Reach | Template | Current | Future 1 | Future 2 |
| Church-1 | 0.0 | 1.5 | 1.8 | 1.8 |
| Church-2 | 0.0 | 1.6 | 2.6 | 2.6 |
| Church-3 | 0.0 | 1.6 | 2.8 | 2.6 |
| Church-4 | 1.7 | 2.0 | 2.3 | 2.2 |
| Church-5 | 0.0 | 0.2 | 0.8 | 0.0 |
| PilCrk-Main 1 | 0.0 | 0.0 | 0.0 | 0.0 |
| PilCrk-Main 2 | 0.0 | 0.0 | 0.0 | 0.0 |
| PilCrk-Main 3 | 0.0 | 0.0 | 0.0 | 0.0 |
| PilCrk-Main 4 | 0.2 | 0.1 | 0.1 | 0.1 |
| PilCrk-Sub1 Trib a | 0.2 | 0.6 | 1.1 | 0.6 |
| PilCrk-Sub1 Trib b | 0.2 | 0.6 | 1.1 | 0.6 |
| PilCrk-Sub1 Trib c | 0.2 | 0.6 | 1.1 | 0.6 |
| PilCrk-Sub2 Trib a | 2.5 | 2.6 | 2.7 | 2.6 |
| PilCrk-Sub3 Trib a | 2.5 | 2.6 | 2.7 | 2.6 |
| PilCrk-Sub3 Trib b | 2.5 | 2.6 | 2.7 | 2.6 |
| PilCrk-Sub4 Trib a | 2.5 | 2.5 | 2.5 | 2.5 |
| PilCrk-Sub5 Trib a | 2.7 | 2.7 | 2.7 | 2.7 |
| PilCrk-Sub7 Trib a | 2.6 | 2.6 | 2.6 | 2.6 |
| PilCrk-Sub8 Trib a | 1.8 | 1.7 | 2.6 | 2.6 |

#### 4.3.2.5 TmpMonMn- Minimum Monthly Temperature

This attribute characterizes the incidence of cold water events in which temperatures are less than 39 deg F (4 deg C) for at least a day every year. Removal of riparian vegetation can accelerate heat loss from streams during the winter and increase the incidence of cold water events that are prejudicial to salmonid productivity. In this study, riparian vegetation is assumed to be at template conditions for all scenarios (near-full shade); consequently, TmpMonMn is assumed to be constant across all scenarios. Based on USGS water temperature data for the Pilchuck Near Bryant (USGS 12168500), mainstem Pilchuck Creek reaches typically experience temperatures less than 1 deg C approximately twice per month in January, the coldest month of the year. This corresponds to a rating of 2.0 based on guidelines provided by Lestelle (2004). A limited amount of Church Creek water temperature data suggest somewhat higher winter temperatures compared to Pilchuck Creek, commensurate with the significantly lower average basin elevation. For this reason, Church Creek reaches as well as Pilchuck Creek tributaries 1a, 1b, and 1c are assigned TmpMonMn values of 1.0 commensurate with less than 7 days in January with temperatures lower than 39 deg F (4 deg C) and days with lower than 35 deg F (1 deg C) occurring less than once per year. The remainder of Pilchuck Creek tributary reaches are assigned an intermediate value of 1.5.

Effect of TmpMonMn in EDT

Lestelle (2004) notes that this attribute is "a high priority for rating", suggesting potential strong influence on population predictions by EDT. TmpMonMn affects the Level 3 attribute "Temperature" during inactive life stages with consequent effects on productivity during these stages. TmpMonMn is not a significant attribute for this pilot study (Table 4-14).

**Table 4-14 TmpMonMn**

| EDT Reach | Template | Current | Future 1 | Future 2 |
|---|---|---|---|---|
| Church-1 | 1.0 | 1.0 | 1.0 | 1.0 |
| Church-2 | 1.0 | 1.0 | 1.0 | 1.0 |
| Church-3 | 1.0 | 1.0 | 1.0 | 1.0 |
| Church-4 | 1.0 | 1.0 | 1.0 | 1.0 |
| Church-5 | 1.0 | 1.0 | 1.0 | 1.0 |
| PilCrk-Main 1 | 2.0 | 2.0 | 2.0 | 2.0 |
| PilCrk-Main 2 | 2.0 | 2.0 | 2.0 | 2.0 |
| PilCrk-Main 3 | 2.0 | 2.0 | 2.0 | 2.0 |
| PilCrk-Main 4 | 2.0 | 2.0 | 2.0 | 2.0 |
| PilCrk-Sub1 Trib a | 1.0 | 1.0 | 1.0 | 1.0 |
| PilCrk-Sub1 Trib b | 1.0 | 1.0 | 1.0 | 1.0 |
| PilCrk-Sub1 Trib c | 1.0 | 1.0 | 1.0 | 1.0 |
| PilCrk-Sub2 Trib a | 1.5 | 1.5 | 1.5 | 1.5 |
| PilCrk-Sub3 Trib a | 1.5 | 1.5 | 1.5 | 1.5 |
| PilCrk-Sub3 Trib b | 1.5 | 1.5 | 1.5 | 1.5 |
| PilCrk-Sub4 Trib a | 1.5 | 1.5 | 1.5 | 1.5 |
| PilCrk-Sub5 Trib a | 1.5 | 1.5 | 1.5 | 1.5 |
| PilCrk-Sub7 Trib a | 1.5 | 1.5 | 1.5 | 1.5 |
| PilCrk-Sub8 Trib a | 1.5 | 1.5 | 1.5 | 1.5 |

### 4.3.2.6 Dissolved Oxygen (DisOxy) and Nutrient Enrichment (NutEnrch)

Dissolved Oxygen is a critical element of aquatic ecosystems and is required by fish and aquatic insects. In unpolluted streams it is nearly always at or near saturation (Figure 4-11). Below 80% aquatic function is impaired.

Dissolved oxygen content is affected by nutrient enrichment and temperature. Although nutrients typically do not have any direct effect on salmonids, they can severely deplete dissolved oxygen through the decomposition of aquatic flora whose growth is stimulated by elevated levels of nutrients.

Excess nutrients => increased plant growth =>
death and decomposition => consumption of dissolved oxygen

High temperatures exacerbate this situation through the stimulation of plant growth and can reduce dissolved oxygen levels on their own due to decrease solubility of oxygen at higher temperatures. Lestelle (2004) provides guidance that index values for dissolved oxygen be set at

4 when mean monthly water temperatures exceeds $20^{o}$ C and super enrichment of nutrients occurs. A lookup table is provided wherein one can determine the Dissolved Oxygen index value by knowing the Nutrient Enrichment value and mean monthly water temperature.

Nutrient Enrichment ratings are tied to benthic chlorophyll-a measurements (performed by Snohomish County in lakes, but not streams) and a narrative description of algae growth. According to the narrative and in consultation with Snohomish County's water quality specialist, the current nutrient enrichment rating is 1. This is likely due to open canopy and low to moderate amounts of nutrients (<1.0 ppm nitrate-N and <0.1 ppm Total P during summer months) encouraging algal growth. Since all of the scenarios are designed to measure the effects of watershed land use and water withdrawals only, riparian canopy (through the Riparian Function attribute) is set to template conditions for all scenarios. If the canopy is closed, as it would be under historical conditions, the nutrient enrichment would be 0 for all scenarios.

Mean monthly water temperatures are currently in the $12\text{-}16^{o}$C range in Church Creek during the summer months when dissolved oxygen might be an issue (likely due to dominance of groundwater in streamflow). In the lower reaches of Pilchuck Creek (PilCrk-Main 1 and 3; from gages at State Route 9 and I-5), mean monthly stream temperatures are in the $16\text{-}20^{o}$C range in years 2000, 2001, and 2004. This is likely elevated over template or historic conditions due to riparian canopy removal (36% adjusted total forest cover; Purser, et al., 2003) and channel changes.

With nutrient enrichment attribute set to 0 and stream temperatures in the $12\text{-}16^{o}$ C range, Dissolved Oxygen is rated 0 in all reaches. This is consistent with data from Church Creek at the City Park where Dissolved Oxygen data has been collected (monthly grab samples) since 1994 and show only one sample with a value below 8.0 mg/L, the State of Washington water quality criteria.

#### 4.3.2.7 Channel Widths

These include: Channel Width-Month Minimum width (ft) and Channel Width-Month Maximum width (ft)

These are shaped (i.e., they vary by month according to a pattern specified in the model), point, non-categorical attributes that represent wetted channel widths during the months of lowest (generally August-September) and highest (December or January most years in western Washington) flow. This attribute is used, in combination with reach length, to estimate the area of channel and thence of each habitat type available to the pertinent life stage in each month. These attributes affect total habitat available (quantity or capacity).

Lestelle (2004) presents the following relationships for estimating wetted width based on discharge:

$$\text{Width} = 4.6\,Q^{0.566} \qquad (4\text{-}5)$$

for confined reaches Church-2 and PilCrk-Main 4 and

$$\text{Width} = 10\ Q^{0.435} \qquad (4\text{-}6)$$

for all other reaches. In these equations, Q was assumed to be the long term average median daily discharge in cfs during the driest month (August) for minimum wetted width, and during the wettest month (January) for maximum wetted width. As with direct flow attributes, median discharges were extracted from the long term record of hourly discharges simulated by the HSPF model for each reach and scenario.

#### 4.3.2.8 BdScour- Bed Scour

Bed scour in salmon spawning areas. Lestelle (2004) assigns values for BdScour based on the expected depth of scour in spawning areas. The purpose of this attribute is to quantify impacts on egg viability and inactive life stages. Experience and physical reasoning indicate that bed scour increases as the frequency and duration of flood discharges greater than the threshold discharge necessary to mobilize bed materials increases. However, quantification of a specific depth of scour within the spawning portion of our modeling reach is extremely difficult and well beyond the scope of this study.

In spite of the of the complexities associated with quantifying scour, as noted by Lestelle (2004), several studies have shown that flow changes associated with land use practices including forestry and urbanization have increased the incidence of salmon redd scour. In lieu of a direct calculation of scour depth, a surrogate procedure was employed that correlated the BdScour attribute rating with the increases in peak flow. This was based on the concept that increases in the magnitude and frequency of flows on the order of bankfull discharge will increase scour. In this scheme, template conditions are assumed to have a moderately low (favorable) rating of 1.5. With the exception of the low-gradient, Church-1 reach, ratings for the other scenarios were determined using the ratio of scenario 2-year peak annual flow to Template 2-year peak annual flow as shown in Figure 4-10. For Church-1, the rating was assumed to be constant at a value of 1.5 across all scenarios because of its low gradient and presumed insensitivity to changes in discharges.

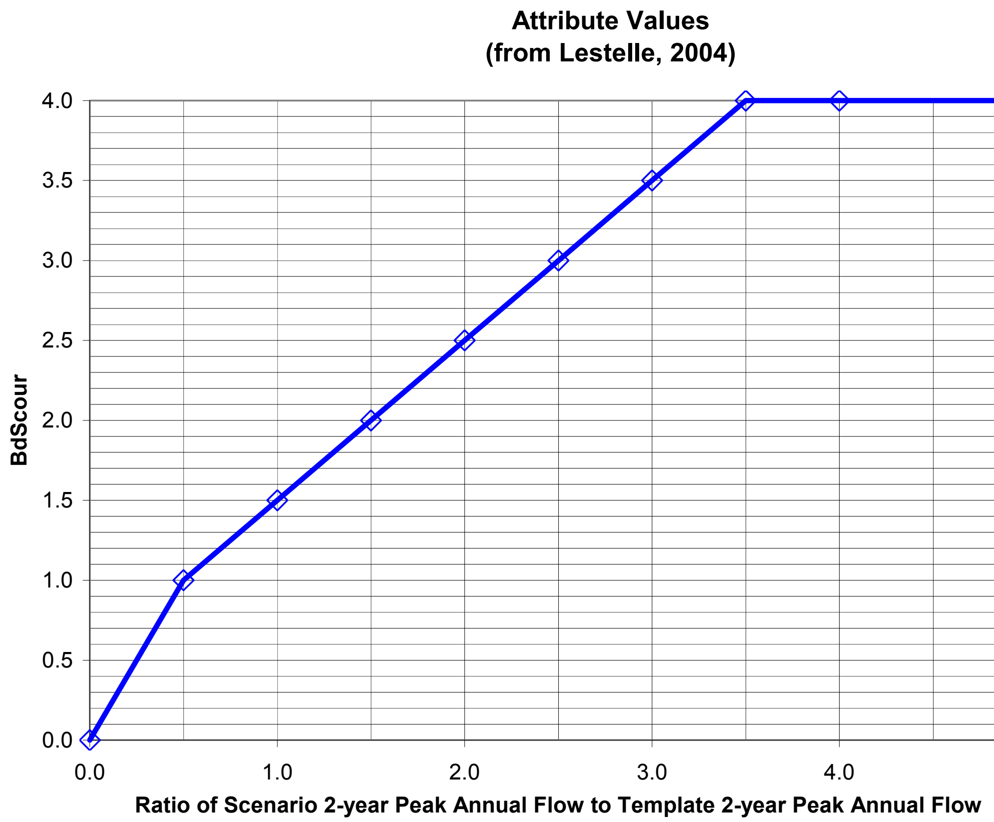

**Figure 4-10 Relations between 2-year Flow Ratio and BdScour Level 2 Rating.**

While it is freely admitted that the proposed rating system is speculative and qualitatively based, it seems conceptually reasonable. The alternative to such a rating scheme would be to make BdScour constant for all scenarios which seems even more arbitrary given understanding of the degree to which increases in storm flows can erode and destabilize channels when such increases occur within a flow range that is competent to move bed materials. Very high values (3.5 or higher) are highlighted by shading in Table 4-15.

**Table 4-15 BdScour**

| EDT Reach | Template | Current | Future 1 | Future 2 |
|---|---|---|---|---|
| Church-1 | 1.5 | 1.5 | 1.5 | 1.5 |
| Church-2 | 1.5 | 2.2 | 2.9 | 3.7 |
| Church-3 | 1.5 | 2.2 | 2.8 | 3.7 |
| Church-4 | 1.5 | 2.3 | 3.0 | 4.0 |
| Church-5 | 1.5 | 2.0 | 2.5 | 3.2 |
| PilCrk-Main 1 | 1.5 | 1.6 | 1.6 | 1.6 |
| PilCrk-Main 2 | 1.5 | 1.6 | 1.6 | 1.6 |
| PilCrk-Main 3 | 1.5 | 1.6 | 1.6 | 1.6 |
| PilCrk-Main 4 | 1.5 | 1.6 | 1.6 | 1.6 |
| PilCrk-Sub1 Trib a | 1.5 | 2.6 | 3.9 | 4.0 |
| PilCrk-Sub1 Trib b | 1.5 | 2.6 | 3.9 | 4.0 |

|  |  |  |  |  |
|---|---|---|---|---|
| PilCrk-Sub1 Trib c | 1.5 | 2.6 | 3.9 | 4.0 |
| PilCrk-Sub2 Trib a | 1.5 | 1.9 | 2.2 | 2.2 |
| PilCrk-Sub3 Trib a | 1.5 | 1.9 | 2.2 | 2.2 |
| PilCrk-Sub3 Trib b | 1.5 | 1.9 | 2.2 | 2.2 |
| PilCrk-Sub4 Trib a | 1.5 | 1.7 | 1.9 | 1.9 |
| PilCrk-Sub5 Trib a | 1.5 | 1.8 | 2.0 | 2.0 |
| PilCrk-Sub7 Trib a | 1.5 | 1.6 | 1.7 | 1.7 |
| PilCrk-Sub8 Trib a | 1.5 | 1.8 | 1.9 | 1.9 |

## 4.4 Level of Transparency in Relation to the Effect of User-Controlled Inputs to EDT

As shown in Table 4-1, there are 46 Level 2 EDT attributes that describe habitat quantity and quality by reach in EDT. Values ranging from 0 to 4 for each of these attributes are entered the EDT user according to guidelines provided by the model developers (Lestelle et al, 2004 and Lestelle, 2004). While these attributes are generally well defined, and their values can be determined from field measurements or distinct qualitative circumstances, the precise EDT model formulation by which they are used to estimate survival of focal species at different life stages in a stream reach is only partially documented.

This points to the need for either greater transparency in the EDT formulation that computes survival from these user inputs, or alternatively, (although the two alternatives are by no means mutually exclusive) a comprehensive set of sensitivity curves that at least provides users with a sense of the relative importance of the level 2 inputs on EDTs population estimates. An example of this kind of curve is provided by Lestelle (2004) on page 19 of the EDT Information Structure Document for Chinook, Coho, and Steelhead, but a comprehensive set of these curves should be provided to users. For purposes of this project, the strongest interest would be in sensitivity curves for our four direct hydrologic parameters that vary with land use and water supply scenarios. The second priority would be to see how the remaining flow-associated EDT values affect reach survival rates.

At a subsequent stage of this study documented in Section 5, pilot project staff were able to decipher and discuss some of the sensitivity relationships mentioned above for coho salmon. This was accomplished through analysis of the EDT rules data base for coho and with assistance from staff of Mobrand-Jones and Stokes (personal communication, Greg Blair, August, 2005, Mobrand Biometrics, 2005).

## 4.5 Alternative Modeling with Matrix of Pathways and Indicators and Quality Indices

A comparison of EDT modeling results was made with two separate, but similar, approaches that assess habitat conditions within watersheds. The first is the well-known Matrix of Pathways and Indicators Matrix (NMFS, 1996). This method was developed by NMFS scientists in the aftermath of the Northwest Forest Plan and the listing of numerous Columbia Basin and Oregon coastal salmon stocks as threatened or endangered under the Endangered Species Act. It was further developed simultaneously with the status reviews being conducted for numerous other West Coast salmon and steelhead stocks.

The Matrix was developed as a preliminary recovery planning tool, and as a template for Section 7 ESA consultations on projects. It is a qualitative evaluation tool that uses field survey or landscape-scale geographic information to assess functioning of habitat under several broad categories. Many of these categories, and the indicators found within them, are pertinent to a focus of this project – separating out the effects of hydrologic changes that result from watershed land cover change and water withdrawals and how those hydrologic changes affect ESA-listed and depressed salmonid populations. We will compare the qualitative results of the Matrix against our quantitative productivity and abundance values for the Chinook salmon reaches for each scenario.

The second approach uses an even more local dataset and effort that focused on the effects of urbanization and the relationship of specific urbanization indicators to metrics of instream habitat and biotic integrity. May, et al. (1997) studied more than 120 reaches from 22 streams in the Puget Sound lowlands across a gradient of urbanization as measured by percent total impervious area (%TIA). In addition to the usual field-surveyed variables, such as large woody debris frequency, most of which are also found in the Matrix of Pathways and Indicators, May, et al. (1997) also measured %TIA, riparian forest dimensions, stream crossing frequencies, etc. and found correlations with measures of biotic integrity. Two measures, Benthic-Index of Biological Integrity (BIBI), and coho/cutthroat ratio were found to vary systematically across the urbanization spectrum where habitat attributes were found to do likewise. For this project we will evaluate these measures for each coho reach for each scenario and discuss in the context of known numbers of spawners that use the basins/reaches. We will further discuss projected B-IBI results in the context of 2001-2003 data collected by Snohomish County.

### 4.5.1 Matrix of Pathways and Indicators

Instream and watershed conditions that contribute to the quality and quantity of salmonid habitat were evaluated for “proper functioning” by NOAA Fisheries (NMFS, 1996). The variables were evaluated according to Pacific Northwest coastal conditions and are therefore pertinent for the current project. “Properly Functioning Condition” or PFC defined the condition necessary to sustain and/or restore populations. The two other classes of functioning are “At Risk” and “Not Properly Functioning.”

Hydrologic function is assessed through an evaluation of hydrologically mature forest cover and impervious area. These are likewise inputs to HSPF and can also be used to directly rate attributes in EDT. Other indicators that are inputs to or can be derived from HSPF and used in EDT include Temperature, Changes in Peak/Base Flows, and Disturbance History (forest cover and late seral-old growth or mature evergreen forest criteria). Sediment/Turbidity, Width/Depth Ratio, and Streambank Condition are other indicators used in the Matrix that are of relevance to the current project. Table 4-16 is a listing of Indicators and criteria for the evaluation of function.

For the current pilot project, historical conditions were assumed to be Properly Functioning. Current conditions vary only as a result of the removal of forest cover from non-riparian areas, the increase in impervious area, also outside of the riparian zone, and the transmission of off-site

**Table 4-16 Indicators and Criteria from NMFS (1996)**

| Indicator | **Properly Functioning Condition** | **At Risk** | **Not Properly Functioning** |
|---|---|---|---|
| Stream Temperature | 50-57° F | 57-60° F (spawning) 57-64° F (migration and rearing) | >60° F (spawning) >64° F (migration and rearing) |
| Changes in Peak/Base Flows | Watershed hydrograph indicates peak flow, base flow and flow timing characteristics are comparable to an undisturbed watershed of similar size, geology and geography | Some evidence of altered peak flow, base flow and/or flow timing relative to an undisturbed watershed of similar size, geology and geography | Pronounced changes to peak flow, base flow and/or flow timing relative to an undisturbed watershed of similar size, geology and geography |
| Disturbance History | <15% ECA (entire watershed) with no concentration of disturbance in unstable or potentially unstable areas and/or refugia, and/or riparian area; and > or = 15% late seral-old growth in watershed | <15% ECA (entire watershed) but disturbance concentrated in unstable or potentially unstable areas and/or refugia, and/or riparian area; and > or = 15% late seral-old growth in watershed | >15% ECA and disturbance concentrated in unstable or potentially unstable areas and/or refugia, and/or riparian area; < 15% late seral-old growth in watershed |
| Sediment/Turbidity | <12% fines in gravel, turbidity low | 12-17% fines in gravel, turbidity moderate | >17% fine at surface or depth in spawning habitat, turbidity high |
| Width/Depth Ratio | <10 | 10-12 | >12 |
| Streambank Condition | >90 % stable | 80-90 % stable | <80% stable |

characteristics such as sediment through a fully functioning riparian area. Instream characteristics shall be assumed to be template except for those elements that are derived from landscape-scale conditions.

Stream temperature was modeled by HSPF and was "ground-truthed" by comparison with data collected by the Stillaguamish Tribe and Snohomish County. Changes in Peak/Base Flows were derived from HSPF. Disturbance History was based on land cover analysis by Snohomish County (Purser, et al., 2003). Equivalent Clearcut Area (ECA) assumed total hydrologically mature forest cover of 80% under historical conditions, which made it necessary to have at least 65% mature forest cover to merit a rating of "PFC" or "At Risk". Late seral-old growth forest was assumed to be equivalent to Mature Evergreen Forest class in Purser, et al. (2003). Sediment/Turbidity was estimated from a combination of field survey data of fines in spawning gravel (SWM 2003) and water quality data collected by the Stillaguamish Tribe and Snohomish County. The rating of these indicators was modified in accordance with the above assumptions for current conditions.

Future conditions relied on HSPF model outputs (Changes in Peak/Base Flows, Temperature) and data developed for future scenarios such as impervious area and forest cover land cover (Disturbance History). Sediment/Turbidity, Streambank Condition, and Width/Depth Ratio were modeled separately using data collected in Church Creek (SWM, 2003) and Pilchuck Creek (SWM, unpublished, 2005).

The effects of the current and future scenarios were evaluated using the checklist format from NMFS (1996). Effects are noted as "Restore" which results when the scenario increases the functioning of the indicator by one or more categories (e.g., from At Risk to Properly Functioning), "Maintain" which results when the functioning of the indicator does not change, or "Degrade" which results when the functioning of the indicator decreases by one or more categories.

### 4.5.2 Quality Indices

While much of the previous research and setting of criteria for fish habitat conditions was performed with a mountainous forest land use setting in mind, May et al. (1997) developed an index evaluation method particular to the lowland watersheds of the Puget Sound (PS). These watersheds differ in several ways from the watersheds of the Oregon Coast Range or the Rocky Mountains of Idaho and Colorado where much previous research on salmonid habitat conditions and their effects on individuals and populations has been performed. The primary differences are low relief, the influence of groundwater on streamflow characteristics, and urbanization. A characteristic that is shared with the Oregon Coast Range is the predominance of rain-driven stormflow.

May et al. (1997) also found that total impervious area and hydrologically mature forest cover are the two most significant predictors of biological integrity. This is consistent with findings from SWM (2002) relating a multimetric Index of Habitat Integrity and these same predictors. They directly affect magnitude and timing of stormflow and indirectly affect bank erosion, large woody debris frequency, substrate characteristics, including bed scour and fine sediments in spawning gravel, and the quantity and quality of spawning and rearing habitat. All these directly and indirectly affect the integrity of the biota including salmonids.

Relative stream power (defined as $Q_2/Q_{winterbasemean}$) or flow ratio "…represents the short-term maximum increase in physical stress experienced by the channel and its habitats and biota." These discharges and relative stream power can be computed from HSPF outputs. These discharges were different under the various scenarios and thus relative stream power varied by scenario.

Total Impervious Area (%) is the predictor used most often by May, et al. (1997) for physical habitat, chemical properties, and biological integrity. May, et al. (1997) found that the point at which imperviousness overwhelms the remaining natural forest cover appears to be when forest cover drops below 30%. They reported that this seemed to be when suburban development dominates over rural land uses. Peak flows become greater in magnitude, shorter in duration, and are more rapidly delivered. As the flow ratio becomes greater, the chance of having frequent large woody debris decreases. This could be related to the associated clearing of riparian zones that accompanies urbanization, but increased peak flows can also wash wood out of streams.

Pools are less frequent with increased peak flows, but this can be related to the deficit of large wood.

Benthic-Index of Biological Integrity (B-IBI) scores were found by May, et al. (1997) to decline with increasing flow ratio. Again, as above, the reduced or altered macro-invertebrate numbers could be related to habitat alteration (loss of wood, substrate embeddedness) and/or changes in the flow regime. Finally, habitat changes were found to occur with flow ratios as low as 13 although generally, ratios less than 20 maintained biotic integrity. Flow ratios between 20 and 35 were correlated with degraded conditions, while flow ratios greater than 35 were correlated with highly degraded instream habitat and biotic integrity.

The other parameter used by May, et al. (1997) to evaluate biological integrity is the coho/cutthroat ratio. They found that in less developed watersheds the ratio is high reflecting the dominance of coho juveniles within the stream salmonid population. As conditions in the watershed deteriorate, the ratio drops. They theorized that coho salmon are more sensitive and less adaptive to poor watershed and stream habitat conditions than cutthroat trout. This is born out somewhat from observations of juvenile rearing densities of coho salmon and cutthroat trout in pools with various cover levels: coho salmon were dominant only in stream segments with >60% cover over pools. Finally, they found that the coho/cutthroat ratio is more sensitive to urbanization (as represented by %TIA) than B-IBI (Fig. 4-12). At %TIA as high as 35, the B-IBI score was 31 (out of 45) while the coho/cutthroat ratio had dropped from a high of 6 to less than 1. Even at %TIA of 5-10% the ratio was less than 2 in their study streams.

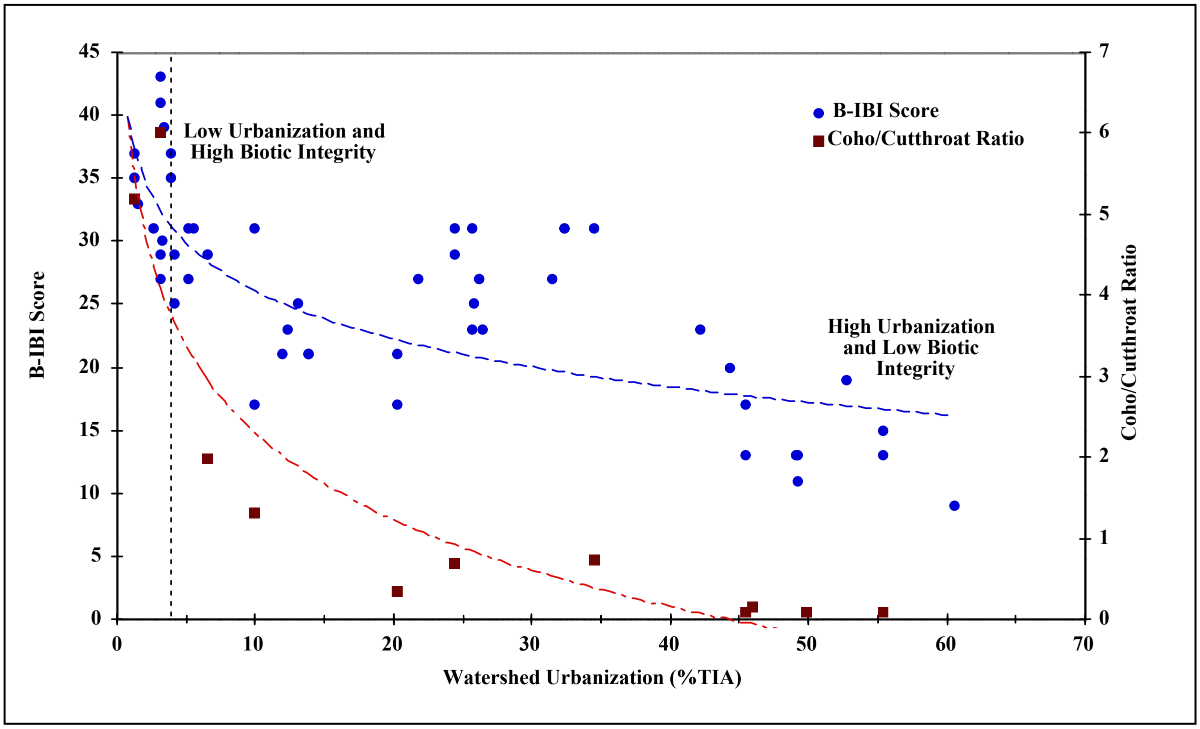

**Figure 4-12 Relationship between watershed urbanization (%TIA) and biological integrity in Puget Sound lowland (PSL) streams. Benthic index of biotic integrity (B-IBI; on left axis) and the abundance ratio of juvenile coho salmon to cutthroat trout used as indices of biological integrity (May, et al., 1997).**

For each of the coho reaches in each of the current and future scenarios, watershed imperviousness was used to predict B-IBI and coho/cutthroat ratio measures and assign error bars based on the data collected by May, et al. and found in Figure 4-12. Further, there was an opportunity to calibrate the use of imperviousness by comparing the 2001 large woody debris data collected by the Stillaguamish Tribe with the relationship found by May, et al. for wood frequency and imperviousness (Figure 4-13).

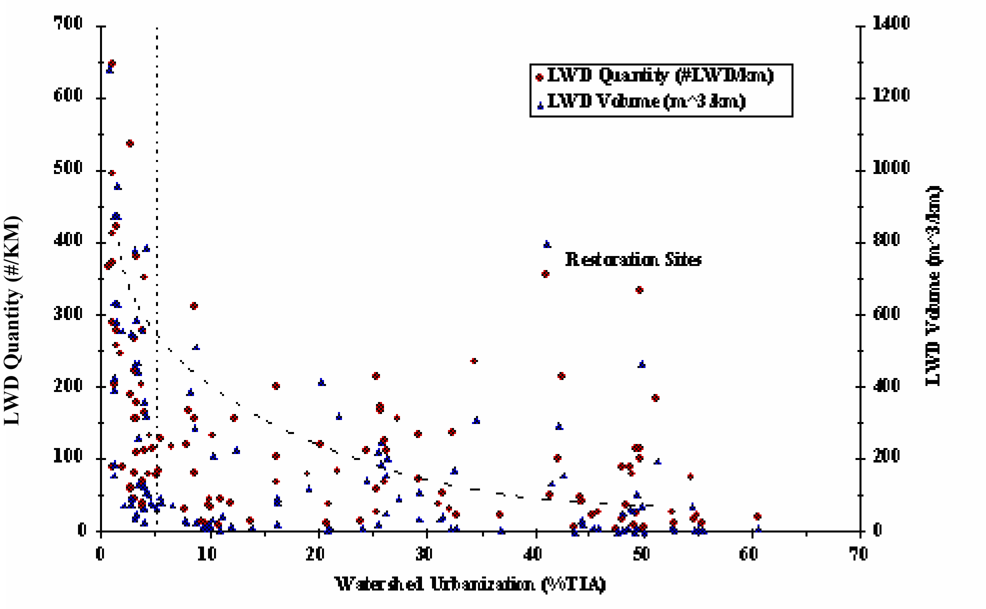

**Figure 4-13 LWD quantity (left axis) and watershed urbanization (%TIA) in Puget Sound lowland (PSL) streams (from May, et al., 1997).**

## 4.6 Conclusion

This section documents the approaches and methods applied to determine reach-specific inputs to the ecological models that will quantify effects of land use and water withdrawal-related flow changes on salmon habitat and populations. Both hydrologically direct and indirect attributes have been described and estimated by reach. Based on the EDT Level two attribute values, it would appear that peak flow and low flow impacts associated with land use change and water withdrawals exhibit the widest range and most extreme values across study scenarios. These trends are most dramatic in Church Creek reaches, second most in Pilchuck Creek tributary reaches, and least in mainstem Pilchuck Creek reaches.

In addition to the documentation of EDT inputs, alternative methods for analyzing the effects of flow changes on habitat and fish have been described, and the flow and flow-related parameters and variables that will be used in these alternative methods have been identified, and their method of incorporation specified.

# Section 5: Ecosystem Modeling

## 5.1 Introduction

Four scenarios were modeled using Ecosystem Diagnosis and Treatment (EDT) and two index methods for the focal species in the pilot basins, Church Creek and Pilchuck Creek. For the EDT modeling, coho salmon were modeled for both basins while Chinook salmon were modeled in Pilchuck Creek only. The Matrix of Pathways and Indicators (NMFS, 1996) was designed primarily for Chinook salmon in forested basins and was therefore applied to Chinook salmon in Pilchuck Creek. The Quality Indices approach of May et al. (1997) was designed primarily for coho salmon and cutthroat trout streams in the Puget Sound lowlands and was therefore applied to coho salmon in both pilot basins.

## 5.2 Models and Applications

The pre-existing EDT stream reach model for the Stillaguamish WRIA 5[1] was configured to run for the pilot project. Reaches were added in Church Creek and for tributaries of Pilchuck Creek; the mainstem Pilchuck Creek reaches were revised to reflect the subbasin characterization used for HSPF. Mainstem Stillaguamish River reaches and the estuary were modified from their previous values to reflect the precepts for the pilot project, i.e., that they are in historic condition.

The model requires inputs of habitat type as percentages. Estimates for backwater pools (related to gradient) were made following guidance given in Lestelle (2004). Previous estimates and interpolations for template condition of small cobble (and gravel) riffles and large cobble (and boulder) riffles were then carried forward to the current condition. Pess et al. (1999) provided some guidance for the estimate of beaver ponds as a percentage of total habitat in relation to flows, gradient, and confinement that was used. This left primary pools, pool tailouts, and glides. An assumption was made that glides were not a significant habitat type historically and their occurrence was restricted to the Pilchuck mainstem reaches at 5% of total habitat. Previously entered estimates for historic tailout values for the mainstem Stillaguamish River were retained; in the remainder of the reaches tailout was set at approximately 10% of primary pool habitat percentage.

Other attributes were assumed to be in a historic or template condition. This is true for all scenarios modeled. The purpose of keeping these attribute values constant across scenarios is to isolate the effects of change in runoff quantity and quality caused by land use as well as water withdrawal-related effects on fish habitat and populations, as distinct from riparian and instream management effects that commonly, but not necessarily, accompany them.

Index methods used parameters generated from the hydrologic modeling (e.g., $Q_{2\text{-yr}}/Q_{\text{meanwinterbase}}$ or flow ratio) or variables such as forest cover or impervious area as inputs to the index tables or graphs.

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[1] The pre-existing stream reach model was filled with data, extrapolations, assumptions, and opinion used in the characterization of the entire Stillaguamish watershed for 2004 draft Chinook Salmon Recovery Plan.

## 5.3 Terminology and Context of EDT Results

Before presenting the results, some background on the terms used in EDT and the potential meaning of the parameter values is useful. *Diversity index* is a measure of life history diversity and geographic distribution relative to the historic condition. Specifically, it is the percentage of life history trajectories[2] that are estimated or calculated to have a *Productivity* value of > 1.0. *Productivity* is also called the *inherent productivity* because it is the ratio of progeny or recruits (returning adults) per spawner at low abundance of spawners (i.e., near the value of 0 spawners). As a practical matter, it characterizes the quality of the environment in which the fish live out their lives. In reality, some changes in this value are related to the marine or nearshore environment and some portion of the change is related to the freshwater portion of the environment, *however, in this study marine and nearshore habitat were assumed to be at template conditions for all scenarios. Therefore, all changes in modeled salmon population parameters are attributable to the changes in freshwater habitat conditions.*

*Capacity* is the carrying capacity of the habitat or the maximum number of returning adults that the system can accommodate and therefore relies predominately on the quantity of key habitat available under each scenario. *Capacity* is also a function of *productivity*. A higher quality reach will have more *capacity* than the same reach at a lower environmental quality. Reported *Abundance* is the *equilibrium abundance* of the scenario. The system is assumed to be at equilibrium when the number of recruited progeny is equal to the number of ancestral spawners, i.e., when *Productivity* is equal to 1. The *Abundance* is always less than the *Capacity*.

The constructed scenarios are somewhat artificial in that riparian, instream, and estuary and marine conditions are assumed to be in a historic or pristine state for all scenarios. The intent with maintaining riparian, instream, and estuary conditions in a historic or template condition is to have the results clearly demonstrate the changes that are related to changes in direct and indirect flow attributes associated with the fresh water environment. Typically, degraded marine survival for non-template conditions is built into the modeling approach by Mobrand-Jones and Stokes (MJS) as the default, but this was overridden in this study so that population parameter changes only reflect human impacts on freshwater habitat.

As described in Section 4, direct flow attributes and indirect attributes have been varied across scenarios using HSPF model results and other broad relationships such as with total impervious area. Given the many assumptions underlying attribute values and in the development of the scenarios themselves, EDT model results found in the tables and graphs below should be understood not taken either literally or as expected values under realistic conditions. What is important is:

- the relative change in Productivity, Capacity, and Abundance (parameters) values as we move from Historic potential to Current to Future 1 to Future 2;
- noting differences in the rate of change in values of parameters as we move from one scenario to another;
- noting differences in the relative change in parameter values between species and basins;

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[2] Life history trajectories are salmon life cycles that differ in some way from each other. Differences may include reach where spawning occurs, length of time in freshwater, timing of spawning or outmigration, etc.

- examining the reach diagnostic reports to see if different level 3 survival factors are affecting the populations dependent on the basin.

## 5.4 Modeling Scenarios in Comparison to Realistic Current and Expected Future Conditions

Note that only the template scenario is considered "realistic" for purpose of estimating viable salmonid population (VSP) parameters (Productivity, Capacity, and Abundance). Current, Future 1, and Future 2 scenarios were designed to provide estimates of the range of changes in salmon population parameters associated with land cover change and water management. They deviate from actual current and planned future outcomes for the basins in the following key respects:

1. <u>Assumption of template channel, riparian and estuarine conditions</u>. In order to distinguish flow-related effects from the effects of direct management of riparian and instream habitat (e.g., riparian forest clearing, channel modifications, wood removal) and to be able to distinguish in-basin effects from downstream effects, attributes in EDT that represent riparian, instream, and estuary conditions were kept in their historic state for all scenarios. This assumption also held for the distribution of habitat types (e.g., primary pools, beaver ponds, large cobble riffles). All losses in productivity, capacity, and abundance are therefore related directly or indirectly to changes in flow resultant either from human development or water withdrawals tied to human development.

2. <u>Future 2 land use assumptions.</u> This projected land use for this scenario is <u>*not*</u> part of Snohomish County's or Stanwood's official plans nor did either jurisdiction request or sanction this scenario. The Future 2 land use scenario projecting urban levels of development throughout Church Creek and in Pilchuck Creek subbasin 1 was conceived by the project team in consultation with the Shared Strategy Water Quantity Subcommittee to test the model application in more intensely developed settings. The scenario represents a higher level of land use intensity typical of several small creek basins within the older, built out areas of Seattle and other Puget Sound cities.

3. <u>Assumption of no stormwater detention</u>. Snohomish County and Stanwood currently require stormwater detention equivalent to the Department of Ecology, 1992 Puget Sound Manual for projects with greater than 5000 square feet of impervious surface. Thus, it is likely that the majority of projects in urban-zoned areas will be required to provide detention in the future. The project's omission of detention has virtually no impact on flows and salmon populations in Pilchuck Creek basin for Future 1 because the basin has negligible planned urban area. The effect of the no-detention assumption on Future 1 flows and salmon population modeling in Church Creek is small because only 13% of the basin is zoned for urban densities, and much of that is already built out. As was noted in Section 1, most of the projected new impervious area under the Future 1 scenario arises from buildout of rural zoned lands which typically do not have detention facilities. In contrast, Future 2 is projected to occur at urban intensities in almost all of Church Creek and in subbasin 1 of Pilchuck Creek. If this occurred, most of the

development would be required to provide detention ponds that would meet or exceed the current Snohomish and Stanwood standards. If this scenario came to pass, high flow impacts on Church Creek would be less than the impacts modeled in this study.

## 5.5 Review of Key EDT Level-2 Attribute Values

To assist the reader in understanding and interpreting the results of EDT modeling, the following table provides a recap of the Level 2 EDT input values for each reach that exhibit the most dramatic change across modeled scenarios. Only attribute values with increases or decreases of at least 1.0 compared to the template value in any scenario are shown. Improving conditions compared to template are indicated by values in ***bold and italic***. Additionally, Figure 4-1 from Section 4 is reproduced here for the convenience of the reader in locating EDT-modeled reaches.

A review of the level-2 input values in this table shows that the most extreme negative environmental trends across scenarios ranging from template to future2 are reflected in five level-2 attributes, Flwlow (base flow), FlwHigh (peak flow), FlwIntraAnn (flow flashiness), BdScour (bed scour), and WidthMn (wetted width during base flow). These dramatic changes occur to some extent in all modeled Church Creek reaches, but most consistently in reaches 2, and 3, to a somewhat lesser extent in 1 and 4, and still less in reach 5. In Pilchuck Creek dramatic increases in values of the five level 2 attributes occurs less consistently than in Church Creek, with large increases in values occurring Pilchuck-1 for peak flow, flashiness, and bed scour (high potential urbanization in future 2 scenario) and Pilchuck-8 for base flow, peak flow, and minimum wetted width (very high potential for base flow loss from pumping in future 1 and future 2).

An improving trend across modeled scenarios is noted only for the base flow attribute (Flwlow) in the rural Pilchuck Creek tributary subbasins 2, 3, 4 and 5 where base flow increases over template conditions occur as a result of lower consumptive water use by rural landscape compared with mature forest cover. This translates to a moderate increase in minimum wetted width during base flow (WidthMn) in the Pilchuck Creek subbasin 5 tributary.

Table 5-1: Recap of Most Dynamic Level 2 Attribute Values Across Scenarios

| **FlwLow Level 2 Values** | | | | |
|---|---|---|---|---|
| EDT Reach | Template | Current | Future 1 | Future 2 |
| Church-1 | 2.00 | 3.33 | 4.00 | 4.00 |
| Church-2 | 2.00 | 3.67 | 4.00 | 4.00 |
| Church-3 | 2.00 | 3.83 | 4.00 | 4.00 |
| Church-4 | 2.00 | 2.25 | 3.83 | 2.83 |
| PilCrk-Sub2 Trib a | ***2.00*** | ***1.33*** | ***1.50*** | ***1.00*** |
| PilCrk-Sub3 Trib a | ***2.00*** | ***1.33*** | ***1.50*** | ***1.00*** |
| PilCrk-Sub3 Trib b | ***2.00*** | ***1.33*** | ***1.50*** | ***1.00*** |
| PilCrk-Sub4 Trib a | ***2.00*** | ***1.17*** | ***1.00*** | ***1.00*** |
| PilCrk-Sub5 Trib a | ***2.00*** | ***0.50*** | ***0.50*** | ***0.50*** |
| PilCrk-Sub8 Trib a | 2.00 | 1.63 | 4.00 | 4.00 |

Table 5-1: Recap of Most Dynamic Level 2 Attribute Values Across Scenarios, continued

| **FlwHigh Level 2 Values** | | | | |
|---|---|---|---|---|
| EDT Reach | Template | Current | Future 1 | Future 2 |
| Church-1 | 2.0 | 3.6 | 3.8 | 4.0 |
| Church-2 | 2.0 | 3.7 | 4.0 | 4.0 |
| Church-3 | 2.0 | 3.7 | 4.0 | 4.0 |
| Church-4 | 2.0 | 3.7 | 4.0 | 4.0 |
| Church-5 | 2.0 | 3.6 | 3.9 | 4.0 |
| | | | | |
| PilCrk-Sub1 Trib a | 2.0 | 3.9 | 4.0 | 4.0 |
| PilCrk-Sub1 Trib b | 2.0 | 3.9 | 4.0 | 4.0 |
| PilCrk-Sub1 Trib c | 2.0 | 3.9 | 4.0 | 4.0 |
| PilCrk-Sub2 Trib a | 2.0 | 3.4 | 3.7 | 3.7 |
| PilCrk-Sub3 Trib a | 2.0 | 3.4 | 3.7 | 3.7 |
| PilCrk-Sub3 Trib b | 2.0 | 3.4 | 3.7 | 3.7 |
| PilCrk-Sub4 Trib a | 2.0 | 2.9 | 3.6 | 3.6 |
| PilCrk-Sub5 Trib a | 2.0 | 3.2 | 3.6 | 3.6 |
| PilCrk-Sub8 Trib a | 2.0 | 2.8 | 3.5 | 3.5 |
| **FlwIntraAnn Level 2 Values** | | | | |
| EDT Reach | Template | Current | Future 1 | Future 2 |
| Church-1 | 2.0 | 2.2 | 2.6 | 3.2 |
| Church-2 | 0.0 | 0.6 | 1.8 | 2.4 |
| Church-3 | 0.0 | 0.2 | 1.8 | 2.4 |
| Church-4 | 0.0 | 0.0 | 1.6 | 2.4 |
| Church-5 | 0.0 | 0.2 | 1.6 | 2.4 |
| | | | | |
| PilCrk-Sub1 Trib a | 2.0 | 2.3 | 3.1 | 3.6 |
| PilCrk-Sub1 Trib b | 2.0 | 2.3 | 3.1 | 3.6 |
| PilCrk-Sub1 Trib c | 2.0 | 2.3 | 3.1 | 3.6 |
| **BenComRch Level 2 Values** | | | | |
| EDT Reach | Template | Current | Future 1 | Future 2 |
| Church-1 | 0.0 | 0.3 | 1.1 | 2.4 |
| Church-2 | 0.0 | 0.3 | 1.1 | 2.4 |
| Church-3 | 0.0 | 0.3 | 1.0 | 2.3 |
| Church-4 | 0.0 | 0.3 | 0.7 | 2.3 |
| Church-5 | 0.0 | 0.3 | 0.8 | 2.2 |
| | | | | |
| PilCrk-Sub1 Trib a | 0.0 | 0.1 | 1.2 | 2.3 |
| PilCrk-Sub1 Trib b | 0.0 | 0.1 | 1.2 | 2.3 |
| PilCrk-Sub1 Trib c | 0.0 | 0.1 | 1.2 | 2.3 |

Table 5-1: Recap of Most Dynamic Level 2 Attribute Values Across Scenarios, continued

| **FnSedi Level 2 Values** | | | | |
|---|---|---|---|---|
| EDT Reach | Template | Current | Future 1 | Future 2 |
| Church-1 | 0.0 | 0.0 | 0.0 | 0.0 |
| Church-2 | 0.0 | 0.3 | 1.1 | 2.4 |
| Church-3 | 0.0 | 0.3 | 1.0 | 2.3 |
| Church-4 | 0.0 | 0.3 | 0.7 | 2.3 |
| Church-5 | 0.0 | 0.3 | 0.8 | 2.2 |
| | | | | |
| PilCrk-Main 1 | 0.0 | 1.5 | 1.5 | 1.5 |
| PilCrk-Sub1 Trib a | 0.0 | 1.2 | 2.0 | 2.4 |
| PilCrk-Sub1 Trib b | 0.0 | 1.2 | 2.0 | 2.4 |
| PilCrk-Sub1 Trib c | 0.0 | 1.2 | 2.0 | 2.4 |
| PilCrk-Sub2 Trib a | 0.0 | 0.0 | 1.3 | 1.3 |
| PilCrk-Sub3 Trib a | 0.0 | 0.0 | 1.3 | 1.3 |
| PilCrk-Sub3 Trib b | 0.0 | 0.0 | 1.3 | 1.3 |
| PilCrk-Sub4 Trib a | 0.0 | 0.0 | 1.2 | 1.2 |
| PilCrk-Sub5 Trib a | 0.0 | 0.0 | 1.2 | 1.2 |
| **Emb Level 2 Values** | | | | |
| EDT Reach | Template | Current | Future 1 | Future 2 |
| Church-2 | 0.0 | 0.0 | 0.4 | 1.1 |
| Church-3 | 0.0 | 0.0 | 0.4 | 1.1 |
| Church-4 | 0.0 | 0.0 | 0.3 | 1.1 |
| Church-5 | 0.0 | 0.0 | 0.3 | 1.1 |
| | | | | |
| PilCrk-Main 1 | 0.0 | 1.4 | 1.4 | 1.4 |
| PilCrk-Sub1 Trib a | 0.0 | 0.0 | 0.6 | 1.1 |
| PilCrk-Sub1 Trib b | 0.0 | 0.0 | 0.6 | 1.1 |
| PilCrk-Sub1 Trib c | 0.0 | 0.0 | 0.6 | 1.1 |

Table 5-1: Recap of Most Dynamic Level 2 Attribute Values Across Scenarios, continued

| **Turb Level 2 Values** | | | | |
|---|---|---|---|---|
| EDT Reach | Template | Current | Future 1 | Future 2 |
| Church-1 | 0.0 | 1.3 | 1.4 | 1.6 |
| Church-2 | 0.0 | 1.3 | 1.4 | 1.6 |
| Church-3 | 0.0 | 1.3 | 1.5 | 1.6 |
| Church-4 | 0.0 | 1.3 | 1.5 | 1.6 |
| Church-5 | 0.0 | 1.3 | 1.5 | 1.6 |
| | | | | |
| PilCrk-Main 1 | 0.0 | 1.0 | 1.0 | 1.0 |
| PilCrk-Main 2 | 0.0 | 1.0 | 1.0 | 1.0 |
| PilCrk-Main 3 | 0.0 | 1.0 | 1.0 | 1.0 |
| PilCrk-Main 4 | 0.0 | 1.0 | 1.0 | 1.0 |
| PilCrk-Sub1 Trib a | 0.0 | 1.4 | 1.5 | 1.6 |
| PilCrk-Sub1 Trib b | 0.0 | 1.4 | 1.5 | 1.6 |
| PilCrk-Sub1 Trib c | 0.0 | 1.4 | 1.5 | 1.6 |
| PilCrk-Sub2 Trib a | 0.0 | 1.4 | 1.4 | 1.4 |
| PilCrk-Sub3 Trib a | 0.0 | 1.2 | 1.4 | 1.4 |
| PilCrk-Sub3 Trib b | 0.0 | 1.2 | 1.4 | 1.4 |
| PilCrk-Sub4 Trib a | 0.0 | 1.2 | 1.4 | 1.4 |
| PilCrk-Sub5 Trib a | 0.0 | 1.2 | 1.4 | 1.4 |
| PilCrk-Sub7 Trib a | 0.0 | 0.0 | 1.3 | 1.3 |
| PilCrk-Sub8 Trib a | 0.0 | 0.0 | 1.3 | 1.3 |
| **MetWatCol (MetSedSls, MscToxWat)** | | | | |
| EDT Reach | Template | Current | Future 1 | Future 2 |
| Church-1 | 0.0 | 0.2 | 0.7 | 1.5 |
| Church-2 | 0.0 | 0.2 | 0.7 | 1.5 |
| Church-3 | 0.0 | 0.1 | 0.7 | 1.5 |
| Church-4 | 0.0 | 0.1 | 0.5 | 1.5 |
| Church-5 | 0.0 | 0.1 | 0.6 | 1.5 |
| | | | | |
| PilCrk-Sub1 Trib a | 0.0 | 0.3 | 0.8 | 1.5 |
| PilCrk-Sub1 Trib b | 0.0 | 0.3 | 0.8 | 1.5 |
| PilCrk-Sub1 Trib c | 0.0 | 0.3 | 0.8 | 1.5 |
| **TmpMonMx** | | | | |
| EDT Reach | Template | Current | Future 1 | Future 2 |
| Church-1 | 0.0 | 1.5 | 1.8 | 1.8 |
| Church-2 | 0.0 | 1.6 | 2.6 | 2.6 |
| Church-3 | 0.0 | 1.6 | 2.8 | 2.6 |

Table 5-1: Recap of Most Dynamic Level 2 Attribute Values Across Scenarios, continued

**BdScour**

| EDT Reach | Template | Current | Future 1 | Future 2 |
|---|---|---|---|---|
| Church-1 | 1.5 | 2.0 | 2.5 | 2.9 |
| Church-2 | 1.5 | 2.2 | 2.9 | 3.7 |
| Church-3 | 1.5 | 2.2 | 2.8 | 3.7 |
| Church-4 | 1.5 | 2.3 | 3.0 | 4.0 |
| Church-5 | 1.5 | 2.0 | 2.5 | 3.2 |
| | | | | |
| PilCrk-Sub1 Trib a | 1.5 | 2.6 | 3.9 | 4.0 |
| PilCrk-Sub1 Trib b | 1.5 | 2.6 | 3.9 | 4.0 |
| PilCrk-Sub1 Trib c | 1.5 | 2.6 | 3.9 | 4.0 |

**WidthMn (Min. Width in feet)**
**(based on Median August Q in Eq. Provided by Lestelle, 2004)**

Values for wetted width in the low flow month (August) are shown for reaches in which there is more than a 20% increase or decrease compared to template conditions for any scenario. Except for a modest gain in the Pilchuck Creek subbasin 5 tributary, four Church Creek tributaries exhibit greatly reduced minimum wetted channel widths associated with very low median August flows associated with water withdrawals. The same situation applies to the subbasin 8 tributary.

| EDT Reach | Template | Current | Future 1 | Future 2 |
|---|---|---|---|---|
| Church-1 | 13.36 | 10.30 | 5.90 | 6.67 |
| Church-2 | 6.35 | 4.05 | 1.07 | 1.71 |
| Church-3 | 12.27 | 8.35 | 0.00 | 0.00 |
| Church-4 | 7.94 | 7.03 | 2.87 | 5.95 |
| PilCrk-Sub5a | ***5.54*** | ***6.57*** | ***6.73*** | ***6.78*** |
| PilCrk-Sub8a | 8.80 | 8.84 | 0.00 | 0.00 |

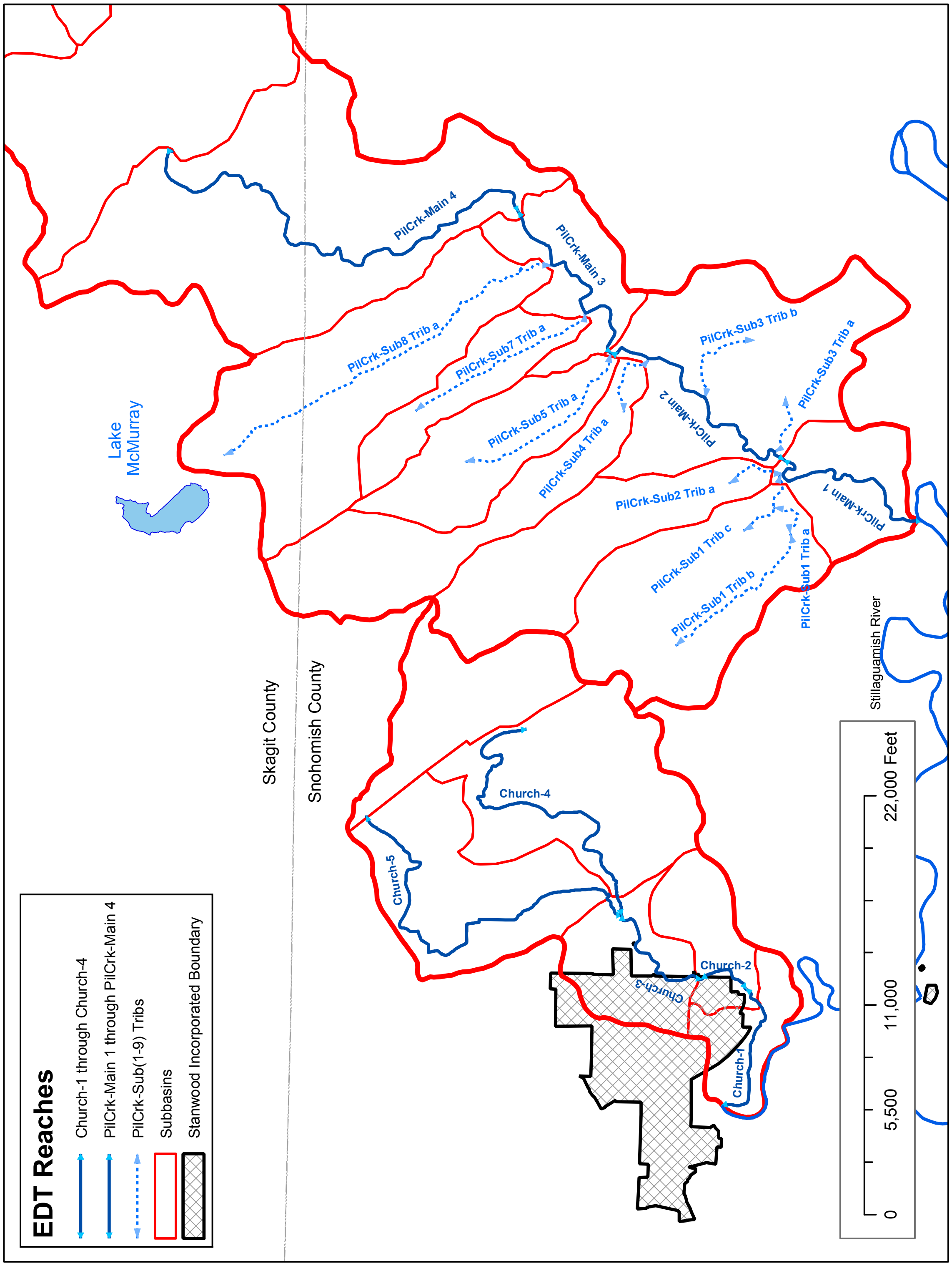

Figure 5-1: EDT Model Reaches, View Zoomed to Church Creek and Lower Pilchuck Creek

Table 5-2 Summary of Results and Changes in VSPs by Scenario and Population

| | Diversity Index | Productivity (R/S) | Capacity No. Rec | Abundance No. Rec. | Diversity Change | Productivity Change[3] | Capacity Change | Abundance Change |
|---|---|---|---|---|---|---|---|---|
| **Template (Historic)** | | | | | | | | |
| Church Creek coho salmon | 100% | 29.5 | 1,492 | 1,441 | N/A | N/A | N/A | N/A |
| Pilchuck Creek coho salmon | 100% | 28.0 | 15,471 | 14,919 | N/A | N/A | N/A | N/A |
| Pilchuck Creek Chinook salmon | 100% | 17.7 | 6,911 | 6,520 | N/A | N/A | N/A | N/A |
| **Current Conditions** | | | | | | | | |
| Church Creek coho salmon | 100% | 24.7 | 1,387 | 1,331 | 0% | -16% | -7% | -8% |
| Pilchuck Creek coho salmon | 100% | 25.6 | 15,798 | 15,181 | 0% | -9% | 2% | 2% |
| Pilchuck Creek Chinook salmon | 100% | 16.7 | 6,976 | 6,559 | 0% | -6% | 1% | 1% |
| **Future 1** | | | | | | | | |
| Church Creek coho salmon | 87% | 16.2 | 1,124 | 1,056 | -13% | -45% | -25% | -27% |
| Pilchuck Creek coho salmon | 76% | 23.7 | 13,750 | 13,172 | -24% | -15% | -11% | -12% |
| Pilchuck Creek Chinook salmon | 100% | 17.9 | 7,013 | 6,619 | 0% | 1% | 1% | 2% |
| **Future 2** | | | | | | | | |
| Church Creek coho salmon | 54% | 4.2 | 941 | 715 | -46% | -86% | -37% | -50% |
| Pilchuck Creek coho salmon | 76% | 23.2 | 13,750 | 13,161 | -24% | -17% | -11% | -12% |
| Pilchuck Creek Chinook salmon | 100% | 16.9 | 7,017 | 6,602 | 0% | -5% | 2% | 1% |

**Notes: "R/S" = recruit/spawner ratio, "No. Rec." = number of recruits**

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[3] All percent change values are relative to Template values

## 5.6 Results and Discussion

### 5.6.1 Flow effects on coho salmon in Church Creek and Pilchuck Creek-Current Scenario

Historic and current conditions were modeled for Church and Pilchuck Creek stream reaches as specified in Section 4 and described above. Coho and Chinook salmon populations were defined as to species, spawning reaches, timing of spawning, etc. The effects on productivity, capacity and abundance of the current conditions compared to historic or template conditions were reported by MJS for coho salmon (Tables 5-3 and 5-5).

**Table 5-3 - Baseline Spawner Population Performance Parameters Flow Assessment Church Creek Coho Salmon**

| Population | Scenario | Diversity index | Productivity | Capacity | Abundance |
|---|---|---|---|---|---|
| Church coho salmon | Current without harvest | 100% | 24.7 | 1,387 | 1,331 |
| | Historic potential | 100% | 29.5 | 1,492 | 1,441 |

It is noted that there is a small reduction in Productivity in Church Creek (16%). Examining the Church Creek reach diagnostics in Appendix A (Tables A-1 through A-5; see example below of Table A-2) and the Strategic Priority Summary (Table 5-4) for the source of this lowered Productivity we find that bed scour during the incubation life stage and flow conditions during 0-age active rearing and 0-age inactive (overwintering) life stages show the largest negative effects with Bed Scour dominating.

In EDT, equilibrium Abundance (A) is proportional to the product of Capacity (C) and (P-1)/P in which P stands for Productivity. This is an algebraic outcome of the Beverton-Holt function, the basis for population modeling. At high levels of productivity, the sensitivity of abundance to change in productivity is low. In contrast, equilibrium abundance is always linearly proportional to capacity, so an N% change in C leads to an N% change in A if productivity is constant. Based on the results shown in Table 5-1, the 8% decrease in Abundance going from Scenario 1 (Template) to Scenario 2 (Current) is dominated by the reduction in Capacity and the system as modeled is said to be "Capacity Dominated" or "Capacity Limited."

Upon further examination of the reach diagnostics it is noted that EDT simulates a loss in key habitat quantity for most life stages in reaches Church-2 and -3. This is at least partly related to reduced minimum flows (relative to historic conditions) leading to less habitat area. In summary, the reach diagnostics indicate that a reduction in survival related to scour of eggs in the redds and to the direct flow effect on survival yield a decrease in Productivity that, combined with a decrease in channel/habitat area from flow-related decreases in width, yield a small decrease in Abundance of 8% in Church Creek under current conditions.

Given the much higher sensitivity of abundance to habitat quantity (Capacity) for the scenario modeled, the restoration priority to address these changes would be to augment stream flow and restore habitat quantity. It must be noted that the absolute productivity values are artificially high due to the assumptions of pristine distributions of key habitat, woody debris and riparian function in Scenario 2 (Current). At lower P values, abundance, A, would become more sensitive to reductions in P. Therefore, it would also be prudent to address the causes of reduced productivity as well. Examining Table 5-4, Channel Stability is indicated as a priority and the only attribute change affecting Channel Stability is bed scour. This suggests the need to mitigate increases in the duration of peak flows that cause scour of spawning gravels.

# Table 5-4 - Stillaguamish Flow Assessment Church Creek Coho Protection and Restoration Strategic Priority Summary

| Geographic area priority | | | Attribute class priority for restoration | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| -<br>Geographic area | Protection benefit | Restoration benefit | *Channel stability* | *Chemicals* | *Competition (w/ hatch)* | *Competition (other sp)* | *Flow* | *Food* | *Habitat diversity* | *Harassment/poaching* | *Obstructions* | *Oxygen* | *Pathogens* | *Predation* | *Sediment load* | *Temperature* | *Withdrawals* | *Key habitat quantity* |
| Church Creek | ◯ | ◯ | ● | | | | | | | | | | | | | | | |
| Lower Stillaguamish River | ◦ | | | | | | | | | | | | | | | | | |
| Still Est Flow Assessment | ○ | | | | | | | | | | | | | | | | | |
| Port Su | | ○ | | | | | | ● | | | | | | | | | | |
| Sara Pass-a | | ◯ | | | ● | | | ● | | | | | | | | | | |
| Port Gard | | ◦ | | | | | | ● | | | | | | | | | | |
| Sara Pass-b | | ○ | | | ● | | | ● | | | | | | | | | | |
| Skag Bay | | | | | | | | ● | ● | | | | | | | | | |
| San Juan | | ◯ | | ● | ● | | | ● | | | | | | | | | | |
| E Strait | | ◯ | | | ● | | | ● | | | | | | | | | | |
| W Strait | | ◯ | | | | | | ● | | | | | | | | | | |
| Coastal BC | | | | | | | | | | | | | | | | | | |

| | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| N Pug Snd | | ○ | | | | | | ● | | | | | | | | | | |
| Sam Bay | | | | | | | | ● | | | | | | | | | | |
| Nook Bay | | | | ● | | | | ● | ● | | | | | | | | | |
| Strait Geo | | ○ | | | ● | | | ● | | | | | | | | | | |
| Cent PSE-c | | ○ | | | | | | ● | ● | | | | | | | | | |
| Cent PSE-b | | ○ | | | | | | ● | ● | | | | | | | | | |
| Shil Bay | | | | | | | | ● | ● | | | | | ● | | ● | | |
| Ell Bay | | | | ● | | | | ● | ● | | | | | | | | | |
| Cent PSE-d | | ○ | | ● | ● | | | ● | ● | | | | | | | | | |
| Cent PSW-d | | ○ | | | | | | ● | ● | | | | | | | | | |
| Cent PSW-c | | ○ | | | | | | ● | ● | | | | | | | | | |
| | | | | | | | | | | | | | | | | | | |

## Table 5-5 - Baseline Spawner Population Performance Parameters Flow Assessment Pilchuck Creek Coho Salmon

| Population | Scenario | Diversity index | Productivity | Capacity | Abundance |
|---|---|---|---|---|---|
| Pilchuck coho salmon | Current without harvest | 100% | 25.6 | 15,798 | 15,181 |
| | Historic potential | 100% | 28.0 | 15,471 | 14,919 |

In Pilchuck Creek there is a relatively smaller reduction in Productivity (9%, Table 5-5) compared to that in Church Creek. Examining Pilchuck reach diagnostics (Tables A-6 through A-19; see examples of Tables A-6 and A-10) we find two predominant sources of reduction in survival. In the mainstem of Pilchuck Creek (Table A-6, Appendix A) sediment load affecting spawning, a change indirectly-related to flow, and loss of key habitat quantity for fry colonization, 0-age and 1-age active rearing, and inactive rearing are the largest contributors to decreased survival. These life stages typically use large substrate and backwater pools.

In the Pilchuck tributaries, also the home of spawning and rearing coho salmon, we find that bed scour during the incubation life stage and flow conditions during the 0-age inactive (overwintering) life stages cause the largest losses. Productivity losses from sediment load and, in one reach, temperature are also found in the tributaries under current conditions. In summary, the reach diagnostics indicate that a reduction in survival related to scour of eggs in the redds and direct flow effect on survival yield a decrease in Productivity and a decrease in Capacity. The response in Equilibrium Abundance is a very small reduction (5%) in Pilchuck Creek under current conditions.

## Table A-2. Church Creek Coho Salmon Level 3 Diagnostic Reach Analysis

Reach: Church-2

| Life stage | Relevant months | % of life history trajectories affected | Productivity change (%) | Life Stage Rank | Channel stability | Chemicals | Competition (w/ hatch) | Competition (other sp) | Flow | Food | Habitat diversity | Harassment/poaching | Obstructions | Oxygen | Pathogens | Predation | Sediment load | Temperature | Withdrawals | Key habitat quantity |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Spawning | Oct-Jan | 3.8% | -2.0% | 5 | | | | | | | | | | | | | • | | | • |
| Egg incubation | Oct-May | 3.8% | -5.6% | 1 | ● | | | | | | | | | | | | | | | • |
| Fry colonization | Mar-May | 4.3% | -1.0% | 9 | | | | | • | | | | | | | | | | | ● |
| 0-age active rearing | Mar-Oct | 3.5% | -4.4% | 3 | | | | | ● | | | | | | | | | | | ● |
| 0-age migrant | Oct-Nov | 4.1% | -1.5% | 6 | | | | | | | | | | | | | • | | | ● |
| 0-age inactive | Oct-Mar | 3.3% | -4.3% | 2 | | | | | ● | | | | | | | | | | | • |
| 1-age active rearing | Mar-May | 3.3% | -1.9% | 4 | | | | | • | | | | | | | | | | | ● |
| 1-age migrant | Mar-Jun | 98.3% | 0.0% | | | | | | | | | | | | | | | | | ● |
| 1-age transient rearing | | | | | | | | | | | | | | | | | | | | |
| 2+-age transient rearing | | | | | | | | | | | | | | | | | | | | |
| Prespawning migrant | Sep-Nov | 100.0% | -0.1% | 7 | | | | | • | | | | | | | | • | | | ● |
| Prespawning holding | Oct-Dec | 3.8% | -1.7% | 8 | | | | | | | | | | | | | • | | | ● |

## Table A-6. Pilchuck Creek Coho Salmon Level 3 Diagnostic Reach Analysis

Reach: PilCrk-Main1

| Life stage | Relevant months | % of life history trajectories affected | Productivity change (%) | Life Stage Rank | Channel stability | Chemicals | Competition (w/ hatch) | Competition (other sp) | Flow | Food | Habitat diversity | Harassment/poaching | Obstructions | Oxygen | Pathogens | Predation | Sediment load | Temperature | Withdrawals | Key habitat quantity |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Spawning | Oct-Jan | 20.4% | -0.4% | 4 | | | | | | | | | | | | | • | | | |
| Egg incubation | Oct-May | 20.4% | -17.2% | 1 | | | | | | | | | | | | | ● | | | |
| Fry colonization | Mar-May | 21.5% | -0.9% | 2 | | | | | | | | | | | | | • | | | |
| 0-age active rearing | Mar-Oct | 21.5% | 0.0% | | | | | | | | | | | | | | | | | ○ |
| 0-age migrant | Oct-Nov | 22.7% | 0.0% | | | | | | | | | | | | | | | | | |
| 0-age inactive | Oct-Mar | 21.8% | -0.5% | 3 | | | | | | | | | | | | | | | | |
| 1-age active rearing | Mar-May | 21.8% | 0.0% | | | | | | | | | | | | | | | | | |
| 1-age migrant | Mar-Jun | 99.1% | 0.0% | | | | | | | | | | | | | | | | | |
| 1-age transient rearing | | | | | | | | | | | | | | | | | | | | |
| 2+-age transient rearing | | | | | | | | | | | | | | | | | | | | |
| Prespawning migrant | Sep-Nov | 100.0% | 0.0% | 6 | | | | | | | | | | | | | | | | ○ |
| Prespawning holding | Oct-Dec | 20.4% | -0.2% | 5 | | | | | | | | | | | | | | | | |

## Table A-10. Pilchuck Creek Coho Salmon Level 3 Diagnostic Reach Analysis

Reach: PilCrk-Sub1Tribc

| Life stage | Relevant months | % of life history trajectories affected | Productivity change (%) | Life Stage Rank | Channel stability | Chemicals | Competition (w/ hatch) | Competition (other sp) | Flow | Food | Habitat diversity | Harassment/poaching | Obstructions | Oxygen | Pathogens | Predation | Sediment load | Temperature | Withdrawals | Key habitat quantity |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Spawning | Oct-Jan | 1.9% | -3.0% | 4 | | | | | | | | | | | | | • | | | |
| Egg incubation | Oct-May | 1.9% | -15.9% | 1 | ● | | | | | | | | | | | | • | | | |
| Fry colonization | Mar-May | 2.9% | -0.1% | 9 | | | | | • | | | | | | | | | | | |
| 0-age active rearing | Mar-Oct | 2.9% | -0.3% | 8 | | | | | | | | | | | | | | | | ○ |
| 0-age migrant | Oct-Nov | 3.2% | -2.5% | 3 | | | | | | | | | | | | | • | | | |
| 0-age inactive | Oct-Mar | 3.1% | -5.2% | 2 | • | | | | ● | | | | | | | | | | | |
| 1-age active rearing | Mar-May | 3.1% | -1.8% | 5 | | | | | • | | | | | | | | | | | |
| 1-age migrant | Mar-Jun | 8.4% | -0.1% | 7 | | | | | | | | | | | | | | | | |
| 1-age transient rearing | | | | | | | | | | | | | | | | | | | | |
| 2+-age transient rearing | | | | | | | | | | | | | | | | | | | | |
| Prespawning migrant | Sep-Nov | 8.5% | 0.0% | 10 | | | | | | | | | | | | | • | | | |
| Prespawning holding | Oct-Dec | 1.9% | -2.2% | 6 | | | | | | | | | | | | | • | | | |

### 5.6.2 Future 1 and Future 2 Scenarios for Coho Salmon

Future scenarios were modeled based on urban development and water withdrawal assumptions made explicit in Sections 3 and 4. In Future 1, growth would build out to the planned densities indicated by the 1995 Snohomish County Comprehensive Plan future land use designations and Stanwood's Comprehensive Plan. Future 2 represents an expanded urban growth boundary and consequent water consumption (see Section 3). Actions and scenarios were created in EDT to reflect tabular values from Section 4 and coho salmon population performance was evaluated under the habitat conditions that this created (Tables 5-6, 5-7).

**Table 5-6 - - Future Scenario Spawner Population Performance Parameters**

**Flow Assessment Future 1 Coho Salmon Church and Pilchuck Creeks**

| Population | Scenario | Diversity index | Productivity | Capacity | Abundance |
|---|---|---|---|---|---|
| Church coho salmon | Future 1 | 87% | 16.2 | 1,124 | 1,056 |
| | Historic potential | 100% | 29.5 | 1,492 | 1,441 |
| Pilchuck coho salmon | Future 1 | 76% | 23.7 | 13,750 | 13,172 |
| | Historic potential | 100% | 28.0 | 15,471 | 14,919 |

The first thing that one may notice about Table 5-6 is that the dramatic change in input rating values for flow and related items (e.g., bed scour) as noted in Section 4 results in a dramatic reduction in Church Creek Productivity (45%) compared to historic potential. There is a relatively smaller loss in capacity (25%) and abundance (27%), compared to historic potential, in the Future 1 scenario in Church Creek, but this is more than twice the loss in Productivity that occurred going from historic potential to current conditions. Changes in just six (6) attributes (Flow High, Flow Low, Fine Sediments, Embeddedness, Benthic Community Richness, and Bed Scour) out of a total of 34 habitat quality-related attributes caused this decrease.

Significant changes in Church Creek attributes in going from the current condition to the Future 1 condition include:

- Flow Low - Church-1, -2, and -3 going to 4.0 (most degraded condition), Church-4 going from 2.25 to 3.83;
- Flow High – reaches Church-1 through Church-3 going to 4.0 and more degraded conditions in Church-4 and -5;
- Bed scour degrades from range of 2.0-2.3 to range of 2.5-3.0 in all Church reaches;
- Maximum temperature ratings increase from 1.5 – 2.0 range to 1.8-2.8 range in Church-1 through -4.

Thus, in keeping with the pattern established in going from template to current conditions, flow and bed scour are thought to be predominately responsible for the dramatic decrease in productivity. The large change in Productivity <u>and</u> loss of key habitat quantity in Church-2 and Church-3 is thought to be responsible for the loss in Capacity and Abundance. As explained above, Capacity is a function of habitat quantity and Productivity; Equilibrium Abundance is a fraction of Capacity that results from density-independent survival.

The second thing that is notable about Table 5-6 is that the Diversity Index for both populations drops below 100%. This means that there has been a loss of life history trajectories with Productivity greater than 1.0 (replacement) and, examining the inputs we see that it is related to one reach in Church Creek (Church-3) going dry (minimum width calculated to be 0.00 ft.). This also occurred in one tributary reach in the Pilchuck system (PilCrk-Sub8).

The Pilchuck Creek coho population suffers a 15% drop in Productivity, compared to historic potential, and likewise decreases in Capacity (11%) and Equilibrium Abundance (12%). This is consistent with the lower intensity of planned development in the Pilchuck Creek basin, compared to Church Creek basin, including the absence of an urban growth area. The losses are thought to predominately come from the highly degraded High Flow ratings, dramatic but localized degradation of Fine Sediment, Embeddedness, and Bed Scour ratings (predominately Subbasin 1); and increased withdrawal of groundwater in one of the tributaries with the consequent dry reach.

Table 5-7 shows the results of the implementation of the Future 2 scenario. The population performance pattern seen in Table 5-6 is repeated here with one change. Whereas in previous scenarios, losses in Capacity and Abundance were similar, in Future 2 in Church Creek we see the loss in Abundance, compared to historic potential, of more than 50% which is greater than the loss in Capacity of 37%. The dramatic decrease in Productivity is exerting influence on Abundance not seen to this extent in previous scenarios. Significant changes in attributes from Future 1 in Church Creek include:

- Bed scour ratings increase again from range of 2.5-3.0 to range of 3.2-4.0;
- Flow Intra-annual from range of 2.5-2.7 to range of 3.2 to 3.6;
- Fine sediment and Embeddedness ratings increase in all Church reaches.

Each of these attributes is likely contributing to the dramatic decrease in Productivity found when comparing Future 2 to Future 1. Bed Scour likely plays the largest role since the rating goes to the most degraded possible. Further, the effects of bed scour cause losses when progeny are closely spaced and least able to avoid mortality (applies to sediment load also).

In Pilchuck Creek Productivity loss for historic potential is about 24%, while Capacity, and hence Equilibrium Abundance, shows a loss of 14 and 15%. Sources of the loss in Productivity for coho salmon in Pilchuck Creek include:

- Flow high – further incremental degradation; all reaches except PilCrk-Sub7 degrade to 3.5 or more degraded rating;
- Flow Intra-annual – further degradation of the rating in PilCrk-Sub1 tributaries;
- Fine sediment degradation in the same tributaries.

The changes in attribute ratings indicate that the changes in population performance going from

Future 1 to Future 2 are restricted to those predominately related to the increase in impervious area from development in lowermost Pilchuck Creek basin (i.e., Subbasin 1). The "water withdrawal' effect is already felt when implementing Future 1. At that time the existing water right in PilCrk-Sub8 is more fully exercised than under current conditions, drying out the reach and contributing to a reduction in the Diversity Index.

## Table 5-7 - Future Scenario Spawner Population Performance Parameters

## Flow Assessment Future 2 Coho Salmon Church and Pilchuck Creeks

| Population | Scenario | Diversity index | Productivity | Capacity | Abundance |
|---|---|---|---|---|---|
| Church coho salmon | Future 2 | 54% | 4.2 | 941 | 715 |
| | Historic potential | 100% | 29.5 | 1,492 | 1,441 |
| Pilchuck coho salmon | Future 2 | 76% | 23.2 | 13,750 | 13,161 |
| | Historic potential | 100% | 28.0 | 15,471 | 14,919 |

### 5.6.3 Flow effects on Chinook salmon in Pilchuck Creek

The effects of modeled current conditions and future scenarios on Productivity and Abundance of Fall Chinook salmon in Pilchuck Creek were analyzed separately (Tables 5-8 through 5-10).

## Table 5-8 - Baseline Spawner Population Performance Parameters

## Flow Assessment Pilchuck Creek Chinook Salmon

| Population | Scenario | Diversity index | Productivity | Capacity | Abundance |
|---|---|---|---|---|---|
| Pilchuck Fall Chinook | Current without harvest | 100% | 16.7 | 6,976 | 6,559 |
| | | | | | |
| | Historic potential | 100% | 17.7 | 6,911 | 6,520 |

Table 5-8 shows a small drop in Productivity (6%) of the mainstem Pilchuck Creek habitat that has less than a 1% negative impact on abundance while Capacity of habitat has increased by approximately 1%, most likely due to moderate median summer base flow increases that increase habitat quantity. The 1% increase in Capacity translates directly to a 1% increase in Abundance, thus, Pilchuck Creek fall Chinook salmon do not appear to be negatively affected by the types of development that have been modeled in this scenario compared to Template. Habitat for Chinook is confined almost exclusively to the mainstem reaches of Pilchuck Creek where the differences in runoff quantity and quality between template and all non-template scenarios are caused predominantly by industrial forestry in the upper Pilchuck. These effects are minor compared to Church Creek reaches or Pilchuck tributary reaches affected by urbanization and/or water extraction. A key point to keep in mind is that all modeled scenarios include the assumptions that habitat composition, woody debris, riparian, and estuary conditions mimic historic or pristine conditions.

The results from running the Future 1 and Future 2 scenarios for Fall Chinook salmon (Tables 5-9 and 5-10) show that Productivity, Capacity, and Equilibrium Abundance are virtually unaffected by actions comprising the scenarios.

## Table 5-9 - Future Scenario Spawner Population Performance Parameters

## Flow Assessment Future 1 Pilchuck Creek Fall Chinook Salmon

| Population | Scenario | Diversity index | Productivity | Capacity | Abundance |
|---|---|---|---|---|---|
| Pilchuck Fall Chinook | Future 1 | 100% | 17.9 | 7,013 | 6,619 |
| | Historic potential | 100% | 17.7 | 6,911 | 6,520 |

## Table 5-10 - Future Scenario Spawner Population Performance Parameters

## Flow Assessment Future 2 Pilchuck Creek Fall Chinook Salmon

| Population | Scenario | Diversity index | Productivity | Capacity | Abundance |
|---|---|---|---|---|---|
| Pilchuck Fall Chinook | Future 2 | 100% | 16.9 | 7,017 | 6,602 |
| | Historic potential | 100% | 17.7 | 6,911 | 6,520 |

# Table 5-11 - Stillaguamish Flow Assessment Fall Chinook Protection and Restoration Strategic Priority Summary

| Geographic area priority | | | Attribute class priority for restoration | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| -<br>Geographic area | Protection benefit | Restoration benefit | *Channel stability* | *Chemicals* | *Competition (w/ hatch)* | *Competition (other sp)* | *Flow* | *Food* | *Habitat diversity* | *Harassment/poaching* | *Obstructions* | *Oxygen* | *Pathogens* | *Predation* | *Sediment load* | *Temperature* | *Withdrawals* | *Key habitat quantity* |
| Lower Pilchuck Creek | ◯ | | | | | | | | | | | | | | | | | |
| Lower Stillaguamish River | ○ | | | | | | | | | | | | | | | | | |
| Still Est Flow Assessment | ○ | | | | | | | | | | | | | | | | | |
| Port Su | ∘ | ◯ | | | ● | | | ● | ● | | | | | ● | | | | |
| Sara Pass-a | ∘ | ◯ | | | ● | | | ● | ● | | | | | | | | | |
| Cent PSE-c | ∘ | ◯ | | ● | ● | | | ● | ● | | | | | | | | | |
| Cent PSW-c | ∘ | ∘ | | ● | ● | | | ● | ● | | | | | | | | | |
| Cent PSW-d | ∘ | ∘ | | ● | ● | | | ● | ● | | | | | | | | | |
| E Strait | ∘ | ○ | | | ● | | | ● | ● | | | | | | | | | |
| W Strait | ∘ | ∘ | | | ● | | | ● | | | | | | | | | | |
| Coastal BC | ∘ | | | | | | | | | | | | | | | | | |
| Cent PSE-d | ∘ | ○ | | ● | ● | | | ● | ● | | | | | | | | | |
| San Juan | ∘ | ○ | | ● | ● | | | ● | | | | | | | | | | |

| | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Strait Geo | ○ | ○ | | ● | ● | | | ● | | | | | | | | | | |
| Cent PSE-b | ○ | ◯ | | ● | ● | | | ● | ● | | | | | | | | | |
| Shil Bay | ○ | | | | ● | | | ● | ● | | | | | ● | | ● | | |
| Ell Bay | ○ | | | ● | | | | ● | ● | | | | | | | | | |
| Port Gard | ○ | ○ | | ● | | | | ● | ● | | | | | | | | | |
| Sara Pass-b | ○ | ○ | | | ● | | | ● | ● | | | | | | | | | |
| Skag Bay | ○ | | | | | | | ● | ● | | | | | | | | | |
| N Pug Snd | ○ | ○ | | ● | ● | | | ● | | | | | | | | | | |
| Sam Bay | ○ | | | | | | | ● | | | | | | | | | | |
| Nook Bay | ○ | | | ● | | | | ● | ● | | | | | | | | | |
| | | | | | | | | | | | | | | | | | | |

### 5.6.4 Dominance of indirect flow-related attributes compared to direct flow attributes.

It is of interest to examine whether direct flow-related attributes such as High Flow and Low Flow or indirectly related attributes such as sediment load attributes are having the most influence on habitat and the populations. As indicated by the reach reports for Church Creek coho salmon, Bed Scour (affects channel stability level 3 survival factor during incubation) is the most common and largest source of decreased survival in the Church Creek reaches. Bed Scour ratings are considered an indirect flow-related attribute; however, in the study values of BdScour were estimated from the ratio of peak flows under the different scenarios to template peak flows. Losses that are directly related to flow statistics are ranked second and appear during 0-age active rearing and 0-age inactive rearing (overwintering) life stages. There was significant loss of key habitat quantity for 0-age active rearing as well. This is likely the result of lower flows during summer leading to less rearing habitat. Continued degradation of bed scour and flow conditions in the future scenarios causes these attributes to contribute to additional Productivity losses.

Pilchuck Creek coho salmon – In the mainstem, loss of key habitat quantity for fry colonization is the predominant loss (in capacity); losses in key habitat quantity for 0-age active rearing, 0-age inactive rearing (overwintering), and 1-age active rearing life stages are the only other significant losses in mainstem reaches. In the tributaries, Bed Scour and overwinter (High) Flows in Subbasin 1 and Fine Sediment affecting spawning in Subbasin 5 tributary are the only significant losses found in Pilchuck Creek for coho salmon under modeled "current" conditions relative to Historic potential. Dramatic changes in a couple of tributary subbasins in the future scenarios was swamped by the weighted (by length) inertia of the non-changing mainstem of Pilchuck Creek.

Pilchuck Creek Fall Chinook salmon – no productivity losses are related to freshwater survival. This is consistent with the fact that no major changes in flow, bed scour, fine sediments, etc. are taking place in the mainstem Pilchuck Creek habitat for fall Chinook salmon.

Overall, in the 12 EDT model runs consisting of 4 scenarios, 2 focal species in Pilchuck Creek Basin, and 1 focal species in Church Creek, model outputs have indicated both direct flow regime attributes and indirect flow-related attributes have played a role in salmon population performance outcomes. Of all level 2 inputs, the most dramatic changes in population responses appear to be related to changes in habitat ratings for bed scour and with loss of key habitat quantity – both **indirect** inputs to EDT that the pilot project has linked to hydrologic change (peak flow and summer base flow respectively). Direct flow regime impacts on survival via EDT's Level 3 "Flow" category appear to have been secondary in determining salmon population parameters of the various scenarios. The most dramatic changes in population occurred for the coho population in Church Creek basin. Although drastic changes occurred in two Pilchuck Creek subbasins (Subbasins 1 and 8), the overall effects on the basin coho population is moderate because of the limited percentage of total habitat area that is affected. Modeled changes in Chinook populations in Pilchuck Creek associated with human activities affecting the freshwater environment were negligible.

## 5.7 Analysis of EDT Population Responses to Direct and Indirect Flow-Related Inputs

As discussed above, Pilchuck Creek Chinook salmon population responses changed only marginally across all scenarios. Changes in flow regime and flow related attributes across scenarios for the mainstem reaches of Pilchuck Creek that comprise Chinook salmon habitat were too small to have any significant effects on Chinook salmon populations. Modeled Pilchuck Creek coho salmon populations suffered moderate overall losses of diversity, productivity, capacity, and abundance in future scenarios due to land cover and water extraction in specific tributaries. In Church Creek, coho population changes across scenarios was more dramatic and more pervasive. In view of this, the following discussion focuses on Church Creek coho salmon population results with the intention that the analysis and conclusion can also apply to coho in tributary reaches of Pilchuck Creek, especially Pilchuck Tributary 1 and Pilchuck Tributary 8.

### Table 5-12 Coho Life Stages by Month for Church Creek with Level 2 Shaping Factors Assumed by EDT

| Life History Stage | Primary Flow Attribute | Oct | Nov | Dec | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Spawning** | FlwDiel | 20% | 90% | 100% | 100% | | | | | | | | |
| **Egg Incubation** | FlwDiel | 20% | 90% | 100% | 100% | 95% | 85% | 50% | 20% | | | | |
| **Fry Colonization** | FlwHi | | | | | | 85% | 50% | 20% | | | | |
| **0-Age Active (Resident) Rearing** | FlwLo | 79% | | | | | 0% | 0% | 21% | 50% | 76% | 100% | 100% |
| **0-Age Migrant** | No Flow Effect | ▨ | ▨ | | | | | | | | | | |
| **0-Age Inactive (overwintering)** | FlwHi | 20% | 90% | 100% | 100% | 95% | 85% | | | | | | |
| **1-Age Active (Resident) Rearing** | FlwHi | | | | | | 85% | 50% | 20% | | | | |
| **1-Age Migrant** | No Flow Effect | | | | | | ▨ | ▨ | ▨ | ▨ | | | |
| **Pre-spawning Migrant** | FlwLo | 79% | 21% | | | | | | | | | | 100% |
| **Pre-spawning Holding** | FlwLo | 79% | 21% | 0% | | | | | | | | | |

### 5.7.1 Analysis of Church Creek Coho Salmon Response to Direct Flow Related Inputs as Predicted by EDT

As discussed in Section 4 of this report, there are four direct flow-related inputs to EDT that were hypothetically significant in the pilot basins; FlwDiel, FlwHi, FlwLo, FlwIntraAnn. Table 5-12 presents information extracted from the EDT "Rule Viewer," a model utility that allows the user to see which level 2 attributes are active in determining survival (productivity) for a specific life stage, focal species, and model reach. This table illustrates three aspects of EDT modeling of the Church Creek coho population; 1) it shows which life stages are active during which months of the year, 2) it shows which level-2 flow attribute EDT uses as the primary input in calculating the mortality and survival (productivity) factor associated with flow regime, and 3) it shows the "shaping" percentages applied by EDT to the user's single level 2 input value to determine monthly values.

As indicated by the tabulation, only three of the four FlwDiel, FlowHi, and FlwLo are operative as primary factors determining flow regime effects on survival in EDT, FlwIntraAnn does not have a primary role in the model for any coho life stage.

The monthly "shaping" of level 2 inputs is significant, because survival factors calculated by the model for each reach and life stage are highly sensitive to the operative level 2 rating for the month which can differ significantly from the value input by the user which generally reflects the month with the highest value when the effect is most potent. For example, values of 4.0 were common for FlwHi in Church Creek reaches for Future 1 and Future 2 (Scenarios 3 and 4). As shown in the table, the effective level 2 ratings used to determine productivity factors by month would be 4.0 in December and January, but would decline to 2.0 in April and would have been zero to negligible until November when they would have bumped up to 3.6.

### 5.7.2 Sensitivity to Direct Flow Related Inputs by Life Stages (Spawning and Egg Incubation)

As shown in Table 5-12, FlwDiel is the primary determinant of flow regime effects on coho survival during these life stages. Reference to the EDT Rule Viewer as well as the specific rules database for coho in EDT shows that FlwDiel acts alone to determine a flow-related survival factor for these life stages as shown in Figure 5-2. Essentially, this figure illustrates EDT's sensitivity to direct flow regime inputs for these two life stages because according to EDT rules FlwDiel is the sole level 2 flow regime attribute utilized. The maximum reduction in productivity possible with FlwDiel is 0.3 with a maximum FlwDiel rating of 4. This would require an average maximum daily stage change of 1.33 feet per hour during the month with the most active changes in stream stage.

FlwDiel acts alone as a primary attribute without modification by other attributes. The purpose of FlwDiel is to characterize ramping rates and quantify the effects of rapid changes in stage such as sometimes occur downstream of a hydroelectric dam. These types of conditions were not present in the pilot basins. A maximum value of FlwDiel of 0.9 was calculated for Church Creek Reach 1 under the Future 2 scenario. FlwDiel had negligible impact on productivity and population in our study. In order to for EDT to predict a 10% reduction in productivity, the average of maximum daily ramping rates within the stormiest month of the year (November

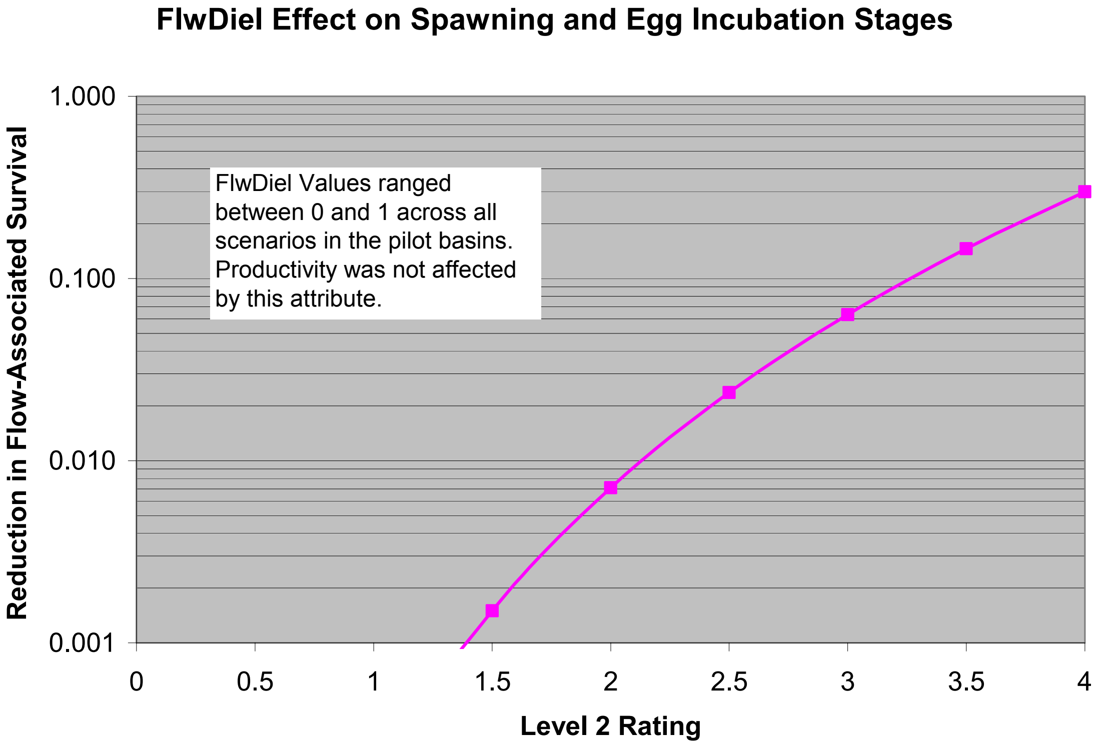

Figure 5-2: FlwDiel Effect on Spawning and Egg Incubation Stages

for Church Creek) would have to exceed 1.0 feet per hour. Because it is the only flow attribute considered by EDT it does not respond to increases to peak flows, high flow durations, or flow flashiness caused by urbanization during these life stages. FlwDiel potentially can have an effect on survival and other population parameters, but stage fluctuations must be larger than those that occur from stormwater runoff. It is probably used more effectively in basins with chronic, severe (daily) shifts in stage downstream of dams that are responding to shifting power demand.

Of significance for this study is that during these life stages, EDT does not correlate survival with the direct flow attributes, FlwHi or FlwIntraAnn, both of which were estimated to be affected by land use and land cover in all non-template scenarios. The effects on survival of peak flow or rapid runoff are dealt with instead through indirectly-related flow attributes such as Bed Scour, seen to be a major factor in the reduced survival and thus productivity of the focal species in the pilot basins, particularly for the future scenarios.

### 5.7.3 EDT Flow Effects on Productivity During Fry Colonization (March-May)

Figure 5-3 shows the effect of peak flow increases (via Flwhi) on mortality and survival during the fry colonization life stage. C1, the lowest curve represents the reduction in survival over the range of possible values of the primary level 2 by itself. This would be equivalent to non-flashy flow regime, a very low-gradient stream (< 0.1% slope), fully functional riparian conditions, heavy woody debris loading, and unconfined channel conditions. The remaining curves in the figure, represent stream conditions in which each of these "modifying" attributes are successively degraded (represented by a value of 4.0). The curves are defined as follows:

C2- Curve C1, plus very flashy hydrology (FlwInterAnn = 4.0)
C3- Curve C2, plus steep stream reach (slope>2%, Grad = 4.0)
C4- Curve C3, plus low riparian function (RipFunc = 4.0)
C5- Curve C4, plus low woody debris loading (WdDeb = 4.0)
C6- Curve C5, plus artificially or naturally narrowly confined channel (Confine = 4.0)

This family of curves illustrates the highly non-linear synergy exhibited by EDT when its rules call for a primary level 2 attribute to be "modified" by multiple secondary level 2 attributes.

In this study, because wood and riparian conditions were assumed to be at template levels for all scenarios, the impact of the level 2 FlwHi on the level 3 survival factor was quite limited and the EDT estimated productivities generally ranged between C3 and C4. The maximum survival loss during fry colonization that occurred in this study was 5% for the Future 1 and Future 2 scenarios, in reach Church 2 (a confined reach) during March. Population response was generally not sensitive to direct flow attributes and their modification during fry colonization.

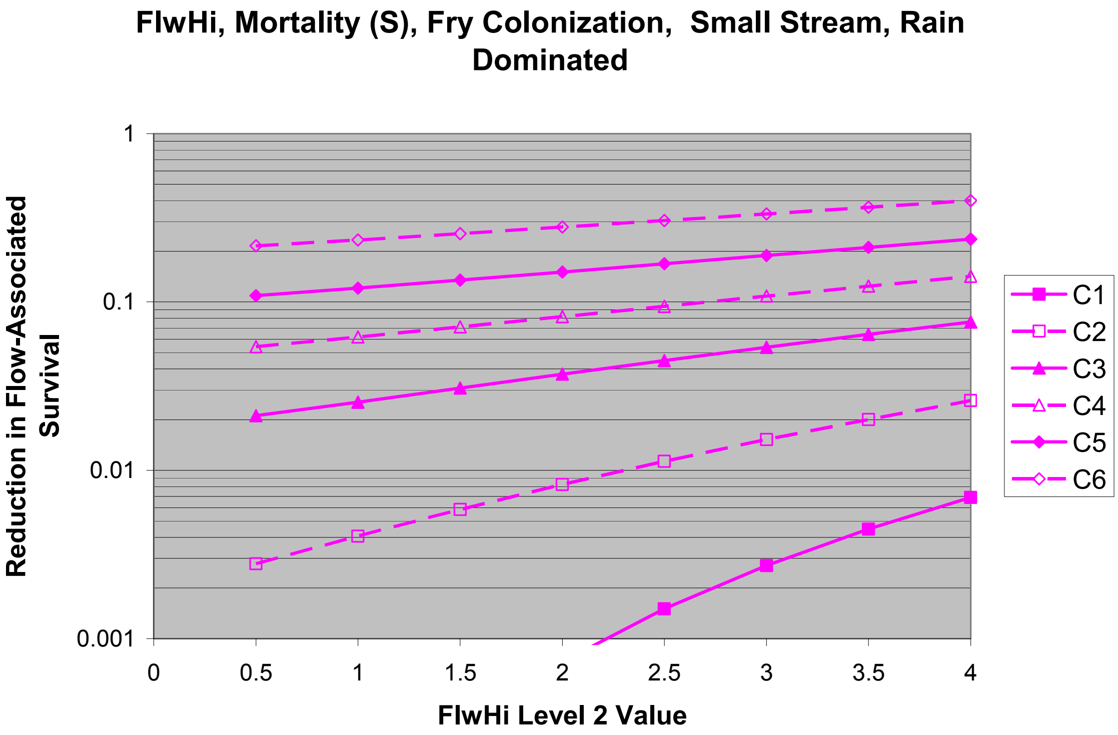

Figure 5-3: Reduction in Survival Related to FlwHi Values for Fry Colonization Life Stage.

### 5.7.4 EDT Modeled Base Flow Effect During 0-Age Active Rearing (March-October)

In 0-age active rearing stage, low flow (Flwlo) is the primary level 2 attribute. In the future scenarios, the lower stream reaches of Church Creek and Pilchuck Creek Tributary 8 were all projected to experience severely depleted base flows because of water extraction to meet growing human population.

As shown in Figure 5-4, the impact of a severe base flow rating on mortality depends on other factors such as embeddedness, riparian function, large woody debris, and habitat structure. In this study, modeled conditions in Church Creek reaches for all scenarios typically fall along the lower-most broken line. This results from assumptions of ideal woody debris and riparian function as well as the presence of high percentages of slack water habitat (pools and beaver ponds). The reduction in survival caused by severe base flow depletion during this life stage was limited to a maximum of 16% (as shown by the broken line in the figure). Consequently, even though the FlwLo rating for July in Church-3 is 4.0 in the Future 1 scenario, the reduction in survival associated with flow regime is only 0.14 instead of the 0.31 indicated by the next highest curve which represents a condition with minimal slack-water habitat. Thus, the study assumptions regarding habitat structure, riparian, and woody debris conditions for all scenarios severely limited the model's response to base flow depletion in the affected reaches. Had these factors been more representative of actual current conditions in Church Creek, it is expected that declines in survival in Church Creek associated with base flow losses would have been doubled or tripled for all non-Template scenarios.

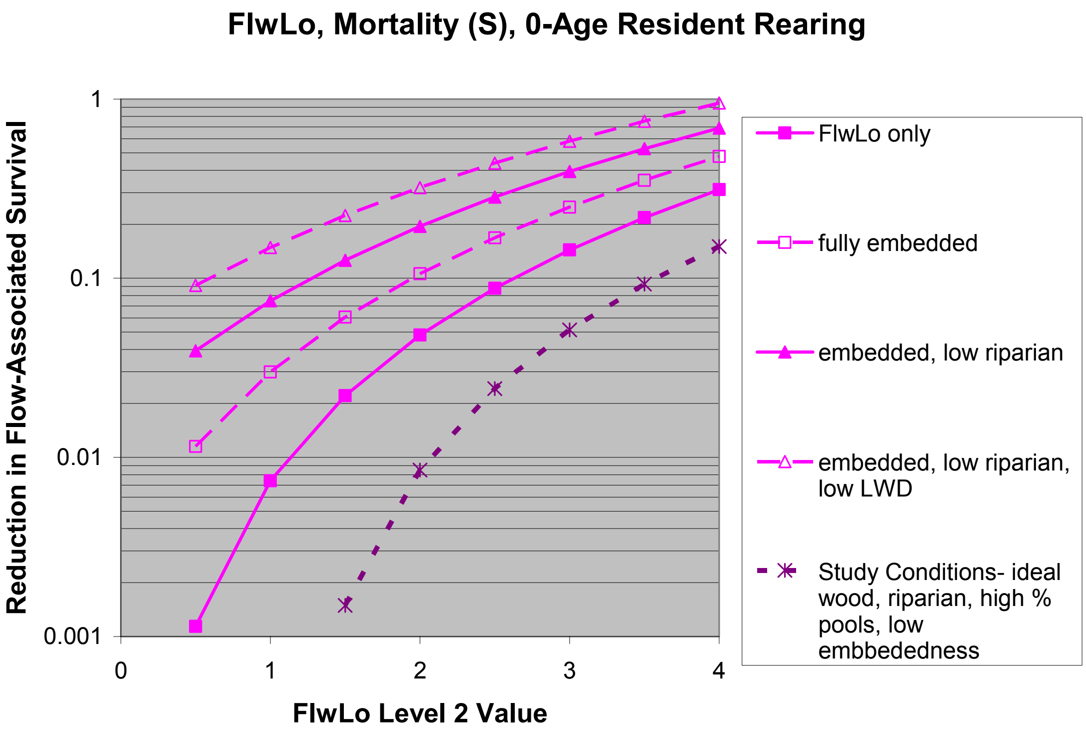

Figure 5-4: Reduction in Survival Related to FlwLo Values for Resident Rearing Life Stage.

### 5.7.5 0-Age Migrant (October-November)

EDT does not model a direct flow attribute-related impact on survival for this life stage.

### 5.7.6 EDT Survival During 0-Age Inactive and 1-Age Active Rearing Life Stages

As seen in Table 5-12, the peak flow attribute, FlwHi, is the primary level 2 attribute affecting survival during 0-Age Inactive and 1-Age Active Rearing life stages. Curve definitions in Figure 5-5 are the same as for the analysis of fry colonization above. During 0-age inactive rearing (overwintering, October-March), it would be possible for survival losses to be as high as 25% to 30% for an unconfined, moderately steep stream with poor riparian function and low woody debris loading (Curve 5). In this study, these two conditions were assumed to be at template levels (level 2 attribute values of 0), effectively limiting the maximum productivity loss to 10% or less (Curve 3) during this life stage. EDT's monthly shaping of FlwHi during this life stage does not effectively limit the impact of increased peak flows.

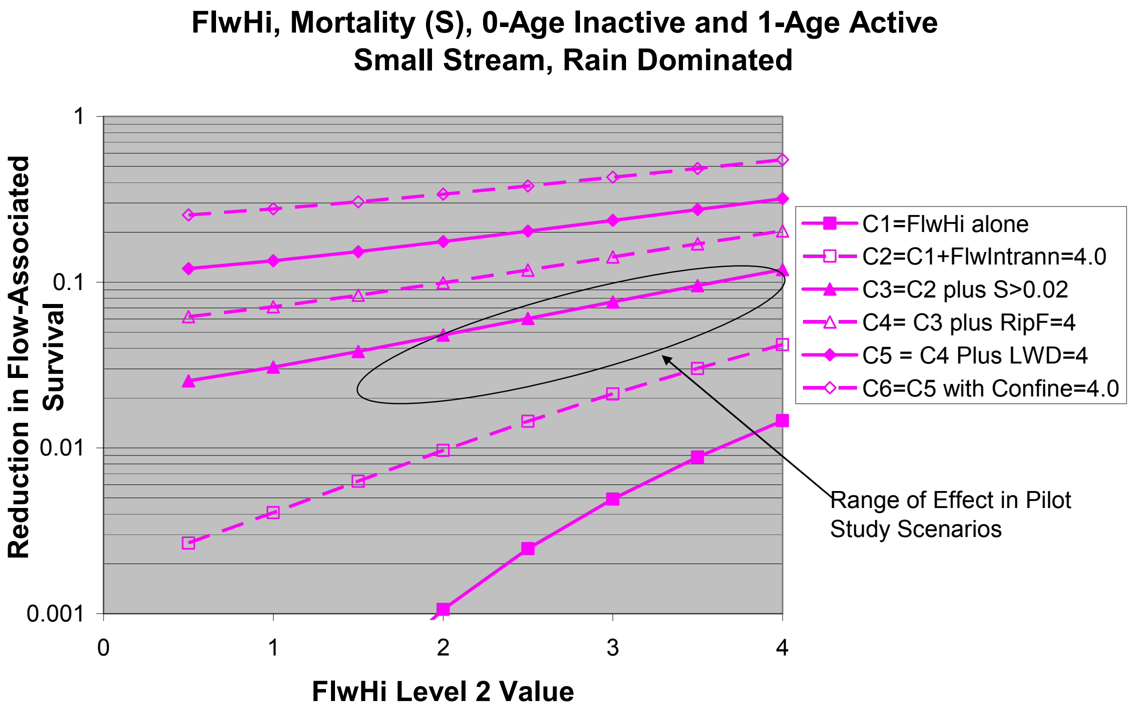

Figure 5-5: Reduction in Survival Related to FlwHi Values for Inactive and Active Rearing Life Stages.

With regard to 1-age active rearing (March-May), as with fry colonization, because of monthly shaping of level 2 input values, the maximum potential impact of flow regime on 1-age resident rearing is on the order of 10% for worst case conditions, i.e. small, moderately steep, unconfined stream reaches and perhaps up to 15% for steep, confined stream. This would be with poor riparian function, low woody debris loading, low Tqmean (flashy conditions resulting in a high level 2 input for FlwIntraAnn). In this study, modeled productivity losses for non-template scenarios were even smaller than this because of the assumptions of high riparian function and full wood loading.

### 5.7.7 1-Age Migrant

EDT does not consider direct flow attributes in calculating survival during this life stage.

### 5.7.8 Pre-Spawning Migrant (September-November)

The exclusive direct flow variable in these life stages is FlwLo; however, as shown in the life stage tabulation, FlwLo (base flow loss) has a potential impact on survival only during the first two months of the period. EDT does not use any other flow regime attribute during this life stage to determine survival from flow regime. Therefore no stresses to fish populations resulting from flow flashiness or high storm peaks are considered during the latter portion of the life stage.

A consistent picture of survival sensitivity during this low flow period could not be inferred from the Rule Viewer, the Coho Rules Database, and the study reach reports. Based on the reach reports, impacts of FlwLo on survival during this life stage were miniscule (<1% drop in survival) in all study reaches; however, according to the Rule Viewer, survival reduction during this life stage should be as much as 6% during September in Church-1, Church-2, Church-3, Pilchuck Tributary-8 which are all affected by water withdrawals in the non-template scenarios and have FlwLo values of 4.0 Finally, the Coho Rules Database indicates a drop in survival of up to 14% when FlwLo=4.0. Given these contradictory sources of information, it is difficult to know what is going on mathematically in EDT.

### 5.7.9 Pre-Spawning Holding Life Stage (October-December)

The key direct flow variable in this life stage is FlwLo, however as shown in Table 5-12, base flow has a potential impact on survival only during the first month of the life stage period. In Figure 5-6 it can be seen that, under the assumed historic conditions for riparian and pools, the maximum loss in survival under the most unfavorable study conditions was 2% (Study Conditions curve at FlwLo = 4).

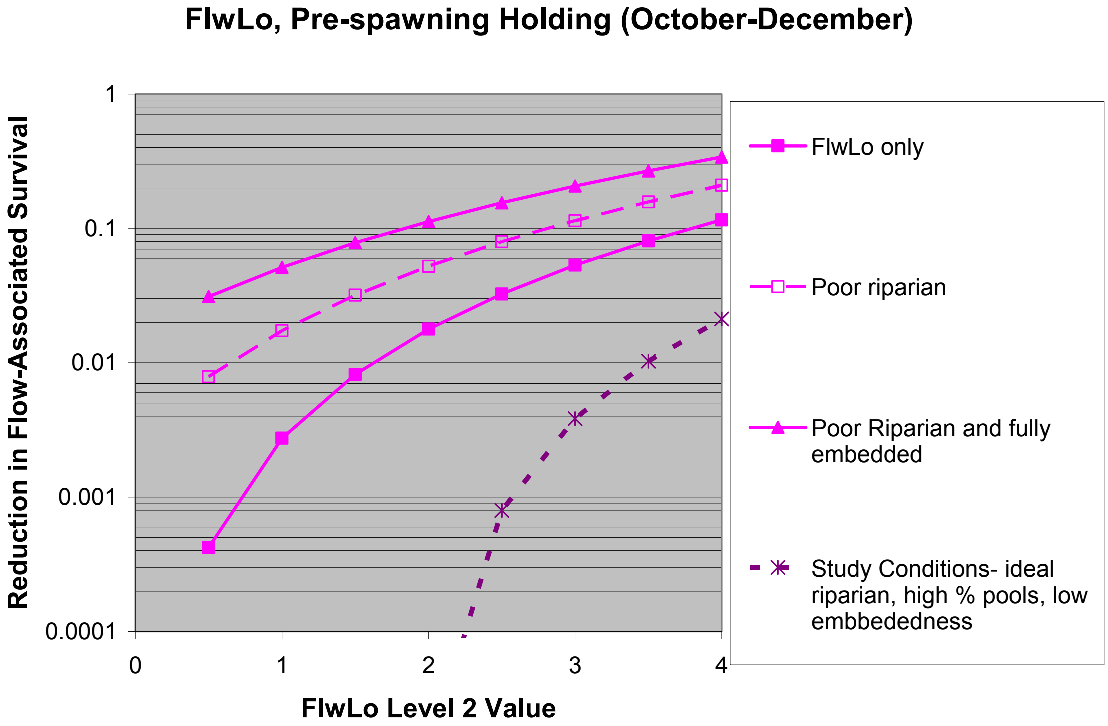

Figure 5-6: Reduction in Survival Related to FlwLo Values During Prespawning Holding Life Stage.

### 5.7.10 Indirect Flow-Related Influence on EDT Population Results

It is worthwhile to contrast the seeming lack of sensitivity of EDT's life stage survival estimates to direct flow attributes with the response to selected indirect attributes[4]. These attributes appear to be the major drivers of the relative differences of coho salmon population performance among the pilot study's modeling scenarios.

### 5.7.11 Channel Stability (Bed Scour) During Egg Incubation

According to the reach analyses discussed earlier, the key Level 3 categories affecting survival and salmon population performance as a whole in the pilot study were Channel Stability and Sediment in descending order of importance. The primary Level 2 attribute that controls Channel Stability survival calculations is BdScour (Bed Scour) in all life stages predicted to be susceptible to channel stability effects[5]. These include Egg Incubation, Fry Colonization, 0-Age Resident Rearing, 0-Age Inactive, and 1-Age Resident Rearing. EDT gives no role to Bed Scour or any modifiers to Channel Stability survival during Spawning, 0-Age Migrant, 1-Age Migrant, Pre-spawning Migrant, or Pre-Spawning Holding life stages.

According to the EDT rules database and results of this study, the effects of BdScour/Channel Stability on survival and overall population performance are hugely more important during the Egg Incubation life stage than all the other life stages combined. Figure 5-7 shows the sensitivity of EDT predicted survival to Level 2 values of BdScour. As shown, even with the optimal riparian and woody debris conditions assumed for all scenarios in this pilot study, survival can be reduced by up to 100% with BdScour level 2 attribute values of 4.0. As shown in the figure, BdScour ratings ranged from 1.5 up to 4.0. Overall coho population results are clearly most affected by these BdScour ratings and their effect on survival during egg incubation.

This points up the critical importance of assigning the most accurate values to BdScour in the current formulation of EDT and underscores its role in indirectly representing the effect of hydrologic changes associated with peak low levels and durations on salmon population performance.

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[4] As a reminder to the reader, these are attributes that are physically driven by flow, such as Bed Scour, but are not the four attributes in the Hydrology category in the Stream Reach Editor dataset that were discussed immediately above.

[5] Level 3 Channel Stability survival effects are actually derived from Bed Scour, Icing, Riparian Function, and Woody Debris. Icing does not occur in the pilot basins; Riparian Function and Woody Debris remain at Template conditions across all scenarios.

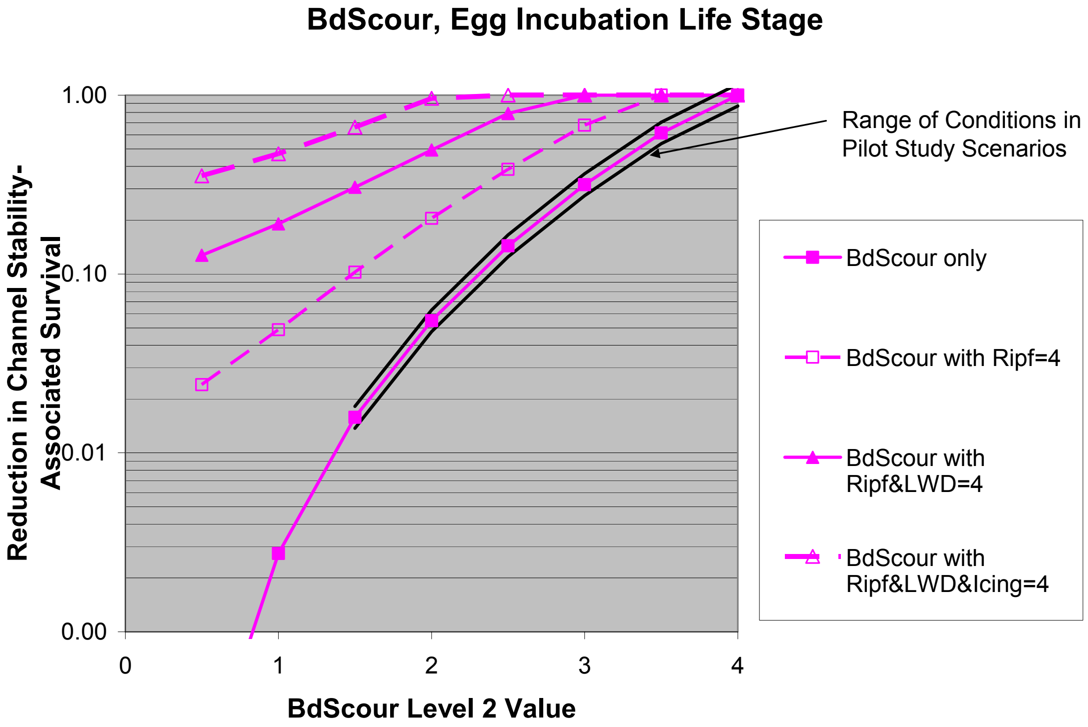


Figure 5-7: Reduction in Survival Related to BdScour Values During Egg Incubation Life Stage.

### 5.7.12 Sediment (Fine Sediment) During Egg Incubation

The second most significant determinant of coho salmon population performance in the pilot study was related to reductions in survival associated with the Level 3 attribute "Sediment Load", again during the egg incubation life stage. The Level 2 attribute "Fine sediment" (FnSedi) characterizes the level of clogging of spawning gravels and the resulting decreased egg-to-fry survival. The EDT response to Level 2 values of FnSedi is shown in Figure 5-8 along with the range of conditions simulated in the pilot study. FnSedi was clearly the second most significant determinant of modeled population performance differences among the modeled scenarios. Note that in this study, FnSedi was estimated from %TIA within the drainage area to each reach for Church Creek as well as for tributaries to Pilchuck Creek.

Fine sediment conditions in the mainstem Pilchuck Creek were hypothesized to be the most significant manifestation of habitat impact from upstream forest practices. Fine sediment inputs were estimated using two different approaches. First, a Geographic Information Systems (GIS) analysis was performed that quantified and overlayed hydrologically mature forest cover (from Purser, et al., 2003), steep slopes (Digital Elevation Model), erodible surficial geology, and roads. A multimetric scoring was then used to estimate the relative potential contribution of fine sediments from the upper Pilchuck Creek subbasins to lower mainstem Pilchuck Creek reaches (where fine sediment would potentially deposit). Second, field transects in pool tailout habitat (spawnable gravel) were sampled using a grid method (Rhodes and Purser, 1998). Three transects each were sampled in Pilchuck Main-2 and 3. Transect means and reach means were consistent with the multimetric score arrived at through the GIS analysis and were then used to rate the attribute according to Lestelle, 2004.

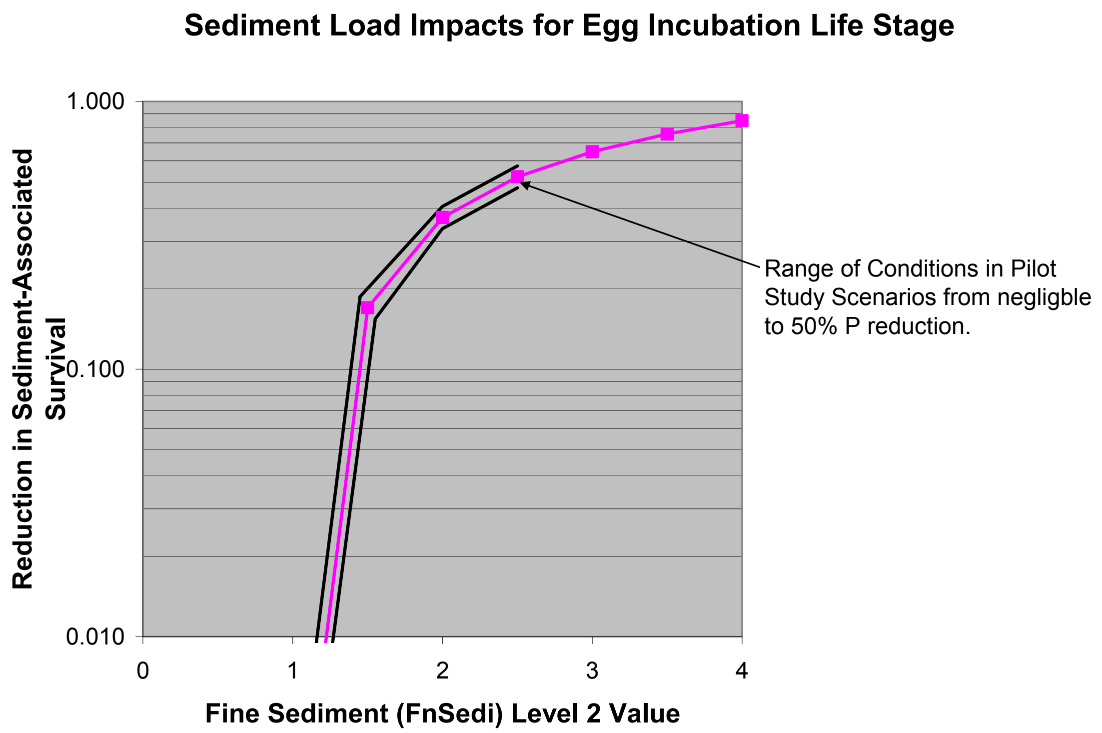
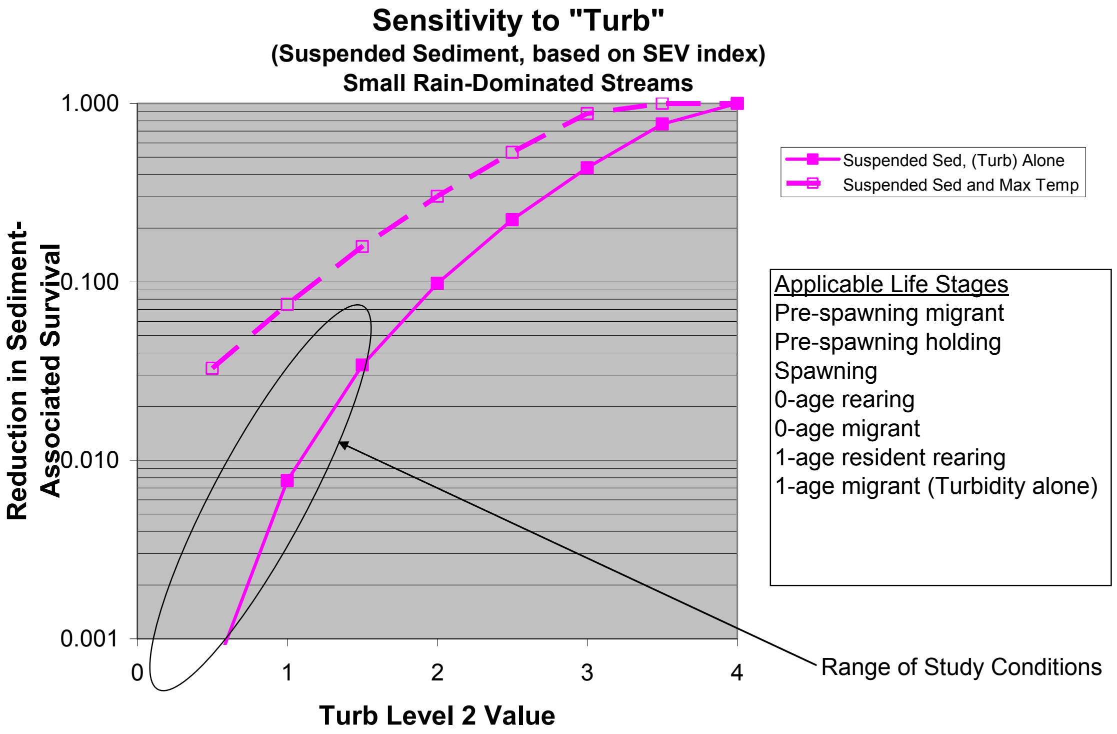


Figure 5-8: Reduction in Survival Related to Fine Sediment Values During Egg Incubation Life Stage.

In most other life stages, the primary Level 2 attribute controlling survival associated with "Sediment" is "Turbidity" which is really a misnomer for a parameter that is related to suspended sediment concentration and duration. Figure 5.9 shows that although Turbidity can potentially affect many life stages significantly, level 2 values estimated for pilot study scenarios were not sufficiently high to produce significant reductions in survival. It is important to note that level 2 values of "Turb" were based on a limited amount of suspended sediment data taken by Snohomish County at sites on both Church Creek and the mainstem of lower Pilchuck Creek.



1.1.1

Figure 5-9: Reduction in Survival Related to Turbidity (suspended sediment) Values During Several Life Stages.

### 5.7.13 Summary- Direct Flow and Indirect Flow-related Inputs

The foregoing analysis of inputs shows clearly that the overall salmon population results of the pilot study were dominated by the indirect flow related inputs for bed scour and fine sediment in spawning gravels. Although it is difficult to estimate precisely, it appears based on the analysis of life stage survival factors that these two attributes explain as much 75% of the overall differences in population performance (productivity, capacity, abundance) among the pilot study scenarios.

It was also found that EDT's use of modifying attributes can have a strong non-linear effect on the degree of influence of the "primary" level 2 attribute. The most relevant consequence of this characteristic of the model for this study was that the impact of differences in level 2 ratings for peak flow (FlwHi) and base flow (Flwlo) between modeling scenarios were significantly suppressed. The primary cause of this suppression of influence of flow regime effects was the assumption taken in the study that habitat type (composition), riparian function, and large woody debris was held constant across template, current, and both future scenarios at optimal levels. The sensitivity analysis suggests that the impact of direct flow attributes on salmon population performance would almost certainly have doubled if not tripled had a more degraded and realistic rating of current habitat type, woody debris loading, and riparian function been used to represent current and future conditions.

Recall that the purpose of using template conditions for these attributes was to isolate and better understand the effects of changes in basin runoff and stream flow caused by land use change and water supply management as distinct from direct impacts on aquatic habitat such as removal of wood, beaver dams, and riparian vegetation. In hindsight, a more useful approach to accomplish the same objective might have been to use observable current conditions for these in-stream and riparian habitat attributes across all scenarios. Still, the pilot study's results do illustrate and underscore a reasonable hypothesis: that protection and restoration of stream buffers, large woody debris, and pool habitat preserve natural robustness that greatly blunts the impacts of increased storm runoff and depleted base flows on salmon population performance.

## 5.8 Conclusions and Recommendations for Further Study Related to EDT Modeling

This study sought to apply a model-based analysis method to trace the impacts of land use and water management actions on flow regime and impacts in turn of flow regime change on habitat as indicated by VSP parameters. The study employed two models, HSPF to simulate the stream flow regime in response to land and water management, and EDT to translate flow regime change and related effects to salmon population performance. The study found that storm runoff, if not treated to suppress peak flows and flow durations reduces salmon population performance considerably. These reductions; however, are reflected in the habitat model primarily through indirect flow-linked inputs quantifying scour of, and fine sediment intrusion into, salmon redds and not through the model's direct flow inputs quantifying peak flow increases, flow flashiness, and base flow reductions. It was found that model inputs characterizing radical changes in winter peaks and summer base flows across study scenarios tended to have a relatively weak influence on salmon populations, but that this was partially an artifact of study assumptions related to woody debris, riparian function, and habitat composition. On the other hand, the use of peak flow changes as a predictor of the severity of bed scour in spawning areas provided an indirect avenue for changes in storm discharge to strongly affect salmon population performance results; however, this technique was outside the construct of the current EDT model or user guidance for model input.

Overall, the methodology employed in this study appears to be a sound as way of comparing scenarios, getting a sense of their relative rank, and at least a semi-quantitative appreciation of the degree to which they differ from one another. The actual numbers reflecting intrinsic productivity, capacity, and equilibrium abundance should be interpreted with full recognition that they are often derived from model inputs with highly variable certainty or proof and that they reflect a limited subset of the range of activities that affect salmonid populations.

### 5.8.1 Improvements to Modeling Procedure

Three types of improvements are recommended to reduce uncertainty and increase accuracy of absolute and comparative results of salmon population performance- improvements in critical EDT inputs, improvements in EDT documentation, and improvements in EDT model structure (rules). These improvements would increase the usefulness of the analytical approach employed in this project in meeting the stated project purposes.

### 5.8.1.1 Improvement of Critical EDT Inputs

1. In future studies the sensitivity of population response to flow regime as modified by characterization of riparian function, woody debris, and habitat composition inputs should be carefully considered. Representation of these factors in their current rather than template condition would have provided a stronger contrast among scenarios with respect to direct flow-related impacts on habitat and salmon population response in the pilot study. This also raises the importance of having adequate field data for attributes such as sediment characteristics, habitat types, and frequency of large woody debris.

2. With regard to EDT model inputs, it would appear that the most benefit in reducing uncertainty would accrue with better approximations of redd bed scour. In this study a simple relationship with 2-year peak annual flow was assumed and although it is qualitatively reasonable, it is otherwise arbitrary. Future studies should use redd scour data to anchor or calibrate a more thorough theoretical formulation for quantifying redd scour depth. For the latter, our recommendation would be to use a formulation consistent with bedload transport theory involving the magnitude and duration of discharges large enough to move redd gravels such as:

   $$\sum\{[(q - q_c)/q_c]^{1.5}\}\Delta t \text{ for } q>q_c \qquad \text{(Eq. 5-1)}$$

   in which q is the unit width discharge, $q_c$ is the critical discharge to move redd gravel and $\Delta t$ is the time step associated with q.

3. Similarly, fine sediment inputs should be based on more thorough field measurements. The extrapolation of those measured values to other scenarios different from field measured conditions will remain a problem. In this study, %TIA of the drainage area was used as an indicator of fine sediment supply. This approach would need to be modified to account for both water quantity and water quality treatment that removes sediment from runoff.

4. It is recommended that automatic “shaping” of level 2 attributes by month be over-ridden by users when measured or simulated flow regime data suggests that standard seasonal ratios employed by EDT are not reflective of the systems being modeled.

5. Future studies whose purpose is to compare scenarios representing different conditions within the freshwater environment should make certain that boundary and initial conditions such as marine survival rates are consistent across all scenarios as was done in this study.

### 5.8.1.2 Improvements of EDT Model Documentation

1. A comprehensive set of sensitivity curves similar to the ones shown in this report would be a great boon to model users since it would help them focus their data collection and attribute estimation efforts on those most likely to affect study results. The sensitivity curves provided in the Rule Viewer are not generally consistent with survival factors computed using the rules database.

2. The model documentation should alert the user to known physical process connections such as between increased peak flow and bed scour that are not linked within the model. Another example of this is the need to link minimum channel width inputs that quantify habitat during low flow conditions with altered base flow conditions.
3. With regard to base flow, the user guidance on rating base flow changes (FlwLo) should use an alternative statistic to mean discharge during the 45-60 day low flow period to assess the severity of base flow changes. In urbanized basins, severe reductions in base flows during inter-storm periods can be masked by use of a mean discharge statistic because of flashy injections of storm water at high rates for short periods of time. Median discharge during the lowest flow month would probably be a more suitable metric of base flow losses.

#### 5.8.1.3 Improvements in EDT Model Formulation

1. In the longer term, EDT or the next generation replacement of EDT model should be designed to take advantage of the dynamic output from continuous hydrologic simulations as inputs rather than resort to flow statistics that provide a much sketchier and static picture of hydrologic regime and habitat conditions.

2. Development of the next generation model should also provide an opportunity to take a more comprehensive look at hydrologic change caused by urbanization in formulating rules governing survival rates at different salmonid life stages. For example, in its current version, with the exception of radical diurnal stage fluctuations associated with hydro-operations, EDT focuses almost exclusively on only two flow statistics: peak flow and base flow. The current approach ignores potential impacts on survival resulting from urban runoff such as out-of-season peak discharges from impervious area during spring and summer rearing life stages.

## 5.9 Quality Index (after May et al. 1997)

### 5.9.1. Introduction

We now turn to a different approach that directly evaluates impervious area-related changes to habitat and populations, although one that is based in the same rules of life stage survival and the environmental attributes necessary to provide for survival. May et al. (1997) studied more than 120 stream segments in 22 watersheds. Relationships were developed between total impervious area (TIA) and biological indicators such as BIBI and juvenile coho/cutthroat ratio (Figure 5-10). These indictors are diagrammatically evaluated and BIBI scores greater than 30 and coho/cutthroat ratios greater than 4.0 are considered to be of “High Biotic Integrity.” BIBI scores less than 20 and coho/cutthroat ratios less than about 2.5 are described as having “Low Biotic Integrity.”

These relationships are from actual situations found in the Puget Sound lowlands and thus they would be expected to differ from relationships developed in areas such as are being considered in the current project. Specifically, the assumptions made in this pilot project, that the estuary, riparian area and channel characteristics are in a historic state, would cause the BIBI scores to be, for a given level of TIA, higher than those found in May et al. (1997). Since we expect higher

BIBI values as a result of the assumptions made for estuary, riparian, and instream conditions, it seems prudent to not use the best fit line from May, et al. (1997) but rather values that are near or at the top of the values found for a particular TIA value. Further, it is notable that even under the randomly developed conditions extant throughout May, et al.'s project area, reaches with TIA of 34% had BIBI scores of as much as 31. Therefore, the assumption that in the pilot project area, under the seemingly contrived conditions of historical estuary, riparian, and instream characteristics, that BIBI scores would be 29 at a TIA of 34%, does not seem unreasonable.

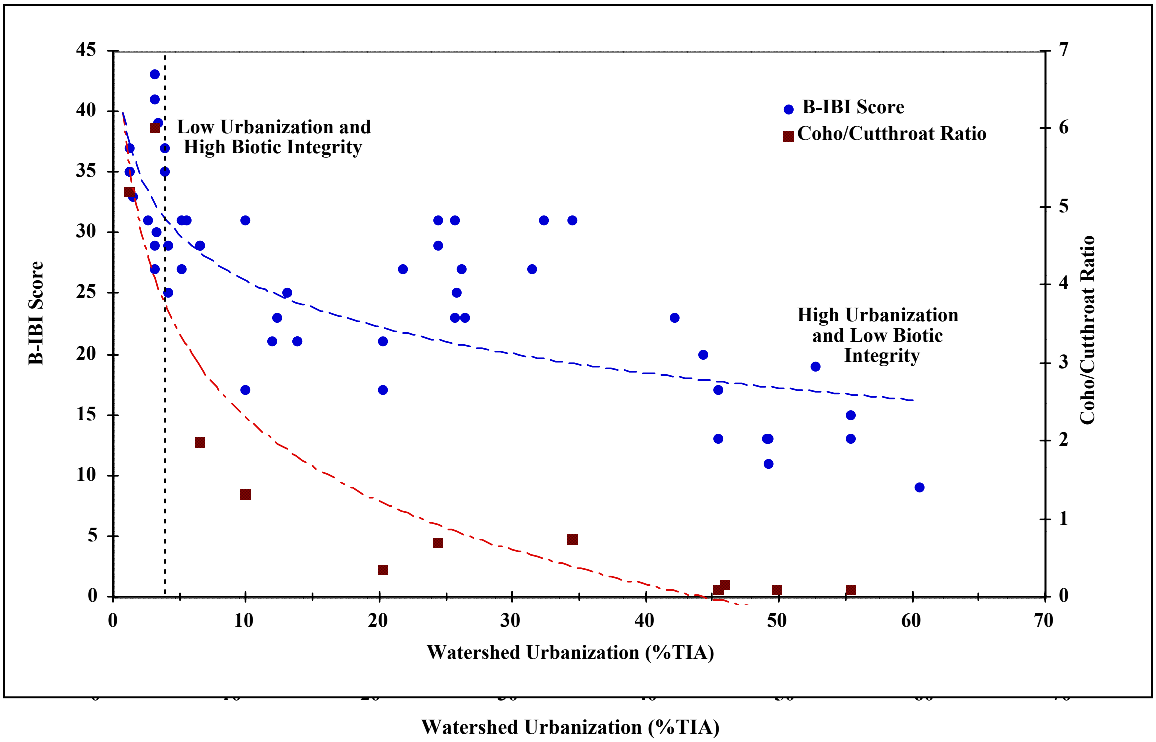


Figure 5-10: Relationship between TIA, BIBI, and Coho/Cutthroat Ratio (May, et al, 1997)

### 5.9.2 Approach and Results

The subbasin impervious area of the project subbasins was used to predict BIBI scores and juvenile coho salmon/cutthroat trout ratios for each reach in Church and Pilchuck Creeks (Table 5-13). First, with regard to BIBI scores across all scenarios, the ratings are consistently within the High Biotic Integrity bubble except for eight (8) reaches under the Future 2 scenario in response to TIA percentages of 33 and 34%. Even at these high TIA percentages, biotic integrity can be moderate according to the empirical model of May et al. (1997). This includes all five (5) Church Creek reaches and three (3) in Pilchuck subbasin 1. A loss in habitat quality occurs, but TIA alone does not predict this loss to be drastic, even given urban densities.

This is consistent with the effect in EDT. TIA-based ratings for Benthic Community Richness become more degraded with increasing imperviousness in these same reaches (Church and Pilchuck subbasin 1). These reaches go from a range of 0.1 to 0.3 under current conditions to a range of 0.7-1.2 under Future 1 conditions to a range of 2.2 to 2.4 under Future 2 conditions. In EDT, BIBI affects the level 3 survival factor food and thus affects the maximum density the population may attain through the rearing life stages. It is noted that food is not identified in any of the diagnostic reports (Tables A-1 through A-5 and A-10 through A-12) and thus is not affecting productivity under the specific current conditions posed in the EDT model. Bed Scour and Fine Sediment (Church Creek reaches), and High Flow and Fine Sediments (in Pilchuck Creek tributary reaches) are having the most significant effects on productivity in these scenarios in these reaches. The differences between the values of BIBI in these reaches and BIBI scores throughout the remainder of the reaches is abrupt; no other reaches are predicted to have BIBI score less than 39. This is a value that is described as being only "slightly divergent from least disturbed condition" (Lestelle 2004).

The coho/cutthroat ratios tell a slightly different story. While no reaches are identified under the "Current" scenario as anything other than being of High Biotic Integrity using the BIBI scores, the three (3) reaches in Pilchuck subbasin 1 land squarely in the middle of a moderate biotic integrity with ratios of 3.0 under this scenario and two (2) Church Creek reaches fall just under the 4.0 ratio threshold. This coincides with changes of 5-8% in Capacity and Abundance predicted by EDT (Tables 5-3 and 5-5).

Going to the more developed Future 1 scenario, all of the Church Creek reaches, the three (3) reaches in Pilchuck subbasin 1 and three (3) additional reaches in Pilchuck subbasins 2 and 3 fall within or immediately adjacent to the "Low Biotic Integrity" bubble. This is significant in Church Creek and is consistent again with the significant reduction in Productivity and lesser reductions in Capacity and Abundance under Future 1 scenario in Church Creek (Table 5-6). Reductions in the ratio value in Pilchuck Creek tributary reaches, but not in all of them and not in the mainstem Pilchuck Creek reaches, is consistent with the much smaller reductions in Productivity, Capacity, and Abundance of coho salmon in Pilchuck Creek (Table 5-6) under this scenario. This pattern is accentuated in the comparison of coho/cutthroat ratios (Table 5-13 and Table 5-14) and VSP parameters for the Future 2 scenario (Table 5-7). With regard to errors about the modeled values predicted from May et al. (1997), empirical data suggests that actual values can be about + or – 1 compared to the modeled values. This does not appreciably change the interpretation.

Table 5-13. Biological Indices related to TIA (after May et al. 1997) for Template and Current Scenarios

| EDT Reach | Template TIA (%) | BIBI | Coho/Cutthroat (ratio) | Current TIA (%) | BIBI | Coho/Cutthroat (ratio) |
|---|---|---|---|---|---|---|
| Church-1 | 0.0 | 50 | >6 | 4.0 | 48 | 3.9 |
| Church-2 | 0.0 | 50 | >6 | 4.0 | 48 | 3.9 |
| Church-3 | 0.0 | 50 | >6 | 3.0 | 48 | 4.3 |
| Church-4 | 0.0 | 50 | >6 | 2.0 | 49 | 5.0 |
| Church-5 | 0.0 | 50 | >6 | 3.0 | 48 | 4.3 |
| PilCrk-Main 1 | 0.0 | 50 | >6 | 1.0 | 49 | 6.0 |
| PilCrk-Main 2 | 0.0 | 50 | >6 | 0.0 | 50 | >6 |
| PilCrk-Main 3 | 0.0 | 50 | >6 | 0.0 | 50 | >6 |
| PilCrk-Main 4 | 0.0 | 50 | >6 | 0.0 | 50 | >6 |
| PilCrk-Sub1 Trib a | 0.0 | 50 | >6 | 7.0 | 46 | 3.0 |
| PilCrk-Sub1 Trib b | 0.0 | 50 | >6 | 7.0 | 46 | 3.0 |
| PilCrk-Sub1 Trib c | 0.0 | 50 | >6 | 7.0 | 46 | 3.0 |
| PilCrk-Sub2 Trib a | 0.0 | 50 | >6 | 1.0 | 49 | 6.0 |
| PilCrk-Sub3 Trib a | 0.0 | 50 | >6 | 2.0 | 49 | 5.0 |
| PilCrk-Sub3 Trib b | 0.0 | 50 | >6 | 2.0 | 49 | 5.0 |
| PilCrk-Sub4 Trib a | 0.0 | 50 | >6 | 1.0 | 49 | 6.0 |
| PilCrk-Sub5 Trib a | 0.0 | 50 | >6 | 1.0 | 49 | 6.0 |
| PilCrk-Sub7 Trib a | 0.0 | 50 | >6 | 0.0 | 50 | >6 |
| PilCrk-Sub8 Trib a | 0.0 | 50 | >6 | 0.0 | 50 | >6 |

Table 5-14. Biological Indices related to TIA (after May et al. 1997) for Future 1 and Future 2 Scenarios

| EDT Reach | Future 1 TIA (%) | BIBI | Coho/Cutthroat (ratio) | Future 2 TIA (%) | BIBI | Coho/Cutthroat (ratio) |
|---|---|---|---|---|---|---|
| Church-1 | 16 | 40 | 1.7 | 33 | 29 | 0.6 |
| Church-2 | 16 | 40 | 1.7 | 34 | 29 | 0.5 |
| Church-3 | 15 | 41 | 1.8 | 34 | 29 | 0.5 |
| Church-4 | 12 | 43 | 2.0 | 34 | 29 | 0.5 |
| Church-5 | 13 | 42 | 1.9 | 34 | 29 | 0.5 |
| PilCrk-Main 1 | 4.0 | 48 | 3.9 | 5 | 47 | 3.5 |
| PilCrk-Main 2 | 3.0 | 48 | 4.3 | 3 | 48 | 4.3 |
| PilCrk-Main 3 | 1.0 | 49 | 6.0 | 1 | 49 | 6.0 |
| PilCrk-Main 4 | 1.0 | 49 | 6.0 | 1 | 49 | 6.0 |
| PilCrk-Sub1 Trib a | 18.0 | 39 | 1.5 | 34 | 29 | 0.5 |
| PilCrk-Sub1 Trib b | 18.0 | 39 | 1.5 | 34 | 29 | 0.5 |
| PilCrk-Sub1 Trib c | 18.0 | 39 | 1.5 | 34 | 29 | 0.5 |
| PilCrk-Sub2 Trib a | 9.0 | 44 | 2.6 | 9 | 44 | 2.6 |
| PilCrk-Sub3 Trib a | 9.0 | 44 | 2.6 | 9 | 44 | 2.6 |
| PilCrk-Sub3 Trib b | 9.0 | 44 | 2.6 | 9 | 44 | 2.6 |
| PilCrk-Sub4 Trib a | 7.0 | 46 | 3.0 | 7 | 46 | 3.0 |
| PilCrk-Sub5 Trib a | 7.0 | 46 | 3.0 | 7 | 46 | 3.0 |
| PilCrk-Sub7 Trib a | 2.0 | 49 | 5.0 | 2 | 49 | 5.0 |
| PilCrk-Sub8 Trib a | 3.0 | 48 | 4.3 | 3 | 48 | 4.3 |

## 5.10 Matrix results on functioning

The Matrix of Pathways and Indicators is used to evaluate the watershed and habitat conditions in the mainstem of Pilchuck Creek that directly affects Pilchuck Creek fall Chinook salmon. Four indicators, Changes in Peak/Base Flows, Disturbance History, Stream Temperature, and Sediment, are evaluated (Table 5-15). Of note in Table 5-15 is that for Fall Chinook salmon in these reaches, stream temperature and changes in peak flow across the scenarios is not deleteriously affecting habitat conditions. Fine sediment ratings also do not change across the scenarios although the matrix evaluates fine sediment conditions as “At Risk” (this is believed to be an artifact of the calculated % embeddedness values based on the ratio of 2-year peak flow to winter base flow for each scenario). For these three indicators then the checklist rating is “Maintained” across all scenarios. This is consistent with the EDT model results.

Table 5-15. Matrix evaluations for Fall Chinook Salmon in Pilchuck Creek.

| EDT Reach | Stream Temperature | | | | Peak Flow | | | | Disturbance History | | | | Fine Sediment | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | template | current | Future 1 | Future 2 | temp | current | F 1 | F 2 | temp | current | F 1 | F 2 | temp | current | F 1 | F 2 |
| PilCrk-Main 1 | pfc | pfc | pfc | pfc | pfc | pfc | pfc | pfc | pfc | npf | npf | npf | ar | ar | ar | ar |
| PilCrk-Main 2 | pfc | pfc | pfc | pfc | pfc | pfc | pfc | pfc | pfc | npf | npf | npf | ar | ar | ar | ar |
| PilCrk-Main 3 | pfc | pfc | pfc | pfc | pfc | pfc | pfc | pfc | pfc | npf | npf | npf | ar | ar | ar | ar |
| PilCrk-Main 4 | pfc | pfc | pfc | pfc | pfc | pfc | pfc | pfc | pfc | npf | npf | npf | ar | ar | ar | ar |

pfc = properly functioning condition

ar = at risk

npf = not properly functioning

With regard to the evaluation of watershed disturbance history a different pattern is evident. While disturbance history under historic or template conditions is assumed to be properly functioning (pfc), and while the upper basin contributing to the four mainstem Pilchuck Creek reaches is mostly forested, the amount of late seral-old growth forest is less than the 15% criteria for properly functioning or at risk conditions, based on classified land cover data from 2001 (Purser, et al., 2003). Disturbance history would be reflected in flow attributes, large woody debris, habitat types, sediment load, etc. in EDT. Since many of these attributes are held constant at the template condition in the current project they are not affecting EDT results. Flow attributes calculated by HSPF for these reaches do not change appreciably since there is adequate hydrologically mature forest cover throughout most of the Pilchuck basin. Thus habitat effects that might result from a deficit in late seral-old growth as reflected in the Matrix evaluation would not show up in EDT because of the initial and constant conditions for riparian and instream habitat.

## 5.11 Summary

Two coho populations and one fall Chinook salmon population were defined and run through two basins draining to the lower Stillaguamish River using the Ecosystem Diagnosis and Treatment model. Reaches were characterized based on Template attribute assumptions, direct flow-related attributes derived from the results of HSPF, a hydrologic model, and indirect flow-related attributes derived from HSPF output or directly from actual (2001) land cover or simulated future land cover (also used to drive HSPF).

EDT model results for the current and two (2) future scenarios indicate that watershed-level urbanization can dramatically affect populations even given a situation where instream, riparian and estuary conditions are assumed to be in pristine condition. Where the effects of urbanization are more localized within a watershed, the overall effect on the population will be related to the percentage of the habitat changed by urbanization. Changes in population performance parameters Diversity, Productivity, Capacity, and Abundance were traced predominately to changes in Bed Scour, High Flow and Low Flow, and key habitat quantity. Populations in Pilchuck Creek that rely on miles of mainstem habitat not directly affected by urbanization are much more resilient. The EDT model appears to be very sensitive to Bed Scour which points to a potential weakness in that Bed Scour is rarely measured and is difficult to measure in such a way as to arrive at the answer needed for EDT attribute rating.

It should be restated that the above results must be taken in the context of the pilot project objectives. First, they must be taken with the assumptions that riparian, instream, and estuary habitats are in template or historic condition and remain so across all scenarios. This was done to be able to isolate the effects of direct and indirect flow-related changes in habitat and populations from conditions that often result from development, but are less related to flow than to direct human disturbance. Second, the results obtained above are those for the particular cases that were modeled, not necessarily for every like watershed in the Puget Sound lowlands. Many factors have contributed to the current results. The objectives of the pilot project are to demonstrate how one could separate out habitat effects from changes in flow regime distinct from other factors and to document it. The method uses off-the-shelf (relatively speaking) hydrologic and ecologic models that are becoming used in applied management settings (as opposed to for exploration or research) with increasing regularity.

Regarding the relative changes in the population performance parameters for coho salmon in Church and Pilchuck Creeks, drastically different responses are noted for a relatively homogeneous land use overlay that affected the whole watershed (Church Creek) or just one to a few subbasins (Pilchuck Creek tributaries). Particularly as seen in the results from the Future 1 and Future 2 scenarios, watershed-level land use/land cover changes affect habitat at the population scale (i.e., the whole population suffers), while land use changes occurring in one to a few tributaries of a population using a larger system can affect Productivity, Capacity, Abundance but little, even while significantly affecting Diversity.

In the geographic areas (Church Creek and two tributary subbasins of Pilchuck Creek) and for the populations where the most dramatic changes occurred (coho salmon), there is a small, but mixed bag of flow-related changes across the three scenarios (current, Future 1 and Future 2): bed scour (tied to changes in the 2-year discharge); high flow (inactive rearing) and low flow (0-age and 1-age active rearing) effects; and losses (from smaller low flow widths and reach dessication) in key habitat quantity are most common and dominant changes (different flows maintained same habitat type distribution so all types grew or shrank proportionally to template habitat type distributions). Effects from sediment load and temperature are at a much smaller scale and more localized in nature.

The Quality Index approach uses total impervious area directly to derive scores of biotic integrity. The results are consistent with EDT results although the Quality Index approach does not predict the capacity of the habitat or the abundance of the populations. It is designed for use as an evaluation of habitat not populations. This can be useful for rapid analysis of areas in need of high levels of mitigation after a history of impervious surface development and could even be used in modeling of future development scenarios to qualitatively show the need for high levels of mitigation. The Matrix of Pathways and Indicators can use the same or similar inputs as EDT, can qualitatively evaluate watershed and habitat conditions, but can not predict the performance of populations.

# Section 6: Management Implications of Flow-Related Salmonid Impacts Analysis

## 6.1 Introduction

Flow regime-related effects on salmon and their habitat were analyzed in Section 5. The Ecosystem Diagnosis and Treatment (EDT) model was run with inputs provided by the hydrologic model HSPF (Hydrologic Simulation Program - Fortran), inputs calculated from HSPF outputs (e.g., channel widths), and inputs calculated from land cover attributes such as total impervious area. Four (4) "scenarios" were analyzed: historic or Template, Current, Future 1 and Future 2. Future 1 represents a landscape scenario based on build out of the 1995 Snohomish County Comprehensive Plan future land use designations plus similar assumptions for Stanwood and Skagit County portions of the pilot basins, Church Creek and Pilchuck Creek. Future 2 represents additional growth that may or may not occur in the next 20-25 years based on infill of the area between the Stanwood Urban Growth Area and Interstate 5 in both pilot basins. Conditions under each scenario were also analyzed using a quality index approach (May, et al., 1997) and the Matrix of Pathways and Indicators (NMFS, 1996).

Note that only the template scenario is considered "realistic" for purpose of estimating viable salmon population parameters (Productivity, Capacity, and Abundance). Current, Future 1, and Future 2 scenarios were designed to provide estimates of the range of changes in salmon population parameters associated with land cover change and water management. They deviate from actual current and planned future outcomes for the basins in the following key respects:

4. <u>Assumption of template channel, riparian and estuarine conditions</u>. In order to distinguish flow-related effects from the effects of direct management of riparian and instream habitat (e.g., riparian forest clearing, channel modifications, wood removal) and to be able to distinguish in-basin effects from downstream effects, attributes in EDT that represent riparian, instream, and estuary conditions were kept in their historic state for all scenarios. This assumption also held for the distribution of habitat types (e.g., primary pools, beaver ponds, large cobble riffles). All losses in productivity, capacity, and abundance are therefore related directly or indirectly to changes in flow resultant either from human development or water withdrawals tied to human development.

5. <u>Future 2 land use assumptions.</u> This projected land use for this scenario is ***<u>not</u>*** part of Snohomish County's or Stanwood's official plans nor did either jurisdiction request or sanction this scenario. The Future 2 land use scenario projecting urban levels of development throughout Church Creek and in Pilchuck Creek subbasin 1 was conceived by the project team in consultation with the Shared Strategy Subcommittee on Water Quantity. The scenario represents a higher level of land use intensity typical of several small creek basins within the older, built out areas of Seattle and other Puget Sound cities.

6. <u>Assumption of no stormwater detention</u>. Snohomish County and Stanwood currently

require stormwater detention equivalent to the Department of Ecology, 1992 Puget Sound Manual for projects with greater than 5000 square feet of impervious surface. Thus, it is likely that the majority of projects in urban-zoned areas will be required to provide detention in the future. The project's omission of detention has virtually no impact on flows and salmon populations in Pilchuck Creek basin for either Future 1 because the basin has negligible planned urban area. The effect of the no detention assumption on Future 1 flows and salmon population modeling in Church Creek is small because only 13% of the basin is zoned for urban densities, and much of that is already built out. As was noted in Section 1, most of the projected new impervious area under the Future 1 scenario arises from build out of rural zoned lands which typically do not have detention facilities. In contrast, Future 2 future build is projected to occur at urban intensities in almost all of Church Creek and in subbasin 1 of Pilchuck Creek. If this occurred, most of the development would be required to provide detention ponds that would meet or exceed the current Snohomish and Stanwood standards. If this scenario came to pass, high flow impacts on Church Creek would be less than the impacts modeled in this study.

## 6.2 Review of Salmon Population Performance Results

### 6.2.1 EDT results

Current human development in the pilot basins, in the context of the above assumptions, led to the effects on productivity, capacity, and abundance of the focal species in the pilot basins, compared to historic conditions, found in Table 6-1.

Table 6-1: Changes in VSP Parameters Compared to Pristine- Current Scenario

| Basin/Species | Productivity Change | Capacity Change | Abundance Change |
|---|---:|---:|---:|
| Church Creek coho salmon | -16% | -7% | -8% |
| Pilchuck Creek coho salmon | -9% | 2% | 2% |
| Pilchuck Creek Chinook salmon | -6% | 1% | 1% |

The losses in Table 6-1 can be attributed to bed scour of eggs in redds, excessive fine sediments suffocating or entombing eggs, and to low flows that reduced survival during juvenile rearing, high flows affecting juvenile overwintering, and losses in habitat quantity for rearing juveniles. In the context of assumptions made for the purpose of this project, Pilchuck Creek Chinook salmon were unaffected by the current level (or essentially any of the scenarios modeled) of human development in the watershed. Forest practices were found to neither shift flows on the mainstem of Pilchuck Creek to any significant degree nor cause significant increases in fine sediment in salmon spawning areas. Losses shown in Table 5-6 of Section 5 are attributed to default marine survival assumptions (see also Table 5-9 in Section 5). Currently, flow diversions are not significant on the mainstem of Pilchuck Creek or its tributaries.

Tables 6-2 and 6-3 illustrate further losses in productivity, capacity, and abundance of the focal species in the pilot basins for the two future scenarios, relative to historic conditions[6].

Table 6-2: Changes in VSP Parameters Compared to Pristine- Future 1

| Basin/Species | Productivity Change | Capacity Change | Abundance Change |
|---|---|---|---|
| Church Creek coho salmon | -45% | -25% | -27% |
| Pilchuck Creek coho salmon | -15% | -11% | -12% |
| Pilchuck Creek Chinook salmon | 1% | 1% | 2% |

Table 6-3: in VSP Parameters Compared to Pristine- Future 2

| Basin/Species | Productivity Change | Capacity Change | Abundance Change |
|---|---|---|---|
| Church Creek coho salmon | -86% | -37% | -50% |
| Pilchuck Creek coho salmon | -17% | -11% | -12% |
| Pilchuck Creek Chinook salmon | -5% | 2% | 1% |

### 6.2.2 Pilchuck Creek Fall Chinook Salmon

As shown in Tables 6-1 to 6-3, effects on Chinook populations modeled by EDT in Pilchuck Creek are negligible or slightly positive across all scenarios. The small increase in performance is due primarily to increases in reach habitat capacity associated with very moderate increases in 2-year discharge. Additionally, small increases in summer base flow were predicted for the mainstem compared to template conditions. In the modeling, Chinook are assumed to use only the mainstem of Pilchuck Creek. As with coho modeling, channel habitat composition, woody debris, and riparian conditions are assumed to be in their historical conditions. Additionally, changes in flow regime and flow-related impacts to the mainstem of Pilchuck Creek resulting from current and future land cover change were estimated to be quite small. Unlike Church Creek or the lower tributaries of Pilchuck Creek, the vast majority of land draining to the mainstem Pilchuck remains in industrial forestry use under current and both future scenarios.

### 6.2.3 Pilchuck Creek Coho Salmon

By comparison with Chinook population results, coho populations are much more affected by land use and water management because of degradation of tributary habitat used by coho (subbasins 1, 2, 3, 4, 5, 7, and 8) which includes various levels of rural land development and impervious area under current conditions. Reductions in productivity and abundance are from 9-11% under current land use conditions and these moderate impacts are primarily associated with

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[6] Losses for Pilchuck Creek Chinook salmon are with respect to the current condition because this incorporated out of basin losses; the historic condition did not.

tributary fine sediment and channel stability (bed scour). In Future 1 and Future 2, productivity and abundance losses approximately double compared to current conditions, primarily as a result of increases in bed scour from unmitigated stormwater runoff and from a loss of habitat capacity and diversity associated with the summer dewatering of tributary 8 as water demand rises and the Tatoosh water source is utilized to its maximum water right. The only distinguishing feature between Future 1 and Future 2 in Pilchuck Creek basin is more intense urban development in Pilchuck subbasin 1 which makes little difference to the overall Pilchuck Creek coho population performance.

### 6.2.4 Church Creek Coho Salmon

Church Creek coho populations show the largest percentage declines in all salmon population metrics across the four modeled scenarios. Church Creek population performance is impacted by bed scour caused by undetained rural and urban (scenario assumption), fine sediment inputs associated with urbanization (TIA), current and project future water withdrawals with associated based flow reductions affecting juvenile rearing survival, and degraded water quality in the highly urbanized future 2 scenario.

### 6.2.5 Index Results

May, et al. (1997), in their study of more than 100 stream reaches in 22 watersheds in the Puget Sound lowlands, found that changes in physical habitat, water quality and biological integrity were strongly related to changes in watershed imperviousness. Using their relationships between total impervious area (TIA) and two measures of biological performance, Benthic-Index of Biologic (also termed Biotic) Integrity (BIBI) and the ratio between juvenile coho salmon and juvenile cutthroat trout, reaches in the current project were evaluated (Table 5-10 in Section 5).

Predicted BIBI scores were high (> 45) in all reaches for the historic and current scenarios. In the Future 1 scenario modeled TIA increased to as much as 16% in Church Creek and to 18% in one subbasin of Pilchuck Creek. BIBI remained moderately high even in these basins (>38). The lowest scores in this scenario are still described as only "slightly divergent from least disturbed condition…" (Lestelle, 2004). Further increases in modeled TIA in Future 2 to 34% in Church Creek and Pilchuck Creek subbasin 1 caused a drop in BIBI to 29 which is noted as being on the border between "[t]otal taxa reduced, particularly intolerant, long-lived, stonefly, and clinger taxa…proportion of tolerant taxa continues to increase" and "[o]verall taxa diversity depressed…few intolerant taxa present" (Lestelle, 2004). In all other subbasins TIA remained at 9% or less and high BIBI scores were predicted (>43).

The coho/cutthroat ratio was more sensitive to increases in TIA. While all subbasins in the historic scenario were rated in the highest biotic integrity category (0% TIA, >6 coho/cutthroat ratio) increases to as little as 7% TIA in one subbasin of the current scenario dropped the ratio to 3.0 and out of the high integrity category. Further increases in TIA modeled in Future 1 found the ratios drop to 2.0 or less in Church Creek and the Pilchuck Creek subbasin 1 described as being the "Low Biotic Integrity" by May et al. (1997). With an increase to 33 or 34% TIA in Future 2 ratios in these same subbasins the ratio dropped to less than 1, indicating a significant qualitative change in the biotic community from a numerical dominance of coho salmon among the juvenile fish to a dominance of cutthroat trout. As noted in Section 5, these results are consistent with the EDT results. The effect is more pronounced in Church Creek because the land cover changes occur throughout the basin while in Pilchuck Creek only one of the subbasins is affected.

### 6.2.6 Matrix Results

The checklist method (NMFS, 1996) of assessing the environmental baseline and the results of management actions was used to evaluate the mainstem Pilchuck Creek subbasins and reaches used by fall Chinook salmon. Four indicators of water quality, flow, and watershed conditions were evaluated. Only Disturbance History, the watershed condition indicator, changed across the scenarios (Table 5-11 of Section 5) becoming degraded to a not properly functioning state as a result of the current and future scenarios. This occurred predominately due to the lack of late seral-old growth forest extant in the Pilchuck Creek watershed, but also because of low overall levels of forest cover in the lowermost reaches. Stream Temperature, Peak Flow and Fine Sediment indicators were maintained across the scenarios.

Normally this would be consistent with degraded fall Chinook salmon habitat conditions due to low levels of large woody debris, shade, cover, and food (some of these can be directly evaluated in the checklist method, but were not), however, as noted above, EDT results for fall Chinook salmon performance in Pilchuck Creek were essentially unchanged across the scenarios. One reason for this is the condition that riparian, instream, and estuary habitat are modeled in their historic state.

Both the index and matrix methods are empirically based approaches that contain an implicit assumption regarding the correlation of land cover disturbances and changes with riparian and channel disturbances. In the case of the index approach, there is an assumption that increases in total impervious area will be accompanied by a host of other negative effects including increased peak flows, reduced water quality, removal of riparian vegetation, channel encroachment or re-engineering, removal of woody debris, and many other effects which admittedly have accompanied historic urbanization. However, this coupling of effects should by no means be assumed universally valid for stream basins undergoing more recent or future urbanization because of increasing implementation of storm water treatment, protection of wetlands and riparian areas by sensitive and critical areas ordinances and other measures. While by no means perfectly conceived or implemented, these protections and mitigations do decouple some of the many effects assumed to be bundled in the index method which is based on historic disturbance patterns going back many decades.

Similarly, the Matrix approach may significantly overstate the restorative value of high percentages of mature forest cover, if other conditions historically associated with forestry such as excessive road density, degraded riparian conditions, unstable slopes, and channels depaupered of wood get insufficient attention.

## 6.3 Management Implications

### 6.3.1 Implications of Church Creek Current Condition Results

Management implications must be cognizant of the series of assumptions made as part of this analysis. A key assumption in this study was that riparian, instream woody debris loading, habitat structure, and estuary conditions were in a historic condition. This clearly had the effect of sharply raising VSP parameter values for all non-template scenarios. As exemplified by the Church Creek coho salmon population (see Table 5-2 of Section 5), the modeled abundance of this stock is nearly 1250 fish (no harvest). Assuming a harvest rate of 30% yields a current abundance of 875. In contrast, the monitored mean Church Creek coho escapement from 1987-1991 was 259 adults (Nelson et al. 1997) or less than one-third the modeled abundance, accounting for harvest. Even if the harvest rate is 50%, the modeled current abundance with harvest would be 625 fish. Under Future 1 and Future 2 scenarios escapement estimates for Church Creek coho would drop to 212 and 140 respectively assuming further habitat degradation does not occur other than what has been modeled. *One interpretation of this is that degraded riparian, instream, and estuary conditions may account for up to one-half to two-thirds of the lost abundance in Church Creek. The explicit potential management options are:*

1. prioritize protection and restoration of riparian, instream, and estuary conditions to realize the lost abundance;
2. prioritize among estuary and freshwater sites based on a more refined analysis of which aquatic habitat is more limiting for the species of concern.

Coho salmon populations can be maintained in basins dominated by rural development if channels, associated wetlands, and estuaries are at a high functional level and water withdrawals are do not excessively reduce base flows.

Noting that even assuming template riparian, instream, and estuary conditions, current levels of TIA in Church Creek cause substantial decreases in Productivity, Capacity and Abundance. Therefore, potential management options should include limits on or incentives for maintaining impervious area at lower levels.

### 6.3.2 Implications of Church Creek Future 1 Condition Results

Future 1 results for Church Creek coho (Table 6-2) suggest that large relative drops in productivity do not necessarily result in commensurate reductions in capacity and abundance at the high levels of productivity resulting from assumed historic riparian, woody debris, and habitat type distribution. Management implications are similar to those arising from Current scenario modeling results. Given excellent channel, estuary, and riparian conditions, reductions in fish numbers (abundance and capacity) will be moderate (~20% loss) for a basin dominated by rural land development even with water withdrawals that annually dewater a mainstem reach of Creek (Church-3) during the month of August. Clearly, this underscores the need to restore and protect riparian, channel, and estuary habitat as mentioned above, but also begs the question of what happens in a rural basin where these conditions are even moderately less than ideal- a realistic scenario that was not modeled in our study. In such a basin, the 58% reduction in productivity associated with peak flow increases from runoff and base flow reductions from pumping in Church 3 could easily put productivity values in the range where impacts to capacity and abundance would be much more severe than those indicated by the Future 1 results shown in Table 6-2. This suggests the following potential management implications in addition to restoration of riparian, instream, and estuary conditions noted above:

- BMPs to reduce storm runoff and promote infiltration for rural residential development

- Actions/incentives to increase or maintain forest cover and protect remaining forest production land from rural conversion
- Actions/incentives to reduce or limit basin impervious area
- Perform detailed hydrogeologic studies for both Pilchuck Creek Tributary 8 (a.k.a. Trib 80) and Bryant-Fure sources aimed at validating or refining study assumptions
- If assumptions are substantiated, pursue source substitution for wells located next to Church Creek and for Tatoosh's well at the head of Pilchuck Subbasin 8.
- Limit total consumptive use and resultant depression of Trib 80 and Church Creek flows by coordinated management (limits) of future withdrawals against inchoate rights by Tatoosh Water Company on Pilchuck Creek Tributary 8, Stanwood at Fure-Bryant wells in Church Creek and on exempt well numbers in both basins.

### 6.3.3 Implications of Church Creek Future 2 Condition Results

As shown by Future 2 results in Table 6-3, urban levels of TIA that are not accompanied by stormwater treatment cause severe drops in productivity to levels that strongly affect capacity and abundance. These losses result primarily from increased redd scour and increased inputs of fine sediment during storm events. These impacts to productivity overwhelm the "buffering capacity" associated with the modeled historical riparian, channel, and estuarine conditions.

In reaches where contributing subbasin TIA is at 33+%, in addition to loss of habitat caused by base flow depletion and bed scour caused by undetained runoff, increased fine sediment loading and other declines in water quality begin to affect simulated coho salmon productivity. As with other effects this is more pronounced in Church Creek because of the watershed-wide conversion of land cover and land use, but it also occurs in subbasin 1 of Pilchuck Creek.

The management implications associate with these results could take several directions:

- "Don't go here", i.e. maintain the predominantly rural character of the basin and implement recommended actions noted above for Future 1.
- If additional urbanization is allowed to occur, strictly enforce stormwater quantity and quality requirements in areas developed to urban density in order to preserve channel stability (apply the 2005 Ecology duration-based standard for detention pond design) and reduce loadings of sediment and other pollutants to the stream.
- Avoid impacts from stormwater treatment loopholes such as "piggy-back" short plats that incrementally fall below treatment requirement thresholds, but cumulatively cause significant impacts to streams.

### 6.3.4 Implications of Results for Water Management

With regard to water management, modeling results indicate that extensive rural residential development, with its dispersed network of limited-volume, localized impacts, and return flow potential does not affect low flow as much as a single, urban water utility situated adjacent to and in hydrologic continuity with a perennial stream. This is not to understate the impact of exempt wells. They do account for a reduction of 1.28 cfs in Church Creek summer base flows in the Future1 scenario. Rather, it is important to point out that the impact of municipal wells similar to the City of Stanwood's Fure and Bryant wells can impact a small stream more than many exempt wells based on the assumptions used in this study: that these wells withdraw approximately 350 gallons per day (from Ecology's Guidance document on setting instream flows), rather than the legal limit of up to 5,000 gpd and return a percentage of the water withdrawn to the creek. The modeled base flow loss of 1.28 cfs from exempt wells in for Future1 is significant in light of Department of Ecology's 2004 stream gage record, which shows a July 2004 mean flow of 0.4 cfs.

The EDT-modeled impact is evident from comparing the effects on Productivity associated with base flow reduction among the Current, Future 1 and Future 2 scenarios. Although total basin area is dominated by rural development which is supplied by exempt wells in Future 1, additional withdrawals of water are also assumed to occur from Stanwood's wells on Church Creek in order to meet increased demand from within its designated urban growth area. In both future scenarios, the only reaches that completely dry up are those affected by Stanwood's well within subbasin Church-3 and Tatoosh's well in subbasin PilCrk-sub8. The potential management options to avoid these future impacts include:

- possible water source substitution for existing water rights;
- metering future exempt wells to ensure that the 350 gpd assumption is being met;
- conservation measures.

### 6.3.5 Implications of Results for Pilchuck Creek Chinook

With regard to fall Chinook salmon and in particular the population modeled in the current project, it is notable that upland forest practices are not shown to significantly reduce salmon populations given maintenance of template (historic) conditions in the riparian, instream, and estuary areas. In the project, %EIA only significantly increased in PilCrk-Main1 and PilCrk-Sub1under Future1 (15.4% and 15.5% respectively) and Future 2 (22% for both) scenarios (Table 3-9, Section 3). These two sub-basins account for the lower 4.8 square miles as compared to the 71.2 square miles of basin area upstream that maintains EIA below 6.7% in Future 2. It seems reasonable that future build-out scenarios modeled for this project would have a limited impact on Chinook salmon since these effects are confined to the lower 7% of the Pilchuck Watershed. Potential management options responsive to this finding include:

- prioritize restoration of riparian, instream, and estuary conditions for Chinook salmon;
- preference for/conservation of forest production land use over rural or urban land uses in subbasins that contain habitat for Chinook salmon;
- limits on or incentives for maintaining impervious area at lower levels in subbasins that contain habitat for Chinook salmon

## References:

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

Bicknell, B.R., Imhoff, J.C., Kittle, J.L. Jr., Jobes, T.H. and A. S. Donigian, Jr. 2004. *HSPF Version 12 User's Manual.* Aqua Terra Consultants, Mountain View, California

Booth, D. B., J. R. Karr, S. Schauman, C. P. Konrad, S. A. Morley, M. G. Larson, P. C. Henshaw, E. J. Nelson, and S. J. Burges. 2001. *Urban Stream Rehabilitation in the Pacific Northwest*. Final Report of EPA Grant Number R82-5284-010. University of Washington, March 30, 2001.

Booth, D.B. and C.R. Jackson. 1997. *Urbanizations of Aquatic Systems- Degradation Thresholds, Stormwater Detention, and the Limits of Mitigation*. Water Resources Bulletin, 33:1077-1090.

Booth, D.B., Hartley, D. and R. Jackson. 2002. *Forest Cover, Impervious-Surface Area, and the Mitigation of Stormwater Impacts*, Journal of the American Water Resources Association, 38(3):835-845.

Cassin, J. *Normative Flow Studies – Draft Small Streams Analysis 2004 Final Report*. Prepared for King County Department of Natural Resources and Parks, Parametrix, Inc. with 01/21/05 comments by Kelly Whiting of KC-DNR, 53 p.

Collins, B.D., and A.J. Sheikh 2003. *Historical aquatic habitat in river valleys and estuaries of the Nooksack, Skagit, Stillaguamish, and Snohomish watersheds*. Unpublished report to the Northwest Fisheries Science center, National Marine Fisheries Service, Seattle, WA.

Dinacola, R.S. 1990. *Characterization and Simulation of Rainfall-Runoff Relations for Headwater Basins in Western King and Snohomish Counties, Washington*; Water-Resources Investigations Report 89-4052 , United States Geological Survey, Tacoma, WA.

Groot, C. and L. Margolis, 1991. *Pacific Salmon Life Histories*. UBC Press, Vancouver, Canada.

HEC (Hydrologic Engineering Center) 2004. *HEC-RAS, Version 3.1.2* [Computer Program]. Davis, CA.

Hunt, B., Weir, J., and Clausen, B. *A stream depletion field experiment*, Ground Water, 39(2), 283–289, 2001.

Hunt, B. *Unsteady stream depletion when pumping from semiconfined aquifer*, J. Hydrologic Eng., 8(1), 12–19. 2003a.

Instream Flow Council. 2002. *Instream Flows for Riverine Resource Stewardshi*p., 411 p.

Kondolf, M.G. and M.G. Wolman 1993. *The Sizes of Salmonid Spawning Gravels*. Water Resources Research 29(7):2275-2285.

Konrad, C. P. 2000. *The Frequency And Extent of Hydrologic Disturbances in Streams in the Puget Lowland, Washington*. Water Resources Series, Technical Report No. 164, University of Washington Department of Civil and Environmental Engineering.

Lestelle, L.C., *Guidelines for Rating Level 2 Environmental Attributes in Ecosystem Diagnosis and Treatment (EDT)*. Mobrand Biometrics, Inc., Vashon, WA.

Lestelle, L. C., Mobrand, L. E. and W. E. McConnaha. 2004. *Information Structure of Ecosystem Diagnosis and Treatment (EDT) and Habitat Rules for Chinook Salmon, Coho Salmon, and Steelhead Trout*. Mobrand Biometrics, Inc Vashon Island, WA, 29 p. plus appendices.

May, C.W., E.B. Welch, R.R. Horner, J.R. Karr and B.W. Mar. 1997. *Quality Indices for Urbanization Effects in Puget Sound Lowland Streams.* Final Report for Washington Department of Ecology. Water Resources Series Technical Report No. 154. Department of Civil Engineering, University of Washington, Seattle, WA.

McConnaha, Willis E. 2003. *Salmonid Habitat Analysis with Special Reference to Ecosystem Diagnosis and Treatment*, 18 p.

McElhany, P., Ruckelhaus, M.H, Ford, M.J., Wright, T.C. and E.P. Bjorkstedt. 2000. Viable Salmonid Populations and Recovery of Evolutionarily Significant Units. NOAA Technical Memorandum NMFS-NWFSC-42.

Mobrand Biometrics, Inc. 2005. *EDT Habitat Rules for Coho Salmon*. Prepared for the Sensitivity Analysis Work Group.

Mobrand Biometrics, Inc. 1999. *The EDT Method*, 36 p.

Mobrand Biometrics, Inc. 2002. *Subbasin Planning with EDT- A Primer*, 59 p.

Mobrand Biometrics, Inc. 2001. *Ecosystem Diagnosis and Treatment, How Rules Work-Translating Level 2 Environmental Correlates into Level 3 Life Stage Survival Factors for Chinook Salmon,* 68 p.

Morgan, D. S. and J.L. Jones, Joseph, *Numerical model analysis of the effects of ground-water withdrawals on discharge to streams and springs in small basins typical of the Puget Sound lowland, Washington*, Water Supply Paper 2492, Reston, Virginia, 1999

Newcomb, R.C., *Ground-Water Resources of Snohomish County Washington*, Geological Survey Water-Supply Paper 1135, 1952.

NRCS 1983. *Soil Survey of Snohomish County Area, Washington; SSURGO (Soil Survey Geographic database)*; United States Department of Agriculture.

NRCS 1989. *Soil Survey of Skagit County Area, Washington; SSURGO (Soil Survey Geographic database)*; United States Department of Agriculture.

Nyholm, T., S. Christensen, and K.R. Rasmussen, *Flow depletion in a small stream caused by groundwater abstraction from wells*, Ground Water, 40(4), 425-437, 2002.

Pess, G. R., B.D. Collins, M. Pollock, T.J. Beechie, A. Haas, and S. Grigsby, 1999. *Historic and Current Factors That Limit Coho Salmon (Oncorhynchus kisutch) Production in the Stillaguamish River Basin, Washington State: Implications for Salmonid Habitat Protection and Restoration*. Report for Snohomish County, WA Department of Public Works and the Stillaguamish Tribe of Indians, Arlington, WA.

Poff, N. L., Allan, J.D., Bain, M.B., Karr, J.R., Prestegaard, K.L., Richter, B.D., Sparks, R.E., and J.C. Stromberg. 1997. *The Natural Flow Regime: A Paradigm for River Conservation and Restoration*. BioScience, 47 (11): 769-784.

Purser, M. D., R. Simmonds, D.D. Wilcox, and Suzy Brunzell, 2003. *Classification and Analysis of August 2001 Land Cover: Snohomish County, WA*. Unpublished report of Snohomish County Department of Public Works Surface Water Management Division and Department of Information Services, Everett, WA.

Reeves, G.H., F.H. Everest, and T.E. Nickelson, 1989. *Identification of Physical Habitats Limiting the Production of Coho Salmon in Western Oregon and Washingto*n. General Technical Report PNW-GTR-245. USDA-Forest Service, Pacific Northwest Research Station, Portland, OR.

Richter, B.D., J.V. Baumgartner, J. Powell, and D.P. Braun. 1996. *A method for assessing hydrologic alteration within ecosystems*. Conservation Biology 10:1163-1174.

Richter, B.D., J.V. Baumgartner, R. Wigington, and D.P. Braun. 1997. *How much water does a river need?* Freshwater Biology 37:231-249.

Richter, B.D., Baumgartner, J.V., Braun, D.P., J. Powell. 1998. *Spatial Assessment of Hydrologic Alteration Within A River Network*. Regulated Rivers: Research and Management, 14:329-240.

Rosgen, D. L. 1996. *Applied river morphology*. Wildland Hydrology Books, Pagosa Springs, CO.

Simmonds, R., M.D. Purser, S. Brunzell, and D.D. Wilcox, 2004. 1991 and 2001 *Land Cover in Water Resource Inventory Areas 5 (Stillaguamish), 7 (Snohomish), and 8 (Cedar-Sammamish).* Unpublished report of Snohomish County Department of Public Works Surface Water

Management Division and Department of Information Services, Everett, WA.

Snohomish County Public Works Surface Water Management (SWM), 2003. *Wadable Stream Habitat Survey Preliminary Results for the Year 2002*. Everett, WA.

Snohomish County Public Works Surface Water Management (SWM), 2002. *Aquatic Habitat summary: Current and Future conditions of Urban and Urbanizing Streams of Snohomish County*. Everett, WA.

Sophocleous, M. A., Koussis, A., Martin, J. L., and Perkins, S. P., *Evaluation of simplified stream-aquifer depletion models for water rights administration*, Ground Water, 33(4), 579–588, 1995.

Spence, B.C., Lomnicky, Hughes, G.A. and R.P. Novitzski. 1996. *An Ecosystem Approach to Salmonid Conservation*. TR-4501-96-6057. ManTech Environmental Research Services Corp., Corvallis, OR., 456 p.

Stillaguamish Technical Advisory Group (STAG), 2000**.** *Technical Assessment and Recommendations for Chinook Salmon Recovery in the Stillaguamish Watershed***,** prepared for the Stillaguamish Implementation Review Committee (SIRC), Everett, WA.

Stillaguamish Implementation Review Committee (SIRC), 2004. *Stillaguamish – WRIA 5 Chinook Salmon Recovery Plan.* June 30, 2004 DRAFT prepared for Shared Strategy for Puget Sound, Seattle, WA

Thomas, B.E., J.M. Wilkinson, and S.S. Embrey, *The Ground-Water System and Ground-Water Quality in Western Snohomish County, Washington ,*U.S. Geological Survey Water-Resources Investigations Report 96-4312, Tacoma, WA, 1997.

USDC-NOAA, National Marine Fisheries Service (NMFS), 1996. *Coastal salmon conservation: working guidance for comprehensive salmon restoration initiatives on the Pacific Coast*. USDC-NOAA, NMFS, Portland, OR. Report dated September 15, 1996.

Washington Forest Practices Board. 1995. *Appendix C- Hydrologic Change*. IN: Board Manual: Standard Methodology for Conduction Watershed Analysis, 57 p (appendix C only).

Wolcott, E. (1973) *Lakes of Washington*, State of Washington Department of Ecology; Water Supply Bulletin; no. 14. vol. 1