# Translating River Modeling Output into EDT Habitat Parameters

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# 1.0 INTRODUCTION

Task 0006AB of the USBR EDT Model Support contract (part of the Yakima River Basin Water Storage Feasibility Study) between the Bureau of Reclamation (the "Bureau") and Mobrand-Jones & Stokes (MJS) requires that MJS:

> *Provide translation rules between the output parameters from the 2-D habitat model to the 9 EDT Level 2 habitat attributes (including side channel attributes). Contractor will work with Bureau staff to ensure that the GIS habitat maps generated from the River 2-D model (which classify habitat by depth, velocity and substrate) correspond in a definitional sense for each of the 9 EDT Level habitat attributes.*

This report, and an associated series of Excel Workbooks[1], documents the completion of that task. The workbooks exemplify the calculations required in translating two-dimensional river modeling output ("R2D" output) and other types of data into EDT habitat parameters.

At the time the contract was written it was thought there were nine habitat attributes. Subsequently through the course of this project, it has been determined that there is a need to track 13 distinct types of habitat, and that four of these habitat types require type-specific qualitative attributes as well.

This document begins with a description of the habitat attributes used in EDT (Section 2). This description is an overview of concepts developed in an earlier report on chinook utilization in mainstem and off-channel habitats by Lestelle et al. (2005). Following this overview, we then describe specific habitat attributes existing in EDT prior to this project and attributes developed in this project (Section 3 – Attributes Related to EDT). Section 4 (Habitat Quantification Procedures) describes steps and mathematical methods for converting R2D model output into a subset of EDT habitat attributes. HEC-RAS model output will be used to determine some of the off-channel habitat attributes. Section 5 (HEC-RAS Calculations) describes these procedures. Finally, Section 6 of this report describes some very specific issues with converting R2D and Riverware flow data to EDT attributes. This section also addresses methods for processing R2D and Riverware model output in the Data Management Interface (DMI) being developed by the Bureau.

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[1] The example workbooks include: "Geomorphic Unit Side Channel Braid Pattern Generation Process.xls", "Pattern Master Table.xls", "Sider Channel Connectivity_V5.xls" and "Wetland Procedures 7-Day Final V2.xls"

# 2.0 DEFINITION OF HABITAT AS USED IN EDT FOR YAKIMA ANALYSIS

## 2.1. Habitat Overview

As schematically summarized in
Figure 1, habitat in EDT is broken into two major types, “in-channel” and “off-channel” (see Lestlelle et al. 2005 for an exhaustive treatment of all EDT habitat attributes from both a geomorphic and ecological perspective). In-channel habitat occurs within the banks of the stream; off-channel habitat occurs on the floodplain, and may have a permanent hydraulic connection to the river or may be hydraulically connected only during floods (periods of overbank flow).

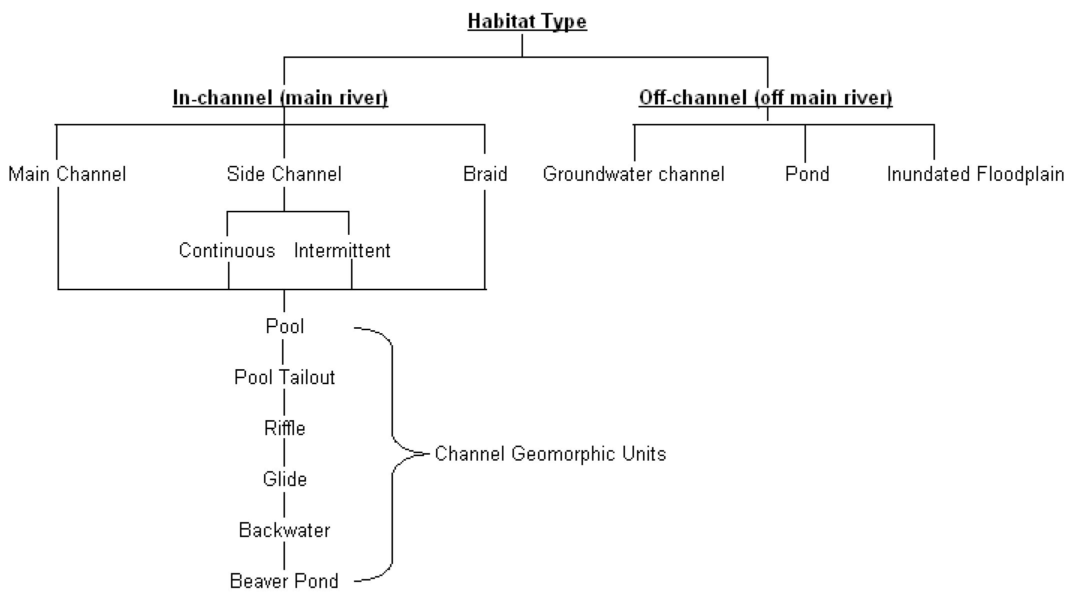


Figure 1. Schematic of relationships among habitat types used in EDT analysis.

Additional distinction between these general categories is that the main river conveys flow during most of the year although some side channels may become separated during low flow periods. The floodplain is defined as the strip of relatively level land bordering a stream that is inundated during periods of high flow (Leopold et al. 1964). Flow source and fish behavior, such as how fish move into a habitat, differ markedly between main channel and off-channel habitats as defined here. The relative importance of main river versus floodplain (off-channel) channels varies widely between salmonid species and life stages.

### 2.1.1. In-Channel Habitat

In-channel habitat is further subdivided into three basic types: the main channel, side channels and braids (Figure 1). The main channel, as its name implies, is larger than the other channel types and therefore carries most of the flow. Side channels are smaller (often considerably smaller) than the main channel, and are segregated from the main channel by stable, vegetated islands that are not submerged at bankfull flow. Braids are shifting channels between unstable gravel bars. Braids are definitively distinguished from side channels by the fact that the gravel bars that define them are submerged at bankfull flow. In turn, each of these three in-channel habitat types is made up of seven "geomorphic units": primary pools, pool tailouts, large cobble/boulder riffles, small cobble/gravel riffles, glides, backwaters (or "backwater pools") and beaver ponds. Geomorphic units represent the microhabitat that is needed by different life stages of salmonid fish. These in- channel features are illustrated in Figure 2. Table 1 defines the seven Geomorphic Units recognized by EDT, and Table 2 defines the main channel, side channels, and braids.

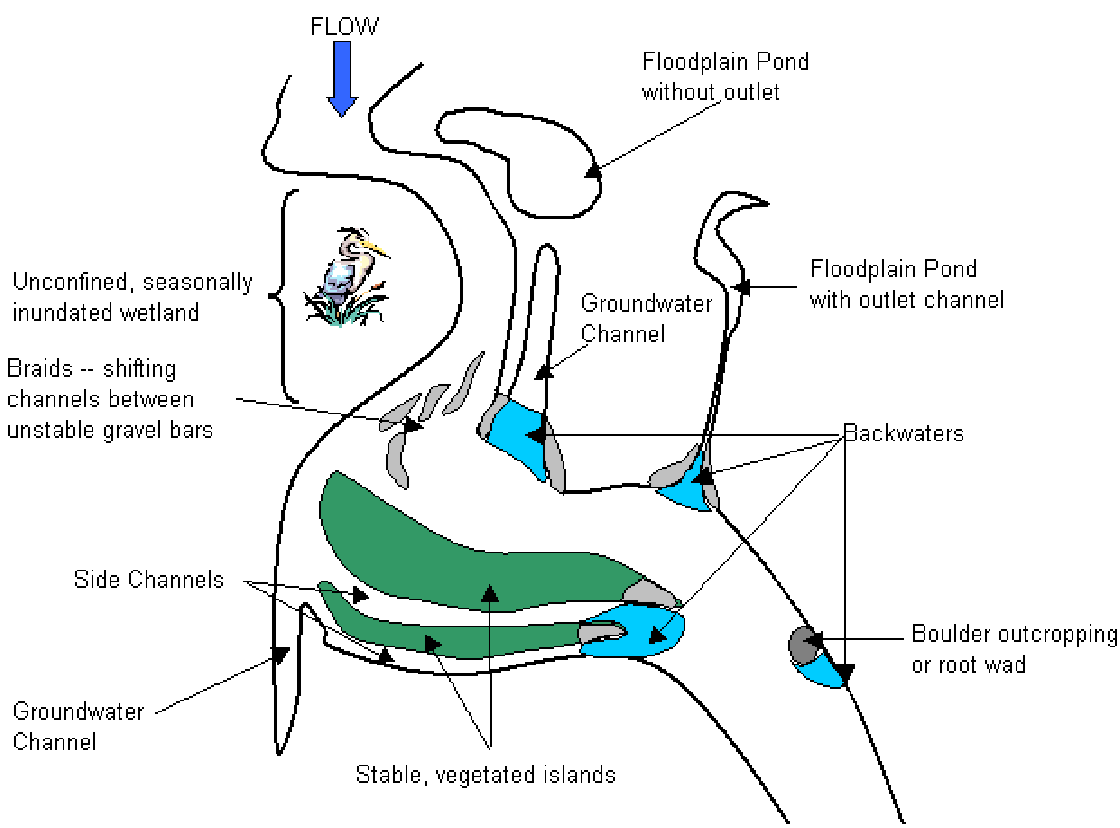


Figure 2. Hypothetical stream reach illustrating habitat types used in EDT analysis.

### Table 1. Geomorphic Units considered by EDT (excepted from Lestelle et al. 2005).

| In channel habitat type | Description |
|---|---|
| Pool | An area of the stream with slow current velocity (<1 fps) and depth greater than riffle and glide geomorphic units. Concave bathymetry. |
| Riffle | An area of the stream with fast current and depth shallower than pool geomorphic units; water surface is visibly broken or turbulent. EDT recognizes two sub-types of riffle: small cobble/gravel rifles (which can be used for spawning) and large cobble/boulder riffles (not typically spawning habitat) |
| Tailout (or “pool tailout”) | The downstream end of a pool where the bed surface gradually rises and water depth decreases, breaking onto a riffle head (or riffle crest). If the scour depression of the pool rises suddenly on its downstream end and breaks immediately onto the riffle, there is no tailout. In large streams and where pools may be relatively shallow, the pool may transition into a glide and not a tailout. In these cases, glides are typically quite long, transitioning into riffles. Both tailouts and glides are transitional geomorphic features between pools and riffles. Some classification systems do not recognize tailouts—under such classification schemes, the upper part of what is called a tailout here is included with the pool and the lower part is included with the riffle. |
| Glide (or “run”) | A transitional feature between a pool and riffle, usually long compared to the length of the pool. It typically does not have distinguishable pool or riffle characteristics, though it might be characterized as a very shallow pool. Glides are shallower than pools and often deeper than riffles. Surface flow is generally unbroken (not turbulent) with faster velocities than in pools. In larger rivers, or at higher flows, these geomorphic features are sometimes called runs, having greater depth and more velocity than the classic, tranquil and shallow glide. In heavily altered streams, pool depth is often lost, resulting in the conversion of pools to glides. |
| Backwater (or “backwater pool”, “alcove”) | A partially enclosed, relatively deep, low-velocity area separated from the main river channel, normally formed *at the confluence* of an off-channel feature or side channel with the main channel, or in the lee of large root wads or boulder outcroppings. These areas tend to have fine substrate, abundant aquatic vegetation, and accumulations of fine woody debris. The outer portion of the backwater (viz., the edge nearest the main channel) may consist of an eddy, but this is not a necessary condition. Confluences of smaller side channels or groundwater channels typically contain backwaters at their mouth and extending up into the channel roughly as far as the normal high water line (the beginning of permanent vegetation). Backwaters at the mouths of very large sloughs may extend 300-400 feet into the slough. . |
| Beaver pond | A dammed pool formed by beaver activity in a small to medium sized stream or in secondary channels of larger rivers. |

## Table 2. Definitions of main channel, side channels and braids as used in EDT.

| Attribute | Definition |
|---|---|
| Habitat type - braid | The proportion of all in-channel wetted area (main channel, side channels and braids) consisting of braids, which are considered to be channels flowing between unstable, unvegetated gravel bars that are submerged at bankfull flow. |
| Habitat type – main channel | The proportion of all in-channel wetted area (main channel, side channels and braids) consisting of main channel habitat. The distinguishing characteristic of the main channel of a reach is that it carries most of the discharge entering the reach, and almost always is wider than any braids or side channels also occurring in the reach. The length of a reach is defined as the length of the main channel. |
| Habitat type –side channel | The mean monthly proportion of the wetted area of all in-channel habitat (main channel, side channels and braids) consisting of side channels. A side channel is an active stream channel separated from the main channel by a vegetated or otherwise stable island (Knighton (1998). The islands tend to be large relative to the size of the channels. Side channels are frequently small watered remnants of the historic river channel within the floodplain. Some side channels carry surface water continuously, from the point of divergence to the point of return, at a given flow, while others become intermittent (are dry at some point(s) between divergence and return) at the same flow (Ward et al. 1999). The frequency of continuous connection to a surface water source can be important in the ecology of various species (Tockner et al. 2000). |

***The relative abundance of in-channel geomorphic units (e.g., pool, riffle, glide, etc.) is based on the combined area of each unit across all in-channel features (main channel, braids and side channels). Off-channel features are not included in this calculation.***

The relative abundance of geomorphic units in a reach is important to describe key habitat by life stage. Each life stage requires a different mix of geomorphic units. Spawners and incubating eggs, for example, are most dependent on the quantity of cobble/gravel riffles and pool tailouts, whereas actively rearing subyearlings are more dependent on pools. A factor that complicates the estimation of carrying capacity on the basis of the quantity and relative abundance of geomorphic units is the fact that the relative abundance of geomorphic units changes with flow. Expressed in terms of percent of wetted area, the proportion of a reach consisting of pools may increase substantially as flows decrease and the stream becomes a series of basins (pools) connected by narrow rivulets (riffles).

**A major element of the current revision of the EDT model is to develop the ability to estimate the effect of seasonally variable flow on the geomorphic unit composition, thereby increasing the accuracy of estimates of flow-dependent changes on key habitat.**

## 2.1.2. Off-channel Habitat

Off-channel habitat features recognized by EDT include ponds, groundwater channels and seasonally flooded wetlands. Table 3 provides the definitions of pools, groundwater channels and seasonally flooded wetlands. As mentioned, all three of these features occur beyond the banks of the river on the floodplain, and a hydraulic connection between them and the main channel may not be permanent (as would be the case for a pond outlet channel that dried up in the summer, or a seasonally flooded wetland that contains standing water only during periods of overbank flow).

### Table 3. Definitions of off-channel habitat types recognized by EDT: groundwater channels, floodplain ponds and seasonally flooded wetlands.

| Attribute | Definition |
|---|---|
| Habitat Type – Groundwater channels | Groundwater channels connect to the main channel or a side channel only at one end at flows less than bankfull. They are usually relict river channels fed by groundwater, though surface flow from higher terraces can also contribute. They can function as overflow channels at some flood stages, and include several subtypes (Ward et al. 1999), including: (1) channels carrying main channel seepage, (2) channels fed by the floodplain aquifer and (3) channels fed by groundwater supplied from adjacent terraces. |
| Habitat Type – Ponds | Floodplain ponds are water-filled depressions, partially or entirely filled with water year-round and that are connected to the main river for all or some period of the year by an outlet channel. To be classified as a floodplain pond, the outlet channel must have a mean depth > 4 inches for a portion of a year (e.g., at least one month, though not necessarily all consecutive days) in most (>50%) years. They are either natural features on the floodplain, representing cut-off oxbows or pools in relict river channels, but they may also be man-made (e.g., floodplain gravel pits). They might be supplied by groundwater or surface water from streams or springs. Ponds that do not meet the criteria for connectivity to the river are either excluded from the analysis or may be included with flooded wetlands. Flooded wetlands often contain ponded areas, either intermittently or perennially filled with water. |
| Habitat Type - Wetlands | Seasonally flooded wetlands frequently occur on the floodplains of large rivers. Geomorphically, they are often remnants of ancient ponds and river channels which filled with sediment and debris over centuries (Saucier 1994, cited in Henning 2004). Seasonally flooded wetlands are typically flooded during annual high water periods either by broad overbank flows or by backwatering through narrow swales. These wetlands may contain seasonal or perennial ponds that do not meet the criteria for connectivity to the river prescribed for floodplain ponds (see definition for HbPond). |

Groundwater channels, ponds, and seasonally flooded wetlands represent a continuum of off-channel habitats—some have a mixture of characteristics and some are transitional. The dominant characteristics of a particular water body are used to classify it to a category. More specifically, the dominant ecologically functional features are considered in this “fish-centric” classification scheme.

The distinction between ecological function and geomorphic origin is evident in the way seasonally flooded wetlands are defined in EDT. An “overflow channel” is a flood swale connected to the main river at its upstream ends only when flows exceed bankfull. Although there are geomorphic distinctions between overflow channels and seasonally flooded wetlands, the two habitat types can be very similar ecologically. Many overflow channels, especially those found in the lower portions of larger rivers, are wide, grass-filled, marshy swales. During floods, they have most of the ecological characteristics of a flooded wetland: abundant aquatic and riparian vegetation, very slow or no current, the capacity to retain floodwaters and delay runoff, silty or muddy substrate, abundant insect and invertebrate populations, and so on. They also provide abundant feeding, resting and refuge areas for fry of many species. Therefore, because fish use them as they do flooded wetlands, they are classed as such.

The continuum between habitat types is also illustrated by the example of overflow channels, which in EDT are considered a sub-type of groundwater channel. Groundwater channels are usually relict river channels fed at least in part by subsurface flow. Groundwater channels also function as overflow channels, at least at higher flood stages. Because groundwater and overflow channels are structurally similar, and because the distinction between them is based almost exclusively on the relative contribution of groundwater, the EDT model classes both as the same type of habitat, distinguishing the former from the latter by means of a greater groundwater influence.

Groundwater Channels. Groundwater channels open to the main river only at their downstream end except during floods and receive varying amounts of subsurface flow. They include several subtypes (Ward et al. 1999), including: (1) channels originating from the seepage of main channel surface water (i.e., very shallow groundwater closely associated with the main river), (2) channels fed by the larger floodplain aquifer (hyporheic zone), and (3) channels fed by lateral groundwater supplied from adjacent terraces.

In the first case, the groundwater channel tends to have "slough-like[2]" characteristics, with little or no water velocity and temperatures similar to the main channel[3]. In the other cases, groundwater channels carry some proportion of spring water. These channels are often called springbrooks (Stanford and Ward 1993), percolation channels (Peterson and Reid 1983), hyporheic channels (Rot 2003), or a form of wall-base channel (Peterson and Reid 1983). Their common characteristic is that groundwater emerges in the channel, tending to provide flow and temperature patterns more stable than the main river. These water bodies sometimes have pond-

2 Because it is used to refer to so many different types of geomorphic feature, the term "slough" should be avoided. The following geomorphic features have been called "sloughs": distributary channels, larger side channels, seepage-fed groundwater channels, oxbows and other large, low velocity geomorphic features.

3 These channels are sometimes called "backwater channels" or "back channels" (Stanford and Ward 1993). We avoid such terminology because of the possibility of confusing this type of off-channel feature with the in-channel geomorphic unit called a "backwater" or "backwater pool" in Table 1.

like characteristics, as they can be moderately deep with little or no apparent velocity. A small pond may form at their head, where the groundwater first emerges, or the lower end may be ponded as it reaches the elevation of the main channel. Groundwater influence often results in higher water clarity than is found in the main channel.

Groundwater channels often have fine particle substrates and stable beds of aquatic vegetation. They are cooler than the main river during summer and warmer during winter. Stanford and Ward (1993) described them as “hotspots” of production for some salmonid species and especially for coho. Peterson and Reid (1983) found percolation channels to be most common on braided sections of rivers, and form when the head of braid or overflow channel becomes plugged by sediment or organic debris. Flow from the main channel continues to percolate through the channel fill and emerges as a spring lower in the channel. This same evolutionary pattern affects side channels in anastomosing rivers, particularly gravel dominated rivers. Wall-base channels can be similarly formed, though the flow source is groundwater emerging from the base or side slope of an adjacent terrace (Peterson and Reid 1983).

<u>Floodplain Ponds</u>. Floodplain ponds are water-filled depressions, partially or entirely filled with water year-round (Dykaar 2000). An important distinction made in EDT is that ponds must be substantially connected to the main river by an outlet channel. “Substantially connected” means that the mean depth in the outlet channel must be > 4 inches for at least 30 days (not necessarily consecutive) in most (>50%) years. Ponds may be natural features on the floodplain, often representing cut-off oxbows or pools in relict river channels, but they may also be man-made (e.g., floodplain gravel pits). They might be supplied by groundwater or surface water from streams or springs. Ponds that do not meet the connectivity criterion are either excluded from analysis or, if they are hydraulically connected to the river by overbank flows expected during seasonal high water periods, they may be classed as seasonally flooded wetlands. Seasonally flooded wetlands often contain ponded areas, either intermittently or perennially filled with water.

On the floodplains of meandering rivers, ponds frequently have very low hyporheic exchange rates. Consequently, ponds in meandering valley segments are vulnerable to high summertime water temperatures and low dissolved oxygen levels. The ponds described by Peterson and Reid (1983) are connected to the main river by small outlet channels that contain little or no water at extreme low flows. This type of pond often contains beaver dams at the mouth of the outlet. Ponds without well-defined outlet channels are only connected to the main river when floodplain inundation occurs (Dykaar 2000, Henning 2004).

Floodplain ponds can provide high quality habitat for summer or winter rearing for some salmonids, both in rain fed and snow pack dominated systems (Brown 2002). Man-made ponds can serve the same ecological function as natural ponds (Henning

2004). Ponds are frequently associated with the floodplains of meandering rivers, a channel pattern characterized by a sinuous, single-thread channel. Meandering channels are extremely stable over time, as are their extensive floodplains and their many ponds and wetlands.

Ponds in meandering rivers are often formed by avulsion and when oxbows are cut off from the main river (Dykaar 2005). Recently created oxbow ponds may be joined to the main river at the lower end by a substantial opening, which often forms a backwater pool in the main river. In such cases, the geomorphic similarity between ponds and groundwater channels is clear, and the feature may equally well be described by either term. So long as the primary attributes of groundwater channels and ponds (passive accessibility, volitional accessibility, depth, temperature, etc) are accurately characterized, the ecological function of the feature will be captured whatever it is called. But to be consistent with conventional usage and to avoid confusion, it is best to call a disconnected oxbow or water-filled basin a “pond”, especially if the feature has already been described as such on maps or documents.

<u>Seasonally Flooded Wetlands</u>. Seasonally flooded wetlands frequently occur on the floodplains of large rivers. Geomorphically, they are often remnants of ancient ponds and river channels which filled with sediment and debris over centuries (Saucier 1994, cited in Henning 2004). Seasonally flooded wetlands are typically flooded during annual high water periods either by broad overbank flows or by backwatering through narrow swales. These wetlands may contain seasonal or perennial ponds that do not meet the hydraulic connectivity criterion for floodplain ponds.

A seasonally flooded wetland is an off-channel habitat type not usually included as a riverine habitat type. Although many seasonal wetlands represent the remnants of ancient ponds and relict channels, which filled with sediment and organic debris over centuries (Dykaar 2000), many lower-river overflow channels are functionally equivalent to seasonally flooded wetlands, and should be classified as such when assessing their impact on fish production.

Historically, major salmon-producing rivers like the Sacramento River (Sommer et al. 2001b), the Willamette River (Dykaar 2000, Gregory et al. 2002), the Chehalis River (Henning 2004, Henning 2005) and the Yakima River (Standford et al. 2002) contained extensive areas of seasonally flooded wetlands. These wetlands typically flooded nearly every year during normal high water events. Depending on flows in the main channel, wetlands may connect to the main river by broad overbank flows or through narrow swales. Seasonally flooded wetlands may be associated with perennial ponds or they may dry entirely during low flow. They are productive for many food items used by both terrestrial and aquatic animals, including migrating fishes and birds (Henning 2004). Lengthy inundation of floodplain wetlands can, however, result in low dissolved oxygen levels, a phenomenon that limits residency by fish (Henning 2005).

# 3.0 ATTRIBUTES RELATED TO HABITAT

The EDT model quantifies habitat in terms of quantity and quality. The amount of in-channel habitat is expressed in terms of **the percent of the wetted area** consisting of geomorphic units in the reach (pools, riffles, glides, etc.). The amount of side channels, the main channel and braids is expressed as a percentage of the total in-channel wetted area.[4] The amount of off-channel habitat is expressed in absolute terms, and specifically in terms of **the acres of wetted area** consisting of ponds, groundwater channels and seasonally flooded wetlands.

The quantity of both in- and off-channel habitat areas are adjusted monthly to reflect changes associated with flow fluctuations and local topographic details. EDT does not store the monthly values for each attribute. Instead these adjustments make use of "patterns," a set of 12 multipliers, one for each month and a single maximum rating across all months. For habitat area, patterns represent the ratio of the area of a feature for a specific month to the maximum area over all months. Thus, the product of the maximum area across all months and the pattern multiplier for a given month is the area for the month under consideration. Patterns are also applied to other seasonally variable attributes to "shape" them over the course of a year by multiplying a maximum across all months attribute rating by a fraction equal to the ratio of a month's rating to the maximum rating over all 12 months.

Habitat is also quantified in terms of quality. Some of the qualitative attributes are "**hydrographic**" in that they relate to fluctuating hydrographic conditions and topographic characteristics peculiar to specific habitat features. **Significantly, only the hydrographic attributes will entail flow modeling (R2D, HEC RAS, and Riverware) and translation of such model output into EDT ratings.** Examples of such attributes include "side channel complexity" – roughly, bank length per square foot of wetted area attributable to side channels – and "passive accessibility for ponds" – the proportion of days per month when overbank flows are large enough reach from streambank to pond and thus, potentially, to sweep juvenile fish into the pond. Most hydrographic habitat attributes can be objectively quantified only by means of stream models, either two-dimensional models or the one-dimensional HEC-RAS model. **A major goal of this project is to develop procedures to predict seasonal (monthly) fluctuations in habitat area and in those seasonally fluctuating hydrographic attributes directly affected by flow.**

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[4] The absolute area by geomorphic unit is the product of the percent wetted area by unit and the total area of all in-channel features in the reach. Similarly, the absolute in-channel area comprised of side channels and braids is the product of their respective percent areas and total in-channel area, while the main channel area is equal to the difference between total in-channel area and the sum of the areas for side channels and braids. The percent areas by geomorphic unit must sum to 1.0, because the relative abundance of geomorphic units within a reach is assumed to be identical within the main channel, side channels and braids. The sum of the percent side channel and braids mostly likely will not equal 1.0 and should never exceed 1.0.

Other habitat attributes are “non-hydrographic” either because they have little relationship to the hydrograph or because the hydrographic effect cannot be assessed with the flow models. Examples of habitat attributes that are relatively insensitive to hydrographic fluctuations or for which the hydrographic relationship cannot be determined include: the number of fish species present, dissolved oxygen content, the number of exotic fish species present and most attributes related to floodplain ponds[5]. Values for non-hydrographic attributes for off-channel habitat features that cannot be derived from a time series of flows with R2D or HEC-RAS analysis must be inferred from conditions in the main channel, general ecological relationships and such empirical observations as are available.

Table 4 lists all of the habitat attributes (quantity and quality) developed for the habitat types described in Section 2 of this report (main channel, side channels, braids and off-channel habitat types). The definition of each attribute is included, as well as its abbreviation (code), whether or not the attribute is “shaped” by a monthly pattern, and whether or not the attribute is “hydrographic”. Hydrographic attributes, again, can be estimated by means of one of the available models (R2D or HEC-RAS ) for which mean daily flow or monthly median flow is the input variable. Essentially, hydrographic attributes must be calculated from the Riverware time series of mean daily flows; non-hydrographic attributes must be estimated by other means.

[5] The depth and “volitional accessibility” of ponds cannot be estimated with R2D output because neither pond depth nor the depth of a pond’s outlet channel (which determines volitional accessibility) is caused by backwatering from the main river. These attributes must therefore be estimated by professional judgment.

### Table 4. Environmental attributes describing side channel, braids, and off-channel habitats. These attributes were developed or modified for the Bureau of Reclamation Yakima Storage Feasibility Analysis.

| Category | Code | Attribute Name & Status | Definition |
|---|---|---|---|
| Accessibility of Off-Channel Features | AccPasGWChan | Passive Accessibility (groundwater channels); hydrographic; shaped | A measure of "passive accessibility" of groundwater channels to juvenile fish. It is expressed in terms of the fraction of days during a month when juvenile fish could be moved (or swept) passively into the habitat. *Note: non-hydrographic unless a HEC-RAS transect including the groundwater channel exists.* |
| | AccPasWet | Passive Accessibility (wetlands); hydrographic; shaped | A measure of "passive accessibility" of seasonally flooded wetlands to juvenile fish. It is expressed in terms of the fraction of days during a month when juvenile fish could be moved (or swept) passively into the habitat. |
| | AccPasPond | Passive Accessibility (ponds); hydrographic; shaped | A measure of "passive accessibility" of floodplain ponds to juvenile fish. It is expressed in terms of the fraction of days during a month when juvenile fish could be moved (or swept) passively into the habitat. |
| | AccVolPond | Volitional accessibility (floodplain ponds); non-hydrographic; shaped | For ponds with outlet channels only, a measure of the degree to which juvenile fish can swim up the outlet channel into a floodplain pond. It is expressed in terms of the fraction of days during a month when juvenile fish can swim into the pond, which is assumed to be the fraction of days per month for which mean depth in the pond outlet is four inches. |
| Side Channel Complexity, Connectivity, and Velocity | ComplexSideChan | Side channel complexity; hydrographic; shaped | A measure of the complexity of side channels expressed in terms of the length of stream margin ("edge") per square foot of wetted area. More precisely, the attribute is expressed in terms of the *increase* in edge per square foot of in-channel habitat that exists because of side channels. |
| | ConnectSideChan | Side channel connectivity; hydrographic; shaped | Average percentage of days in month when side channels are completely connected to the primary channel (i.e., proportion of month during which channels carry surface water from divergence to return points). "Connection" implies a depth of at least 4 inches. |
| | VelocitySideChan | Side channel velocity type; hydrographic; shaped | The average velocity type of side channels within the reach, where "velocity type" refers to the proportion of side channel wetted area with a velocity low enough to retain salmonid fry (<50 mm) indefinitely. Estimated maximum sustainable water velocity for fry and small parr is assumed to be 0.4 fps. |
| Water Depth of Off-Channel Features | DepthGWChan | Mean depth (groundwater channels); hydrographic; shaped | The mean depth in feet of groundwater channels in the vicinity of the reach under consideration. |
| | DepthPond | Mean depth (floodplain ponds); non-hydrographic; shaped | The mean depth in feet of floodplain ponds in the vicinity of the reach under consideration. Available models cannot estimate mean monthly depth. |
| | DepthWet | Mean depth (wetlands); hydrographic; shaped | The mean depth in feet of seasonally flooded wetlands in a reach. |
| Dissolved Oxygen (Water Quality) In- | DisOxy | Dissolved oxygen (main stream); non-hydrographic; shaped | Monthly mean dissolved oxygen content within the water column for all in-channel habitat types (main channel, braid and side channel) in the reach under consideration. |

## Table 4 continued. Environmental attributes describing side channel, braids, and off-channel habitats. These attributes were developed or modified for the Bureau of Reclamation Yakima Storage Feasibility Analysis.

| Category | Code | Attribute Name & Status | Definition |
|---|---|---|---|
| channel and Off-channel Features | DisOxyGWChan | Dissolved oxygen (groundwater channels); non-hydrographic; shaped | Monthly mean dissolved oxygen content within the water column for all groundwater channels in the vicinity of the reach under consideration. |
| | DisOxyPond | Dissolved oxygen (floodplain ponds); non-hydrographic; shaped | Monthly mean dissolved oxygen content within the water column for all floodplain ponds in the vicinity of the reach under consideration. |
| | DisOxyWet | Dissolved oxygen (wetlands); non-hydrographic; shaped | Monthly mean dissolved oxygen content within the water column for all seasonally flooded wetlands in the vicinity of the reach under consideration. |
| Fish Community Richness (Biological Community) In-channel and Off-channel Features | FshComRch | Fish community richness (main channel); non-hydrographic; shaped | Number of fish species for all in-channel (main channel, braid and side channel) habitat types. |
| | FshComRchGWChan | Fish community richness (groundwater channels); non-hydrographic; not shaped | Number of fish species for all groundwater channels in the vicinity of the reach under consideration. |
| | FshComRchPond | Fish community richness (floodplain ponds); non-hydrographic; not shaped | Number of fish species for all floodplain ponds in the vicinity of the reach under consideration. |
| | FshComRchWet | Fish community richness (wetlands); non-hydrographic; not shaped | Number of fish species for all seasonally flooded wetlands in the vicinity of the reach under consideration. |
| Fish Species Introductions (Biological Community) In-channel and Off-channel Features | FspIntro | Fish species introductions (main stream); non-hydrographic; not shaped | Number of exotic fish species present in all in-channel (main channel, braid and side channel) habitat features in the reach under consideration. |
| | FSpIntroGWChan | Fish species introductions (groundwater channels); non-hydrographic; not shaped | Number of exotic fish species present in all groundwater channels in the reach under consideration. |
| | FspIntroPond | Fish species introductions (floodplain ponds); non-hydrographic; not shaped | Number of exotic fish species present in all floodplain ponds in the reach under consideration. |
| | FspIntroWet | Fish species introductions (wetlands); non-hydrographic; not shaped | Number of exotic fish species present in all seasonally flooded wetlands in the reach under consideration. |

## Table 4 continued. Environmental attributes describing side channel, braids, and off-channel habitats. These attributes were developed or modified for the Bureau of Reclamation Yakima Storage Feasibility Analysis.

| Category | Code | Attribute Name & Status | Definition |
|---|---|---|---|
| Habitat Geomorphic Units for In-channel Features | HbBckPls | Habitat type - backwater pools; hydrographic; shaped | Proportion of all in-channel wetted area (main channel, side channels and braids) consisting of backwater pools. Backwater pools are formed at the confluence of an off-channel feature or side channel with the main channel, on in the lee of a root wad or rock outcrop. They are partially enclosed, low-velocity areas distinct from the main channel, typically having fine substrate, abundant aquatic vegetation and accumulations of fine woody debris. Depending on flow and channel configuration, the outer portion of the backwater (nearest the main channel) may be an eddy |
| | HbBvrPnds | Habitat type - beaver ponds; hydrographic; shaped | Proportion of all in-channel wetted area (main channel, side channels and braids) consisting of beaver ponds. Note: these are pools located in the main or side channels, and are not off-channel habitat. |
| | HbGlide | Habitat type – glide; hydrographic; shaped | The proportion of all in-channel wetted area (main channel, side channels and braids) consisting of glides. Note: despite general agreement that it is important to recognize a habitat type intermediate between pools and riffles, the definition of glides varies widely (Hawkins et al. 1993), The definition used here is from the ODFW habitat survey manual (Moore et al. 1997): “an area with generally uniform depth and flow with no surface turbulence, generally in reaches of <1% gradient”. Glides may have some small scoured areas but are distinguished from pools by their overall homogeneity and lack of structure. They are generally deeper than riffles with few obstructions and low habitat complexity. |
| | HbLrgCbl | Habitat type - large cobble/boulder riffles; hydrographic; shaped | The proportion of all in-channel wetted area (main channel, side channels and braids) consisting of large cobble/boulder riffles. Particle sizes of substrate modified from Platts et al. (1983) based on information in Gordon et a. (1991): gravel (0.2 to 2.9 inch diameter), small cobble (2.9 to 5 inch diameter), large cobble (5 to 11.9 inch diameter), boulder (>11.9 inch diameter). |
| | HbPlTails | Habitat type - pool tailouts; hydrographic; shaped | The proportion of all in-channel wetted area (main channel, side channels and braids) consisting of pool tailouts. |
| | HbPls | Habitat type - primary pools; hydrographic; shaped | The proportion of all in-channel wetted area (main channel, side channels and braids) consisting of pools, excluding beaver ponds. |
| | HbSmlCbl | Habitat type - small cobble/gravel riffles; hydrographic; shaped | The mean monthly proportion of the wetted area of all in-channel habitat (main channel, side channels and braids) consisting of small cobble/gravel riffles. Particle sizes of substrate modified from Platts et al. (1983) based on information in Gordon et a. (1991): gravel (0.2 to 2.9 inch diameter), small cobble (2.9 to 5 inch diameter), large cobble (5 to 11.9 inch diameter), boulder (>11.9 inch diameter). The EDT Model includes the option of shaping this attribute by month (new feature January 2006). |
| Habitat In-channel Features | HbBraid | Habitat type – braid; hydrographic; shaped | Proportion of all in-channel wetted area (main channel, side channels and braids) consisting of braids, which are considered to be channels flowing between unstable, unvegetated gravel bars that are submerged at bankfull flow. |

## Table 4 continued. Environmental attributes describing side channel, braids, and off-channel habitats. These attributes were developed or modified for the Bureau of Reclamation Yakima Storage Feasibility Analysis.

| Category | Code | Attribute Name & Status | Definition |
|---|---|---|---|
| | HbSideChan | Habitat type – side channel; hydrographic; shaped | The mean monthly proportion of the wetted area of all in-channel habitat (main channel, side channels and braids) consisting of side channels. A side channel is an active stream channel separated from the main channel by a vegetated or otherwise stable island (Knighton (1998). The islands tend to be large relative to the size of the channels. Side channels are frequently small watered remnants of the historic river channel within the floodplain. Some side channels carry surface water continuously, from the point of divergence to the point of return, at a given flow, while others become intermittent (are dry at some point(s) between divergence and return) at the same flow (Ward et al. 1999). The frequency of continuous connection to a surface water source can be important in the ecology of various species (Tockner et al. 2000) and is described by Side Channel Connectivity (ConnectSideChan). |
| Habitat Types – Off-channel Features | HbGWChan | Habitat type – wetted area of groundwater channels; hydrographic; shaped | The area in acres of groundwater channels. Groundwater channels connect to the main channel or a side channel only at one end at flows less than bankfull. They are usually relict river channels fed by groundwater, though surface flow from higher terraces can also contribute. They can function as overflow channels at some flood stages, and include several subtypes (Ward et al. 1999), including: (1) channels carrying main channel seepage, (2) channels fed by the floodplain aquifer and (3) channels fed by groundwater supplied from adjacent terraces. |
| | HbPond | Habitat type - wetted area of floodplain ponds; non-hydrographic; shaped | The area in acres of floodplain ponds. Floodplain ponds are water-filled depressions, partially or entirely filled with water year-round and that are connected to the main river for all or some period of the year by an outlet channel. To be classified as a floodplain pond, the outlet channel must have a mean depth > 4 inches for a portion of a year (e.g., at least one month, though not necessarily all consecutive days) in most (>50%) years. They are either natural features on the floodplain, representing cut-off oxbows or pools in relict river channels, but they may also be man-made (e.g., floodplain gravel pits). They might be supplied by groundwater or surface water from streams or springs. Ponds that do not meet the criteria for connectivity to the river are either excluded from the analysis or may be included with flooded wetlands. Flooded wetlands often contain ponded areas, either intermittently or perennially filled with water. |
| | HbWet | Habitat type - wetted area of seasonally flooded wetlands; hydrographic; shaped | The area in acres of seasonally flooded wetland. Seasonally flooded wetlands frequently occur on the floodplains of large rivers. Geomorphically, they are often remnants of ancient ponds and river channels which filled with sediment and debris over centuries (Saucier 1994, cited in Henning 2004). Seasonally flooded wetlands are typically flooded during annual high water periods either by broad overbank flows or by backwatering through narrow swales. These wetlands may contain seasonal or perennial ponds that do not meet the criteria for connectivity to the river prescribed for floodplain ponds (see definition for HbPond). |
| Hyporheic exchange in Off-channel features | HypExGWChan | Hyporheic exchange (groundwater channels); non-hydrographic; not shaped | A measure of the proportion of the volume of groundwater channels contributed by groundwater. In the absence of explicit hydrological information, hyporheic influence will be assumed to be minimal at the upstream end of unconfined valley segments and maximal at the downstream end. |

## Table 4 continued. Environmental attributes describing side channel, braids, and off-channel habitats. These attributes were developed or modified for the Bureau of Reclamation Yakima Storage Feasibility Analysis.

| Category | Code | Attribute Name & Status | Definition |
|---|---|---|---|
| Obstruction due to Exotic Veg for Off-channel Features | ObstrVegGWChan | Obstructing littoral vegetation (groundwater channels); non-hydrographic; shaped | Incidence and density of patches of impenetrable littoral exotic vegetation (canary reed grass, purple loosestrife, etc.) in shallow, near-shore areas that limit accessibility of groundwater channels in the vicinity of the reach under consideration. |
| | ObstrVegPond | Obstructing littoral vegetation (floodplain ponds); non-hydrographic; shaped | Incidence and density of patches of impenetrable littoral exotic vegetation (canary reed grass, purple loosestrife, etc.) in shallow, near-shore areas that limit accessibility of floodplain ponds in the vicinity of the reach under consideration. |
| | ObstrVegWet | Obstructing littoral vegetation (wetlands); non-hydrographic; shaped | Incidence and density of patches of impenetrable littoral exotic vegetation (canary reed grass, purple loosestrife, etc.) in shallow, near-shore areas that limit accessibility of seasonally flooded wetlands in the vicinity of the reach under consideration. |
| Off-channel Pond proximity | ProxPond | Proximity to main channel or side channel (floodplain ponds); hydrographic; shaped | Mean monthly distance in feet from pond to the main river, where length is measured along the outlet channel from the edge of the pond to the edge of the river. |
| Minimum Temperature (Water Quality) In-channel and Off-channel Features | TmpMonMn | Temperature – daily minimum (by month) (main stream); hydrographic; shaped | Minimum daily water temperatures within all in-channel (main channel, braid and side channel) habitat features during a month. |
| | TmpMonMnGWChan | Temperature – daily minimum (by month) (groundwater channels); non-hydrographic; shaped | Minimum daily water temperatures within all groundwater channels during a month. |
| | TmpMonMnPond | Temperature – daily minimum (by month) (floodplain ponds); non-hydrographic; shaped | Minimum daily water temperatures within all floodplain ponds during a month. |
| | TmpMonMnWet | Temperature – daily minimum (by month) (wetlands); non-hydrographic; shaped | Minimum daily water temperatures within all seasonally flooded wetlands during a month. |
| Maximum Temperature (Water Quality) In-channel and Off-channel Features | TmpMonMx | Temperature – daily maximum (by month, for main channel); hydrographic; shaped | Maximum daily water temperatures within all in-channel (main channel, braid and side channel) habitat features during a month. |
| | TmpMonMxGWChan | Temperature – daily maximum (by month) (groundwater channels); non-hydrographic; shaped | Maximum daily water temperatures within all groundwater channels during a month. |
| | TmpMonMxPond | Temperature – daily maximum (by month) (floodplain ponds); non-hydrographic; shaped | Maximum daily water temperatures within all floodplain ponds during a month. |

## Table 4 continued. Environmental attributes describing side channel, braids, and off-channel habitats. These attributes were developed or modified for the Bureau of Reclamation Yakima Storage Feasibility Analysis.

| Category | Code | Attribute Name & Status | Definition |
|---|---|---|---|
| | TmpMonMxWet | Temperature - daily maximum (by month) (wetlands); non-hydrographic; shaped | Maximum daily water temperatures within all seasonally flooded wetlands during a month. |
| Suspended Sediment (Water Quality) In-channel and Off-channel Features | Turb | Turbidity (main channel); hydrographic; shaped | The severity of suspended sediment (SS) episodes within the main channel and side channels. Note: although this attribute was originally called turbidity and still retains that name for continuity, it is more correctly thought of as suspended sediment (SS). SS is sometimes characterized in terms of turbidity, but it is more accurately expressed in terms of suspended solids. "Turbidity" is an optical property of water that consists of the scattering of light because of suspended particles, including very fine particles such as clays and colloids. Turbidity in the optical sense is expressed in terms of nephelometric turbidity units (NTUs). Suspended solids represents the actual measure of mineral and organic particles transported in the water column, either expressed as total suspended solids (TSS) or suspended sediment concentration (SSC)—both as mg/l. Technically, turbidity is not SS but the two are usually well correlated. If only NTUs are available, an approximation of SS can be obtained through relationships that correlate the two. The metric applied here is the Scale of Severity (SEV) Index taken from Newcombe and Jensen (1996), derived from: $SEV = a + b(\ln X) + c(\ln Y)$ , where, X = duration in hours, Y = mg/l, a = 1.0642 , b = 0.6068, and c = 0.7384. Duration is the number of hours out of month (with highest SS typically) when that concentration or higher normally occurs. Concentration would be represented by grab samples reported by USGS. See rating guidelines. |
| | TurbGWChan | Turbidity (groundwater channels); non-hydrographic; shaped | The severity of suspended sediment (SS) episodes within groundwater channels in the vicinity of the reach under consideration. Values inferred from main channel and general ecological relationships. |
| | TurbPond | Turbidity (floodplain ponds); non-hydrographic; shaped | The severity of suspended sediment (SS) episodes within the floodplain ponds in the vicinity of the reach under consideration. Values based on empirical observation or general ecological inference. |
| | TurbWet | Turbidity (wetlands); non-hydrographic; shaped | The severity of suspended sediment (SS) episodes within seasonally flooded wetlands in the vicinity of the reach under consideration. Values inferred from general ecological relationships. |

# 4.0 HABITAT QUANTIFICATION PROCEDURES

This section explains and illustrates the essential elements of quantifying the habitat features just described in terms of EDT attributes. The more technical computations are exemplified by one of the included Excel Workbooks, and the critical procedural details are summarized in **Error! Reference source not found.** at the conclusion of this document. Appendix A lists all habitat-related EDT attributes, and defines the EDT ratings for each attribute.

Habitat quantification procedures described in this section all relate to attribute ratings derived from the R2D or HEC-RAS models. The procedures are described as a series of steps building up to a reach level characterization for EDT attributes derived from the supporting models. We begin with an overview on how aerial photos are used to help interpret R2D model output (Step One). Next, we describe procedures necessary to summarize the R2D output for in-channel and off-channel features (Step Two). Step Three describes the procedures necessary to determine in-channel geomorphic unit area from the R2D output. Additional EDT attributes derived from the R2D output are described in Step Four:

- channel wetted width,
- side channel complexity,
- depth of groundwater channels, ponds and wetlands,
- pond proximity,
- side channel velocity, and
- volitional accessibility ponds.

Finally, Step Five describes procedures for computing area of seasonally flooded wetlands using HEC-RAS model output.

**Step One: Superimposing R2D output and aerial photographs**

Before habitat quantity and quality can be quantified, R2D output must first be overlaid on aerial photographs of all reaches affected by a storage option. This initial step is critical because R2D output cannot easily be interpreted apart from its visual context in the landscape, and because off-channel features rarely will be recognizable from R2D output alone.

It is also essential that R2D modeling be conducted over a range of flows, and that one of the flows approximates bankfull. A bankfull simulation is necessary primarily to identify the full complement of side channels and to distinguish them from braids. If a secondary channel is not continuous at bankfull flow, it is by definition not a side channel, but some type of off-channel feature (e.g., a groundwater channel).

Moreover, side channels defined by islands supporting relatively little vegetation may be visually indistinguishable in aerial photographs from braids defined by gravel bars covered with grass. Ambiguities of this type are resolved by the fact that braids disappear at bankfull flow: the gravel bars that define them are submerged.

Finally, R2D modeling must be conducted over a range of flows because all habitat parameters that are not estimated by professional judgment or inference from nearby observations must be estimated by regressions or lookup tables based on flow. For example, the wetted area covered by side channels, the proportion of side channels that retain continuous flow, and the velocity distribution inside side channels are all determined by the discharge entering the reach. Because it would be prohibitively time-consuming to simulate all of the flows that might occur under a given scenario, it is necessary to develop regressions or lookup tables that allow an attribute to be estimated on the basis of flows in the Riverware time series. In many cases, the median monthly flow for the scenario will be the input value for the appropriate regression or lookup table.

Use of median monthly flows from the Riverware time series will generally occur when the attribute at issue *does not quantify the frequency of occurrence* for a specified condition. Actual mean daily discharge values in the Riverware time series must be used for attributes that quantify frequency of flows during the month.

**Step Two: Manual Delineation of Side Channels, Groundwater Channels, Ponds, Pond Outlets, Backwater Pools and Beaver Ponds**

After aerial photographs and bankfull R2D output have been superimposed in GIS, the next step is to delineate all off-channel features, all side channels and a number of geomorphic units not easily distinguished by R2D output. This delineation must be done on the simulation of bankfull flow.

Side channels are manually defined by drawing “hash marks” at their points of divergence and return. A polygon is constructed of the wetted channel area between these marks to define the wetted area of the side channel. All side channels in a reach, including “side channels on side channels”, are defined in this way and each side channel must be uniquely numbered. Individual numbering of side channels is necessary because side channel connectivity is based on the relative number of side channels that remain continuous at specified flows. The wetted areas inside these polygons henceforth are recognized as side channels in all subsequent R2D model analyses (flows less than bankfull).

Floodplain pond and groundwater channel polygons define the margins of “putative ponds” and groundwater channels. These features must be identified by hand and characterized as either a ponds or groundwater channels. Because ponds are not considered fish habitat unless they are drained by an outlet that meets a minimum hydraulic connectivity criterion, they must at this stage be considered “putative”;

their status will be confirmed only after a review of empirical observations supports their accessibility to fish[6]. Pond outlet channels must also be identified to characterize pond outlet features. Outlet channels not only are critical in determining pond accessibility, and thus whether the feature should be classed as fish habitat at all, but the length of the outlet channel between the pond and the main river also defines the pond proximity attribute, which affects pond habitat quality.

Backwater pools and known beaver ponds must also be defined by polygons and attributed appropriately. Neither of these features can be reliably identified from R2D output alone without visual interpretation (see next section for details on how in-channel geomorphic units are defined from R2D output). Both of these features will show up simply as pools in the output. Known or suspected beaver ponds must be manually defined by drawing either labeling a pool polygon in the R2D output as a beaver pond or cutting a new polygon from a larger pool unit.

Backwater pools typically form at the mouths of groundwater channels and side channels, or in the lee of rock outcropping or log jams, but they are not invariably found at such locations. Therefore, pools identified from the R2D output at the confluences of groundwater channels and side channels, and below outcroppings and log jams, must first be examined. Where evidence suggest a portion of the pool is in fact a backwater pool then a new backwater pool unit must be cut from the larger pool polygon. Very large groundwater channels frequently have pool-like characteristics a considerable distance from the main channel confluence. In accordance with Lestelle et al. (2005), backwater pools in very large groundwater channels will be assumed to extend 400 feet above the confluence, or to the upper extent of pool habitat as indicated by R2D output, whichever is smaller.

The end result of this phase of the analysis is the creation of a GIS data layer at bankfull flow containing the following items: Reach ID, flow, the percent in-channel wetted area occupied by side channels, backwater pools and beaver ponds; and the area in acres of off-channel habitat consisting of groundwater channels and putative ponds. This classification of habitat features is permanent and applied to all subsequent R2D analyses at flows less than bankfull. Wetted area and other important values of these habitat features are recalculated for each subsequent R2D model run. Additional calculations on numerical characteristics of the features just defined by polygons will be needed in order to estimate various qualitative attributes. Description of these calculations will be deferred until Sections 5.0 and 6.0.

[6] Again, because outlet channels are not usually filled by backwatering from the main river, R2D output cannot be used to estimate the frequency of occurrence of criteria depths in pond outlets. Thus the fundamental issue of accessibility to fish cannot be addressed by R2D output.

**Step 3: Defining Geomorphic Units**

After the habitat features that cannot be identified with R2D model output have been identified by visual interpretation of model output and aerial photographs (previous step), automated GIS procedures can be invoked that will identify and quantify the remaining in-channel geomorphic units. The basis of these procedures is described below.

Output from two-dimensional river models consists of pairs of velocity and depth estimates associated with a point in space. The Froude number is a hydraulic parameter defined in terms of velocity and depth as follows:

$$Froude\,number = \frac{v}{\sqrt{g}\,d}$$

where *v* = velocity (fps), *g* = the gravitational constant, and *d* = depth (feet).

A number of habitat scientists (Panfil and Jocobsen 2005; Jowett 1993) have determined that different geomorphic units are fairly reliably associated with different ranges of Froude numbers as calculated from R2D output. Bureau of Reclamation scientists, using R2D output for upper Yakima reaches, have determined that pools, riffles and glides can be recognized by the following ranges of Froude numbers extracted from R2D output:

Pools = Froude numbers < 0.09

Riffles = Froude numbers > 0.42

Glides = 0.09 >= Froude number <= 0.42

Bureau scientists have validated their procedure by comparing their predictions with visual estimates of geomorphic units in the Easton reach of the upper Yakima River. They found they correctly identified pools 68% of the time, glides 71% of the time, and riffles 61% of the time, an accuracy that corresponds to that reported in the literature. Additional comparisons of predicted vs. observed classifications are in underway. These criteria may change, as once more information is available.

The R2D output must be summarized to show the proportion of the wetted area of a reach consisting of pools, riffles and glides. Because the R2D model cannot distinguish between small cobble/gravel riffles and large cobble/boulder riffles, riffles will be subdivided into large- and small-substrate components based on the relative proportion of small and large substrate in the reach. This information has already been collected and, therefore, it remains only to apportion total riffle area into large- and small-substrate sub-types on the basis of these existing reach specific estimates.

As mentioned previously, backwater pools and beaver ponds are not identifiable as such by R2D model output; they simply appear as pools. Therefore the wetted areas defined by the backwater pool and beaver pond polygons created in the previous step must be subtracted from the area initially attributed to the primary pool category.

Finally, the R2D model output cannot distinguish the wetted area of pool tail-outs. This area is subtracted from the primary pool area based on ratios of pool tailouts to total pool area that have been developed by J&S staff. These ratios are a general rule-of-thumb and appear to provide a reasonable approximation of pool tailout area. These gradient-based ratios are summarized in Table 5.

### Table 5. Relationship between pool area and tail-out area as a function of reach gradient. Rough relationship consistent with personal observations of J&S fisheries staff.

| Reach Gradient Range | Tailout Area as a Fraction of Area of Primary Pool plus Tailout |
|---|---|
| < 0.5 % | 25% |
| >0.5% to <= 1.0% | 15% |
| >1.0% to <= 1.5% | 10% |
| >1.5% to <= 4.0% | 5% |
| >4.0% | 0% |

Therefore, in order to estimate pool tail-out area properly, an appropriate fraction of net pool area (Froude-number-based pool area minus the area of backwater pools and beaver ponds) must be assigned to the tail-out category on the basis of reach gradient. At this time it is unclear if this area needs to be subtracted from the reach primary pool area or glide area. Additional analysis of the R2D output is necessary to answer this question.

A final consideration in quantifying geomorphic units involves classification errors along the stream margins. Stream margins have low velocity-to-depth ratios, and therefore would be classified as pools by a procedure based strictly on Froude number. Such a classification would be geomorphically and biologically incorrect. While stream margins are almost always slow, they are not deep relative to surrounding habitat features, they do not lie immediately below much higher velocity riffles or transition into tail-outs and, most importantly, they are not utilized by fish as pools are utilized. The slow, shallow margin of a stream most nearly approximates a glide in terms of its physical structure and biological utilization. Therefore it has been decided to classify all stream margin habitat with a Froude number <0.09, a depth <= 0.8 ft and a velocity <= 0.3 fps as glide. The queries required for geomorphic unit assessment must identify areas with these characteristics and subtract them from the reach totals for glide.

Table 6 summarizes the calculations entailed in estimating percent in-channel area allocated to the seven distinct geomorphic units.

### Table 6. Process of estimating percent in-channel wetted area comprised of the seven geomorphic units recognized by EDT. Procedures for combining Froude-number-based estimates of pools, riffles and glides with classifications based on visual interpretation and existing EDT database.

| Primary Pools | Tail-outs | Backwater Pools | Beaver Ponds | Glides | Small Cobble/Gravel Riffles | Large Cobble/Boulder Riffles | SUM |
|---|---|---|---|---|---|---|---|
| Net pool area is % in-channel area Froude # pools,[a] less % wetted area backwater pools & beaver ponds, less marginal areas with Froude #<0.09, depth<=0.8 ft & velocity <= 0.3 fps | Net pool area times fraction representing tail-out as a function of reach gradient. | Manually drawn polygons enclosing Froude # pools[a] below mouths of side channels & groundwater channels & below outcroppings and log-jams. | Manually drawn polygons enclosing Froude # pools[a] known to represent beaver ponds. | % in-channel area Froude # glides,[b] less pool tail-outs, plus marginal areas with Froude #<0.09, depth<=0.8 ft & velocity <= 0.3 fps. | % in-channel area Froude # riffles[c] times % of riffles classed small cobble/gravel for reach in existing EDT database. | % in-channel area Froude # riffles[c] times % of riffles classed small cobble/gravel for reach in existing EDT database. | 100% |

a. The fraction of the in-channel wetted area for which Froude number is <0.09. In-channel wetted area includes the main channel and all side channels and braids, and excludes all groundwater channels, ponds and seasonal wetlands.

b. The fraction of the in-channel wetted area for which Froude number is >=0.09 and <=0.42. In-channel wetted area includes the main channel and all side channels and braids, and excludes all groundwater channels, ponds and seasonal wetlands.

c. The fraction of the in-channel wetted area for which Froude number is >0.42. In-channel wetted area includes the main channel and all side channels and braids, and excludes all groundwater channels, ponds and seasonal wetlands.

The end result of the analysis of geomorphic unit composition must be the creation of a GIS data layer with the following fields: Reach ID, Flow, and percent in-channel area by geomorphic unit.

<u>Computing patterns to shape geomorphic unit composition across months.</u> Although patterns to shape geomorphic unit composition cannot be developed until a much later step in the analytical process as it requires the Riverware flow time series, it is logically appropriate to discuss this process in the context of a discussion of geomorphic units.

Estimating the composition of in-channel wetted area in terms of geomorphic units, side channels and braids entails the same procedure, as does estimating the patterns that shape composition of any attribute across the months of the year. Accordingly, the procedures for estimating monthly composition and patterns for geomorphic units, side channels and braids will be discussed together.

Table 7 and Table 8 illustrate the process. The first step is to develop regressions giving the percent wetted area occupied by each geomorphic unit, and by all side channels and braids, as a function of flow. For the sake of generality, flow in Table 7 and Table 8 is presented in a relative sense, with the highest flow simulated by R2D models being 1.0 and all lesser flows expressed as fraction of the highest flow. These regressions are then applied to the **median monthly flow** expected under a scenario, and the percent wetted area across geomorphic units is summed. As seen in the "Pre-Lookup Table" portion of Table 7, this process results in a geomorphic unit composition that does not sum to 100%. Therefore, the regression-based values for each feature under a given flow in the Pre-Lookup table are divided by the sum of the percent areas across all geomorphic units and re-tabulated in a revised Lookup table. This procedure "normalizes" the wetted area composition to 100%. The same normalization procedure is applied to the percent wetted area consisting of side channels and braids. In Table 8, the final Lookup Table is used to estimate percent wetted area occupied by each feature as determined by the monthly median flow predicted under the scenario. Finally, in the lower portion of Table 8, the pattern is generated by dividing the monthly percent area for each feature by the maximum area occupied over the entire year. The mathematical details of this process are captured in the Workbook "Geomorphic Unit Side Channel Braid Pattern Generation Process.xls".

## **Step Four: Writing and Running GIS Procedures to Calculate Flow-specific Habitat Parameters**

At this point in the analytical process, the groundwork has been laid for the calculation of most EDT habitat parameters. Much of this work will be accomplished through the creation of GIS procedures that compute values from the spatial and hydraulic information the previous steps have created. Although it is not necessary here to describe the actual procedures that are needed, it is necessary to describe their function and role in the analytical scheme sufficiently well that provisions can be made for their creation.

A number of habitat parameters can be estimated by procedures that manipulate hydraulic and spatial data in relatively straightforward ways. These parameters and their procedures will be described in sufficient detail to allow GIS specialists to write precise processes at a later date and to guide development of the DMI application. The DMI application is the key tool for translating the support model outputs into EDT habitat parameters.

## Table 7. Example of lookup tables for composition of geomorphic units, side channels and braids in a hypothetical reach.

**Two-Dimensional Modeling Output**

| Relative Flow (flow relative to maximum modeled) | Backwater Pools | Beaver Ponds | Glides | Large Cobble Boulder Riffles | Small Cobble Gravel Riffles | Primary Poolls | Pool Tail-outs | Total % Wetted Area by Geomorphic Unit | Total % Wetted Area Braids | Total % Wetted Area Side Channels |
|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 2% | 1% | 61% | 5% | 24% | 6% | 1% | 100% | 0% | 15% |
| 0.85 | 3% | 1% | 52% | 6% | 30% | 7% | 2% | 100% | 0% | 15% |
| 0.7 | 4% | 1% | 40% | 8% | 35% | 9% | 2% | 100% | 0% | 10% |
| 0.5 | 4% | 1% | 36% | 9% | 35% | 12% | 3% | 100% | 0% | 6% |
| 0.3 | 5% | 2% | 17% | 9% | 36% | 25% | 6% | 100% | 2% | 5% |
| **Regressions of percent wetted area consisting of Geomorphic Unit as a function of flow** | | | | | | | | | | |
| **Intercept** | 0.059 | 0.024 | 0.016 | 0.115 | 0.428 | 0.287 | 0.072 | | 0.020 | -0.009 |
| **Coefficient** | -0.035 | -0.015 | 0.592 | -0.061 | -0.164 | -0.252 | -0.063 | | -0.024 | 0.165 |

**Pre-Lookup Table**

| Range of Flows to Evaluate (Modeled, Un-modeled) | Backwater Pools | Beaver Ponds | Glides | Large Cobble Boulder Riffles | Small Cobble Gravel Riffles | Primary Poolls | Pool Tail-outs | Total % Wetted Area by Geomorphic Unit | Total % Wetted Area Braids | Total % Wetted Area Side Channels |
|---|---|---|---|---|---|---|---|---|---|---|
| **1.6** | 0.32% | 0.05% | 96.29% | 1.69% | 16.57% | 0.00% | 0.00% | **114.92315%** | 0.00% | 25.54% |
| **1.3** | 1.37% | 0.49% | 78.53% | 3.53% | 21.48% | 0.00% | 0.00% | **105.40735%** | 0.00% | 20.59% |
| **1** | 2.41% | 0.94% | 60.77% | 5.38% | 26.40% | 3.54% | 0.88% | **100.31036%** | 0.00% | 15.64% |
| **0.95** | 2.59% | 1.01% | 57.81% | 5.68% | 27.22% | 4.80% | 1.20% | **100.29945%** | 0.00% | 14.82% |
| **0.9** | 2.76% | 1.09% | 54.85% | 5.99% | 28.04% | 6.06% | 1.51% | **100.28854%** | 0.00% | 13.99% |
| **0.85** | 2.94% | 1.16% | 51.89% | 6.30% | 28.85% | 7.32% | 1.83% | **100.27763%** | 0.00% | 13.17% |
| **0.7** | 3.46% | 1.38% | 43.01% | 7.22% | 31.31% | 11.10% | 2.77% | **100.24490%** | 0.33% | 10.69% |
| **0.65** | 3.63% | 1.46% | 40.05% | 7.52% | 32.13% | 12.36% | 3.09% | **100.23399%** | 0.45% | 9.87% |
| **0.5** | 4.15% | 1.68% | 31.17% | 8.44% | 34.59% | 16.14% | 4.03% | **100.20126%** | 0.81% | 7.40% |
| **0.4** | 4.50% | 1.83% | 25.25% | 9.06% | 36.22% | 18.66% | 4.66% | **100.17944%** | 1.05% | 5.75% |
| **0.35** | 4.68% | 1.90% | 22.29% | 9.36% | 37.04% | 19.92% | 4.98% | **100.16853%** | 1.17% | 4.92% |
| **0.3** | 4.85% | 1.97% | 19.33% | 9.67% | 37.86% | 21.18% | 5.29% | **100.15761%** | 1.29% | 4.10% |

**Lookup Table**

| Range of Flows to Evaluate (Modeled, Un-modeled) | Backwater Pools | Beaver Ponds | Glides | Large Cobble Boulder Riffles | Small Cobble Gravel Riffles | Primary Poolls | Pool Tail-outs | Total % Wetted Area by Geomorphic Unit | Total % Wetted Area Braids | Total % Wetted Area Side Channels |
|---|---|---|---|---|---|---|---|---|---|---|
| **1.6** | 0.28% | 0.04% | 83.79% | 1.47% | 14.42% | 0.00% | 0.00% | **100.00000%** | 0.00% | 22.22% |
| **1.3** | 1.30% | 0.47% | 74.50% | 3.35% | 20.38% | 0.00% | 0.00% | **100.00000%** | 0.00% | 19.53% |
| **1** | 2.41% | 0.93% | 60.58% | 5.36% | 26.32% | 3.52% | 0.88% | **100.00000%** | 0.00% | 15.59% |
| **0.95** | 2.58% | 1.01% | 57.64% | 5.66% | 27.14% | 4.78% | 1.20% | **100.00000%** | 0.00% | 14.77% |
| **0.9** | 2.75% | 1.08% | 54.69% | 5.97% | 27.95% | 6.04% | 1.51% | **100.00000%** | 0.00% | 13.95% |
| **0.85** | 2.93% | 1.16% | 51.75% | 6.28% | 28.77% | 7.29% | 1.82% | **100.00000%** | 0.00% | 13.13% |
| **0.7** | 3.45% | 1.38% | 42.90% | 7.20% | 31.23% | 11.07% | 2.77% | **100.00000%** | 0.33% | 10.67% |
| **0.65** | 3.62% | 1.45% | 39.96% | 7.51% | 32.05% | 12.33% | 3.08% | **100.00000%** | 0.45% | 9.85% |
| **0.5** | 4.15% | 1.68% | 31.11% | 8.43% | 34.52% | 16.10% | 4.03% | **100.00000%** | 0.81% | 7.38% |
| **0.4** | 4.50% | 1.82% | 25.20% | 9.04% | 36.16% | 18.62% | 4.66% | **100.00000%** | 1.05% | 5.74% |
| **0.35** | 4.67% | 1.90% | 22.25% | 9.35% | 36.98% | 19.88% | 4.97% | **100.00000%** | 1.17% | 4.91% |
| **0.3** | 4.84% | 1.97% | 19.30% | 9.66% | 37.80% | 21.14% | 5.29% | **100.00000%** | 1.29% | 4.09% |

Table 8. Example of estimating monthly compositions and patterns for geomorphic units, side channels and braids in a hypothetical reach. Monthly composition by geomorphic unit is based on the lookup table in Table 7.

| | | Scenario Monthly Composition by Geomorphic Unit | | | | | | | | Scenario Side Channels and Braids | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| SCENARIO MONTHLY MEDIAN FLOW | Month | Backwater Pools | Beaver Ponds | Glides | Large Cobble Boulder Riffles | Small Cobble Gravel Riffles | Primary Poolls | Pool Tail-outs | Total % Wetted Area Across All Geomorphic Units | Total % Wetted Area Braids | Total % Wetted Area Side Channels |
| 0.85 | January | 2.9% | 1.2% | 51.7% | 6.3% | 28.8% | 7.3% | 1.8% | 100.0% | 0.0% | 13.2% |
| 0.9 | February | 2.8% | 1.1% | 54.7% | 6.0% | 28.0% | 6.0% | 1.5% | 100.0% | 0.0% | 14.0% |
| 0.95 | March | 2.6% | 1.0% | 57.6% | 5.7% | 27.1% | 4.8% | 1.2% | 100.0% | 0.0% | 14.8% |
| 1 | April | 2.4% | 0.9% | 60.6% | 5.4% | 26.3% | 3.5% | 0.9% | 100.0% | 0.0% | 15.6% |
| 1.6 | May | 0.3% | 0.0% | 83.8% | 1.5% | 14.4% | 0.0% | 0.0% | 100.0% | 0.0% | 25.5% |
| 1.3 | June | 1.3% | 0.5% | 74.5% | 3.4% | 20.4% | 0.0% | 0.0% | 100.0% | 0.0% | 20.6% |
| 0.5 | July | 4.1% | 1.7% | 31.1% | 8.4% | 34.5% | 16.1% | 4.0% | 100.0% | 0.8% | 7.4% |
| 0.4 | August | 4.5% | 1.8% | 25.2% | 9.0% | 36.2% | 18.6% | 4.7% | 100.0% | 1.0% | 5.7% |
| 0.35 | September | 4.7% | 1.9% | 22.3% | 9.3% | 37.0% | 19.9% | 5.0% | 100.0% | 1.2% | 4.9% |
| 0.3 | October | 4.8% | 2.0% | 19.3% | 9.7% | 37.8% | 21.1% | 5.3% | 100.0% | 1.3% | 4.1% |
| 0.65 | November | 3.6% | 1.5% | 40.0% | 7.5% | 32.1% | 12.3% | 3.1% | 100.0% | 0.4% | 9.9% |
| 0.7 | December | 3.4% | 1.4% | 42.9% | 7.2% | 31.2% | 11.1% | 2.8% | 100.0% | 0.3% | 10.7% |

| | Scenario Geomorphic Unit Pattern | | | | | | | Scenario Side Channel and Braid Pattern | |
|---|---|---|---|---|---|---|---|---|---|
| Month | Backwater Pools | Beaver Ponds | Glides | Large Cobble Boulder Riffles | Small Cobble Gravel Riffles | Primary Poolls | Pool Tail-outs | Braids | Side Channels |
| January | 0.60 | 0.59 | 0.62 | 0.65 | 0.76 | 0.35 | 0.35 | 0.00 | 0.52 |
| February | 0.57 | 0.55 | 0.65 | 0.62 | 0.74 | 0.29 | 0.29 | 0.00 | 0.55 |
| March | 0.53 | 0.51 | 0.69 | 0.59 | 0.72 | 0.23 | 0.23 | 0.00 | 0.58 |
| April | 0.50 | 0.47 | 0.72 | 0.55 | 0.70 | 0.17 | 0.17 | 0.00 | 0.61 |
| May | 0.06 | 0.02 | 1.00 | 0.15 | 0.38 | 0.00 | 0.00 | 0.00 | 1.00 |
| June | 0.27 | 0.24 | 0.89 | 0.35 | 0.54 | 0.00 | 0.00 | 0.00 | 0.81 |
| July | 0.86 | 0.85 | 0.37 | 0.87 | 0.91 | 0.76 | 0.76 | 0.63 | 0.29 |
| August | 0.93 | 0.92 | 0.30 | 0.94 | 0.96 | 0.88 | 0.88 | 0.81 | 0.23 |
| September | 0.96 | 0.96 | 0.27 | 0.97 | 0.98 | 0.94 | 0.94 | 0.91 | 0.19 |
| October | 1.00 | 1.00 | 0.23 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 0.16 |
| November | 0.75 | 0.74 | 0.48 | 0.78 | 0.85 | 0.58 | 0.58 | 0.35 | 0.39 |
| December | 0.71 | 0.70 | 0.51 | 0.75 | 0.83 | 0.52 | 0.52 | 0.25 | 0.42 |

Many habitat parameters can be estimated relatively easily. These parameters and their estimation procedures are described below. Five habitat parameters, however, entail calculations that are considerably more complex. Although a general overview of the estimation procedure for these parameters will be described here, a more detailed description of the estimation procedures will be deferred to Section 7.0.

Maximum and Minimum Channel Width: Maximum and minimum channel width is estimated by simply dividing **the wetted area** of the reach during the month of maximum mean flow by **reach length**, and vice versa for minimum channel width. Accordingly, procedures should be written to estimate these parameters, and to store the values in files liked to each reach affected by the project[7]. The pattern for channel width is simply the ratio of the computed monthly mean width to the maximum monthly computed mean width.

Habitat Area. To reiterate, it is clearly essential that queries be developed to calculate and store the wetted areas of all of the habitat features manually delineated by polygons (side channels, braids, ponds and groundwater channels), as well as all of the relative areas (percent wetted area) of the geomorphic units comprising in-channel habitat.

Side Channel Complexity. Side channel complexity quantifies the proportion of streambank "edge" per unit wetted area that is attributable to side channels. It is computed as a percent difference in ratios:

$$Side\,Channel\,Complexity = \frac{(Edge/Area_{REACH} - Edge/Area_{MAIN\ CHANNEL})}{Edge/Area_{MAIN\ CHANNEL}}$$

where $Edge/Area_{REACH}$ is the ratio of wetted perimeter of all side channel and main channel areas to total wetted area for the entire reach, and $Edge/Area_{MAIN\ CHANNEL}$ is the ratio of wetted perimeter of the main channel area to the total wetted area for the main channel only. Note that off-channel habitat features are excluded from this calculation.

Procedures must be written that can be applied specifically to each affected reach that 1) distinguish the main channel from side channels and braids, 2) compute the wetted perimeter and wetted area of the main channel alone and of the entire reach, and 3) link these values to a specific reach and flow. It is not necessary that a reach- and

[7] The "reaches affected by the project" are defined in terms of the Black Rock Reservoir project, which has a wider geographic impact than any of the other storage proposals being evaluated. In this context, the affected area includes include all reaches downstream of existing storage facilities: the Yakima River below Keechelus Dam, the Kachess River below Kachess Dam, the Cle Elum River below Cle Elum Dam, the Naches River below the Bumping confluence, the Bumping River below Bumping Dam, and the Tieton River below Rimrock Dam. A total of 84 (73 mainstem and large tributary reaches, 11 reaches in small creeks receiving irrigation returns) of 416 reaches in the Yakima Subbasin are potentially affected by the Black Rock project. All of these reaches, or at least the mainstem and major tributary reaches, must be evaluated for fisheries impacts.

flow-specific complexity value be passed on to the DMI process, so long as the perimeters and areas, and the applicable flow and reach, are identified.

The reach-specific pattern for the side channel complexity attribute cannot be computed until a much later process, when monthly complexity values have been computed and these values have been transformed into EDT ratings. The process of creating a pattern for complexity uses the "standard pattern", which consists simply of estimating the ratio of the *rating* of the attribute for a given month to the *maximum rating* for the attribute across all months. Note that the values upon which EDT ratings are based are usually numerically quite different from the ratings themselves, and that patterns are based on ratings.

Table 9 exemplifies the process of computing values, assigning ratings and developing patterns for the side channel complexity attribute in a hypothetical reach.

## Table 9. Example of calculating side channel complexity values, EDT ratings and patterns for a hypothetical reach

| | Input Values from GIS Queries | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| Month | Reach Wetted Perimeter (ft) | Reach Wetted Area ($ft^2$) | Perimeter/Area, Reach | Main Channel Wetted Perimeter (ft) | Main Channel Wetted Area ($ft^2$) | Perimeter/Area, Main Channel | Complexity Value | Complexity Rating | Complexity Patern |
| JAN | 95,040 | 792,000 | 0.12 | 57,024 | 712,800 | 0.08 | 50.0% | 2.125 | 0.56 |
| FEB | 235,752 | 1,254,000 | 0.19 | 138,622 | 1,128,600 | 0.12 | 53.1% | 2.087 | 0.55 |
| MAR | 264,000 | 1,320,000 | 0.20 | 128,040 | 1,188,000 | 0.11 | 85.6% | 1.680 | 0.45 |
| APR | 396,000 | 1,650,000 | 0.24 | 126,720 | 1,485,000 | 0.09 | 181.3% | 0.688 | 0.18 |
| MAY | 594,000 | 1,980,000 | 0.30 | 149,688 | 1,782,000 | 0.08 | 257.1% | 0.214 | 0.06 |
| JUN | 425,568 | 1,716,000 | 0.25 | 212,784 | 1,544,400 | 0.14 | 80.0% | 1.750 | 0.46 |
| JUL | 101,376 | 792,000 | 0.13 | 81,101 | 712,800 | 0.11 | 12.5% | 3.000 | 0.80 |
| AUG | 39,600 | 396,000 | 0.10 | 31,680 | 356,400 | 0.09 | 12.5% | 3.000 | 0.80 |
| SEP | 16,500 | 330,000 | 0.05 | 14,025 | 297,000 | 0.05 | 5.9% | 3.441 | 0.91 |
| OCT | 10,560 | 264,000 | 0.04 | 9,293 | 237,600 | 0.04 | **2.3%** | **3.773** | **1.00** |
| NOV | 17,160 | 330,000 | 0.05 | 14,758 | 297,000 | 0.05 | 4.7% | 3.535 | 0.94 |
| DEC | 68,640 | 660,000 | 0.10 | 52,166 | 594,000 | 0.09 | 18.4% | 2.605 | 0.69 |

| Translation Regressions: Complexity Values to EDT Complexity Ratings | | | | |
|---|---|---|---|---|
| Complexity Value | Complexity Rating | Value Interval for Regression | Regression Constant | Regression Coefficient |
| 300% | 0.0 | >=300% | | |
| 200% | 0.5 | 200% to <300% | -0.5 | 1.5 |
| 150% | 1.0 | 150% to <200% | -1 | 2.5 |
| 100% | 1.5 | 100% to <150% | -1 | 2.5 |
| 60% | 2.0 | 60% to <100% | -1.25 | 2.75 |
| 20% | 2.5 | 20% to <60% | -1.25 | 2.75 |
| 12.5% | 3.0 | 12.5% to <20% | -6.666666667 | 3.833333333 |
| 5% | 3.5 | 5% to <12.5% | -6.666666667 | 3.833333333 |
| 0% | 4.0 | 0% to <5% | -10 | 4 |

The Complexity Value column in the top right of Table 9 represents the difference of edge/area for the reach as a whole and the main channel alone divided by the edge/area of the main channel. This value is translated into an EDT rating on the basis of the relationships in the lower portion of the table.

Note also that the Excel Workbook Pattern Master.xls (attached as an appendix to this report) includes all calculations in Table 9 and in all other tables presented in this section.

Depth of Groundwater Channels, Ponds and Wetlands. Although procedures for estimating wetland depth have not yet been described, and pond depth cannot be estimated with either R2D or HEC-RAS, depth parameters for all off-channel habitat types are discussed here in the context of patterns and considerations relating to multiple features per reach.

The depth of groundwater channels, at least, can be estimated from R2D output, so long as depth is primarily attributable to backwatering. Therefore, it is necessary to develop a procedure to estimate the mean depth of groundwater channel polygons and to link this value to a specific reach and flow. Estimating pond depth is problematic with the tools available because ponds are often located some distance from the main river (and thus are outside R2D coverage) and because backwatering is not usually the primary determinant of pond depth (groundwater, evaporation and surface inflow from tributaries usually play significant roles). Therefore monthly ratings for the pond depth attribute must be estimated by professional judgment and/or empirical observation. Wetland depth can be approximated from appropriately placed HEC-RAS transects, but this process is complicated by the fact that wetlands typically drain rather slowly. Therefore, the wetted area and depth of seasonal wetlands does not immediately fall to zero when discharge falls below bankfull. Because of the special need to allow for drainage time during periods of flow below bankfull, the procedures for estimating wetland area are discussed separately.

In spite of these complications, the relationship between depth and EDT ratings is the same for all off-channel features, and patterns are all “standard” for the depth attributes. Table 10 summarizes the relationship between values and EDT ratings for depth and illustrates the computation of a standard pattern just like that described for side channel complexity.

If more than one groundwater channel occurs in a single reach, the depth assigned to this attribute is the weighted mean, where the weighting factor is the relative wetted area of the groundwater channels under the flow simulated. The same consideration applies to assigning depth to ponds in reaches containing more than one pond. Considerations related to multiple features do not apply to wetlands because seasonal wetlands are always considered as a unit within a reach, regardless of whether all wetland features are actually contiguous.

### Table 10. Example of calculating EDT depth ratings and patterns for a hypothetical off-channel habitat feature.

| | | | | Translation Regressions: Depth Values to EDT Depth Ratings | | | | |
|---|---|---|---|---|---|---|---|---|
| **Month** | **Depth of Feature (ft)** | **EDT Depth Rating** | **Depth Patern** | **Depth Value** | **Depth Rating** | **Value Interval for Regression** | **Regression Coefficient** | **Regression Constant** |
| JAN | 1.6 | 2.900 | 0.73 | 6.0 | 0.0 | >6.0 ft | | |
| FEB | 4.0 | 1.000 | 0.25 | 5.0 | 0.5 | 5ft to <6 ft | -0.5 | 3 |
| MAR | 4.5 | 0.750 | 0.19 | 4.0 | 1.0 | 4 ft to <5 ft | -0.5 | 3 |
| APR | 5.6 | 0.200 | 0.05 | 3.0 | 1.5 | 3 ft to < 4 ft | -0.5 | 3 |
| MAY | 6.5 | 0.000 | 0.00 | 2.5 | 2.0 | 2,5 ft to <3 ft | -1 | 4.5 |
| JUN | 5.0 | 0.500 | 0.13 | 2.0 | 2.5 | 2.0 ft to < 2.5 ft | -1 | 4.5 |
| JUL | 3.0 | 1.500 | 0.38 | 1.5 | 3.0 | 1.5 ft to < 2.0 ft | -1 | 4.5 |
| AUG | 1.5 | 3.000 | 0.75 | 1.0 | 3.5 | 1.0 ft to < 1.5 ft | -1 | 4.5 |
| SEP | 1.0 | 3.500 | 0.88 | 0.5 | 4.0 | 0.5 ft to < 1.0 ft | -1 | 4.5 |
| **OCT** | **0.3** | **4.000** | **1.00** | | 4.0 | <0.5 ft | | |
| NOV | 0.8 | 3.700 | 0.93 | | | | | |
| DEC | 1.0 | 3.5 | 0.88 | | | | | |

<u>Pond Proximity.</u> Pond proximity is basically the length of the pond outlet -- the distance in feet from the beginning of a pond outlet to the edge of the main river (the bank of the main channel or a side channel). Technically, this attribute is hydrographic, because this distance changes slightly as the width of the main river increases and decreases with flow. Therefore, for rivers or geographic portions of rivers with numerous ponds, queries could be written to estimate the distance along outlet channels from the bank of the main river to the edge of the pond for each flow modeled. As with other attributes, regressions of outlet length as a function of the flow interval modeled would be developed, and these regressions should be applied to the median monthly flows expected under a scenario. The median monthly lengths computed by this process should then be transformed into EDT ratings on the basis of the relationships summarized in Table 10 (and repeated below), and the standard pattern should be created from the monthly ratings (ratio of monthly rating to maximum monthly rating).

However, the distance intervals over which pond proximity is rated as an EDT attribute are large relative to the seasonal changes that can be expected in the width of the main river. Specifically, the distance intervals defining proximity ratings of 0 to 4 are, respectively, 0 – 200 ft, 200 – 500 ft, 500 – 1,200 ft, 1,200 – 3,600 ft, and > 3,600 ft, respectively. Because hydrographic fluctuations in the monthly mean width of main and side channels are usually less than 200 ft, the smallest interval in the rating range, it is probably acceptable consider pond proximity a constant. This is especially true within the Yakima Subbasin, where ponds with consistently accessible outlet channels are relatively rare. We conclude that it is acceptable to estimate pond proximity once, at bankfull flow, and then to use this value for all months and all scenarios.

Side Channel Velocity Type. Side channel velocity type indexes the suitability of side channel habitat in terms of the ability of salmonid fry to hold position against a current. The convention adopted in EDT is that fry can hold position indefinitely in water flowing at 0.4 fps or less[8]. Therefore, the task in rating this attribute is to determine the proportion of the wetted area of *all* side channels in the reach that carry flows with a mean velocity of 0.4 fps or less, and then to assign an EDT rating on the basis of the relationships summarized in Table 11. More specifically, procedures must be written to estimate the mean velocity of all wetted points within the side channel polygons in a reach, and a series of regressions must be generated that give the mean percent of side channel area with velocities <= 0.4fps as a function of the flows modeled under R2D. Median monthly flows for a scenario are then substituted into these regressions to estimate the proportion of side channel area with acceptable velocity, and these monthly percentages are converted into EDT ratings on the basis of the regressions in Table 11. The applicable pattern to shape the attribute over months is the standard, rating-based pattern.

Table 11. Relationship between EDT rating for side channel velocity type and proportion of side channel wetted area in which velocity is 0.4 fps or less.

| Velocity Type Value (% area <= 0.4 fps) | Velocity Type Rating | Value Interval for Regression | Regression Coeffficient (slope) | Regression Constant (intercept) | Check |
|---|---|---|---|---|---|
| 100.0% | 0 | | | | |
| 90.0% | 0.5 | 90 to 100% | -5.00 | 5.00 | 0.5 |
| 82.5% | 1 | 82.5 to less than 90% | -6.67 | 6.50 | 1 |
| 75.0% | 1.5 | 75 to less than 82.5% | -6.67 | 6.50 | 1.5 |
| 52.5% | 2 | 52.5 to lss than 75% | -2.22 | 3.17 | 2 |
| 40.0% | 2.5 | 40 to less than 52.5% | -4.00 | 4.10 | 2.5 |
| 27.5% | 3 | 27.5 to less than 40% | -4.00 | 4.10 | 3 |
| 10.0% | 3.5 | 10 to less than 27.5% | -2.86 | 3.79 | 3.5 |
| 0.0% | 4 | 0 to less than 10% | -5.00 | 4.00 | 4 |

Volitional Accessibility Ponds. Volitional accessibility of ponds is determined by the frequency of days in a month when mean depth on the outlet channel is at least four inches. As mentioned, however, none of the models available are capable of estimating outlet depth reliably. Therefore, at the present time, ratings or this attribute must be assigned on the basis of professional judgment.

**Step Five: Making Provisions for Seasonal Wetlands and Off-channel Attributes**

HEC-RAS analysis along transects that intersect ponds, the heads of groundwater channels and known or presumed locations for seasonal wetlands was identified as an

[8] A maximum approach velocity of 0.4 fps has been adopted by WDFW as the criterion for fish screens. Velocities of 0.4 fps or less have been shown to eliminate impingement risk of newly emergent fry in irrigation screens.

alternative model for characterizing these features. The alternative is to base the ratings simply on the basis of professional judgment.

Off-channel attributes such as passive accessibility require a hydraulic model capable of estimating the depth and extent of overbank flow on the floodplain. R2D models are too time- and labor-intensive to run for flows extending far into the floodplain. HEC-RAS simulations can be used to evaluate habitat conditions under substantial flooding[9]. HEC-RAS transects intersecting the head of each groundwater channel and the margin of each pond must be created if passive accessibility of these features is to be calculated from hydraulic modeling. More precisely, at this step in the process, two points defining the streambank and the head of a groundwater channel or the margin of a pond must be entered into the GIS database. Subsequent HEC-RAS simulations of a range of **supra-bankfull** flows will be performed along the transect defined by these points.

The area of seasonal wetlands can also be calculated from HEC-RAS output. The initial step in doing so consists of manually adding pairs of points to a GIS data layer that define a transect for a subsequent HEC-RAS estimates of the area of inundated floodplain under a range of supra-bankfull flows. As with groundwater channel and pond transects, one point should define the streambank while the other should be sufficiently far off stream to be above any areas likely to be inundated under modeled flows. Every reach should include at least four transects, one for each bank at the upper and lower reach boundaries. Unconfined reaches, and/or those known to be subject to frequent flooding, should receive additional transects. Procedures are described in more detail in the next section of this report.

**Step Six: Analyzing Flows Less Than Bankfull**

The last step in this process is to analyze R2D output at flows less than bankfull. Each flow simulated in the R2D models is superimposed over the aerial photographs and the polygons defining ponds, groundwater channels, beaver ponds and backwater pools and the hash marks that define side channels created at the bankfull flow simulation.

After superimposing these data layers, three operations must be performed:

- Braids must be identified and encircled by polygons attributed to the "braid" habitat type. As mentioned, a fundamental characteristic of braids is that the gravel bars that define them are submerged at bankfull flow. Therefore, for

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[9] Provisions for modeling extensive flooding of the floodplain with R2D were not made early in the process for reasons other than the time required for such simulations. Initially, the decision was made to base as many habitat quantification procedures as possible on median monthly flows, because it was considered unlikely that the river would ever be managed for overbank flows in any reach. While this premise is still true, it is nonetheless also true that flooding will occur occasionally under almost any scenario, and some habitat attributes are intrinsically defined by the frequency and extent of flooding.

the first and all subsequent sub-bankfull flows, polygons must be drawn around any newly visible braids. These polygons can include both banks and upper and lower boundary lines defining the uppermost and lowermost braid in the cluster (or simply the upstream and downstream end of a small braid). Most reaches in the Yakima basin do not include braids at any flow so this step is expected to be required for only a few reaches.

- Individual side channels must be inspected for continuity and continuity status recorded. Continuity is defined as water entering side channel and flow continuously to outlet of side channel.
- The bankfull-flow polygons for backwater pools must be inspected to verify that they still circumscribe backwater pools accurately. Inaccurate polygons must be redrawn and/or deleted.
- After inspection/revision of backwater pool polygons, all of the procedures computing habitat area and qualitative attributes are invoked again.

## 4.1 Summary

At this point the groundwork has been laid for all subsequent habitat analysis. As well, the first points in a series of regressions linking flow to habitat attributes will have been developed. Although the details of these calculations will be presented in Section 6.0 (DETAILED HABITAT CALCULATIONS AND DMI ISSUES), it is appropriate to point out here that the "bankfull flow points" for the following regressions will have been generated by this point:

1. Percent in-channel area occupied by braids = f(Q)[10];
2. Percent in-channel area occupied by primary pools = f(Q);
3. Percent in-channel area occupied by tail-outs = f(Q);
4. Percent in-channel area occupied by small cobble/gravel riffles = f(Q);
5. Percent in-channel area occupied by large cobble/boulder riffles = f(Q);
6. Percent in-channel area occupied by glides = f(Q);
7. Percent in-channel area occupied by beaver ponds = f(Q);
8. Percent in-channel area occupied by backwater pools = f(Q);
9. Percent in-channel area occupied by side channels = f(Q);
10. Side channel complexity = f(Q);
11. Side channel velocity type = f(Q);

[10] The dependant variable for this point will be 0, because braids disappear at bankfull flow by definition.

12. Side channel connectivity = f(Q)[11];
13. Area (acres) of groundwater channel(s) = f(Q);
14. Area (acres) of pond(s) = f(Q)[12].
15. Depth of groundwater channel(s) = f(Q);
16. Depth of pond(s)[13] = f(Q);
17. Proximity of pond(s) to main channel = f(Q);
18. Volitional accessibility of pond(s) = f(Q).

Each of these 18 regressions need not be calculated for each reach affected by a specific storage scenario. Some reaches will not contain side channels, braids, or off-channel habitat, so regressions evaluating such features are unnecessary. However, reaches containing all of the habitat types previously described will require all regressions. The minimum number of regressions needed for a reach will be the seven giving the composition of in-channel area in terms of geomorphic units (for very confined reaches with essentially no floodplain, side channels, braids or off-channel habitat).

The remaining regressions all relate to habitat conditions during flooding (overbank flow) and therefore entail the use of HEC-RAS simulations (see Section 5.0). There are four such regressions:

1. Depth of seasonal wetlands = $f(Q_{overbank})$;
2. Passive accessibility of seasonal wetlands = $f(Q_{overbank})$;
3. Passive accessibility of groundwater channels = $f(Q_{overbank})$;
4. Passive accessibility of pond(s) = $f(Q_{overbank})$.

Thus, for complex reaches as many as 22 regressions or lookup tables might be required. Well defined, automated GIS procedures to compute, store and summarize key parameters will greatly simplify these tasks. Most of this development can be completed as each support model is completed for a particular area of the basin.

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[11] In this particular case, the point will not be used in a regression, but a lookup table.

[12] Pond area may be based on a monthly lookup table instead of a regression and, in any case, cannot be calculated with available discharge-based tools. Professional judgment or some other tool will be needed.

[13] Pond depth may be based on a monthly lookup table instead of a regression and, in any case, cannot be calculated with available discharge-based tools. Professional judgment or some other tool will be needed

# 5.0 HEC-RAS CALCULATIONS

All of the habitat attributes related to flooding (passive accessibility of ponds, wetlands and groundwater channels; seasonal wetland area) must be estimated from HEC-RAS analyses at strategically placed transects (previous step). This section describes in general terms an approach for using HEC-RAS output to estimate the previously mentioned attributes. The details of estimating these complex attributes individually will be presented in Section 6.0.

The first objective of a HEC-RAS analysis it to estimate operational bankfull flow for the reach under consideration and to locate the point in space that represents the crest of the bank at the threshold of flooding along a specific transect. Operational bankfull flow is to be understood as the flow that results in water entering the floodplain in the face of natural banks, dikes, levees, road embankments, etc. Operational bankfull flow is contrasted with “statistical bankfull flow”, which is usually expressed in terms of a recurrence interval (often the Q1.5y – Q2y) and does not consider local topography. A reasonably accurate estimate of operational bankfull flow is essential because passive accessibility occurs only when the river is actually flowing outside its banks. In addition, the crest of the bank along a specific transect is important because the distance from this point to the limit of inundation defines the width of a seasonal wetland (or a portion of a seasonal wetland).

Figure 3 schematically illustrates the way HEC-RAS output along a three transects placed at the upstream and downstream boundaries of two contiguous reaches are used to estimate wetland area (in reality, the HEC-RAS transects are perpendicular to stream flow). The discussion of the process illustrated by Figure 3 also is germane to calculating passive accessibility because it results in the estimate of an “inundation width” – a distance from bank crest to the furthest on the floodplain reached by overbank flow. If this inundation width extends to the head of a groundwater channel or the edge of a pond along one of the transects defined in step five of the previous section, then the groundwater channel or pond is considered to be passively accessible for the flow modeled.

Figure 3 shows a pair of hypothetical reaches analyzed by HEC-RAS along transects defined at the reach boundaries. The dark blue area, the margins of which represent the bank crests, represents the wetted area of the main channel in the figure. The distances L1 and L2 do not represent reach lengths, which are shown by the dark black line down the middle of the main channel, but rather the north-south projections of the distances between the reach breaks. The distances w1 – w8, extending from the stream bank crests to points on the floodplain, represent inundation widths for the modeled flow as estimated by HEC-RAS output.

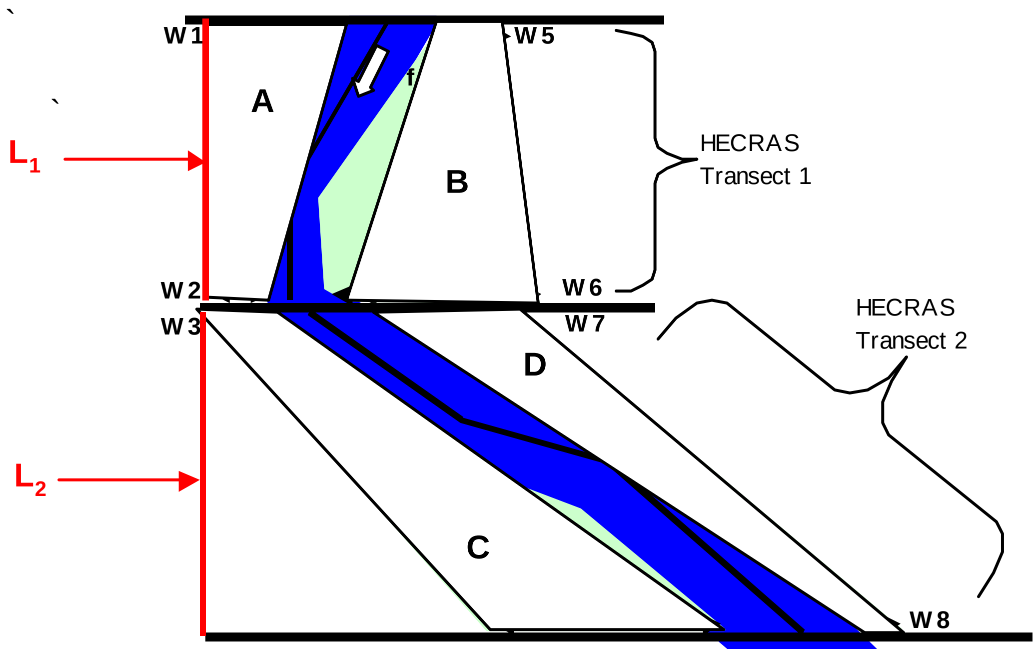


Figure 3. Illustration of process of computing wetted area of seasonal wetlands during periods of overbank flow using output from the HEC-RAS model.

In Figure 3, the green shading (both light and dark) represents "true" areas of floodplain inundation. The areas shaded in light green – the trapezoids A, B, C and D -- represent an inundation area that can be computed from HEC-RAS and GIS analysis. Explicitly, the area of seasonal wetland created by the flow modeled in this example would be the areas of the light green trapezoids: for trapezoid A, area = (w1 + w2)/2 * L1. Thus, the area of seasonal wetland in the upper reach in Figure 3 would be (w1 + w2 + w5 + w6)/2 * L1, and the wetland area for the lower reach would be (w3 + w4 + w7 + w8)/2 * L2.

Regarding passive accessibility, if the head of a groundwater channel or the margin of a pond on a HEC-RAS transect is within the inundation width for a specific overbank flow, then that groundwater channel or pond is passively accessible but *only while that overbank flow is occurring*. Therefore, the inundated widths HEC-RAS predicts along transects associated with ponds and groundwater channels must be overlaid on the aerial photographs and the polygons defining ponds and groundwater channels. If a procedure cannot be written to automatically identify the intersection of an inundated width with a pond or groundwater channel, then this condition must be determined by visual inspection. But by whatever means, it is necessary to determine those overbank flows that extend to ponds and groundwater channels, and to record the flows that link these features to the main channel for use in computing scenario-specific passive accessibility (see Section 6.0).

# 6.0 EXPLICIT HABITAT CALCULATIONS AND DMI ISSUES FOR COMPLEX ATTRIBUTES

## 6.1. Wetland Area, Depth and Passive Accessibility

The calculation of these three attributes for wetlands are related, so all three will be described in a single section. Because the series of calculations begins with wetland area, this attribute will be discussed first. (Note: all of the calculations described below are included in the Excel Workbook "Wetland Procedures 7 Day.xls", which should be consulted for mathematical details).

### 6.1.1. Wetland Area

As previously mentioned, the major factor complicating the estimation of wetland attributes is the fact that wetlands fill rapidly during floods but drain quite slowly after flows fall below bankfull. The assumption made by EDT is that inundation occurs to the limit of backwatering virtually instantaneously. Wetland draining and the loss of wetted area, on the other hand, are assumed to occur over a seven-day period, with 1/7$^{th}$ of the area lost each day flows remain below bankfull. If flows again exceed bankfull during this 7-day period then the wetland area is reset back to the maximum area and the 7-day period is restarted.

The first step in calculating wetland area is to develop a regression between flow and wetted area. The HEC-RAS procedures and the geometrical considerations behind estimating the area covered by specific flood flows were described in the previous section. On the basis of a series of such calculations covering a range of flows above bankfull, a table like Table 12 is developed.

Regressions like those in Table 12 are then applied to the chronological series of mean daily flows in the Riverware time series for the scenario being assessed. The actual chronological series of daily values must be used in sequence because the draining of areas following flooding is event-specific, as is timing of overbank flows. It is assumed that the range of flows simulated with HEC-RAS is wide enough to include all of the flows included in the time series. The instantaneous area of flooded floodplain is determined by applying the regression applicable to the range of flows that includes the flow being estimated (by means of a nested series of IF statements or their equivalents).

## Table 12. Series of hypothetical flow-specific regressions needed to calculate seasonal wetland area as a function of flows greater than operational bankfull.

| Flow | Flooded Area (acres) | Flow range covered by Regression | Regression Coefficient (slope) | Regression Intercept (constant) |
|---|---|---|---|---|
| 5000 | 0 | 5,000 cfs = operational bankfull | | |
| 6000 | 200 | From 5,000 - 6,000 | **0.2** | **-1000** |
| 7000 | 250 | From 6,000 - 7,000 | **0.05** | **-100** |
| 8000 | 350 | From 7,000 - 8,000 | **0.1** | **-450** |
| 9000 | 500 | From 8,000 - 9,000 | **0.15** | **-850** |
| 10000 | 850 | From 9,000 - 10,000 | **0.35** | **-2650** |

Although the area is computed on a daily basis, the EDT rating for this attribute is the average area for all days in the month.

Table 13 represents a small portion of a spreadsheet that calculates flooding and the 7-day recession of wetted area for the floodplain in a hypothetical reach in which operational bankfull flow is assumed to be 5,000 cfs. The far right column in Table 13 represents wetland area allowing for drainage rate and interruptions of drainage caused by new episodes of overbank flow. Wetland area increases every day that overbank flow increases from the previous day; drainage does not begin until flows have dropped below bankfull. Once flows have dropped below bankfull, $1/7^{th}$ of the area is lost per day. Finally, the area assigned to a day is either the area flooded by the flow occurring on that day (e.g., June 18), or the wetted area *remaining* from flooding on a previous day (June 19), *whichever is larger*.

## Table 13. Estimation of area of seasonal wetland on a daily basis from Riverware flow estimates. For a hypothetical reach or portion of a reach.

| WATER YEAR | Date | Julian Date | Flow Entering Reach | Wetland Area from Daily Flow Regressions | Calc 1 | Calc 2 | Calc 3 | Calc 4 | Calc 5 | Calc 6 | Area Allowing for Drainage Time |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 2006 | 15-Jun | 166 | 4743 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | **0.00** |
| 2006 | 16-Jun | 167 | 5258 | **51.60** | **51.60** | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | **51.60** |
| 2006 | 17-Jun | 168 | 5398 | **79.60** | **79.60** | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | **79.60** |
| 2006 | 18-Jun | 169 | 5651 | **130.20** | **130.20** | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | **130.20** |
| 2006 | 19-Jun | 170 | 5401 | **80.20** | **111.60** | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | **111.60** |
| 2006 | 20-Jun | 171 | 5524 | **104.80** | **104.80** | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | **104.80** |
| 2006 | 21-Jun | 172 | 5201 | **40.20** | **89.83** | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | **89.83** |
| 2006 | 22-Jun | 173 | 4806 | 0.00 | 0.00 | **74.86** | 0.00 | 0.00 | 0.00 | 0.00 | **74.86** |
| 2006 | 23-Jun | 174 | 4401 | 0.00 | 0.00 | 0.00 | **59.89** | 0.00 | 0.00 | 0.00 | **59.89** |
| 2006 | 24-Jun | 175 | 4184 | 0.00 | 0.00 | 0.00 | 0.00 | **44.91** | 0.00 | 0.00 | **44.91** |
| 2006 | 25-Jun | 176 | 4165 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | **29.94** | 0.00 | **29.94** |
| 2006 | 26-Jun | 177 | 3920 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | **14.97** | **14.97** |
| 2006 | 27-Jun | 178 | 569 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | **0.00** |

The algorithms behind the calculations in Table 13 are shown in . The numbers in column I represent the maximum of the values in columns C through H. The maximum value function allows the selection of the larger of the areas representing daily floodplain inundation or floodplain drainage, respectively. Column C determines whether a flooded area on a given day is larger than the area on the previous day and, if not, whether the previous day's area was $6/7^{th}$ of the area two days ago. If flooded area increases on a given day, this value is recorded in Column C (and column I as the flooded area for the day). If the area recorded in Column C for the previous day is *not* $6/7^{th}$ of the area two days ago, then $6/7^{th}$ of the area on the previous day is entered. Column C is thus entering the area associated with the flow on a given day, or the $1/7^{th}$ loss in area from the previous day attributed to wetland draining. Columns D through H make similar computations for wetland area following 2-7 days of draining. An inspection of the Excel Workbook "Wetland Procedures 7 Day.xls" will make the logic behind this procedure clear.

The process just described must be applied to each day in the Riverware time series. The mean area for all of the days comprising each month represents the monthly mean area for seasonal wetlands. The pattern applied across months is simply the ratio of the area for a given month to the maximum area across all months.

### 6.1.2. Wetland Depth

A cross-section of HEC-RAS output across a hypothetical stream/floodplain transect is shown in Figure 4. The stream bathymetry and water surface elevation at bankfull flow are shown in dark blue, while water surface elevation and the inundated width of floodplain under a specific flood flow are shown in green. It is possible to compute depth along a series of points on the floodplain (vertical lines), and to compute mean depth as the average of these values.

It will be necessary to conduct a series of HEC-RAS analyses such as that illustrated in Figure 4 to develop a regression of mean wetland depth on flow. Such a regression, however, does not finish the story because of the assumption that wetlands drain over a seven-day period.

To accommodate water retention in wetlands, it is necessary to develop a regression giving wetland depth as a function of wetland *area*. This is so because the calculations underlying wetland area have been designed to reflect a seven-day wetland drainage cycle. Therefore information as shown in Table 15 must be created to allow wetland depth to be estimated from the areas expected under the range of flows modeled by HEC-RAS.

Table 14. Example of calculations needed to compute wetland area allowing for a linear, 7-day decay of area during periods of flow less than bankfull and instantaneous flooding when flows exceed bankfull.

| A | B | C | D | E | F | G | H | I |
|---|---|---|---|---|---|---|---|---|
| 2 | Instantaneous Wetland Area from Daily Flow Regressions | Calc 1 | Calc 2 | Calc 3 | Calc 4 | Calc 5 | Calc 6 | Area Allowing for Drainage Time |
| 3 | 0 | | | | | | | |
| 4 | 0 | | | | | | | |
| 5 | 0 | | | | | | | |
| 6 | 0 | | | | | | | |
| 7 | 0 | | | | | | | |
| 8 | 0 | | | | | | | |
| 9 | 0 | | | | | | | |
| 10 | 51.6 | =IF(B10>B9,B10,IF( C9<>(1-1/7)*C8,(1-1/7)*C9,0)) -- equals 51.6 | =IF( AND(C10=0,C9=(1-1/7)*C8),C8*(1-2/7),0) | =IF( AND(D10=0,D9=(1-2/7)*C7),(1-3/7)*C7,0) | =IF( AND(E10=0,E9=(1-3/7)*C6),(1-4/7)*C6,0) | =IF( AND(F10=0,F9=(1-4/7)*C5),(1-5/7)*C5,0) | =IF( AND(G10=0,G9=(1-5/7)*C4),(1-6/7)*C4,0) | =MAX(B10:H10) -- equals 51.6 |
| 11 | 79.6 | 79.6 | 0 | 0 | 0 | 0 | 0 | 79.6 |
| 12 | 130.2 | 130.2 | 0 | 0 | 0 | 0 | 0 | 130.2 |
| 13 | 80.2 | 111.6 | 0 | 0 | 0 | 0 | 0 | 111.6 |
| 14 | 104.8 | 104.8 | 0 | 0 | 0 | 0 | 0 | 104.8 |
| 15 | 40.2 | 89.82857143 | 0 | 0 | 0 | 0 | 0 | 89.8 |
| 16 | 0 | 0 | 74.85714286 | 0 | 0 | 0 | 0 | 74.9 |
| 17 | 0 | 0 | 0 | 59.88571429 | 0 | 0 | 0 | 59.9 |
| 18 | 0 | 0 | 0 | 0 | 44.91428571 | 0 | 0 | 44.9 |
| 19 | 0 | 0 | 0 | 0 | 0 | 29.94285714 | 0 | 29.9 |
| 20 | 0 | 0 | 0 | 0 | 0 | 0 | 14.97142857 | 15.0 |
| 21 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0.0 |

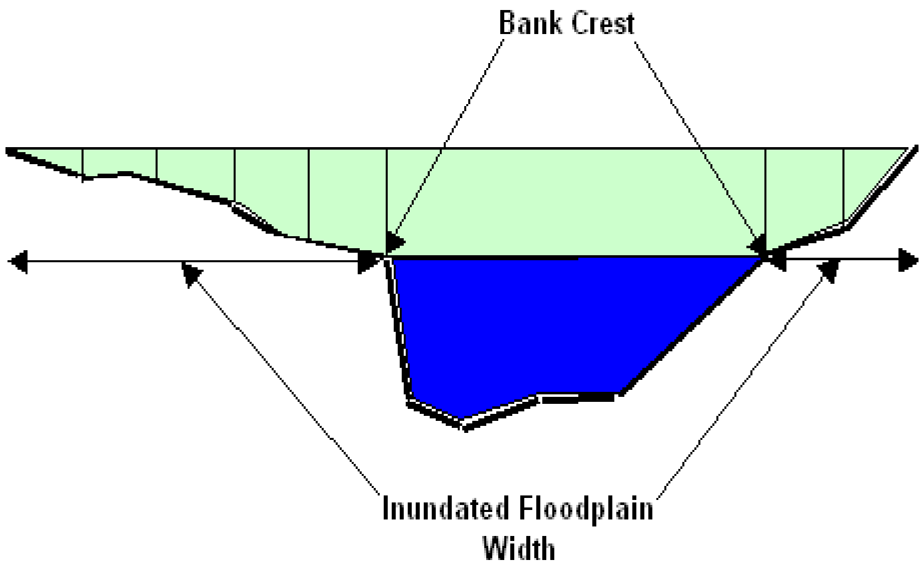


Figure 4. Cross section of hypothetical stream and floodplain at bankfull flow and at a flow greater than bankfull illustrating how the mean depth of seasonal wetlands is estimated. Flood flows/water surface elevations in green; bankfull flow/water surface elevation in blue.

Table 15. Example of table giving a series of regressions of wetland depth as a function of wetland area for a hypothetical reach.

| Flow | Flooded Area (acres) | Mean Depth (feet) of flooded area | Applicable Area Interval | Slope coefficient, m | Constant, b |
|---|---|---|---|---|---|
| 4000 | 0 | 0 | | | |
| 5200 | 200 | 6 | From 0 - 200 acres | 0.03 | 0 |
| 6400 | 250 | 7 | From 200 - 250 acres | 0.02 | 2 |
| 7600 | 350 | 12 | From 250 - 350 acres | 0.05 | -5.5 |
| 8800 | 500 | 18 | From 350 - 500 acres | 0.04 | -2 |
| 10000 | 850 | 20 | From 500 - 850 acres | 0.005714286 | 15.14285714 |

After the relationships depicted in Table 15 have been established, it is a relatively simple matter to link the area and depth spreadsheets (or functional equivalents of spreadsheets), to compute wetland depth as a function of area for every day in the time series, and then to estimate monthly mean depth as the average of the days comprising each month over the Riverware time series.

The final step is to convert mean monthly depth of wetlands into 0-4 ratings for the EDT attribute (Table 16) and compute a monthly pattern using the standard method of the ratio of the mean monthly *rating* to the maximum *rating* across all months.

Table 16. Relationship between mean monthly wetland depth (in feet) and EDT wetland depth ratings. Note that regressions do not apply to mean depths >= 6 ft or <=0.5 ft, because the EDT ratings are 0.0 for all depths >= 6 ft and 4.0 for all depths <= 0.5 ft, respectively.

| Monthly Mean Depth Value (ft) | Depth Rating | Applicable Depth Interval | Regression Slope | Regression Constant |
|---|---|---|---|---|
| 6 | 0 | >= 6 ft, rating = 0 | | |
| 5 | 0.5 | From 5 ft to < 6 ft | -0.5 | 3 |
| 4 | 1 | From 4 ft to < 5 ft | -0.5 | 3 |
| 3 | 1.5 | From 3 ft to < 4 ft | -0.5 | 3 |
| 2.5 | 2 | From 2.5 ft to <3 ft | -1 | 4.5 |
| 2 | 2.5 | From 2 to < 2.5 ft | -1 | 4.5 |
| 1.5 | 3 | From 1.5 ft to < 2 ft | -1 | 4.5 |
| 1 | 3.5 | From 1 ft to < 1.5 ft | -1 | 4.5 |
| 0.5 | 4 | From 0.5 ft to < 1 ft | -1 | 4.5 |
| <.5 | 4 | Less than 0.5 ft, rating = 4 | | |

## 6.1.3. Passive Accessibility, Wetlands and Groundwater Channels

Passive accessibility of groundwater channels, ponds and wetlands describes the likelihood that juvenile fish might be swept into these features by overbank flows. These attributes are determined by the mean monthly frequency of overbank flows. Passive accessibility is not assumed to occur during drainage of an off-channel feature. The core of this computational step is the estimation of the mean proportion of days in a month that flows exceed bankfull *and extend far enough into the floodplain to link the main channel hydraulically to the off-channel feature.* Table 17 summarizes the relationship between the mean fraction of days per month of passive accessibility and the EDT rating for passive accessibility.

Table 17. Relationship between EDT rating for passive accessibility and the mean percent of days per month that overbank flows link an off-channel feature to the main channel. For groundwater channels, the flow must extend from the crest of the streambank to the head of the channel. For ponds, the flow must extend from streambank crest to the pond's edge. By contrast, passive accessibility of seasonally flooded wetlands is assumed to occur with any overbank flow, although the area of wetland made available maybe very small.

| Passive Accessibility Value (% days/month of overbank flow) | EDT Passive Accessibility Rating | Applicable Accessibility Interval | Regression Slope | Regression Constant |
|---|---|---|---|---|
| 26.7% | 0 | > 26.7% | | |
| 20.0% | 0.5 | From > 20.0% to <= 26.7% | -7.50 | 2.00 |
| 16.7% | 1 | From > 16.7% to <= 20.0% | -15.00 | 3.50 |
| 13.3% | 1.5 | From > 13.3% to <= 16.7% | -15.00 | 3.50 |
| 10.0% | 2 | From > 10.0% to <= 13.3% | -15.00 | 3.50 |
| 6.7% | 2.5 | From > 6.7% to <= 10.0% | -15.00 | 3.50 |
| 4.2% | 3 | From > 4.2% to <= 6.7% | -20.00 | 3.83 |
| 1.7% | 3.5 | From > 1.7% to <= 4.2% | -20.00 | 3.83 |
| 0.0% | 4 | From > 0.0% to <= 1.7% | -30.00 | 4.00 |

Computation of passive accessibility for a seasonally flooded wetland is straightforward: the value is simply the mean percent days per month when overbank flows occur. Logically, an area of seasonal wetland must be accessible whenever flooding occurs, even though the area affected may be quite small. Computation of passive accessibility for ponds and groundwater channels, however, requires not just that overbank flows occur, but that they extend from the main channel bank to the head of a groundwater channel or an edge of the pond proper (*viz.,* not merely the pond outlet).

In the Section 5 of this report we identified the need to record specific flows conferring passive accessibility on ponds and groundwater channels. This information is used to compute the mean number of days of passive accessibility by month (the mean over all days in the Riverware time series for each month). This is then translated to an EDT 0-4 rating using the relationships in Table 17. The pattern for these attributes is the standard pattern described elsewhere.

Table 18 and Table 19 illustrate the process just described for a hypothetical reach. Table 18 is a small excerpt from a spreadsheet that tracks overbank flows over the entire Riverware time series and identifies those days on which flooding is extensive enough to make a specific pond or groundwater channel passively accessible.

Table 18. Illustration of computation of passive accessibility for an off-channel habitat feature in a hypothetical reach. In this hypothetical example, 5,000 cfs has been identified by HEC-RAS simulation as a sufficiently large overbank flow to establish passive accessibility.

| WATER YEAR | Date | Month | Discharge Entering Reach | Feature Accessible under Flow Modeled? Assume accessibility if flow >= 5,000 cfs (1 = yes, 0 = no) |
|---|---|---|---|---|
| 2007 | 5/22 | 5 | 4073 | 0 |
| 2007 | 5/23 | 5 | 4526 | 0 |
| 2007 | 5/24 | 5 | 4936 | 0 |
| 2007 | 5/25 | 5 | 5097 | 1 |
| 2007 | 5/26 | 5 | 5332 | 1 |
| 2007 | 5/27 | 5 | 5410 | 1 |
| 2007 | 5/28 | 5 | 5512 | 1 |

Table 19. Illustration of computation of mean monthly passive accessibility rating, and passive accessibility pattern, for the hypothetical reach previously analyzed by the computations in Table 18.

| MONTH | Accessibility Value | Accessibility Rating | Accessibility Pattern |
|---|---|---|---|
| 1 | 0.00% | 4.0 | 1.00 |
| 2 | 2.47% | 3.3 | 0.84 |
| 3 | 0.70% | 3.8 | 0.95 |
| 4 | 2.03% | 3.4 | 0.86 |
| 5 | 6.59% | 2.5 | 0.63 |
| 6 | 3.48% | 3.1 | 0.78 |
| 7 | 0.00% | 4.0 | 1.00 |
| 8 | 0.00% | 4.0 | 1.00 |
| 9 | 0.00% | 4.0 | 1.00 |
| 10 | 0.00% | 4.0 | 1.00 |
| 11 | 0.58% | 3.8 | 0.96 |
| 12 | 0.98% | 3.7 | 0.93 |

To summarize, wetland passive accessibility is assumed to exist under any overbank flow. HEC-RAS analyses are assumed to have been used to determine the magnitude of overbank flow necessary for specific ponds and groundwater channels to become passively accessible. In Table 18, this threshold flow was assumed to be 5,000 cfs (*viz.*, 5,000 cfs is the threshold discharge for passive accessibility for any specific off-channel feature). Note that a number of "Feature Accessible?" columns, each with a different threshold flow, will be necessary for reaches containing multiple off-channel habitat features.

Table 19 estimates the monthly percent of passively accessible days as the ratio of the sum of the number of days of passive accessibility (the number of 1s in the right-most column of Table 18) to the total days by month over the time series. The relationships in Table 17 are then used to translate values into EDT ratings, and the standard pattern is generated from mean monthly ratings.

If a reach contains more than one pond and/or groundwater channel, the passive accessibility rating assigned to each type of feature should be the weighted mean rating, where the weighting factor is relative wetted area of each feature over the days of passive accessibility. Multiple seasonal wetland areas within a single reach are considered as a unit, so there is no need to estimate a mean rating over spatially disjunct wetlands. The method of estimating weighted mean passive accessibility for reaches containing multiple ponds and/or groundwater channels is also illustrated in the Excel Workbook “Wetland Procedures 7 Day.xls”.

## 6.2. Side Channel Connectivity

Side channel connectivity quantifies the impact of the proportion of side channels that remain hydraulically connected at a given flow. A “hydraulically connected” side channel is one that carries surface flows from the point of diversion to the point of return to the main channel. As mentioned, this attribute is based on a visual interpretation of R2D model output and the creation of reach-specific files that identify each side channel and record the flows under which the side channel remains connected. All of the algorithms described here are illustrated in the Excel Workbook “Side Channel Connectivity_V5.xls”

The goal of the visual interpretation step is the generation of a dataset as shown in. This dataset identifies all of the side channels in a reach and tabulates which R2D modeled flows result in connectivity and which do not. Unlike many similar flow/habitat attribute tables, is not used to develop a series of regressions tied to specific ranges of flow. Rather, the table is used as a lookup table in which the “range_lookup” parameter is set to “TRUE”. Setting the range_lookup parameter to TRUE results in the return of a value closest to the lookup value without being greater than the lookup value. For example, consider the named range “Reach_Lookup” which includes the array P2:V13 in. The value returned for the expression VLOOKUP (1199, Reach_Lookup, 2, TRUE) would be “Y”, whereas the value for VLOOKUP (1199, Reach_Lookup, 5, TRUE) would be “N”. This method was used for simplicity’s sake and to automate the assignment of a connectivity value to flows below the lowest flow modeled (see next paragraph). Table 20 is depicted as a portion of a spreadsheet, which it does in fact represent in the Workbook “Side Channel Connectivity_V5.xls”. Presenting Table 20 as a spreadsheet will also facilitate understanding of further calculations.

Table 20. Example of side channel connectivity lookup table for a hypothetical reach containing six side channels (blue numbers). Used as the named range "Reach1_Lookup" in subsequent illustrations.

| | P | Q | R | S | T | U | V |
|---|---|---|---|---|---|---|---|
| 1 | **Flow** | **1** | **2** | **3** | **4** | **5** | **6** |
| 2 | **400** | Y | N | Y | N | N | N |
| 3 | 600 | Y | N | Y | N | N | Y |
| 4 | 800 | Y | Y | Y | N | N | Y |
| 5 | 1000 | Y | Y | Y | N | N | Y |
| 6 | 1200 | Y | Y | Y | Y | N | Y |
| 7 | 1400 | Y | Y | Y | Y | N | Y |
| 8 | 1600 | Y | Y | Y | Y | N | Y |
| 9 | 1800 | Y | Y | Y | Y | N | Y |
| 10 | 2000 | Y | Y | Y | Y | Y | Y |
| 11 | 2200 | Y | Y | Y | Y | Y | Y |
| 12 | 2400 | Y | Y | Y | Y | Y | Y |
| 13 | **2600 (named range Max_Flow)** | Y | Y | Y | Y | Y | Y |

Table 21 shows a portion of a 366-row matrix (one row for each day of the year) that determines the connectivity of each side channel in a hypothetical six-side-channel reach as a function of the median flow by day. At risk of stating the obvious, the median flows shown in column S of Table 21 represent the median value of the 23 flow values in the Riverware time series for each day[14]. The 1s and 0s in columns T through Y represent the outcomes of a lookup function assessing connectivity or lack of connectivity, respectively, by side channel as it is given by the relationships in Table 20. Side Channel #2 (column U in Table 18), for example, is connected for the first three flows, but not the last six, because connectivity of side channel #2 was not demonstrated by modeling for flows less than 800 cfs in Table 20.

All of the cells in columns T through Y make use of the connectivity/flow relationships in Table 20 to assess connectivity for a particular side channel at a particular flow. Explicitly, the content of cell T3 in Table 16 (and of all other cells in columns T through Y) is as follows:

IF($S3>Max_Flow,1,IF(ISERROR(VLOOKUP($S3,Reach1_Lookup,Q1+1,TRUE)),
0,IF(VLOOKUP($S3,Reach1_Lookup,Q1+1,TRUE) = "N",0,1)))

[14] February 29 is included in the time series, resulting in 366 days in the year. There are 5 February 29s in the Riverware time series.

## Table 21. Excerpt from spreadsheet estimating connectivity status of side channels in a hypothetical reach as a function of median flow by day over the Riverware time series of daily flows.

| | P | Q | R | S | T | U | V | W | X | Y |
|---|---|---|---|---|---|---|---|---|---|---|
| 1 | Riverware Median Flow - Lookup | | | | Connected -- 1 - Yes, 0 - No | | | | | |
| 2 | Date | Month | Julian Day | Median Flow | Status Side Chan 1 | Status Side Chan 2 | Status Side Chan 3 | Status Side Chan 4 | Status Side Chan 5 | Status Side Chan 6 |
| 3 | 10/15 | 10 | 288 | 1169 | 1 | 1 | 1 | 0 | 0 | 1 |
| 4 | 10/16 | 10 | 289 | 1223 | 1 | 1 | 1 | 1 | 0 | 1 |
| 5 | 10/17 | 10 | 290 | 1198 | 1 | 1 | 1 | 0 | 0 | 1 |
| 6 | 10/18 | 10 | 291 | 799 | 1 | 0 | 1 | 0 | 0 | 1 |
| 7 | 10/19 | 10 | 292 | 506 | 1 | 0 | 1 | 0 | 0 | 0 |
| 8 | 10/20 | 10 | 293 | 483 | 1 | 0 | 1 | 0 | 0 | 0 |
| 9 | 10/21 | 10 | 294 | 428 | 1 | 0 | 1 | 0 | 0 | 0 |
| 10 | 10/22 | 10 | 295 | 336 | 0 | 0 | 0 | 0 | 0 | 0 |
| 11 | 10/23 | 10 | 296 | 336 | 0 | 0 | 0 | 0 | 0 | 0 |

In order to understand the expression above, it is necessary to know that "Max_Flow" is a named range for the maximum flow modeled (here, 2,600 cfs), and "Reach1_Lookup" is a named range for the array P2:V13 in Table 20 (the side channel/flow/connectivity lookup table). Thus, the expression does the following:

- If flow exceeds 2,600 cfs, the side channel is connected.
- If the flow to be evaluated is less than 400 cfs, and the VLOOKUP expression therefore returns an error because no flows <400 cfs are included in the lookup array, a *lack of connectivity* is assumed. Note that this is a relatively conservative assumption because, although connectivity for flows < 400 cfs is unknown because no flows lower than 400 cfs were modeled, connectivity for Side Channels 1 and 3 *was* observed at 400 cfs. Ideally R2D modeling will cover the range of median flows in Riverware.
- If neither of the above conditions is true, the value returned is either 0 (not connected) or 1 (connected) depending upon whether the lookup function returns an "N" or a "Y".

The final step in assigning connectivity ratings to the side channels in a given reach is to calculate the proportion of days per month that each side channel is connected in Table 21, to assign an EDT rating to each side channel on the basis of the relationships summarized in Table 22, and to compute the mean rating over all side channels as illustrated by Table 23. The mean monthly rating over all side channels is the rating assigned to this attribute for each reach. The pattern assigned to the attribute is the standard, rating-based pattern.

Table 22. Relationship between EDT connectivity rating and percent days of month during which side channel is completely connected.

| Connectivity Value (% days per month) | Connectivity Rating | Value Interval for Regression | Regression Coeffficient (slope) | Regression Constant (intercept) | Check |
|---|---|---|---|---|---|
| 100% | 0 | | | | |
| 97% | 0.5 | 97 to 100% | -15.00 | 15.00 | 0.5 |
| 93% | 1 | 93 to less than 97% | -15.00 | 15.00 | 1 |
| 90% | 1.5 | 90 to less than 93% | -15.00 | 15.00 | 1.5 |
| 78% | 2 | 78 to lss than 90% | -4.29 | 5.36 | 2 |
| 67% | 2.5 | 67 to less than 78% | -4.29 | 5.36 | 2.5 |
| 50% | 3 | 50 to less than 67% | -3.00 | 4.50 | 3 |
| 33% | 3.5 | 33 to less than 50% | -3.00 | 4.50 | 3.5 |
| 7% | 4 | 7 to less than 10% | -1.88 | 4.13 | 4 |

Table 23. Illustration of computation of monthly side channel connectivity rating for a hypothetical reach containing six side channels. Top portion calculates mean percent days per month of full connectivity on basis of median daily connectivity values in Table 21, and bottom portion transforms percent connectivity values into ratings on the basis of relationships in Table 22.

| | | Connectivity % by Month and side channel | | | | | |
|---|---|---|---|---|---|---|---|
| Month # | Month | % Days Channel 1 | % Days Channel 2 | % Days Channel 3 | % Days Channel 4 | % Days Channel 5 | % Days Channel 6 |
| 11 | Nov | 100% | 0% | 100% | 0% | 0% | 0% |
| 12 | Dec | 100% | 0% | 100% | 0% | 0% | 23% |
| 1 | Jan | 100% | 35% | 100% | 0% | 0% | 87% |
| 2 | Feb | 100% | 29% | 100% | 0% | 0% | 100% |
| 3 | Mar | 100% | 100% | 100% | 61% | 0% | 100% |
| 4 | Apr | 100% | 100% | 100% | 100% | 30% | 100% |
| 5 | May | 100% | 100% | 100% | 100% | 58% | 100% |
| 6 | Jun | 100% | 100% | 100% | 100% | 60% | 100% |
| 7 | Jul | 100% | 100% | 100% | 45% | 0% | 100% |
| 8 | Aug | 100% | 94% | 100% | 26% | 0% | 100% |
| 9 | Sep | 100% | 100% | 100% | 100% | 63% | 100% |
| 10 | Oct | 81% | 55% | 81% | 42% | 0% | 58% |

| | | Connectivity Rating by Month and side channel | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Month # | Month | Rating Channel 1 | Rating Channel 2 | Rating Channel 3 | Rating Channel 4 | Rating Channel 5 | Rating Channel 6 | Reach Rating |
| 11 | Nov | 0.00 | 4.00 | 0.00 | 4.00 | 4.00 | 4.00 | **2.67** |
| 12 | Dec | 0.00 | 4.00 | 0.00 | 4.00 | 4.00 | 3.66 | **2.61** |
| 1 | Jan | 0.00 | 3.43 | 0.00 | 4.00 | 4.00 | 1.62 | **2.18** |
| 2 | Feb | 0.00 | 3.57 | 0.00 | 4.00 | 4.00 | 0.00 | **1.93** |
| 3 | Mar | 0.00 | 0.00 | 0.00 | 2.67 | 4.00 | 0.00 | **1.11** |
| 4 | Apr | 0.00 | 0.00 | 0.00 | 0.00 | 3.54 | 0.00 | **0.59** |
| 5 | May | 0.00 | 0.00 | 0.00 | 0.00 | 2.76 | 0.00 | **0.46** |
| 6 | Jun | 0.00 | 0.00 | 0.00 | 0.00 | 2.71 | 0.00 | **0.45** |
| 7 | Jul | 0.00 | 0.00 | 0.00 | 3.14 | 4.00 | 0.00 | **1.19** |
| 8 | Aug | 0.00 | 0.99 | 0.00 | 3.61 | 4.00 | 0.00 | **1.43** |
| 9 | Sep | 0.00 | 0.00 | 0.00 | 0.00 | 2.61 | 0.00 | **0.43** |
| 10 | Oct | 1.90 | 2.86 | 1.90 | 3.24 | 4.00 | 2.76 | **2.78** |

## Table 24. Computational Summary of EDT habitat attributes.

| Attribute | Modeling Needed and/or Possible? | Model Used | Flow Data Needed | Visual Interpretation Needed? | Regression Needed to Evaluate Scenario? | Critical Parameter(s) | Computation of Value Used to Assign EDT Rating | Considerations re. Multiple Features per Reach | COMMENTS |
|---|---|---|---|---|---|---|---|---|---|
| AccPasGWChan: Passive Accessibility (groundwater channels) | yes | HEC-RAS | Riverware daily flow time series | Yes; to determine hydraulic connection of head of channel to main river. | No; need only threshold flow for hydraulic connection. | Threshold flow – the particular flood flow that extends to head of channel. | % of days in month over Scenario time series in which flows reach threshold | Compute weighted mean EDT ***rating*** on basis of relative wetted areas. | Monthly pattern is the standard rating-based pattern (rating month x / maximum rating across all months). **NOTE: unless otherwise stated, all habitat-related EDT attributes have "standard" patterns.** |
| AccPasPond: Passive Accessibility (ponds) | yes | HEC-RAS | Riverware daily flow time series | Yes; to determine hydraulic connection of head of pond to main river. | No; need only threshold flow for hydraulic connection. | Threshold flow – the particular flood flow that extends to head of pond. | % of days in month over Scenario time series in which flows reach threshold | Compute weighted mean EDT ***rating*** on basis of relative wetted areas. | Monthly pattern is the standard rating-based pattern (rating month x / maximum rating across all months). |
| AccPasWet: Passive Accessibility (wetlands) | yes | HEC-RAS | Riverware daily flow time series | No | Yes -- wetted area of floodplain as a function of discharge entering reach. | Existence of overbank flows -- flows equal to or exceeding operational bankfull | % of days in month over Scenario time series that overbank flows occur, **excluding** days wetland retains water during drainage (periods without overbank flow). | none -- inundated floodplain evaluated as total area rather than discrete areas | Estimate threshold flow for overbank flows carfeully if available HEC-RAS simulations do not clearly identify threshold discharge. |

## Table 24 continued. Computational Summary of EDT habitat attributes.

| Attribute | Modeling Needed and/or Possible? | Model Used | Flow Data Needed | Visual Interpretation Needed? | Regression Needed to Evaluate Scenario? | Critical Parameter(s) | Computation of Value Used to Assign EDT Rating | Considerations re. Multiple Features per Reach | COMMENTS |
|---|---|---|---|---|---|---|---|---|---|
| AccVolPond: Volitional accessibility (floodplain ponds) | Not possible | N/A | N/A | N/A | N/A | N/A | % of days in month over Scenario time series in which mean depth of outlet channel is at least four inches. | Compute weighted mean EDT ***rating*** on basis of relative wetted area. | Because depth of pond outlet channels is not usually determined by backwatering from main river, it cannot be modeled by R2D or HEC-RAS. Attribute must be rated on basis of professional judgment. |
| ComplexSideChan: Side channel complexity | yes | R2D | Median monthly flow | Yes -- "hash marks" must be drawn at divergence and return points of all side channels in reach at bankfull flow. No further visual interpretation is needed for this attribute. | Yes -- complexity value as a function of the discharges modeled by R2D. | The ratio of the wetted perimeter to the wetted area ("edge per square foot") for all in-channel features and for the main channel only.. | The complexity value is the percent difference in edge per unit wetted area between the reach as a whole and the main channel of the reach only: $(X_{reach} - X_{main\ channel}) / (X_{main\ channel})$ | None -- side channels are evaluated as a complex for this attribute. | |

## Table 24 continued. Computational Summary of EDT habitat attributes.

| Attribute | Modeling Needed and/or Possible? | Model Used | Flow Data Needed | Visual Interpretation Needed? | Regression Needed to Evaluate Scenario? | Critical Parameter(s) | Computation of Value Used to Assign EDT Rating | Considerations re. Multiple Features per Reach | COMMENTS |
|---|---|---|---|---|---|---|---|---|---|
| ConnectSideChan: Side channel connectivity | yes | R2D | median daily flow by Julian date over Scenario time series | yes -- in addition to defining side channels at bankfull flow with hash marks, one must visualy determine whether each side channel is continuous at all less-than-bankfull flows modeled. | No, but a lookup table giving connectivity by side channel (yes = 1, no = 0) over the series of flows modeled by R2D must be developed. | Flow at which side channel becomes intermittent -- specific to individual side channels. | % of days in each month for which median daily flow equalled or exceeded the minimum flow for connectivity. | Side channel connectivity by reach is the simple mean of the **ratings** assigned to each side channel individually, | The algorithm that assesses connectivity assumes that connectivity is lost at flows below the lowest flow modeled with R2D, even if connectivity existed at that flow. Therefore, the range of flows evaluated should include a flow lower than any likely to occur under a contemplated scenario. |
| DepthGWChan: Mean depth (groundwater channels) | yes | R2D | median monthly flow | yes: polygons must be drawn around each groundwater channel at bankfull flow. No further visual interpretation or drawing is needed for this attribute | yes -- one or more regressions giving mean depth as a function of the flows modeled with R2D. | Mean depth across all modeled points within the wetted perimeter of each groundwater channel. | Simple average of depth. | Grondwater channel depth by reach is the area-weighted mean of the **ratings** assigned to each channel individually,. | Depths from R2D may underestimate true depth if the channel receives considerable groundwater input or surface flows from upland areas. |

## Table 24 continued. Computational Summary of EDT habitat attributes.

| Attribute | Modeling Needed and/or Possible? | Model Used | Flow Data Needed | Visual Interpretation Needed? | Regression Needed to Evaluate Scenario? | Critical Parameter(s) | Computation of Value Used to Assign EDT Rating | Considerations re. Multiple Features per Reach | COMMENTS |
|---|---|---|---|---|---|---|---|---|---|
| DepthPond: Mean depth (floodplain ponds) | none possible | none | none | --- | --- | --- | --- | Pond depth by reach is the area-weighted mean of the **ratings** assigned to each pond individually. | Must be based on professional judgment/observation. |

## Table 24 continued. Computational Summary of EDT habitat attributes.

| Attribute | Modeling Needed and/or Possible? | Model Used | Flow Data Needed | Visual Interpretation Needed? | Regression Needed to Evaluate Scenario? | Critical Parameter(s) | Computation of Value Used to Assign EDT Rating | Considerations re. Multiple Features per Reach | COMMENTS |
|---|---|---|---|---|---|---|---|---|---|
| DepthWet: Mean depth (wetlands) | yes | HEC-RAS | mean daily flow time series | possibly -- a bathymetric map must be generated with bank and inundation limits identified, such that a mean depth can be calculated over the up- and down-stream HEC-RAS transects defining the wetland. | yes -- a regression giving mean depth of floodwater over floodplain as a function of wetland area must be generated (see comments). | Mean depth along upper and lower HEC-RAS transects for feature. | Simple average of monthly average depths over Riverware time series. | None -- wetlands considered as a unit within a reach. | Because flooded wetlands are assumed to retain water for seven days after flows have fallen below bankfull (with area declining by 1/7th per day), mean depth must reflect this week-long drainage pattern. Therefore, HEC-RAS output must be used to generate three regressions: one giving wetland area as a function of supra-bankfull flow; one giving mean wetland depth as a function of supra-bankfull flow; and one that integrates the two previous regressions to give **mean depth as a function of area**. The latter is necessary because the drainage pattern is keyed to wetland area. |

## Table 24 continued. Computational Summary of EDT habitat attributes.

| Attribute | Modeling Needed and/or Possible? | Model Used | Flow Data Needed | Visual Interpretation Needed? | Regression Needed to Evaluate Scenario? | Critical Parameter(s) | Computation of Value Used to Assign EDT Rating | Considerations re. Multiple Features per Reach | COMMENTS |
|---|---|---|---|---|---|---|---|---|---|
| DisOxyGWChan: Dissolved oxygen (groundwater channels) | none | none | none | --- | --- | --- | --- | --- | Default is D.O. of main channel. Professional judgment or empirical observations may modify. |
| DisOxyPond: Dissolved oxygen (floodplain ponds) | none | none | none | --- | --- | --- | --- | --- | Default is slightly larger "maximum hit" than is estimated for main channel. Pattern should also reflect earlier decline, later recovery, than main channel. Professional judgment or empirical observations may modify. |
| DisOxyWet: Dissolved oxygen (wetlands) | none | none | none | --- | --- | --- | --- | --- | Default is somewhat larger "maximum hit" than is estimated for main channel. Pattern should also reflect earlier decline, later recovery, than main channel. Professional judgment or empirical observations may modify. |

## Table 24 continued. Computational Summary of EDT habitat attributes.

| Attribute | Modeling Needed and/or Possible? | Model Used | Flow Data Needed | Visual Interpretation Needed? | Regression Needed to Evaluate Scenario? | Critical Parameter(s) | Computation of Value Used to Assign EDT Rating | Considerations re. Multiple Features per Reach | COMMENTS |
|---|---|---|---|---|---|---|---|---|---|
| FshComRchGWChan: Fish community richness (groundwater channels) | none | none | none | --- | --- | --- | --- | --- | Default is the rating for the main channel, perhaps with several fewer species. Professional judgment or empirical observations may modify. |
| FshComRchPond: Fish community richness (floodplain ponds) | none | none | none | --- | --- | --- | --- | --- | Default is the rating for the main channel with several fewer species. Professional judgment or empirical observations may modify. |
| FshComRchWet: Fish community richness (wetlands) | none | none | none | --- | --- | --- | --- | --- | Default is the rating for the main channel with several fewer species. Professional judgment or empirical observations may modify. |
| FSpIntroGWChan: Fish species introductions (groundwater channels) | none | none | none | --- | --- | --- | --- | --- | Default is the rating for the main channel with several fewer species. Professional judgment or empirical observations may modify. |

## Table 24 continued. Computational Summary of EDT habitat attributes.

| Attribute | Modeling Needed and/or Possible? | Model Used | Flow Data Needed | Visual Interpretation Needed? | Regression Needed to Evaluate Scenario? | Critical Parameter(s) | Computation of Value Used to Assign EDT Rating | Considerations re. Multiple Features per Reach | COMMENTS |
|---|---|---|---|---|---|---|---|---|---|
| FshSpIntroPond: Fish species introductions (floodplain ponds) | none | none | none | --- | --- | --- | --- | --- | Default is the rating for the main channel with several fewer species. Professional judgment or empirical observations may modify. |
| FSpIntroWet: Fish species introductions (wetlands) | none | none | none | --- | --- | --- | --- | --- | Default is the rating for the main channel with several fewer species. Professional judgment or empirical observations may modify. |
| HbBraid: Habitat type - braid | yes | R2D | median monthly flow | yes -- reach segments containing braids must be delimited by hash marks and attributed to braids. Braid wetted area will be estimated as the total wetted area between the hash marks. | yes -- the % wetted area (in-channel) consisting of braids must given as a function of the flows modeled with R2D. If the regression line is straight over all flows, a single regression suffices; if not, a series of regressions between pairs of modeled flows must be used (the default) | Percent wetted area consisting of braids. | Median monthly flow under a scenario is substituted into the braid regression. | Braids within a reach are lumped by wetted area -- no site-specific considerations are necessary within a reach. | Braids do not exist at flows less than bankfull. Thus, they are identified only at lower flows and must be defined manually with polygons as they become visible. |

## Table 24 continued. Computational Summary of EDT habitat attributes.

| Attribute | Modeling Needed and/or Possible? | Model Used | Flow Data Needed | Visual Interpretation Needed? | Regression Needed to Evaluate Scenario? | Critical Parameter(s) | Computation of Value Used to Assign EDT Rating | Considerations re. Multiple Features per Reach | COMMENTS |
|---|---|---|---|---|---|---|---|---|---|
| HbGWChan: Habitat type - wetted area of groundwater channels | yes | R2D | median monthly flow | yes -- polygons must be drawn around all features identified as groundwater channels at bankfull flow and attributed as such. No further visual interpretation or plygon drawing is needed for this attribute. | yes -- the wetted area (acres) consisting of groundwater channels must given as a function of the flows modeled with R2D. If the regression line is straight over all flows, a single regression suffices; if not, a series of regressions between pairs of modeled flows must be used (the default) | Wetted area of groundwater channels per reach. | Median monthly flow under a scenario is substituted into the groundwater channel regression. | The area of groundwater channels within a reach is considered as a unit -- no site-specific considerations are necessary within a reach. | R2D may underestimate the area of groundwater channels with significant groundwater input and/or surface inflow from upland areas. Professional judgment or site familiarity may dictate the use of slighly higher values. |

## Table 24 continued. Computational Summary of EDT habitat attributes.

| Attribute | Modeling Needed and/or Possible? | Model Used | Flow Data Needed | Visual Interpretation Needed? | Regression Needed to Evaluate Scenario? | Critical Parameter(s) | Computation of Value Used to Assign EDT Rating | Considerations re. Multiple Features per Reach | COMMENTS |
|---|---|---|---|---|---|---|---|---|---|
| HbPond: Habitat type - wetted area of floodplain ponds | Not possible | --- | --- | --- | --- | --- | --- | Wetted areas simply summed. | Available models likely will not estimate wetted areas of floodplain ponds, especially the effect of changes in groundwater input and/or surface input from upland areas. Polygons can be drawn around ponds as seen in aerial photo GIS overlays to give a rough, month-specific area, which can then be adjusted by month on the basis of professional judgment. |

## Table 24 continued.  Computational Summary of EDT habitat attributes.

| Attribute | Modeling Needed and/or Possible? | Model Used | Flow Data Needed | Visual Interpretation Needed? | Regression Needed to Evaluate Scenario? | Critical Parameter(s) | Computation of Value Used to Assign EDT Rating | Considerations re. Multiple Features per Reach | COMMENTS |
|---|---|---|---|---|---|---|---|---|---|
| HbSideChan: Habitat type – side channel | yes | R2D | median monthly flow | yes -- "hash marks" must be drawn at divergence and return points of all side channels in reach at bankfull flow. No further visual interpretation or manual adjustments are needed for this attribute | yes -- % in-channel wetted area consisting of side channels as a function of the flows modeled with R2D.   If the regression line is straight over all flows, a single regression suffices; if not, a series of regressions between pairs of modeled flows must be used (the default) | % wetted area in-channel consisting of side channels. | Median monthly flow under a scenario is substituted into the side channel regression. | None -- the wetted area of side channels within a reach is treated as a unit. | The wetted area delineated by hash marks at bankfull flow represents a boundary in space defining the side channel habitat type.  All characteristics occurring within this boundary are assigned to the side channels of the reach.  This works well for velocity distribution, complexity, etc, expected to occur at flows lower than bankfull.  Special care, however, should be given to any scenario for which median monthly flow is larger than bankfull or the near-bankfull flow that was modeled with R2D.  Linear regressions extrapolated beyond the range of observation are likely to be misleading. |

## Table 24 continued. Computational Summary of EDT habitat attributes.

| Attribute | Modeling Needed and/or Possible? | Model Used | Flow Data Needed | Visual Interpretation Needed? | Regression Needed to Evaluate Scenario? | Critical Parameter(s) | Computation of Value Used to Assign EDT Rating | Considerations re. Multiple Features per Reach | COMMENTS |
|---|---|---|---|---|---|---|---|---|---|
| HbWet: Habitat type - wetted area of seasonally flooded wetlands | yes | HEC-RAS | mean daily flow time series in chronological order | not necessarily -- what is needed is an estimate for the distance from the bank edge to the limit of floodplain inundation on both sides of the bank and at the top and bottom of the reach. The area of wetland will be estimated as the sum of the products of the "mean inundation width" and the main channel length for both banks. This may not involve "visual interpretation" of the sort needed to identify, say, intermittent side channels. | Yes: areas in acres of inundated floodplain as a function of discharge entering reach. | Location of crest of streambank and limit of inundation in floodplain. | Area of trapezoids defined by bank crest and inundation limit. | none | |
| HypExGWChan: Hyporheic exchange (groundwater channels) | Not possible | --- | --- | --- | --- | --- | --- | --- | Attribute cannot be estimated with available models and so must be based on professional |

## Table 24 continued. Computational Summary of EDT habitat attributes.

| Attribute | Modeling Needed and/or Possible? | Model Used | Flow Data Needed | Visual Interpretation Needed? | Regression Needed to Evaluate Scenario? | Critical Parameter(s) | Computation of Value Used to Assign EDT Rating | Considerations re. Multiple Features per Reach | COMMENTS |
|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | | judgment. |
| ObstrVegGWChan: Obstructing littoral vegetation (groundwater channels) | No | --- | --- | --- | --- | --- | --- | --- | Attribute cannot be estimated with available models and so must be based on professional judgment. |
| ObstrVegPond: Obstructing littoral vegetation (floodplain ponds) | No | --- | --- | --- | --- | --- | --- | --- | Attribute cannot be estimated with available models and so must be based on professional judgment. |
| ObstrVegWet: Obstructing littoral vegetation (wetlands) | No | --- | --- | --- | --- | --- | --- | --- | Attribute cannot be estimated with available models and so must be based on professional judgment. |
| ProxPond: Proximity to main channel or side channel (floodplain ponds) | yes | R2D | Median monthly flow | No | Yes – outlet channel length from pond to edge of main channel or side channel as a function of flow entering reach. | Location of outlet channel mouth at specific flows. | | Area-weighted mean. | In most instances, and acceptable alternative is to estimate pond proximity at bankfull flow and hold this value constant over months and scenarios. |

## Table 24 continued. Computational Summary of EDT habitat attributes.

| Attribute | Modeling Needed and/or Possible? | Model Used | Flow Data Needed | Visual Interpretation Needed? | Regression Needed to Evaluate Scenario? | Critical Parameter(s) | Computation of Value Used to Assign EDT Rating | Considerations re. Multiple Features per Reach | COMMENTS |
|---|---|---|---|---|---|---|---|---|---|
| TmpMonMnGWChan: Temperature – daily minimum (by month) (groundwater channels) | Not possible | --- | --- | --- | --- | --- | --- | --- | Default is main channel rating. |
| TmpMonMnPond: Temperature – daily minimum (by month) (floodplain ponds) | Not possible | --- | --- | --- | --- | --- | --- | --- | Default is main channel rating. |
| TmpMonMnWet: Temperature – daily minimum (by month) (wetlands) | Not possible | --- | --- | --- | --- | --- | --- | --- | Default is main channel rating. |
| TmpMonMxGWChan: Temperature – daily maximum (by month) (groundwater channels) | Not possible | --- | --- | --- | --- | --- | --- | --- | Default is main channel rating, although often groundwater channels are cooler than the main channel. |
| TmpMonMxPond: Temperature – daily maximum (by month) (floodplain ponds) | Not possible | --- | --- | --- | --- | --- | --- | --- | Default is main channel rating, although often ponds are warmer than the main channel. |
| TmpMonMxWet: Temperature - daily maximum (by month) (wetlands) | Not possible | --- | --- | --- | --- | --- | --- | --- | Default is main channel rating, although often wetlands are warmer than the main channel. |

## Table 24 continued. Computational Summary of EDT habitat attributes.

| Attribute | Modeling Needed and/or Possible? | Model Used | Flow Data Needed | Visual Interpretation Needed? | Regression Needed to Evaluate Scenario? | Critical Parameter(s) | Computation of Value Used to Assign EDT Rating | Considerations re. Multiple Features per Reach | COMMENTS |
|---|---|---|---|---|---|---|---|---|---|
| TurbGWChan: Turbidity (groundwater channels) | Not possible | --- | --- | --- | --- | --- | --- | --- | Default is rating for main channel although usually groundwater channels are significantly less turbid than the main channel. |
| TurbPond: Turbidity (floodplain ponds) | Not possible | | --- | --- | --- | --- | --- | --- | Default is rating for main channel, although ponds vary widely in this respect. |
| TurbWet: Turbidity (seasonal wetlands) | Not possible | | --- | --- | --- | --- | --- | --- | Default is main channel rating although wetlands are usually less turbid than the main channel. |
| VelocitySideChan: Side channel velocity type | Yes | R2D | Median Monthly Flow | No | Yes – percent wetted area of side channel with velocity <= 0.4 fps as a function of discharge entering reach. | Proportion of pixels within side channel polygon with velocity <= 0.4 fps. | Simple proportion of pixels with criterial velocity. | None – side channel treated as a complex for this attribute. | |

## Appendix A. Definition of Ratings for EDT Habitat attributes.

| Code | Attribute | Definition | Index Value 0 | Index Value 1 | Index Value 2 | Index Value 3 | Index Value 4 |
|---|---|---|---|---|---|---|---|
| **AccPasGWChan**<br>**AccPasWet** | Passive accessibility (off-channel habitat excluding ponds) | A measure of "passive accessibility" of off-channel habitat features (groundwater channels, ponds and seasonally flooded wetlands) to juvenile fish. It is expressed in terms of the fraction of days during a month when juvenile fish could be moved (or swept) passively into the habitat. | 6-30 (30 day month) or 20-100% of month | 4-6 (30 day month) or 13-20% of month | 2-4 days (30 day month) or 7-13% of month | 0.5-2 days (30 day month) or 2-7% of month | 0-0.5 day (30 day month) or 0-2% of month |
| **AccVolPond** | Volitional accessibility (ponds) | A measure of the degree to which juvenile fish can swim up the outlet channel into a floodplain pond. It is expressed in terms of the fraction of days during a month when juvenile fish can swim into the pond. | 25-30 days (30 day month) or 83-100% of month (mean depth in outlet >4 inches on passable days) | 10-25 days (30 day month) or 33-83% of month (mean depth in outlet >4 inches on passable days) | 3-10 days (30 day month) or 10-33% of month (mean water depth in outlet >4 inches on passable days) | 0.5-3 days (30 day month) or 2-10% of month (mean water depth in outlet >4 inches on passable days) | 0-0.5 day (30 day month) or 0-2% of month (mean water depth in outlet >4 inches on passable days) |
| **WidthMn** | Channel width - monthly minimum width (ft) | Average in-channel width for a reach during the month of lowest flow (average monthly conditions). Computed by dividing in-channel wetted area (area of main channel, side channels and braids) during lowest flow month by reach length. | Index Values not used; enter absolute minimum width estimate in feet. | | | | |

## Appendix A continued. Definition of Ratings for EDT Habitat attributes.

| Code | Attribute | Definition | Index Value 0 | Index Value 1 | Index Value 2 | Index Value 3 | Index Value 4 |
|---|---|---|---|---|---|---|---|
| **WidthMx** | Channel width - monthly maximum width (ft) | Average in-channel width for a reach during the month of highest flow (average monthly conditions). Computed by dividing in-channel wetted area (area of main channel, side channels and braids) during Peak flow month by reach length. | Index Values not used; enter absolute maximum width estimate in feet. | | | | |
| **ComplexSideChan** | Side channel complexity | A measure of the complexity of side channels expressed in terms of the length of stream margin ("edge") per square foot of wetted area. The attribute is expressed explicitly in terms of the *increase* in edge per square foot across all in-channel habitat features that exist because of side channels. | Increase in edge/area of > 200% due to presence of side channels; rating of zero is assigned when increase exceeds 300% | Increase in edge/area of 100-200% due to presence of side channels. | Increase in edge/area of 20-100% due to presence of side channels. | Increase in edge/area of 5-20% due to presence of side channels. | Increase in edge/area of 0-5% due to presence of side channels. |
| **ConnectSideChan** | Side channel connectivity (mean monthly) | Average percentage of days in month when side channels are completely connected to the primary channel (i.e., proportion of month during which channels carry surface water from divergence to return points). "Connection" implies a depth of at least 4 inches. Expressed as an area-weighted mean across all side channels. | '29-30 (30 day month) or 97-100% of month has full connection. | 27-29 days (30 day month) or 90-97% of month has full connection. | 20-27 days (30 day month) or 67-90% of month has full connection. | 10-20 days (30 day month) or 33-67% of month has full connection. | 0-10 days (30 day month) or 0-33% of month has full connection. |
| **DepthGWChan**<br>**DepthPond**<br>**DepthWet** | Mean monthly depth (off-channel habitat types) | The mean monthly depth in feet of groundwater channels, ponds and seasonally flooded wetlands. | Mean depth 5-10 ft | Mean depth 3-5 ft | Mean depth 2-3 ft | Mean depth 1-2 ft | Mean depth 0-1 ft |

## Appendix A continued. Definition of Ratings for EDT Habitat attributes.

| Code | Attribute | Definition | Index Value 0 | Index Value 1 | Index Value 2 | Index Value 3 | Index Value 4 |
|---|---|---|---|---|---|---|---|
| **DisOxy**<br>**DisOxyGWChan**<br>**DisOxyPond**<br>**DisOxyWet** | Dissolved oxygen | Monthly mean dissolved oxygen content within the water column for all in-channel (main channel, braid and side channel) habitat types and for each off-channel habitat type (groundwater channels, ponds and seasonally flooded wetlands). | > 8 mg/L (allows for all biological functions for salmonids without impairment at temperatures ranging from 0-25 C) | > 6 mg/L and < 8 mg/L (causes initial stress symptoms for some salmonids at temperatures ranging from 0-25 C) | > 4 and < 6 mg/L (stress increased, biological function impaired) | > 3 and < 4 mg/L (growth, food conversion efficiency, swimming performance adversely affected) | < 3 mg/L |
| **FshComRch**<br>**FshComRchGWChan**<br>**FshComRchPond**<br>**FshComRchWet** | Fish community richness | Number of fish species for all in-channel (main channel, braid and side channel) habitat types, and for each off-channel habitat type (groundwater channel, pond and seasonally flooded wetland). | 2 or fewer fish taxa | 3-7 fish taxa | 8-17 fish taxa | 18-25 fish taxa | > 25 fish taxa |
| **FSpIntro**<br>**FSpIntroGWChan**<br>**FSpIntroPond**<br>**FspIntroWet** | Fish species introductions | Extent of introductions of exotic fish species within all in-channel (main channel, braid and side channel) habitat types, and within each off-channel habitat type (groundwater channel, pond and seasonally flooded wetland) in the vicinity of the reach under consideration | No non-native species reported or known to be in the sub-drainage of interest. | 1-2 non-native species reported or known to be in the sub-drainage of interest. | 3-7 non-native species reported or known to be in the sub-drainage of interest. | 8-14 non-native species reported or known to be in the sub-drainage of interest. | 15 or more non-native species reported or known to be in the sub-drainage of interest. |

## Appendix A continued. Definition of Ratings for EDT Habitat attributes.

| Code | Attribute | Definition | Index Value 0 | Index Value 1 | Index Value 2 | Index Value 3 | Index Value 4 |
|---|---|---|---|---|---|---|---|
| **HbBckPls** | Habitat type - backwater pools | Proportion of all in-channel wetted area (main channel, side channels and braids) consisting of backwater pools. Backwater pools are formed at the confluence of an off-channel feature or side channel with the main channel, on in the lee of a root wad or rock outcrop. They are partially enclosed, low-velocity areas distinct from the main channel, typically having fine substrate, abundant aquatic vegetation and accumulations of fine woody debris. Depending on flow and channel configuration, the outer portion of the backwater (nearest the main channel) may be an eddy | Absolute estimates of percent wetted area are entered instead of Index Values. Data entered may be month-specific. | | | | |
| **HbBraid** | Habitat type - braids | Proportion of all in-channel wetted area (main channel, side channels and braids) consisting of braids, which are considered to be channels flowing between unstable, unvegetated gravel bars that are submerged at bankfull flow | Absolute estimates of percent wetted area are entered instead of Index Values. Data entered may be month-specific. | | | | |
| **HbBvrPnds** | Habitat type - beaver ponds | Proportion of all in-channel wetted area (main channel, side channels and braids) consisting of beaver ponds. Note: these are pools located in the main or side channels, and are not off-channel habitat | Absolute estimates of percent wetted area are entered instead of Index Values. Data entered may be month-specific. | | | | |

## Appendix A continued. Definition of Ratings for EDT Habitat attributes.

| Code | Attribute | Definition | Index Value 0 | Index Value 1 | Index Value 2 | Index Value 3 | Index Value 4 |
|---|---|---|---|---|---|---|---|
| **HbGlide** | Habitat type - glide | The proportion of all in-channel wetted area (main channel, side channels and braids) consisting of glides. Note: despite general agreement that it is important to recognize a habitat type intermediate between pools and riffles, the definition of glides varies widely (Hawkins et al. 1993), The definition used here is from the ODFW habitat survey manual (Moore et al. 1997): "an area with generally uniform depth and flow with no surface turbulence, generally in reaches of <1% gradient". Glides may have some small scoured areas but are distinguished from pools by their overall homogeneity and lack of structure. They are generally deeper than riffles with few obstructions and low habitat complexity. | Absolute estimates of percent wetted area are entered instead of Index Values. Data entered may be month-specific. | | | | |

## Appendix A continued. Definition of Ratings for EDT Habitat attributes.

| Code | Attribute | Definition | Index Value 0 | Index Value 1 | Index Value 2 | Index Value 3 | Index Value 4 |
|---|---|---|---|---|---|---|---|
| **HbGWChan** | Mean monthly wetted area of groundwater channels | The area in acres of groundwater channels. Groundwater channels connect to the main channel or a side channel only at the downstream end at flows less than bankfull. They are usually relict river channels fed by groundwater, though surface flow from higher terraces can also contribute. They can function as overflow channels at some flood stages, and include several subtypes (Ward et al. 1999), including: (1) channels carrying main channel seepage, (2) channels fed by the floodplain aquifer and (3) channels fed by groundwater supplied from adjacent terraces. | Absolute area estimates in acres used instead of Index Values | | | | |
| **HbLrgCbl** | Habitat type - large cobble/boulder riffles | The proportion of all in-channel wetted area (main channel, side channels and braids) consisting of large cobble/boulder riffles. Particle sizes of substrate modified from Platts et al. (1983) based on information in Gordon et a. (1991): gravel (0.2 to 2.9 inch diameter), small cobble (2.9 to 5 inch diameter), large cobble (5 to 11.9 inch diameter), boulder (>11.9 inch diameter). | Absolute estimates of percent wetted area are entered instead of Index Values. Data entered may be month-specific. | | | | |
| **HbPlTails** | Habitat type - pool tailouts. | The proportion of all in-channel wetted area (main channel, side channels and braids) consisting of pool tailouts. | Absolute estimates of percent wetted area are entered instead of Index Values. Data entered may be month-specific. | | | | |
| **HbPls** | Habitat type - primary pools | The proportion of all in-channel wetted area (main channel, side channels and braids) consisting of pools, excluding beaver ponds. | Absolute estimates of percent wetted area are entered instead of Index Values. Data entered may be month-specific. | | | | |

## Appendix A continued. Definition of Ratings for EDT Habitat attributes.

| Code | Attribute | Definition | Index Value 0 | Index Value 1 | Index Value 2 | Index Value 3 | Index Value 4 |
|---|---|---|---|---|---|---|---|
| **HbPond** | Wetted area of floodplain ponds | The area in acres of floodplain ponds. Floodplain ponds are water-filled depressions, partially or entirely filled with water year-round. They are usually hydraulically isolated ("land-locked"), and must have a passable (mean depth > four inches) outlet channel to the main river during at least one entire month in most (>50%) years. They are either natural features on the floodplain, representing cut-off oxbows or pools in relict river channels, but they may also be man-made (e.g., floodplain gravel pits). They might be supplied by groundwater or surface water from streams or springs and may not be hydraulically connected to the river at all flows. | Absolute area estimates in acres used instead of Index Values | | | | |

## Appendix A continued. Definition of Ratings for EDT Habitat attributes.

| Code | Attribute | Definition | Index Value 0 | Index Value 1 | Index Value 2 | Index Value 3 | Index Value 4 |
|---|---|---|---|---|---|---|---|
| **HbSideChan** | Habitat type – side channel | The mean monthly proportion of the wetted area of all in-channel habitat (main channel, side channels and braids) consisting of side channels. A side channel is an active stream channel separated from the main channel by a vegetated or otherwise stable island (Knighton (1998). The islands tend to be large relative to the size of the channels. Side channels are frequently small watered remnants of the historic river channel within the floodplain. Some side channels carry surface water continuously, from the point of divergence to the point of return, at a given flow, while others become intermittent (are dry at some point(s) between divergence and return) at the same flow (Ward et al. 1999). The frequency of continuous connection to a surface water source can be important in the ecology of various species (Tockner et al. 2000). | Absolute estimates of percent wetted area are entered instead of Index Values. Data entered is month-specific. | | | | |

## Appendix A continued. Definition of Ratings for EDT Habitat attributes.

| Code | Attribute | Definition | Index Value 0 | Index Value 1 | Index Value 2 | Index Value 3 | Index Value 4 |
|---|---|---|---|---|---|---|---|
| **HbSmlCbl** | Habitat type - small cobble/gravel riffles | The mean monthly proportion of the wetted area of all in-channel habitat (main channel, side channels and braids) consisting of small cobble/gravel riffles. Particle sizes of substrate modified from Platts et al. (1983) based on information in Gordon et a. (1991): gravel (0.2 to 2.9 inch diameter), small cobble (2.9 to 5 inch diameter), large cobble (5 to 11.9 inch diameter), boulder (>11.9 inch diameter). | Absolute estimates of percent wetted area are entered instead of Index Values. Data entered may be month-specific. | | | | |

## Appendix A continued. Definition of Ratings for EDT Habitat attributes.

| Code | Attribute | Definition | Index Value 0 | Index Value 1 | Index Value 2 | Index Value 3 | Index Value 4 |
|---|---|---|---|---|---|---|---|
| **HbWet** | Wetted area of seasonally flooded wetlands | The area in acres of seasonally flooded wetland. Seasonal wetlands frequently occur on the floodplains of large rivers. Geomorphically, they are often remnants of ancient ponds and river channels which filled with sediment and debris over centuries (Saucier 1994, cited in Henning 2004). Functionally, many lower-river overflow channels are seasonal wetlands, and should be classified as such in terms of their impact on fish production. Seasonal wetlands are typically flooded during annual high water periods either by broad overbank flows or by backwatering through narrow swales. They may be associated with perennial ponds or they may dry up during low flow. | Absolute area estimates in acres used instead of Index Values | | | | |

## Appendix A continued. Definition of Ratings for EDT Habitat attributes.

| Code | Attribute | Definition | Index Value 0 | Index Value 1 | Index Value 2 | Index Value 3 | Index Value 4 |
|---|---|---|---|---|---|---|---|
| **HypExGWChan**<br><br>**HypExPond** | Hyporheic exchange (groundwater channels and ponds) | A measure of the proportion of the volume of a pond or groundwater channel contributed by groundwater. In the absence of explicit hydrological information, hyporheic influence will be assumed to be minimal at the upstream end of unconfined valley segments and maximal at the downstream end. | Very strong evidence that hyporheic groundwater is the major source of flow within the channel or pond. Thermal and water clarity characteristics of hyporheic exchange are strongly evident. Habitat is likely located within the lower end of an unconfined reach of the main river. | Although substantial hyporheic exchange is occurring, hyporheic water is diluted by surface flows. Thermal and water clarity characteristics indicate strong influence of hyporheic input but dilution from other sources is evident. Habitat may be located in the lower portion of an unconfined reach of the main river or may receive ground water contributions from an adjacent terrace. | Evidence of hyporheic exchange exists but is not strong. Thermal and water clarity characteristics indicate modest hyporheic influence. Habitat may be located in the middle of an unconfined reach of the main river or may receive some ground water from an adjacent terrace. | Weak evidence that groundwater is contributing to the channel or pond. Thermal and water clarity characteristics reflect minimal groundwater influence. Habitat may be located within the upper third of an unconfined reach or within a large floodplain of a meandering, single-thread river channel. Groundwater may enter from an adjacent terrace. | No evidence of groundwater influence on the channel or pond. Thermal and water clarity characteristics distinctly different from hyporheic inflow. Habitat may be located at the top end of an unconfined reach or within a large floodplain of a meandering, single-thread river channel. |
| **ObstrVegGWChan**<br>**ObstrVegPond** | Obstructing littoral vegetation | Incidence and density of patches of obstructing littoral vegetation (canary reed grass, purple loosestrife, etc.) in shallow, near-shore areas that limit accessibility of groundwater channels and ponds. | Obstructing littoral vegetation not present | Less than 50% of suitable habitats colonized by obstructing littoral vegetation and scouring by flood events common. | More than 50% of suitable habitats colonized by obstructing littoral vegetation, but scouring by flood events is common. | Essentially all appropriate habitats colonized obstructing littoral vegetation, but scouring by flood events is common. | Obstructing littoral vegetation colonizes all appropriate habitats, and scouring by flood events is rare. |
| **ProxPond** | Proximity to main channel or side channel (pond) | Mean monthly distance in feet from pond to the main river, where length is measured along the line of lowest elevation extending from the side of the pond closest to the main river to the edge of the river. The "line of lowest elevation" will be the outlet channel, if one exists. | Pond is located within 200 ft of the main channel or a side channel. | Pond is between 200 and 500 ft from the main channel or a side channel. | Pond is between 500 and 1,200 ft from the main channel or a side channel. | Pond is between 1,200 and 3,600 ft from the main channel or a side channel. | Pond is more than 3,600 ft from the main channel or a side channel. |

## Appendix A continued. Definition of Ratings for EDT Habitat attributes.

| Code | Attribute | Definition | Index Value 0 | Index Value 1 | Index Value 2 | Index Value 3 | Index Value 4 |
|---|---|---|---|---|---|---|---|
| **TmpMonMx**<br>**TmpMonMxGWChan**<br>**TmpMonMxPond**<br>**TmpMonMxWet** | Temperature - daily maximum (by month) | Maximum daily water temperatures within all in-channel (main channel, braid and side channel) habitat features, and within each off-channel habitat (groundwater channel, pond and seasonally flooded wetland) during a month. | Warmest day < 10 C | Warmest day>10 C and <16 C | > 1 d with warmest day 22-25 C or 1-12 d with >16 C | > 1 d with warmest day 25-27.5 C or > 4 d (non-consecutive) with warmest day 22-25 C or >12 d with >16 C | > 1 d with warmest day 27.5 C or 3 d (consecutive) >25 C or >24 d with >21 C |
| **TmpMonMn**<br>**TmpMonMnGWChan**<br>**TmpMonMnPond**<br>**TmpMonMnWet** | Temperature - daily minimum (by month) | Minimum daily water temperatures within all in-channel (main channel, braid and side channel) habitat features, and within each off-channel habitat (groundwater channel, pond and seasonally flooded wetland) during a month. | Coldest day >4 C | < 7 d with <4 C and minimum >1 C | 1 to 7 d < 1 C | 8 to 15 days < 1 C | > 15 winter days < 1 C |
| **Turb**<br>**TurbGWChan**<br>**TurbPond**<br>**TurbWet** | Turbidity (in-channel habitat and off-channel habitat types) | The severity of suspended sediment (SS) episodes within the main channel and side channels, and in each off-channel habitat type (groundwater channels, ponds and wetlands). Note: although this attribute was originally called turbidity and still retains that name for continuity, it is more correctly thought of as suspended sediment (SS). The metric applied here is the Scale of Severity (SEV) Index taken from Newcombe and Jensen (1996), derived from: SEV = a + b(lnX) + c(lnY) , where, X = duration in hours, Y = mg/l, a = 1.0642 , b = 0.6068, and c = 0.7384. Duration is the number of hours out of month (with highest SS typically) when that concentration or higher normally occurs. Concentration would be represented by grab samples reported by USGS. See rating guidelines. | SEV Index <= 4.5 Clear with infrequent (short duration-- several days per year) concentrations of low concentrations (< 50 mg/l) of suspended sediment. No adverse effects on biota of these low doses. | SEV Index >4.5 and <= 7.5 Occasional episodes (days) of low to moderate concentrations (<500 mg/L), though very short duration episodes (hours) may occur with of higher concentrations (500 to 1000). These concentrations are always sublethal to juvenile and adult salmonids-though some behavioral modification may occur. | SEV Index >7.5 and <= 10.5 Occasional episodes of moderate to relatively high concentrations (>500 and <1000 mg/L), though shorter duration episodes (<1 week) may occur with higher concentrations (1000-5000 mg/L). The higher concentrations stated can be expected to result in major behavioral modification, severe stress, severely reduced forage success and direct mortality. | SEV Index >10.5 and <= 12.5 On-going or occasional episodes (periodic events annually lasting weeks at a time) of high concentrations of suspended sediment (>5000 and <10000 mg/L), or shorter duration episodes lasting hours or days of higher concentrations. These conditions result in direct, high mortality rates. | SEV Index >12.5 Extended periods (month) of very high concentrations (>10000 mg/L). These represent the most extreme severe conditions encountered and result in very high mortality of fish species. |

## Appendix A continued. Definition of Ratings for EDT Habitat attributes.

| Code | Attribute | Definition | Index Value 0 | Index Value 1 | Index Value 2 | Index Value 3 | Index Value 4 |
|---|---|---|---|---|---|---|---|
| **VelocitySideChan** | Side channel velocity type | The average velocity type of side channels within the reach, where "velocity type" refers to the proportion of side channel wetted area with a velocity low enough to retain salmonid fry (<50 mm) indefinitely. Estimated maximum sustainable water velocity for fry and small parr is assumed to be 0.4 fps. | Water velocity through side channels is very slow, suitable for holding newly emergent salmonid fry without displacement by velocity OR 90-100% of the wetted area is estimated to have water velocities that do not exceed 0.4 fps. | Water velocity through side channels tends to be slow, though a small percentage of areas (relatively few in number) contain moderately fast flows. Small juveniles would be able to hold within the lower velocity areas but might have difficulty holding in faster areas. OR 75-90% of the wetted area has water velocities that do not exceed 0.4 fps. | Water velocity through side channels is diverse, ranging from areas of very low velocity to areas of relatively high velocities. Small juveniles are able to hold within the lower velocity areas but not in the faster areas. OR 40-75% of the wetted area has water velocities that do not exceed 0.4 fps. | Water velocity through side channels tends to be high, though some areas (relatively few in number) contain very slow flows. Small juveniles are able to hold only within the slowest areas. OR 10-40% of the wetted area has water velocities that do not exceed 0.4 fps. | Water velocity through side channels is very high, representing a very high-energy condition, typically associated with very high gradient and/or high discharges within confined channels or channels with low width to depth ratios. Salmonid fry and small parr are unable to hold position within the channel without significant velocity cover. OR <10% of the wetted area has water velocities that do not exceed 0.4 fps. |

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