Subbasin Planning with EDT: A Primer

This document is intended to be a practical guide for fisheries biologists and other planners in the use of the EDT model in subbasin planning. A good practical guide proceeds from general to specific, including a concrete example of how general principles were applied in a real-world situation. Accordingly, this manual will show how general principles were applied in developing a subbasin plan for spring chinook salmon in the Yakima River subbasin (hereafter referred to as "the Yakima"). The Yakima is a large and environmentally diverse system, with a wide range of anthropogenic impacts. This very complexity makes the Yakima a good case study, as many planners will find in the Yakima examples of problems similar to their own.

Section 1 of this Primer provides some background information on EDT and subbasin planning. Section 2 presents the general procedures and Yakima example for applying EDT to subbasin planning.

I. Background

This section will provide the reader with information about the conceptual context in which subbasin planning occurs, as preparation for the subsequent detailed discussion of an application of the EDT method to subbasin planning. We will begin with a brief description of the nature of EDT, focusing on some perceptions and misperceptions about the methodology. Following this description will be a very general overview of the role of EDT in subbasin planning.

A. The Nature of EDT

It is important to begin by dispelling some of the mystery and confusion that surrounds the EDT methodology, by clearing up ambiguous terms, addressing the unfamiliarity of EDT output, and discussing the applications for which EDT is best suited.

1. Scientific vs. Statistical Models

EDT is a model—and confusion often surrounds the term model because there are different types of models. EDT is a *scientific model*, and not a *statistical model* (Hilborn and Mangel 1997). A scientific model explains the mechanisms behind phenomena to form an overall hypothesis; a statistical model provides correlation-based predictions without necessarily explaining the underlying mechanism.

As a scientific model, EDT constructs a working hypothesis of a watershed and a population, which enables us to understand complex ecological systems well enough to design effective enhancement strategies. This working hypothesis also provides metrics to monitor progress and testable hypotheses to refine knowledge. A statistical model, on the other hand, seeks to reduce complexity to a small number of predictive or correlated variables. Both types of models are complementary, and both are essential. We must have insightful scientific models to generate meaningful hypotheses that, in turn, must be tested and revised by statistical models.

To validate a scientific model as a planning tool is to demonstrate its applicability and utility. We suggest three criteria for judging the usefulness of such a model:

1. Its predictions are consistent with observations;
2. It provides clear and reasonable explanations for observations; and
3. It provides useful guidance for management and enhancement.

2. EDT Output

The output from EDT is frequently unfamiliar to many fisheries biologists—this can lead to misunderstandings. For example, the EDT model does not "grow" virtual fish through successive life stages and regions, producing a time series of population abundance. Instead, EDT draws upon an environmental database and a set of mathematical algorithms to compute productivity, capacity, and life history diversity parameters for the targeted population. Because it is deterministic, issues of power and precision are not pertinent.

At a more fundamental level, EDT is not inductive and predictive so much as it is deductive and explanatory. That is to say, it does not attempt to discover some fundamental property of population performance from other observations or relationships. Rather, EDT assumes that all such relationships are known and states them explicitly. Computer power is then used to integrate many individually simple premises and deduce their implications. As mentioned above, these implications are reduced to just three numbers—productivity, carrying capacity, and life history diversity.

Thus, EDT does no more and no less than allow the planner to see the forest instead of a bewildering multitude of trees. To make the metaphor more precise, EDT allows the planner to make a conditional estimate of the maximum size and growth rate of the forest as a function of the nature of the forest environment and the biological capabilities of its trees.

3. Appropriate Application

It is important to understand the applications for which EDT is best suited. Simply stated, EDT should be used to identify key limiting factors (their nature and location) and to identify those enhancement actions most likely to achieve specified biological objectives for a target population. The appropriate role of EDT is thus in the initial design of an enhancement project, in the design of a monitoring and evaluation (M&E) plan for such a project, and in the refinement or revision of a project after a significant amount of M&E data has been collected.

B. EDT and Subbasin Planning

The role of EDT in subbasin planning is illustrated in Figure 1. In this figure, an arrow from one box to another indicates either a cause and effect relationship or a necessary sequence of actions. The three boxes labeled *Environmental Data*, *EDT: Biological Rules*, and *Population Performance* represent core issues surrounding EDT. The arrows from *The*

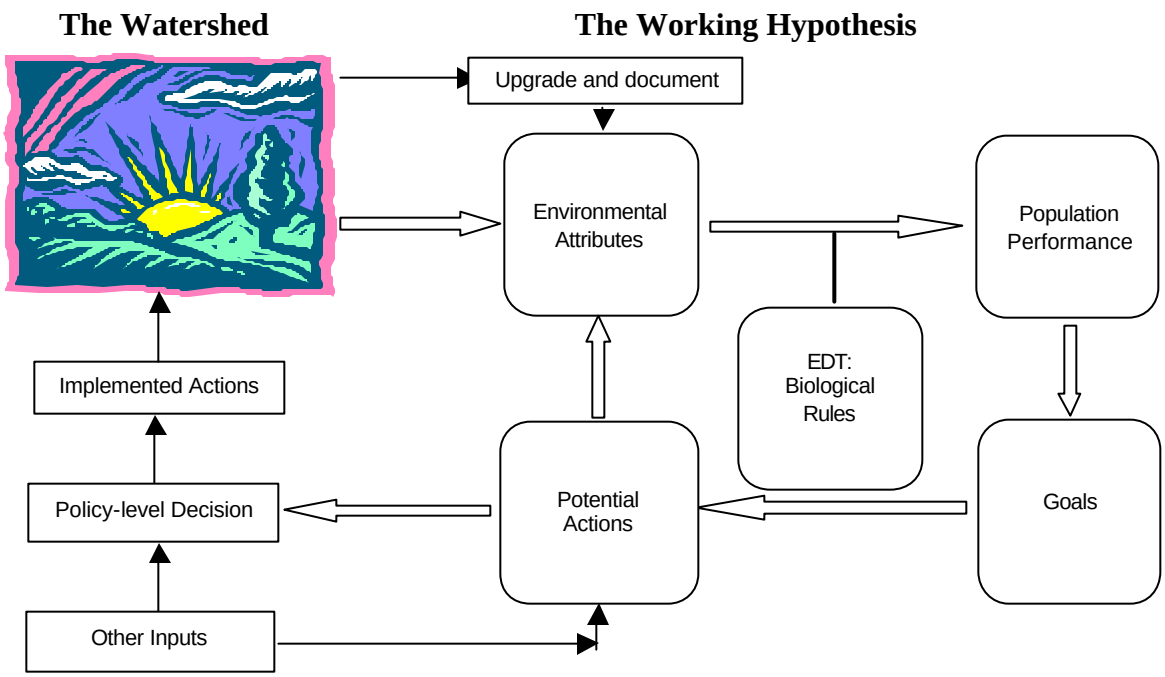


Figure 1. Schematic diagram of the role of EDT in Subbasin Planning.

Watershed and *Environmental Data* to *Population Performance* represent the assumptions that environmental quality and quantity limit the performance (abundance and productivity) of populations. EDT bridges the gap between our description of the environment and population performance. It integrates knowledge of the environmental attributes critical to fish with species-specific environmental requirements, reproductive potential, and life history patterns to predict productivity and carrying capacity (the contents of the *Population Performance* box). EDT can predict the performance of a population subject to current, historic, or hypothetical environmental conditions. When the current population and environment is modeled and performance is compared to a goal statement, shortcomings can be ascribed to specific environmental problems occurring at particular times and places. The very identification of such key environmental problems usually implies a number of different kinds of remedial actions. The impact of various remedial actions on problematic environmental conditions is then stipulated, EDT is used to estimate the biological response to the new, improved environment, and the performance of the population in this hypothetical future environment is once again compared to the goal.

A large portion of an EDT analysis consists of repeated estimates of the impact of alternative enhancement actions on population performance. Much of the effort at this time should consist of consultations with appropriate specialists to predict the impact of specific enhancement actions on key environmental variables (note the arrow from *Other Inputs* to *Potential Actions* in Figure 1).

After a series of iterations in which alternative actions are refined with respect to their expected environmental impact and evaluated in terms of expected population response and various kinds of risk, a series of candidate actions is presented to local and regional

decision makers. These decision makers will then pick one or more actions for implementation after considering the planners' best estimates of biological effectiveness and risk, as well as the financial, political and legal implications of alternative actions. Monitoring begins as soon as a plan is put into action, and environmental changes are captured in a revised environmental database.

If a well designed monitoring plan is implemented, the *Working Hypothesis* (Figure 1) can be tested against observed changes in environmental attributes and population performance.

One essential element of the use of EDT in subbasin planning remains to be described: the role of the reference condition referred to as the *Template* in an EDT analysis. The Template represents the potential of a watershed and is often likened to the historic condition. Typically the Template is a reconstruction of the environment as it existed prior to Euro-American development, circa 1850. The Template represents a local definition of *normative* conditions, where normative implies natural and evolutionarily formative for endemic species (Williams et al. 1996).

A central element of an EDT analysis consists of the *diagnosis*. It is as true in ecology as physiology that disease can only be understood by comparing and contrasting it with health. Thus, in EDT, the patient (i.e., the Current condition) is diagnosed by describing the most important ways in which it differs from the normative, historic environment. Specifically, a diagnosis in EDT consists of the identification and prioritization of those environmental changes that have played the greatest role in reducing population performance from historic (Template) levels. It is, therefore, necessary to model the Template as thoroughly as the Current condition is modeled.

There are other reasons for modeling the Template. One reason is that many subbasins have been altered so radically over the past 150 years as to be virtually unrecognizable as the same drainage. This is most definitely true of the Yakima. In the recent past some Yakima biologists were confused by the simplified channel structure in the middle and lower portions of the basin, by high water temperatures in the lower river, and by a distribution of spawning and rearing areas for anadromous salmonids restricted largely to the upper river. They formed notions of the ecologically important portions of the basin that were almost the exact inverse of what has subsequently been learned to be true—ascribing the highest fundamental ecological value to the upper fifth of the drainage and discounting much of the rest as little more than a migration corridor. Yakima planners have therefore become acutely aware that the most productive portions of a basin can be so transformed by development as to be unrecognizable, and that productive remnants reflect mainly the idiosyncrasies of development. In summary, the *blueprint for success* can only be found by reconstructing the Template.

A final reason for modeling the Template is that it allows a fundamental measure of production potential to be associated with every reach in the basin. If the difference between Template and Current production potential for a given reach is considered to represent *restoration potential*, then this very difference can serve to begin the prioritization process for habitat restoration projects. EDT does in fact make such an assumption, and the estimation of restoration potential is a fundamental piece of the diagnosis.

II. Application of EDT to Subbasin Planning

This section of the Primer presents the actual steps involved in applying the EDT model to subbasin planning: defining reaches, summarizing baseline data, estimating environmental attributes, and diagnosis. The section on estimating attributes includes a complete, detailed discussion of how this step was applied in the Yakima.

A. Defining Reaches

It is debatable whether defining the reach structure should precede the assembling, documenting and summarizing of baseline data. To some degree, one depends upon the other: one cannot know which portions of the basin most warrant segregation and individual analysis before knowing the nature and location of specific problems. On the other hand, the utility of collating baseline data is undermined if it cannot be conveniently associated with specific reaches, or the reach structure is substantially reorganized after many environmental attributes have been allocated.

The experience of Yakima planners is that much time and effort is saved if considerable thought is invested in defining the reach structure at the beginning of the process. The structure of the basin thus becomes fixed in the mind of the planner, and environmental and biological information can be efficiently allocated across the subbasin.

Defining reaches for an EDT analysis consists of three steps: (1) defining the geographic scope, (2) describing environmentally homogeneous reaches, and (3) coding the hydrography of the basin – *viz.*, indicating the direction of water flow and the spatial relationship of tributaries such that it can be *understood* by a computer program.

1. Geographic Scope

Defining the geographic scope for an EDT analysis is a relatively straightforward exercise that begins with the identification of all current and historic fish-bearing streams and then discusses the extent of use in those streams.

Identifying Fish-Bearing Streams

In the present context, *fish* means salmon, steelhead, rainbow trout (resident *O. mykiss*), or bull trout. It is sufficient, but not necessary, for a stream to be used for spawning for it to be included. For example, a stream in which no spawning occurs should be included if significant numbers of juveniles rear in it (e.g., fry in springbrooks or parr in irrigation returns). It is also sufficient, but not necessary, to have documented evidence of use. In most subbasins a substantial number of *undocumented* streams will be included because they occur among other streams for which use has been documented, they are accessible, and they provide adequate spawning and/or rearing habitat.

The list of streams must be as inclusive as practicable. A stream should be included if even one of the targeted species uses, or is suspected of using, it. Streams that were used historically should also be included, even if historic use occurred in reaches that are now

inaccessible (e.g., above unladdered dams). Conversely, if current use is actually more extensive than historic use—as in the reaches above a newly laddered waterfall, then the geographic scope should be defined by the current use.

A word of caution is necessary here. It is worth noting that all fish-bearing streams will be individually analyzed. Therefore, it is advisable to exercise some judgment in deciding whether to include very small streams, especially low- or mid-elevation second or third order streams. Almost all very small but perennial streams at moderate elevations and a surprising number of intermittent streams as well[1] are used by rainbow/steelhead juveniles and occasionally by spawning adults. A large subbasin will include hundreds of tributaries like this. The planner must compare the total accessible area of streams of this type with the total area of larger streams and decide whether it is worth the effort to include them. Yakima planners decided to exclude most second order and some third order streams from their analysis, especially when they occurred in areas with a high drainage density that did not support bull trout. This decision was based as much upon available time and manpower as ecological significance. The perception of a point of diminishing returns also played a role, as the benefits of inclusiveness fell while uncertainty about environmental data rose. Even so, the Yakima subbasin includes 371 reaches.

Determining Uppermost Point of Use

The next step in defining geographic scope consists of determining how much of each fish-bearing stream is utilized. This decision often resolves to identifying the location of a passage barrier (e.g., an impassible waterfall or dam). It may also simply reflect the upper limit of observation of a target species or, frequently, professional judgment as to the probable upper limits of use.

When presence–absence data are unavailable, a number of generalizations based on gradient are helpful. For many reasons, chinook salmon are unlikely to be found above a half-mile to mile-long reach of 4% gradient. Streams this steep are likely to be rather small, and probably do not have the flow or depth required by adult chinook. Such reaches are also likely to have a step-pool character (Montgomery and Buffington 1997). Almost all gravels and smaller substrate particles in step-pool channel segments are scoured and re-deposited on an annual basis (*ibid.*), making them unsuitable for fall spawners like chinook and coho. Moreover, reaches with a step-pool configuration do not represent preferred rearing habitat for either chinook or coho juveniles (Groot and Margolis 1995) and are, therefore, unlikely to attract or hold immigrants. Reaches with a gradient of 6% or more likely consist of a series of cascades (*ibid.*) and thus would exclude even steelhead if the reach were more than a mile or so in length.

Table 1 is a modified excerpt from a file that was created for the Yakima subbasin by the Washington State Conservation Commission as part of their Limiting Factors Analysis. The much larger table from which Table 1 is excerpted forms the basis for a series of maps showing current and historic distribution by species. Rows in the table are fish-bearing streams with the indentation pattern reflecting tributaries. Cell entries in the

[1] Indeed, as much as 45% of steelhead spawning in Satus Creek (the major steelhead producer in the Yakima Subbasin) takes place in intermittent tributaries.

Table 1. Example of exercise to define geographic scope for EDT analysis (modified excerpt from Yakima Limiting Factors Analysis, Haring 2002).

					Species				Upper Extent (RM)		
Stream Name					**Spring Chinook**	**Fall Chinook**	**Summer Steelhead**	**Coho**		**Source**	**Comments**
Yakima River						1,3(S,R)			127.9	1,2,5,6,7	Upper dist. based on observed chinook passing Roza Dam in October
					1,3(S,R)		1,3(S,R)		214.5	1,2,5	Dist. to Keechelus Dam currently and to the outlet of Keechelus Lake (source of Yakima River) historically.
								1(S,R)	202.5	7C	Distribution to Easton Dam
								3(S,R)	214.5	1,2,5	Dist. to Keechelus Dam currently and to the outlet of Keechelus Lake (source of Yakima River) historically.
	Naches River					2,3(S,R)			18.0	7B	Dist. to confluence of Tieton R.
					1,3(S,R)		1,3(S,R)	1,3(S,R)	44.6	1,2,5	Dist. to mouth of Bumping R (source of Naches R).
		Cowiche Cr.			2,3(R)		2,3(S,R)	1,3(S,R)	7.30	1,5,7,7B	Dist. to confluence of NF and SF
			NF Cowiche				3(S,R)	3(S,R)	3.30	2	Dist. upstream to forested area
			SF Cowiche				2,3(S,R)	3(S,R)	17.50	2	Dist. to confluence of Unnamed RB trib @ RM 17.5

Sources Referenced in Yakima Salmonid Distribution Table

1WDFW - Streamnet/WARIS/PHS Database
2WDFW - Yakima Species Interaction Study
a- Todd Pearson
3WDFW Staff:
a - Brent Renfrow, Area Habitat Biologist
b - Eric Anderson, Area Fish Biologist
c - John Easterbrooks, Fish Program Manager
d - Rick Watson, Area Fish Biologist
e - Jim Cummins, Area Fish Biologist
f - Richard Visser, Area Fish Biologist
g - Perry Harvester, Area Fish Biologist
4WDFW - Salmonid Stock Inventory: Bull Trout/Dolly Varden (1998)
5NWPPC Sub-Basin Plan (1990)
6YN - Spawning Ground Survey
7YN - YKFP Survey
a- Scott Nicolai
b-Jim Dunnigan
c-Mark Johnston
d-Henry Fraser

Upper Extent column are the uppermost river mile at which the species is found for the stream under consideration. The entries in cells under the various species columns indicate the nature of use and whether use is current or historic. The nature of use is indicated by an "S" for spawning and an "R" for rearing; documented current use is coded as a "1," probable current use as a "2," and historic use as a "3." Finally, the numbers in the "Source" column document the source of the information for the stream and species under consideration.

Subbasin planners should replicate the exercise illustrated by Table 1 for their own subbasins. It is helpful to break reaches at species-specific distribution limits (see next section), and it is important to begin systematically documenting all facts and conjectures at the outset of analysis.

2. Describing Environmentally Homogeneous Reaches

After the geographic scale has been defined, the next step in defining a reach structure for a subbasin is to break fish-bearing streams into *environmentally homogeneous* reaches that reflect the hydrography of the basin. The goal is to assess habitat from the perspective of a fish and to identify areas within which rearing conditions are, as nearly as possible, comparable.

An approach that was useful in the Yakima subbasin was to make an initial cut in terms of a process-based classification system like that of Montgomery and Buffington (1997). Although this is not the place to describe process-based channel classification in detail, it is necessary to describe how such classification systems are used in defining reaches for EDT. Excellent descriptions of the nature and utility of process-based classification systems can be found in Montgomery and Buffington (1993 and 1997).

This approach to reach definition recognizes relationships between channel morphology and fish habitat and the geomorphological processes that create and maintain channels of a certain general type. Channels are first broken into the general valley classes of colluvial, bedrock, alluvial, or estuarine. Colluvial channels occur in steep headwater areas; they are characterized by poorly defined channels filled with unsorted materials supplied mainly by debris flows. Bedrock valleys are typically confined, relatively straight, and deeply incised, with thin, patchy accumulations of cobble and gravel. The ratio of sediment supply to transport capacity is grossly unbalanced in colluvial and bedrock channels, with supply vastly exceeding transport in the former and the transport exceeding supply in the latter. Sediment supply and transport are more nearly balanced in alluvial valleys that consequently have substantial alluvial deposits. As alluvial valleys and channel reaches are generally more productive than either colluvial or bedrock channels, their basic morphological types and geological determinants warrant some additional discussion here. The five basic types of alluvial channel are determined primarily by gradient, confinement, and channel roughness. These five channel types, in increasing order of gradient, are dune-ripple, pool-riffle, plane bed, step-pool, and cascade. Dune-ripple channels are sand-bottomed, meandering, and always very flat, typically with gradients less than 0.05 %. Pool-riffle channels are found between gradients of roughly 0.1 to 1.5% and are characterized by horizontal meandering, point

bars, and alternating riffles and pools. Plane bed channels, which typically look like straight, homogeneous runs, often have gradients of 1.5 to 3.0%. Step-pool channels, with their regular sequences of small waterfalls and plunge pools, are usually found at gradients between 3.0 and 6.5%. Cascades occur at gradients of 6.5% or more.

Clearly, these alluvial, colluvial, bedrock, and estuarine channel types are not equally valuable as fish habitat. With many caveats, pool-riffle channels are generally the most valuable to the most species and life stages, cascades are the least valuable, and all other types fall into some species-specific pattern. The different channel types also respond differently to changes in sediment loading or discharge, with the steeper types tending to retain their basic morphology while lower gradient types tend to change. Importantly, increasing confinement can have the same effect as an increase in slope, whereas as an increase in channel roughness, especially the roughness associated with large woody debris, can have the same effect as a decrease in slope. Thus, an increase in confinement can transform a pool-riffle channel to a plane bed channel, while an increase in wood loading can force a plane bed channel into a pool-riffle configuration. Therefore, it is reasonable to base the reach structure for an EDT analysis largely on a combination of gradient, confinement, and wood loading.

Several other features must be incorporated into a reach structure. Any obstruction (e.g., dam, culvert, cascade) that significantly restricts adult or juvenile passage, or causes mortality to adults or juveniles, should be identified as a stand-alone reach. Hatcheries or acclimation sites and lakes or reservoirs also must also be identified as a reach. Other potential reach breaks may be included at the discretion of the planner. As previously mentioned, the uppermost distribution limit of each target species is an appropriate reach end-point. Other features that might be considered break points include unique or special geomorphological areas, such as alluvial fans, confined canyons, or delta distributaries; transitional areas between urban, agricultural, or forested areas; point sources of sediment or pollutants; sharp thermal gradients; a marked change in riparian quality or substrate composition; and so on.

In the final analysis, there is no absolute best choice when defining a reach structure for EDT analysis. The planner must try to *see* the world from the perspective of a fish and must recognize the basic geomorphological processes that create and maintain habitat. Beyond this is only a judicious weighing of the trade-off between effort and ecological resolution.

3. Describing Subbasin Hydrography

Reach structure must also reflect the confluences of all fish-bearing streams if the EDT software is to *know* the proper migration routes. Often this requirement splits an environmentally homogeneous reach into two or more pieces, as when a number of tributaries enter a confined pool-riffle canyon reach. This is simply the price of describing basin hydrography.[2]

[2] The price, however, is usually small since the analysis of one such segment may simply be copied to the others.

Hydrographic requirements also include provisions to indicate the direction of water flow—which is to say, provisions to identify the specific reaches upstream and downstream of a given reach. These requirements, and a number of other aspects of reach definition, are illustrated in Table 2, an excerpt from a file describing the hydrographic structure of the Toppenish Creek watershed in the Yakima subbasin. The Reach field identifies a particular reach in a sequence of reaches by appending a number to the stream name, with upstream reaches having higher numbers. An upstream reach that is not a tributary is the *Upstream Reach*, while a tributary entering at the upstream end of a reach is the *Tributary Upstream Reach*. If a reach ends at a fork, select either fork as the Upstream Reach and the remaining fork becomes the Tributary Upstream Reach. Downstream reaches are identified by the *Downstream Reach*, and the reach length in miles is indicated in the Length field.

The Description field describes the reach. It always includes its end points by river mile and should, if possible, indicate briefly why it was segregated. The descriptions for Toppenish Cr.-1A, Toppenish Cr.-3A, Toppenish Cr.-7A, and Simcoe Cr.-4A, for instance, indicate that they are major irrigation diversions, which must be reflected in the reach structure. Note that these reaches are considered points by the model: they are assigned a length of zero. Other reaches (Toppenish Cr.-7, Simcoe Cr.-4) were singled out because they are totally dewatered by a diversion dam during the irrigation season. Still others were chosen because they define an alluvial fan (e.g., Toppenish Cr.-7). Some were chosen because they are an incised and/or channelized reach (e.g., Toppenish Cr.-5, Toppenish Cr.-6, Simcoe Cr.-1). Other were chosen because they support poor riparian vegetation (e.g., Agency Cr.-1, Simcoe Cr.-5), define the end point of an historic hydrological feature (e.g., Toppenish Cr.-4), or mark the endpoint of accessibility for one or more species (e.g., Toppenish Cr.-12, Toppenish Cr.-13, others).

B. Summarizing Baseline Data

There are a number of good reasons to devote a significant amount of time and effort to assembling and summarizing baseline data at the outset of an EDT analysis. One of the most important is the fact that the sheer quantity of information for even *data-poor* subbasins is so great that the efficiency and accuracy of subsequent steps will suffer if they are undertaken without an organized summary of findings. Equally important is the need to begin documenting information sources early and diligently. The picture of the ecological structure and function of a subbasin is always a complex mosaic, with many different sources for different pieces of the puzzle. *Much of the value of an EDT analysis is lost if a complete, explicit record of the source of facts and the rationale for inferences is not preserved.* It is also extremely useful to integrate all relevant findings into a report—indeed, it is essential to do so if EDT workshops are planned. A workshop attended by a wide variety of natural resource specialists familiar with a particular subbasin can be invaluable in forming a more complete, interdisciplinary understanding of complex phenomena, and in reaching a consensus on the facts. Such workshops are impossible without a comprehensive but thoroughly digested summary of basic facts and issues.

Baseline information should be summarized along three axes. The first is spatial, reflected in the reach structure described above. The second is temporal, as some facts

Table 2. Illustration of coding reaches and hydrography in EDT with an excerpt from the Yakima Subbasin hydrography file (Toppenish Creek watershed).

Stream Name	Reach	Upstream Reach	Tributary Upstream Reach	Secondary Tributary Upstream Reach	Downstream Reach	Length	Descrip
Toppenish Cr	**Toppenish Cr.-1**	Toppenish Cr.-1A			Yakima R.-3	3.40	Mouth to Tainer Gate Diversion and Juvenile Bypass (RM 0 to 3.4).
Toppenish Cr	**Toppenish Cr.-1A (Diversion)**	Toppenish Cr.-2			Toppenish Cr.-1	0.00	Tainer Gate Diversion and Juvenile Bypass
Toppenish Cr	**Toppenish Cr.-2**	Toppenish Cr.-3			Toppenish Cr.-1A (Diversion)	7.30	Tainer Gate to Highway 97 Bridge (RM 3.4 to 10.7)
Toppenish Cr	**Toppenish Cr.-3**	Toppenish Cr.-3A			Toppenish Cr.-2	15.80	Highway 97 Bridge to Toppenish Unit II Pump Diversion (RM 10.7 to 26.5)
Toppenish Cr	**Toppenish Cr.-3A**	Toppenish Cr.-4			Toppenish Cr.-3	0	Unit II Diversion and bypass (RM 26.5)
Toppenish Cr	**Toppenish Cr.-4**	Toppenish Cr.-5			Toppenish Cr.-3A	2.60	Unit II Pump Diversion to Island Rd. Bridge, approximate western boundary of his toric anastomosis (RM 26.5 to 29.1)
Toppenish Cr	**Toppenish Cr.-5**	Toppenish Cr.-6	Simcoe Cr.-1		Toppenish Cr.-4	3.60	Island Rd. Bridge to Simcoe Cr. ; incised and channelized reach (RM 29.1 to 32.7)
Simcoe Cr	**Simcoe Cr.-1**	Simcoe Cr.-2			Toppenish Cr.-5	5.90	Mouth to Stephenson Rd.; deeply incised reach (RM 0 to 5.9).
Simcoe Cr	**Simcoe Cr.-2**	Simcoe Cr.-3	Agency Cr.-1		Simcoe Cr.-1	3.60	Stephenson R. to Agency Cr. (RM 5.9 to 9.5)
Agency Cr	**Agency Cr.-1**	Agency Cr.-2			Simcoe Cr.-2	6.30	Mouth to Job Corps site (poor riparian) (RM 0 to 6.3).
Agency Cr	**Agency Cr.-2**				Agency Cr.-1	2.70	Job Corps site to impassible falls (RM 6.3 to 9.0)
Simcoe Cr	**Simcoe Cr.-3**	Simcoe Cr.-4			Simcoe Cr.-2	0.90	Agency Cr. to Wesley Rd. ; beginning of perennial flows (RM 9.5 to 10.4)
Simcoe Cr	**Simcoe Cr.-4**	Simcoe Cr.-4A			Simcoe Cr.-3	3.50	Wesley Rd. to Simcoe Feeder Canal diversion dam; dewatered reach (RM 10.4 to 13.9)
Simcoe Cr	**Simcoe Cr.-4A**	Simcoe Cr.-5			Simcoe Cr.-4	0.00	Simcoe Feeder Canal (RM 13.0)
Simcoe Cr	**Simcoe Cr.-5**	Simcoe Cr.-6	Wahtum Cr.		Simcoe Cr.-4A	0.50	Simcoe Feeder Canal to Wahtum Cr.; poor riparian (RM 13.9 to 14.4)
Wahtum Cr.	**Wahtum Cr.**				Simcoe Cr.-5	4.00	Mouth to steelhead access limit (RM 0 to 4.0)
Simcoe CR	**Simcoe Cr.-6**		NF Simcoe Cr.	SF Simcoe Cr.	Simcoe Cr.-5	5.50	Wahtum Cr. to forks (RM 14.4 to 19.9)
Simcoe Cr NF	**NF Simcoe Cr.**				Simcoe Cr.-6	4.00	Mouth to access limit (RM 0 to 4).
Simcoe Cr SF	**SF Simcoe Cr.**				Simcoe Cr.-6	4.00	Mouth to access limit (RM 0 to 4).

relate to the Template, some to the Current state, and some to a specific season. The third captures the justification or rationale behind a piece of information.

This third dimension is related to the documentation issue described above but is more than mere footnoting. An effort must always be made to assess the accuracy of the data input into the model. Indeed, every piece of information entered into the EDT model is evaluated in terms of its *level of proof*. EDT tracks four levels of proof: (1) thoroughly established, generally accepted, good peer-reviewed empirical evidence in its favor, (2) strong weight of evidence in support but not fully conclusive, (3) theoretical support with some evidence from experiments or observations, and (4) speculative, little empirical support. A thorough understanding of this sort of *metadata* will be essential in the later stages of analysis, when it is necessary to choose between alternative enhancement strategies with comparable expected benefits.

1. Information Types

Both biotic and abiotic information about the environment, as well as demographic information about the target species, are entered into the EDT model. To be more precise, digitized information of this sort (referred to as *Level-2 or Environmental Attribute Ratings*) is entered into the model. Raw information or data (referred to as *Level 1 or Landscape data*) must be converted to categorical Environmental Attribute ratings before they can be input to the model. The goal of this particular exercise, however, is merely to summarize, annotate, and document observed data relating to the demographics of the targeted species and key biotic and abiotic aspects of the subbasin.

Biological Data

The EDT model requires a wide range of biological data. In an effort to ease planners' workloads, a *baseline biological dataset* will already have been entered into the model before subbasin planning begins. This baseline data includes stock-specific information on fecundity, sex-specific age distributions, relative hatchery/wild fitness, and all pertinent information regarding existing hatchery programs. The planner is encouraged to arrange with his or her watershed administrator to review this data to ensure it is as accurate and up-to-date as possible. The planner, however, is responsible for entering biological data relating to spawning sites and times, harvest rates, and life history patterns (the first six items in the list below).

1. Population name. Planners must supply a unique name to identify the race and approximate area used by the population for spawning (e.g., upper Yakima spring chinook).
2. Spawning distribution. Planners must indicate the reaches in which the natural population is known to spawn as well as the reaches it is believed to have spawned in historically. All life histories (see below) subsequently modeled will originate from these reaches. Planners may create as many spawning populations as they wish, and each may have different beginning and ending dates for spawning, but no two populations may overlap in space (spawn in the same reach or reaches).

3. Adult run and spawn timing. Planners must indicate the weeks in which spawning typically begins and ends. If spawning is significantly earlier in the upper portions of a drainage than in the lower portions, two (non-overlapping) populations should be created with different spawning dates.
4. Life history patterns. In EDT modeling, a *life history pattern* consists of a distinct combination of juvenile and adult age distributions for different components of the same population. More specifically, it consists of a set of proportions (summing to 1.0) describing the prevalence of a number of such alternative patterns. An illustration of a description of alternate life history patterns within the same EDT population would be a population of spring chinook in which 40% of the fish smolt as subyearlings and 60% as yearlings. A number of different juvenile and adult age distributions for widely divergent stocks have been entered into the model as templates for creating life history patterns. The planner's task will be to indicate the specific age distributions most characteristic of the target population and then to specify the proportion of the population that expresses each pattern.
5. Harvest rates. Planners must provide estimated harvest rates for each population. Once again, the planner will address this issue by identifying which pre-loaded harvest regime best describes the population (e.g., a harvest pattern like that of Willamette spring chinook, Cowlitz spring chinook, or upriver spring chinook).
6. Sex-specific age distribution, age-specific sex ratios, and age-specific fecundity. Baseline biological data will have already been entered into the model for these parameters.
7. Hatchery data. Baseline data will also have been compiled for the following hatchery parameters:
   a. Hatchery location (tributary and river mile)
   b. Species reared
   c. Fish size and weight at release
   d. Total number of fish released by species
   e. Release locations (tributary and river mile)
   f. Donor stock (local, adjacent drainage, distant drainage)
   g. Release date(s)
   h. Survival information if available (smolt-to-adult survival, smolts/spawner, catch/escapement, etc.)
   i. Mean number of adult returns
   j. Stray rates if known
   k. Proportional contribution of hatchery fish to the natural spawning escapement
   l. Number and location of hatchery carcasses returned to the river

Environmental Data

Planners must supply a wide range of environmental data that can be broadly classified as biotic, physical/structural, or water chemistry related. At the beginning of the

baseline summarization process, it is probably more useful to the planner to be aware of the specific nature of the data than to ponder how it will be processed into Environmental Attributes (Level 2 inputs) for the model. This topic, conversion of Landscape (Level 1) data into Environmental Attribute (Level 2) values, will be discussed in considerably more detail in a subsequent section. Accordingly, planners should direct their attention to Tables 3–5, which define required environmental attributes that can be characterized as biotic, physical/structural, or water chemistry related, respectively.

Table 3. Biotic environmental attributes to be summarized in EDT analysis.

Environmental Attribute	Description
Benthic community richness	Measure of the diversity and production of the benthic community. Expressed in terms of overall macroinvertebrate abundance and the numbers of species of Ephemerella, Plecoptera and Tricoptera present.
Fish community richness	A measure of the richness of the fish community. Expressed in terms of the number of fish species per reach.
Fish pathogens	The presence of pathogenic organisms (relative abundance and species composition) having the potential to affect the survival of stream fishes. Expressed in terms of the frequency, severity and type of fish diseases that have occurred in the drainage as well as the frequency and geographic range of hatchery fish outplants.
Number of exotic fish species	The extent of introductions of exotic fish species in the vicinity of the stream reaches under consideration. Expressed as the number of exotic species known to be present in the sub-drainage of interest.
Harassment	The relative extent of poaching and/or harassment of fish within the reach. Expressed in terms of proximity to cities and towns and ease of access.
Hatchery fish outplanting	The number and degree of dispersion of hatchery fish outplants made into a drainage over the past 10 years. Expressed in terms of the number of releases made in the last decade as well as the number of release points.
Predation risk	The level of predation risk on targeted fish species due to presence of top-level carnivores or unusual concentrations of other fish-eating species. This is a classification of per-capita predation risk, in terms of the likelihood, magnitude, and frequency of exposure to potential predators (assuming other habitat factors are constant). Expressed in terms of the per capita risk relative to normative conditions. Human activities can affect concentrations of fish-eating predators relative to conditions that existed prior to Euro-American settlement. In some cases, predator risk has been *reduced* as some fish-eating species have declined sharply due to human activity (e.g., bull trout, coho). Other activities, such as construction of dams, have concentrated some fish-eating species, like northern pikeminnow, at critical fish passage sites in the Columbia River. These changes in relative concentrations (or effectiveness) may have altered predation risk on salmon species compared to historic levels in some areas.
Salmon carcasses	Relative abundance of anadromous salmonid carcasses within watershed (e.g., HUC 5 level) that can serve as nutrient sources for many wildlife and fish species. Expressed in terms of the mean number of carcasses of all species expected within a HUC 5 watershed each year.

Table 4. Physical/structural environmental attributes to be summarized in EDT analysis.

Environmental Attribute	Description
Bed scour	The average depth of scour on small-cobble/gravel riffles, pool tailouts and glides during bankfull flows. Particle size classes defined as follows: gravel (0.2 to 2.9 inch diameter), small cobble (2.9 to 7 inch diameter), large cobble (7 to 11.9 inch diameter), boulder (>11.9 inch diameter). Expressed in terms of the average expected depth of disturbance (cm).
Natural confinement	The degree to which the valley floodplain of the reach is confined by natural features. Expressed as the ratio between the width of the valley floodplain and the bankfull channel width. Note: this attribute addresses the natural (pristine) state of valley confinement only. The extent that reaches are confined by hydromodifications (e.g., diking) is addressed under the heading "anthropogenic confinement".
Anthropogenic confinement	The extent that man-made structures within or adjacent to the stream channel constrict flow (as at bridges) or restrict flow into the stream's floodplain (due to streamside roads, revetments, diking or levees), or the degree to which the channel has been ditched or channelized. Expressed in terms of the proportion of the stream's perimeter has been disconnected from its floodplain. Thus, a stream totally diked on one bank but unaffected on the other would have an anthropogenic confinement score of 50%.
Embeddedness	The extent that larger cobbles or gravel are surrounded or covered by fine sediment. Expressed as the proportion of the surface area of dominant substrate particles that is covered by fine sediment.
Diel flows	Variability in flow during a daily period. This attribute is informative mainly for highly regulated rivers or when flow is heavily influenced by storm-water runoff. Expressed in terms of the mean monthly flow variation over a 24-hour period.
Peak flow	A measure of between-year variation in magnitude of high flow levels and/or the extent of change in expected monthly high flows relative to an undisturbed watershed of comparable size, geology, and geography (or as would have existed in the pristine state). Expressed as degree of change in variability or expected magnitude of peak flows relative to the normative condition. Species adapted to disturbance events (such as floods) of intermediate intensity, as occurred in most pristine watersheds of the Pacific Northwest, can be negatively affected by increases in the frequency and magnitude of disturbance. Changes in flow runoff patterns associated with channelization, revetment, and timber harvest can increase both magnitude and frequency of high flow events resulting in increased intensity of disturbance. Conversely, hydrologic regimes that have been shifted to more stable patterns (i.e., less variation and reduced high flows) can result in loss of habitat quality if channel/habitat forming events occur much less frequently.
Minimum flows	A measure of between-year variation in the severity of low flows during the month of minimum flow. Variation in low flows is relative to an undisturbed watershed of comparable size, geology, and geography (or as would have existed in the pristine state). Expressed as degree of change in variability or expected magnitude of minimum flows relative to the normative condition. This attribute defines how low flow (e.g., during late summer) has changed relative to the undisturbed state. Changes are considered in both overall level of flow and between-year variation. Increased variation in low flow or overall reduced low flow can result in survival reduction due to increased exposure or migration difficulties.

Table 4 continued. Physical/structural environmental attributes to be summarized in EDT analysis.

Environmental Attribute	Description
Fine sediments	Percentage of fine sediment within pool-tailouts, glides, and riffles. Expressed as an absolute percent or a percent range.
Gradient	The average gradient of the main channel of the reach over its entire length. Expressed as an absolute percent.
Pool habitat	Percentage of the wetted channel surface area of a reach comprising primary pools.
Pool tail-out habitat	Percentage of the wetted channel surface area of a reach comprising pool tailouts and glides. Typically, about 20-25% of the total area of a primary pool will consist of a tailout.
Backwater pool habitat	The percentage of the wetted channel surface area of a reach comprising backwater pools. Backwater pools are partially enclosed habitat units located along the channel margins which are hydraulically connected to the main channel or a side channel at one end at most times. As defined here backwater pools include "alcoves" as described by Nickleson et al. (1992). They are typically restricted to the non-vegetated floodway of the main channel, often comprising the mouths of sloughs and other kinds of “parapotamon” (a channel connected only at one end to the existing main channel). Backwater pools provide low-velocity rearing habitat. They often are relatively shallow with fine-grained substrates, and are particularly important as nursery areas for coho and chinook fry and summer rearing for parr. They also serve as refuge areas during winter, particularly within deeper backwater pools.
Small cobble/gravel riffle habitat	The percentage of the wetted channel surface area of a reach comprising riffles the substrate of which is dominated by small cobbles and gravel. Particle size classes are defined as follows: gravel (0.2 to 2.9 inch diameter), small cobble (2.9 to 7 inch diameter), large cobble (7 to 11.9 inch diameter), boulder (>11.9 inch diameter).
Large cobble/boulder riffle habitat	The percentage of the wetted channel surface area of a reach comprising riffles the substrate of which is dominated by large cobbles and boulders. Particle size classes are defined as follows: gravel (0.2 to 2.9 inch diameter), small cobble (2.9 to 7 inch diameter), large cobble (7 to 11.9 inch diameter), boulder (>11.9 inch diameter).
Beaver dam habitat	Percentage of the wetted main channel surface area of a reach comprising beaver dams. Note that beaver dams in side channels or sloughs and other types of off-channel habitat are not included.
Glide habitat	The percentage of the wetted channel surface area of a reach comprising glides. Glides are channel units of relatively constant depth and non-turbulent flow often found in plane bed or dune-ripple channels. Although the distinction between a deep glide and a primary pool is not sharp, pools generally are formed by a physical depression in the stream bottom, and would hold water even if the rest of the reach were dried up. The steambed underneath " glides" is relatively flat, regardless of the depth of the water above it. In addition, water velocity in pools is quite low, typically 1 fps or less. Velocities in glides may be appreciably greater: “runs” are classed as “glides.”
Side Channel habitat	The percentage of the wetted channel surface area of a reach comprising side channels. Side channels are smaller secondary channels that flow largely outside the floodway of the main channel. They are hydraulically connected to the main channel at both ends at most times, and are typically separated from the main channel by high ground supporting maturing trees or other permanent vegetation.

Table 4 continued. Physical/structural environmental attributes to be summarized in EDT analysis.

Environmental Attribute	Description
Off-channel habitat factor	A multiplier used to estimate the amount of off-channel habitat as a function of the wetted surface area of the all combined in-channel habitat. Off-channel habitat consists of oxbows, backswamps, riverine ponds, and the channels that connect them to the main channel or its side channels. They are distinguished from side channels by the fact they usually are connected to the main channel only at one end and consequently have virtually no current. The channels of natural riverine systems tend to meander across their floodplains over time. This movement of channels results in a variety of topographic features along a floodplain. Some of these features form and maintain wetlands, marshes, and ponds. The aquatic sites comprising these areas are considered off-channel habitats.
Natural hydrologic regime	The natural flow regime within the watershed of interest. Flow regime is construed as the seasonal pattern of flow over a year. Here, it is inferred by identification of flow sources, and applies to an unregulated river or to the pre-regulation state of a regulated river. The various natural hydrological regimes in the Northwest include: • Groundwater dominated. Strongly buffered peak flows (as in a springbrook or a river like the Metolius in Oregon). • Spring snowmelt dominated, non-glacial. Temporally regular and moderate peak and low flows. • Rain-on-snow transitional. Consistent spring peak and fall low flows with inconsistent and flashy winter or early spring flows. • Rainfall dominated. Flashy winter and early spring peaks, consistently low summer flows and variable spring and fall flows. • Glacial. High, turbid low flows and generally buffered peak flows except for occasional outburst floods and rain-on snow events.
Regulated hydrologic regime	The change in the natural hydrograph caused by the operation of hydroelectric facilities, excluding daily flow fluctuations. Expressed in terms of the degree to which the natural hydrograph is distorted, particularly in terms of normative maximum and minimum flows.
Icing	The magnitude and frequency of icing events (ice jams and anchor ice deposition).
Obstructions	Obstructions to fish passage by physical barriers -- not dewatered reaches or passage hindrances caused by temperature, pollution or low DO. Expressed as the number of obstructions, the life stages they affect, and the degree to which passage is limited.
Riparian function	A measure of the degree to which riparian function that has been altered within the reach. The riparian zone is characterized by its vegetation—trees, brush, grass, and sedges. This zone and the stream channel are interdependent. The zone comprises those areas near the stream channel that affect the channel and are affected by it. Expressed as an estimate of the percent of remaining functional attributes (overbank flows, vegetated streambanks and groundwater interactions).
Large Woody Debris loading	The amount of large wood within the reach. "Large wood" is defined as a piece > 50 cm diameter at its midpoint (based on standard Timber-Fish-Wildlife definitions). Expressed in terms of the diversity of kinds of accumulations and the sizes, decay classes, and species of the pieces present; the frequency of cross-channel jams or pieces; and especially the degree to which large wood is a dominant influence on channel diversity (e.g., pools, gravel bars, and mid-channel islands).

Table 4 continued. Physical/structural environmental attributes to be summarized in EDT analysis.

Environmental Attribute	Description
Diversions	The number, relative size and screening status of water withdrawals in the reach. This attribute indexes the probability of death due to entrainment and subsequent stranding in irrigation ditches. Expressed in terms of the number, cumulative percent discharge diverted and screening status of the diversions in the reach.
Maximum width	Average width of the wetted channel during the month when flows are typically highest. If the stream is braided or contains multiple channels, width is estimated as the sum of the wetted widths along a transect cutting all channels. Expressed as an absolute estimate in feet.
Minimum width	Average width of the wetted channel during the month when flows are typically lowest. If the stream is braided or contains multiple channels, width is estimated as the sum of the wetted widths along a transect cutting all channels. Expressed as an absolute estimate in feet.

Table 5. Water quality environmental attributes to be summarized in EDT analysis.

Environmental Attribute	Description
Alkalinity	Alkalinity of water (mg/L) at moderate flows. Alkalinity is broadly correlated with the productive capacity of streams, with respect to both primary production and fish production. The correlation between alkalinity and fish production is believed to be due to the role alkalinity plays in the production of food organisms.
Dissolved oxygen	Average dissolved oxygen (mg/L) within the water column for the specified time interval.
Metals/pollutants in sediments and soils	The concentration of heavy metals and miscellaneous toxic pollutants in stream sediments and/or soils adjacent to the stream. Expressed in terms of adverse physiological impacts on, or mortality of, benthic organisms, fish and riparian vegetation.
Metals in water column	The concentration/toxicity of dissolved heavy metals in the water column. Expressed in terms of exposure duration/toxicity.
Miscellaneous toxic pollutants in water column	The concentration/toxicity of pollutants other than heavy metals in the water column. Expressed in terms of the number of substances present and their collective chronic or acute toxicity to benthic organisms and fish.
Nutrient enrichment	The amount of nutrient enrichment consisting of ammonia, nitrogen and phosphorous. Expressed as a spectrum of concentrations ranging from baseline to super enrichment/eutrophication.
Minimum daily water temperature	Minimum water temperatures within the stream reach during a month. Expressed in terms of the mean number of days per year minimum daily water temperature is below 4°C or below 1°C.
Maximum daily water temperature	Maximum water temperatures within the stream reach during a month. Expressed in terms of the mean number of days per year maximum daily water temperature exceeds 10, 16, 22, 25 and 27.5^{o}C.

Table 5 continued. Water quality environmental attributes to be summarized in EDT analysis.

Environmental Attribute	Description
Spatial variation in water temperature	The extent of water temperature variation within the reach as influenced by inputs of cool groundwater. Expressed in terms of the magnitude of groundwater discharges in a reach.
Turbidity	The relative frequency and intensity of episodes of turbid water within the reach. Expressed in terms of the mean number of days per year turbidity exceeds certain ranges of turbidity levels (NTU's)

2. Retrieving and Annotating Data

Although planners will be provided an initial environmental attribute dataset (the *coarse screening data*) for their subbasins, they should anticipate the need to refine this data.

Data Retrieval

Planners will therefore need to examine coarse screening data closely and judge for themselves whether it represents a reasonable description of conditions. The coarse screening data will be accompanied by an explanation of the techniques used to estimate it, and an initial estimate of its utility can be based on the adequacy of individual derivations. A final decision about the usefulness of the data, however, will require comparison of actual coarse screening values and those values estimated by the planners.

Planners should be prepared to make use of a number of different kinds of information in testing the coarse screening data or developing substitutes for it. Table 6 summarizes many of the kinds of information that have proven useful in the Yakima subbasin. Table 7 lists a number of specific sources for EDT input data. Table 7 emphasizes data that may be examined on the Internet and, whenever possible, downloaded free of charge.

It may be beneficial to planners to consider which types and sources of data proved most useful to Yakima subbasin planners. At the agency level, the most useful *sources* were organizations actively involved in the management or study of land, water, and wildlife. In no particular order, the five agencies most helpful to Yakima planners were:

- The Yakama Nation Fisheries and Wildlife Programs;
- The Central Washington University Geography Department;
- The Yakima Project of the Bureau of Reclamation;
- The US Forest Service (Naches and Cle Elum Ranger Districts);
- The Washington Department of Fish and Wildlife; and
- The Washington State Conservation Commission

Yakama Nation Fisheries and Wildlife staff members were an invaluable source of demographic and life history data for targeted stocks, as well as for on-reservation

Table 6. Types of information useful in estimating EDT input parameters.

Type	Description
Maps	For the Current condition, electronic map software is most useful (e.g., Maptech's Terrain Navigator). A wealth of information can be obtained from such packages, including estimates of reach length and slope, confinement, approximate amount of side channel and off-channel habitat, dam locations, etc. General Land Office (GLO) maps or other historic maps are often invaluable in reconstructing the Template, as are the earliest USGS topographic maps.
Aerial photographs and videos	Sets of aerial photographs taken by various agencies (state Departments of Transportation, Indian tribes, the US Forest Service, the Bureau of Reclamation, etc.) can be extremely useful in estimating Current channel type composition, in determining appropriate end points for reaches, and in assessing LWD loading, riparian condition, etc. Evidence of existing or filled side channels or off-channel habitat, aggradation or incision/head-cutting, etc., can often be detected in older aerial photos and can be used in reconstructing the Template. Aerial videos, if available are even more useful in this regard, as well as in determining the habitat unit composition of individual reaches.
Photographs	If they can be dated and located accurately, photographs of a stream can be useful in verifying current or historic channel type, LWD loading, current or historic upland conditions, riparian condition, etc. Photos of catches can document the historic existence of salmon or steelhead in a particular drainage.
Surveys	GLO survey notes can be very valuable in reconstructing the Template in terms of quantity of off-channel habitat, extent of side channels, springbrooks and beaver dams, riparian/LWD conditions, etc. US Forest Service Stream Survey Reports often provide much of the input data for an EDT analysis, although the particular definitions used for certain habitat parameters (e.g., percent pools) affects the way values should be interpreted.
Studies and Reports	State and tribal fisheries agencies, Northwest universities and fish and wildlife coops have published a tremendous number of papers on fisheries issues in the last two decades. Some of these studies were published in refereed journals, but many more are summarized in Bonneville Power Administration (BPA) annual reports or completion reports. These papers represent one of the best information sources for species-specific life history patterns, abundances, survival rates and habitat requirements. Limiting Factors Analysis reports published by the Washington State Conservation Commission, as well as the Subbasin Summaries published by the Northwest Power Planning Council (NPPPC), are as useful in summarizing habitat conditions as many BPA reports are in summarizing demographic and life history data. These information sources should be among the first examined. Planners should also be aware of special studies commissioned by court cases or special events. In the latter category fall many local historic reports published in Washington State in honor of the state Centennial.
Databases	State and Federal land and water management agencies frequently maintain large databases on flow and/or water temperature, and state Ecology Departments maintain large databases on water quality.
Narratives	Descriptions found in books, journals, diaries and archived notes from early explorations can often provide information on historic habitat conditions and fisheries found nowhere else.

Table 7. Potential sources for obtaining EDT input data.

Source	Comments
Local, state-wide, university and national libraries	Particularly good sources of historic data, especially old maps, photographs and journals. Almost all libraries now maintain Web sites that, at a minimum, allow easy access to holdings; many allow materials to be downloaded for no charge. A list of Web sites for major Northwest University libraries follows: **http://www.lib.uidaho.edu/** University of Idaho Library **http://www.isu.edu/library/** Idaho State University Library **http://www.lib.montana.edu/** Montana State University at Bozeman Library **http://www.lib.umt.edu/** University of Montana Library **http://libweb.uoregon.edu/** University of Oregon Library **http://osulibrary.orst.edu/** Oregon State University Library **http://www.lib.washington.edu/** University of Washington Library **http://www.wsulibs.wsu.edu/** Washington State University Library The site **http://www.wsulibs.wsu.edu/holland/masc/usgstoposindex.htm** provides access to historic topographic maps in Washington State that may be downloaded free of charge, while **http://www.ohs.org/collections/maps/maptosee.htm** provides freely downloadable Oregon State historic maps.
Commercial digital topographic map vendors	Digital topographic map software from a variety of top commercial providers may be ordered from the site **http://www.gpsnow.com/or.htm**
Local Bookstores	A good source of descriptions of the local histories: descriptions of the historic environment in a general sense.
Local, state-wide, university and national historic societies, museums and collections.	Holdings are predictably heavy on the history of development, and may thus be useful in shaping a picture of environmental change. Many also include collections of old photographs, some small fraction of which may be very useful in describing structural details of streams in historic times.

Table 7 continued. Potential sources for obtaining EDT input data.

Source	Comments
Tribal, state and national fish, wildlife, water and land management agencies	**Tribal and state fish and wildlife agencies** are indispensable for demographic and life history information on target stocks. **The Bureau of Reclamation** (**http://www.usbr.gov/main/**, currently Web-inaccessible) may be an invaluable source of flow and other hydrological data for irrigated basins. **The US Forest Service** is a valuable source for watershed condition and stream habitat surveys (which are, however, usually confined to smaller streams in forested areas). The **Bureau of Land Management** (BLM; **http://www.blm.gov/**, currently Web-inaccessible) also can supply environmental information on local streams, and the BLM office in Portland, OR (503-952-6001), can advise of the availability and costs of obtaining General Land Office maps and field notes, which often provide the earliest and best descriptions of steams and streamside corridors. The **National Marine Fisheries Service** (**http://www.nmfs.noaa.gov/**) and the **US Fish and Wildlife Service** (currently Web-inaccessible due to a court case – as are all other Dept. of Interior Agencies) provide critical status information on species/ESU's listed under the Endangered Species Act and habitat deemed critical for their survival. The US Geological Survey (**http://www.usgs.gov/**) provides downloadable information on current and historic flows in selected streams throughout the Northwest, as well as ordering information on all USGS maps and aerial photos. The US Environmental Protection Agency (**http://yosemite.epa.gov/R10/HOMEPAGE.NSF/webpage/INDEX?opendocument** **Pacific Northwest Region 10**) is a good source of water quality information. State Departments of Ecology are particularly good sources of water quality problems, and a list of streams and violations on the 303(d) list may be found at the following sites: Washington State: **http://www.ecy.wa.gov/programs/wq/303d/** Oregon: **http://www.deq.state.or.us/wq/303dlist/303dpage.htm** Idaho: **http://yosemite.epa.gov/R10/WATER.NSF/6cb1a1df2c49e4968825688200712cb7/5c6b7bf2420c272888256a4800613a68?OpenDocument** Montana: **http://water.montana.edu/docs/tmdl/303d/css/winstyles.css** For subbasins covered, the ICBEMP site, **http://www.icbemp.gov/spatial/html/datalist.shtml**, provides a wealth of land- and water-management data as well.
Archives of corporations with holdings in the watershed	Timber corporations such as Weyerhauser or Boise Cascade, frequently maintain some kind of historic archive for local operations.
Web-based imagery	A number of Web sites managed by state agencies offer on-line aerial photos of selected drainages and reaches, but coverage is usually far from complete. A free, much more comprehensive source of aerial photographs of fair quality is Microsoft's Terraserver site, **www.terraserver.com**. Yakima planners made use of this resource repeatedly in confirming or describing reach-specific habitat unit allocation and other aspects of channel structure and riparian condition. Planners should note that Terraserver images are most useful for examining streams of higher order. Resolution is often too poor to discern much of the habitat unit structure for third and even some fourth order streams.

habitat data and watershed analyses conducted under the Timber, Fish, and Wildlife Program, the Washington State Department of Natural Resources, and private corporations (e.g., Plum Creek Timber). The contributions of the staff and students of the Central Washington University Geography Department cannot be overstated. They provided much of both the detail and theory that informs our understanding of the normative structure and function of the Yakima River Basin. The staff members of the Yakima Project of the Bureau of Reclamation were equally helpful. They provided access to an absolute treasure trove of current and historic flow and water temperature data, as well as a number of historic maps (dating from the era in which the irrigation system of the Yakima Valley was being surveyed and designed) and more recent aerial photographs that fundamentally changed our understanding of the normative structure of the river. The US Forest Service generously shared all of their steam survey reports, as well as evaluations of various habitat enhancement projects and the findings of other monitoring programs addressing channel stability and water temperature. The utility of Forest Service Stream Survey Reports warrants special mention, as they provide estimates of at least half of the environmental attributes EDT requires. The staff members of the Washington Department of Fish and Wildlife were as forthcoming and knowledgeable about the life history and demographics of local stocks as were the Yakama Nation personnel. WDFW habitat and hydraulic permitting staff, focused as they are on specific and widely distributed sites, were able to help us refine or revise descriptions of environmental attributes in particular reaches of particular streams. Last, but not least, the Washington State Conservation Commission staff did yeoman work in collecting and summarizing environmental data for the Yakima subbasin. Their Limiting Factors Analysis probably represents the most complete annotated bibliography of fish habitat in the Yakima subbasin yet written. Indeed, it could form the core of the Summary Report for an EDT analysis, if augmented by tables and other data summaries that reflect the particular reach structure developed for an EDT analysis.

Creating an Annotated Bibliography or Database

The first step in creating an annotated bibliography is to assemble the relevant documents, tables, and figures. A word of advice here: whenever possible, assemble data in electronic format. Compact discs are especially useful. In this day and age, almost all data except perhaps certain historic documents have been transcribed into some kind of an electronic file, and the planner can usually obtain the necessary files with tactful persistence. Even archived information not usually found in digital format, such as maps and historic photographs, can be scanned. It is well to remember that all useful or important information will eventually find its way into an analysis or a report, and the easiest way of accomplishing this is to have source information in digital format from the outset. Information that cannot be obtained in, or transformed into, digital format should be photocopied. All source information, digital or hard copy, must be filed in an EDT archive for future reference.

The annotation process should start with the first piece of information collected, and it should address six major points.

1. The source of the information must be recorded: a standard citation for a published document; a detailed description for a piece of gray literature; and a name, title and agency for a personal communication, etc.

2. The information should then be attributed to as narrow a geographic range as possible—ideally to a reach or series of reaches, but at least to a sub-drainage within the subbasin.
3. The era (Current or Template) should be noted, as well as the seasonality, if applicable.
4. If the information applies to a certain species or run (e.g., fall chinook vs. spring chinook), this should also be noted.
5. Important *metadata* (e.g., caveats on interpretation based on the circumstances under which data were collected or recorded) must also be noted in order to establish level of proof and generality.
6. Finally, and most critically, the findings must be translated into one or more EDT input parameters, or at least definitely associated with one or more EDT input parameters.

For example, a time series of daily maximum and minimum water temperatures for a reach or series of reaches clearly should be associated with the EDT input parameters *Maximum daily water temperature* and *Minimum daily water temperature*. Because the rules by which raw max/min temperature data are transformed into EDT input parameters are computationally tedious, it may be sufficient early on to state that a certain file in a certain location addresses these parameters directly and generally indicates that summer temperatures in a certain location are or are not a problem. Alternatively, the source information can be processed when obtained, and the annotation would document specific EDT input values. However thoroughly input data is digested as it is collected, it is important that its implications for an EDT analysis be stated as clearly as possible.

To be most useful to the planner, this data summary should take the form of an annotated bibliography or ideally an annotated database. In the former case, the planner would develop a bibliographical database using software such as ProCite. Each entry would include a number of key words, which would include all EDT input parameters, reach names, temporal categories, etc. Alternatively, a relational database such as MS Access could serve as the platform for this information, with fields instead of keywords for reaches, environmental attributes, sources, and so on. In either case, the planner would be able to sort and review masses of data quickly when it was time for entering data or for producing a detailed justification for some assertion. The alternative to taking the time to organize input data in this way—piles of unrelated reports and/or a subdirectory full of haphazardly categorized files—should make it clear to the experienced report writer that this is time well spent.

C. Estimating Environmental (Level 2) Attributes

In this section, the general principles of estimating environmental attributes will be presented, followed by a detailed application of these principles to the Yakima.

1. General Principles

Estimating environmental attributes should be approached systematically and with the appropriate frame of mind. The planner should always bear in mind that the goal is not so much to produce an exact description of every reach, as it is to produce a reasonable description that can be shown to be consistent with documented observations and widely accepted relationships. A determined effort to maintain consistency with observations and accepted relationships will almost always result in meaningful ecological input for the model. Moreover, each attribute will be associated with a rationale and a level of proof assessment. The latter will flag potential errors for future revision, and the former will indicate exactly how an erroneous evaluation might be corrected.

This task, however, includes a multitude of details, and the proper attitude will only help so much. A systematic approach will definitely make the work go more smoothly. In order to maximize the efficiency of dealing with a multitude of details, the planner should strongly consider each of the issues discussed below.

Compiling observed (landscape or Level 1) data. Compile all landscape data so that it can be quickly re-organized along different dimensions—e.g., by a specific attribute within a particular drainage, or all attributes within a single reach. A relational database (e.g., MS Access or Paradox) of condensed data findings will make life much, much easier.

Examining Environmental Attribute Definitions and Ratings. The definitions of the environmental attributes and their ratings should be thoroughly understood at the very outset of planning—before estimating environmental attribute values and even before the compilation and condensation of raw (landscape) data. With attribute definitions and distinctions clearly in mind, the planner can often assign a environmental attribute rating on the fly, as raw data is being condensed, saving considerable time and effort. More importantly, beginning the exercise with a firm conceptual grasp of the environmental attribute categories will greatly lessen the likelihood of incorrect ratings and subsequent revision, a very inefficient process indeed.

Certain attributes, such as r*iparian function* and *confinement-hydromodifications,* are somewhat easily confused or misunderstood. Other confusions may involve *average annual peak flow* and *intra-annual flow pattern*. The habitat types *glides* and *pools* may be confused, as well as the hydrological variables *hydrologic regime-regulated* and *diel flow variation.* Certain aspects of the definitions of other variables may also lead to misunderstandings, including the attributes *natural confinement*, *embeddedness*, and *fine sediment* as well as the habitat types *backwater pools*, *side channels*, and *pool tail-outs.* A discussion of some important distinctions and qualifications concerning these attributes follows.

- Confinement-hydromodifications (Confine Hydro) refers strictly to anthropogenic physical exclusion of the stream from its floodplain and specifically to an artificial confinement tight enough to accelerate flows, simplify microhabitat, and increase bedload transport capacity in the affected reach. It is important to understand that the degree of confinement implied by this measure is substantial—certainly a confinement no wider than two or three bankfull channel widths. Thus, a narrowly

diked reach would be ranked high on this measure, but a reach bordered by levees set back several hundred yards from the ordinary high water mark would not. Consider the extent of the setback and its effect on flow and bed dynamics, and microhabitat features along the stream margin in the reach to arrive at a rating conclusion. Set back levees should be reflected in the riparian function attribute (RipFunc), which indexes the degree to which all of the various functions of the floodplain have been eliminated. These functions include normative extent and frequency of overbank flows, as well as groundwater–surface water interactions and the density, maturity, and species composition of streambank vegetation.

- Average annual peak flow (FlwHigh) and intra-annual flow patterns (FlwIntraAnn) refer to different aspects of the same general impact and are in fact usually closely correlated. Average peak flow describes the degree to which the mean annual flood has been changed in magnitude relative to its normative value, and is defined in terms of changes in the *two-year flood*—the flow with a recurrence interval of two years. Intra-annual flow pattern refers to the rapidity of storm water runoff response (rates of change in flow) during the wettest month; it is expressed in terms of the fraction of a year that the daily mean discharge rate exceeds the annual mean discharge (T_{Qmean}). If peak annual flows are moderately, or strongly increased, storm runoff response rates are usually increased as well (and vice versa).

- Deeper glides may easily be confused with pools when interpreting aerial photographs, or even at the conceptual level. Conceptually, a deep glide (HbGlide) differs from a pool (HbPls) by having moderate velocities (> 1 fps) rather than very low or near-zero velocities, and in having a flat rather than a concave bed. Note that *runs* are considered a subset of *glides* in the EDT model.

- Hydrologic regime-regulated (HydroRegimeReg) describes the impact to the annual hydrograph of an upstream dam. If the dam is operated in a run-of-the-river fashion, or stores only a small proportion of the mean annual flow, its impact on the downstream hydrograph will be small. By this measure, reaches of the Snake or Columbia immediately downstream of hydroelectric dams would be ranked rather low for HydroRegimeReg. Conversely, most of the upper Yakima River lies below three storage reservoirs that collectively capture a third of the mean annual runoff in the spring. This water is released in the summer and early fall for irrigation, changing the annual hydrograph qualitatively. Therefore, the HydroRegimeReg metric is scored high for much of the upper Yakima. Although diel flow variation (FlwDiel) also reflects the impact of upstream dams, it reflects an impact over a much shorter time period (24 hrs), and it is expressed in terms of *ramping rate*—the expected fluctuation of the water surface elevation in terms of inches per hour. In recent years, the Bureau of Reclamation has attempted to limit ramping rates in reaches below diversions or storage reservoirs in the mainstem Naches and Yakima Rivers. Consequently, FlwDiel is ranked relatively low in many of the same reaches with a high HydroRegimeReg rating.

- Natural confinement (Confine) is not so much conceptually slippery as it is difficult to estimate by an observer not physically present in the area. Natural confinement is expressed as the ratio of the width of the valley to bankfull channel width. *Valley width* is the width of the active floodplain, which receives water during large flood

events and is susceptible to channel forming processes such as widening, meandering, braiding, and avulsion. It does not include raised terraces or other areas that do not flood or confine an incised channel. The estimation of active floodplain width can be surprisingly difficult when the only resource is a topographic map with 40-foot contours.

- With regard to embeddedness (Emb) and fine sediment (FnSedi), the planner must remember that both of these measures apply only to riffles and pool tail-outs. Also, embeddeness as a measure of substrate characteristics is only appropriate where cobble and gravel substrates exists.
- The planner must be aware of the kind of habitat types referred to as backwater pools (HbBckPls) and side channels (HbSdChan). The former refers to the mouth of an *alcove* or *cul-de-sac*: technically, a *parapotamon,* or a body of water connected only at one end to the main channel. More specifically, a backwater pool refers only to that portion of the mouth of such a cul-de-sac lying within the floodway, almost always below the zone of permanent vegetation. The EDT definition of a side channel is relatively similar to conventional usage except that side channels are distinguished from braids by the requirement that permanent vegetation or trees exist on the land separating the side channel from the main channel and that the side channel be considerably smaller than the main channel.
- A pool tail-out (HbPlTails) is the glide at the downstream end of a pool. Pool tail-outs are discriminated from other glides because salmon so frequently use them for spawning because of their hydraulic properties. In the Yakima, pool tail-outs were generally assumed to amount to 25% of the area allocated to pools.

Estimate Environmental Attribute Ratings. Begin the actual estimation of environmental attribute ratings with a reading of the coarse-screening dataset but, as previously mentioned, try to form an independent assessment of the environmental determinants of natural production first. The coarse-screening dataset is based largely on rather broad ecological information—elevation, ecoregion, geology, precipitation, and so on—and on robust generalities applicable to most streams in a general ecological context. Most of the values in the coarse-screening dataset would have to be considered *uncertain*—based on broad generalities or extrapolations. Therefore, the planner should expect to refine many of these values.

To study the coarse-level data before assessing narrowly local observations is to risk forming distorted notions of dominant processes that may have to be painfully unlearned later. On the other hand, a planner who has already formed a fairly clear impression of local details should expect to profit from the discrepancies between coarse-screening data and local observations. Significant discrepancies between general relationships and local observations are always informative. For example, if a particular reach is substantially cooler in the summer than it *should* be—based on relationships between shading, aspect, discharge, and elevation—perhaps the reach is situated in a major upwelling area, a circumstance that would be quite significant in other contexts. On the other hand, the lack of any plausible reason for an exception to a thoroughly reviewed, widely accepted relationship is reason for pause. A local report of an unimpaired benthic invertebrate community in a reach known for high water

temperatures and nutrient concentrations might indicate a mistake in the local database. Therefore, assess environmental attributes by comparing a pre-existing picture of dominant local processes to the coarse-level dataset, and be prepared to benefit from discrepancies between the two.

Develop Local Reference Reaches. Perhaps the strongest advice to new planners facing the task of populating the EDT model with Environmental Attributes is this:

> ***"Develop the best possible set of local 'reference reaches' for every high priority attribute"***

Reference reaches are reaches in which an attribute or set of attributes are estimated as accurately as possible. It is always desirable to include a *best-case reference* and a *worst-case reference*, although other variants like *highly representative* or *best characterized* can also be useful. Best- and worst-case references are what they sound like: accurately characterized reaches in which some condition is as good or bad as it gets in a relatively homogeneous watershed or valley segment.

Establishing accurate reference points is critical because, absent information for a reach, much of the actual rating is done by comparison—to reference reaches, to other reaches classified earlier, and to different portions of the subbasin. This must be so because the number of reaches even in data-rich subbasins always exceeds the number of high-certainty, reach-specific observations. It should be so because it ensures consistency in the rating process, clearly ties all estimates to a limited number of sites and observations, and tends to keep the range of variation of attribute values within reasonable levels.

Reference reach attribute values are modified to describe nearby non-reference reaches (*comparison reaches*) by means of what might be called *environmental gradients* as well as by *geomorphic associations*. In this context, an environmental gradient is a relationship between an environmental attribute and some more easily measured, continuous environmental variable (e.g., channel slope or river mile). The concept can be illustrated by the relationship between pool habitat and channel slope. To be sure, a host of factors besides slope affects the proportion of pools and other types of channel unit in a reach. Nevertheless, slope can be the deciding factor if everything else is similar in benchmark and comparison reaches. Given this caveat, pool habitat generally increases as slope decreases. Based on WDFW habitat standards, as stated in the Wild Salmonid Policy, pool area in high quality habitat should roughly double from ~30% in reaches with a slope of more than 5% to ~55% when slope is less than 2%. This equates very roughly to a loss of 5% pool area per degree of slope.

Geomorphic associations, on the other hand, refer to expected conditions in valley segments of a particular geomorphic character, such as alluvial or bedrock canyons, meandering lower river reaches, alluvial fans, deltas, and so on. Geomorphic associations are actually less useful in describing comparison reaches than in comparing different benchmarks, as attributes tend to vary qualitatively across geomorphic types. Indeed, comparison and reference reaches should generally be within the same geomorphic unit. In any case, the kind of guidance a planner can find in geomorphic associations can best be described by a number of examples. To continue with the habitat type theme, confined alluvial canyons, for example, generally consist primarily of glides with a smaller proportion of

riffles and an even smaller proportion of pools, while meandering lower river valley segments typically consist primarily of pools and glides, and aggraded/braided lake inlet reaches often consist almost entirely of riffles.

2. Example from the Yakima

The preceding set of instructions was quite general and abstract. The following section of this Primer will illustrate many of the general principles described above by showing how they were applied in the Yakima. To this end, we will describe how the habitat type attributes were actually estimated for the Yakima Current and Template conditions.

Habitat Type—Current Condition

Quantifying habitat type consists of estimating the proportion of the wetted area of a reach that consists of the following types of channel units: primary pools, pool tail-outs, small cobble/gravel riffles, large cobble/boulder riffles, backwater pools, beaver dams, glides, side channels, and off-channel habitat. While the reference/comparison reach approach clearly can be used to estimate these attributes, and will be used to refine and adjust ratings among reaches, it was not the primary method by which initial values were estimated in the Yakima. This was because a good deal of classification had already been done in smaller tributaries, and aerial photographs as well as aerial videos were available for mainstem reaches, allowing habitat types to be relatively easily estimated. Accordingly, this section will first describe how existing habitat type data was used, how aerial photos and videos were analyzed, and how the reference/comparison reach process was used to quantify a minority of reaches and to check the reasonableness of other estimates generated by other methods.

The Cle Elum and Naches Ranger Districts (Wenatchee National Forest) of the U.S. Forest service have produced a large number of *stream survey reports*, which proved to be extremely useful for EDT modeling. These reports used the well-known Hankin and Reeves (1988) approach to inventorying habitat type, which corresponds very closely to the process and to the habitat types used in EDT. Indeed, in many cases the original reach breakdown proposed for the EDT model was changed to match the Forest Service breakdown because the latter better delineated *structurally and functionally homogeneous* stream segments.

Forest Service steam survey reports generally include a narrative description of the characteristics of the reaches inventoried as well as a tabular summary at the end of the report. The information condensed into the tabular summaries is exceedingly valuable and often provides everything or nearly everything needed to describe the following environmental attributes:

- Habitat type (pools, rifles, glides, and side channels by area directly; off-channel habitat, backwater pools, and beaver ponds by inference from the text)
- Natural confinement (from bankfull width and valley width estimates) and Anthropogenic confinement (from estimates of revetments, road encroachment, channel entrenchment, etc.

- Riparian function (from estimates of vegetative ground cover—density, species composition, and maturity)
- Embeddedness (either >35% embedded or <35% embedded)
- Obstructions (partial or total passage barriers due to waterfalls, cascades, or man-made structures such as culverts)
- Maximum temperature
- Gradient
- Woody debris (pieces/mile by size class)

The bulk of the information needed to quantify these attributes, for most of the Naches drainage and for all upper Yakima tributaries upstream of Umtanum Creek, came from Forest service stream surveys.

Much of the time, the habitat type breakdown summarized in the stream survey reports were used directly. Sometimes, however, the estimate of pool habitat was changed because the definition employed in the survey seemed unnecessarily restrictive—e.g., "pools must be longer than they are wide," or "maximum depth must exceed 36 inches." In such instances, the text usually provided the basis for a rough adjustment of pool area (and thus the relative area of all other types). Statements such as "pool frequency standards were not met because x % of the pools did not meet the minimal depth criterion" were used to adjust pool habitat upward (and other habitat types downward). This statement implies that the definition of pools was more liberal in the EDT assessment than was sometimes true in the Forest Service stream inventories. This is indeed the case: for EDT purposes, no minimum length or depth requirement was imposed on pool habitat.

The habitat type breakdown for Current condition tributaries on Forest Service land (most of the tributaries in the subbasin) was based on these stream survey reports. However, most of the habitat type data for mainstem Naches and Yakima reaches and for lower basin tributaries (e.g., Ahtanum, Satus, and Toppenish Creeks) were estimated from aerial photographs, aerial video (Yakima mainstem only), and the professional judgment of biologists familiar with the stream.

Figure 2 below illustrates a typical aerial photograph from which habitat type estimates were made. This particular photo is of the upper Yakima near Easton, Washington, and was obtained free of charge from Microsoft's Terraserver site (http://terraserver.homeadvisor.msn.com). An aerial video, rather than a series of aerial photographs, was used to break out habitat types in the mainstem Yakima. The images in the video were in color and were considerably sharper than individual photographs. Moreover, the ability to detect motion and surface turbulence in the video, as well as to see different shades of blue and green, made it much easier to detect pools and to distinguish pools from glides. Nevertheless, the Terraserver photo is illustrated because the principles involved in analyzing photos and video are the same.

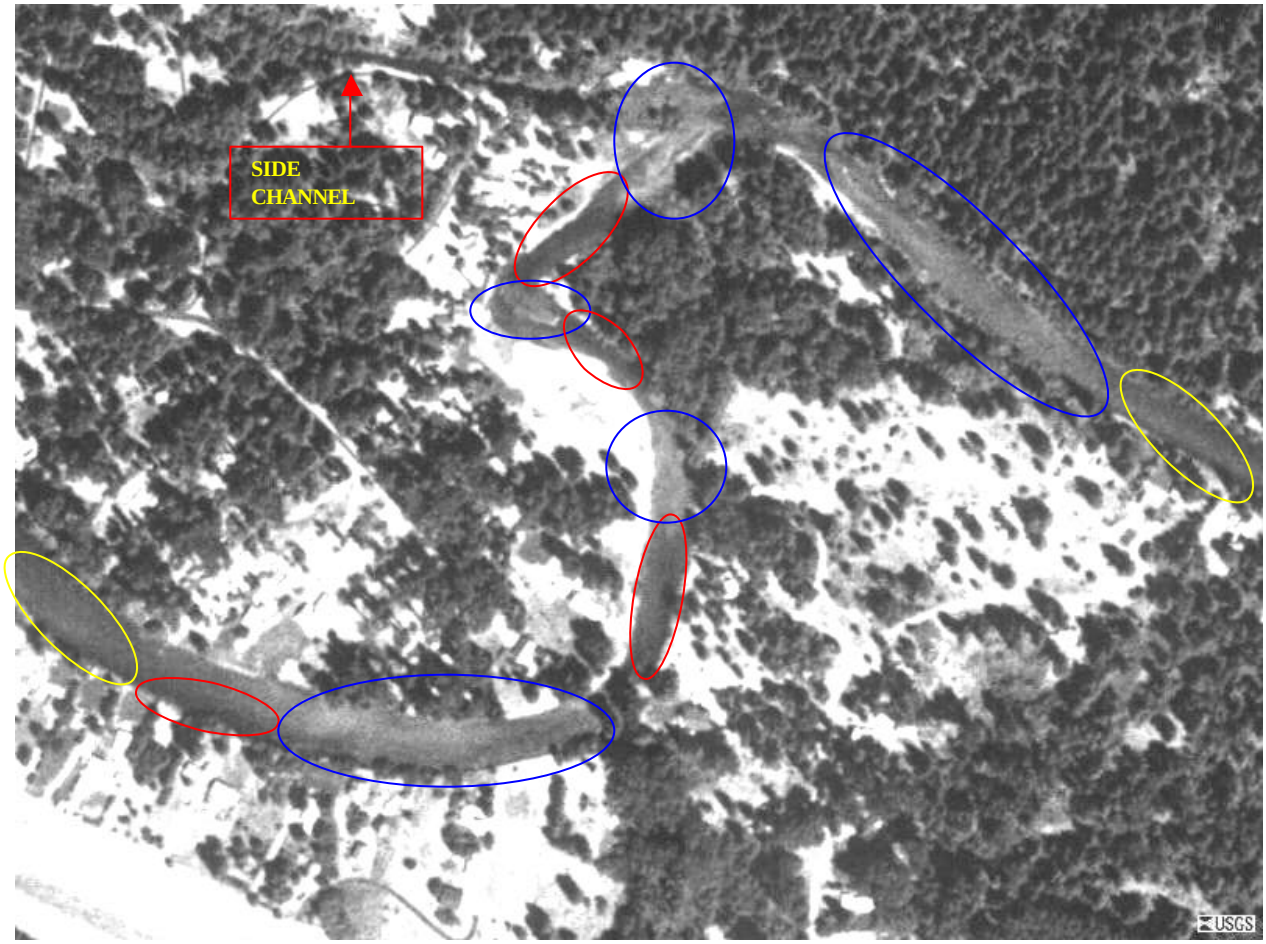


Figure 2. Aerial photo (Terraserver) of upper Yakima River near Easton, Washington, showing pools (red circles), riffles (blue circles), glides (yellow circles), and side channels.

The red circles or ellipses circumscribe pools; the blue are for riffles, and the yellow represent glides. A side channel is indicated in the upper left of the photo. No backwater pools, beaver ponds, or off-channel habitat units are evident in this photo. Pools were identified by their darker color (dark green in the videos) and lack of surface turbulence, and often by obvious hydraulic controls, such as logjams or bedrock outcroppings as well. Riffles were identified by exposed rocks and gravel, by a much lighter color, and by obvious surface turbulence. Glides were identified to a large degree by elimination: anything not something else was often considered a glide. Although glides usually have a darkness intermediate to pools and riffles, and though their surface appeared either smooth or to consist of small standing waves (runs), it was often difficult to distinguish glides from pools in photographs (although the ability to distinguish motion made it much easier in the video). Beyond distinguishing habitat types in individual photos or video frames, the procedure for assessing habitat type by reach consisted of simply tabulating the visually estimated proportion of wetted area occupied by each habitat type, and then taking the average over all photos/frames needed to cover the reach. An attempt was made to include approximately the same length of stream in each photo or frame, but there was no way to standardize the total area between photos and frames.

Neither a pre-existing analysis of habitat type composition nor really useful aerial photographs or videos exist for many streams in the Yakima Subbasin. Among the most important steams in this category are Ahtanum Creek, a major historic producer of steelhead and coho, and Satus and Toppenish Creeks, the largest current producers of steelhead. Consequently, the habitat composition of these streams had to be determined by the benchmark/comparison reach approach.

Table 8 and Figures 3 and 4 summarize the environmental gradient relationship data that were used to estimate comparison reaches on the basis of benchmarks. Table 9 summarizes the geomorphic associations that were used primarily to refine and compare benchmarks. The plots of Naches data in Figure 3 and of Naches data and Northeast Oregon, Deschutes, and Alaskan data in Figure 4 are presented mainly to give the planner a sense of the strength of various relationships. The regression lines are presented mainly to show that a relationship does (or does not) exist. Although most of the regressions shown were in fact significant, no statistical use was made of any regression in rating habitat type.

Table 8. General relationship between channel width, reach gradient, natural channel confinement, and large woody debris observed in 95 reaches of the Naches River drainage inventoried by the Naches Ranger District, USFS.

Habitat Unit	Correlation to Channel Width	Correlation to Gradient	Correlation to Confinement	Correlation to LWD
Pools	Positive	Negative	Negative	Slightly positive
Riffles	None	Positive	Positive	Slightly negative
Glides	None	Negative	Negative	Slightly negative
Side Channels	Positive	Negative	Slightly Negative	Positive

Table 9. General relationships between habitat types and selected geomorphic valley segments.

Habitat Unit	Canyon	Alluvial Fan	Unconfined Anastomosing	Meandering
Pools	Minor	Minor	Co-dominant	Co-dominant
Riffles	Subdominant	Dominant	Co-dominant	Subdominant
Glides	Dominant	Minor	Subdominant	Co-dominant
Side Channels	Minor	Dominant	Subdominant	Minor

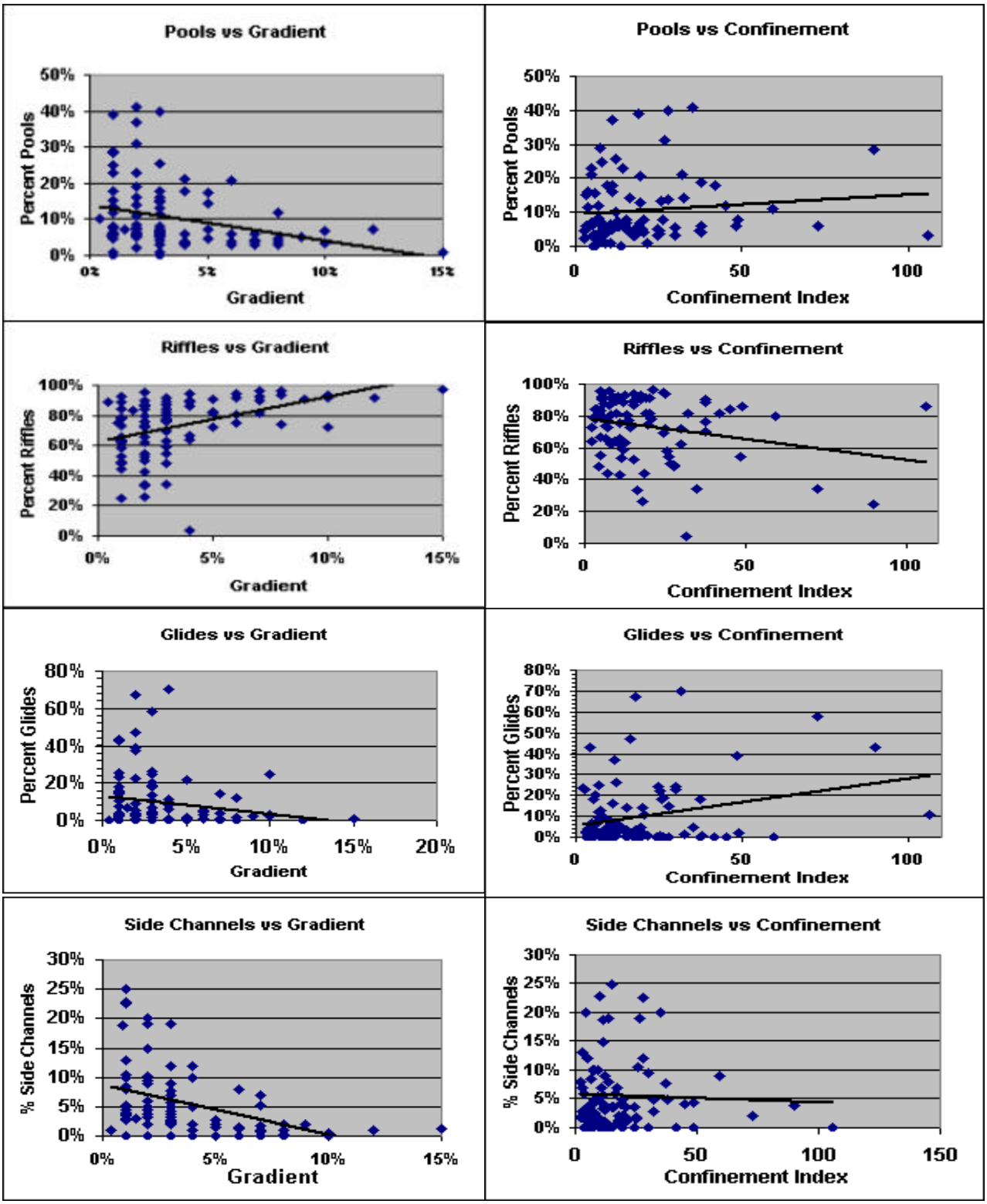


Figure 3. Relationships between percent pool, riffle, glide, and side channel, and reach gradient and reach confinement. Note: *Confinement Index* is the ratio of valley width to bankfull channel width. Therefore, larger Confinement Indices correspond to *decreasing* levels of confinement.

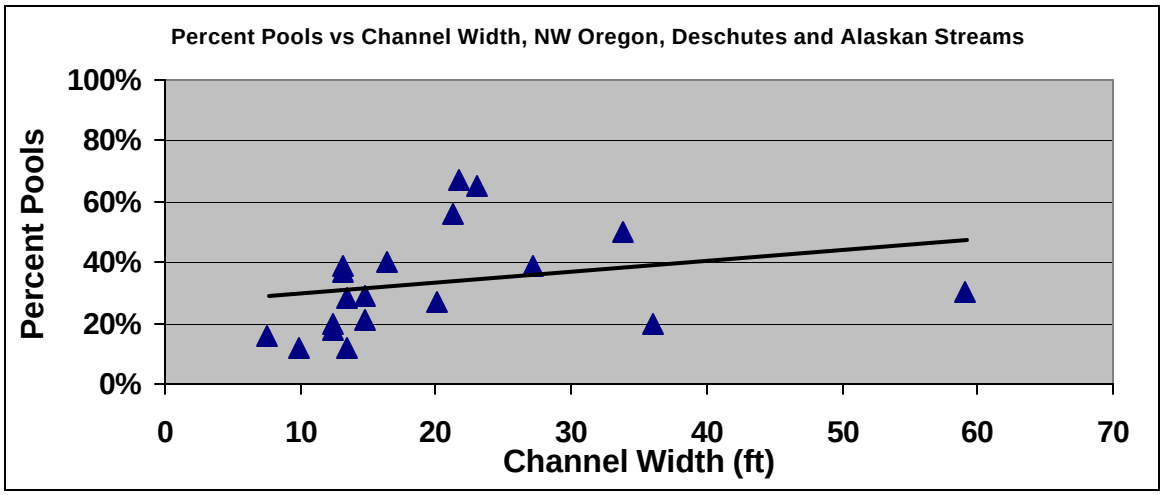


Figure 4. Relationship between percent pool area and channel width in 19 unmanaged watersheds in NE Oregon, the Deschutes drainage and Alaska (Peterson 1992).

Reference/comparison reach procedures employed in estimating habitat type will be illustrated by three reaches on Ahtanum Creek: Ahtanum Creek from the Wapato Irrigation Project diversion to the forks (the reference reach; A in Figure 5), Ahtanum Creek from the mouth to the confluence with Bachelor Creek (comparison reach 1; B in Figure 5), and the North Fork Ahtanum Creek from its mouth to Nasty Creek (comparison reach 2; C in Figure 5). The reference reach was chosen because it is closely paralleled by a road and is therefore easily walked for an assessment of habitat type composition. The reach was walked and inventoried with the following results:

Backwater pools	Beaver Ponds	Glides	Large Cobble Boulder Riffles	Pools	Pool Tail-outs	Small Cobble Gravel Riffles	Side Channels	SUM
0.00%	0.00%	10%	10%	9.0%	3%	60%	8%	1.00

Table 10 summarizes the reference and comparison reaches in terms of various environmental factors correlated with habitat type composition. Information on LWD loading and in the *other factors* column was culled from the Washington State Limiting Factors Analysis (Haring 2001).

On the basis of the factors listed in Table 10, there should be little difference between the reference reach and Comparison reach 2 (NF Ahtanum): gradient, LWD loading and sinuosity are comparable, and the comparison reach is just slightly steeper. The substrate is, however, larger in Comparison 2, which also suffers from fairly frequent landslides and bed scour (Haring 2001). It was concluded that Comparison 2 should approximate a plane-bed channel, with fewer pools than the reference, more glides/runs, fewer small cobble/gravel riffles, and more large cobble/gravel riffles. The pronounced sinuosity of Comparison 1 (lowermost reach of mainstem) suggests a greater proportion of pool habitat than the reference. This inference is not invalidated by the sediment loading and bank sloughing observations--Haring (2001) reports the benthic invertebrate community is unimpaired. Both Haring and aerial photographs indicate anthropogenic confinement

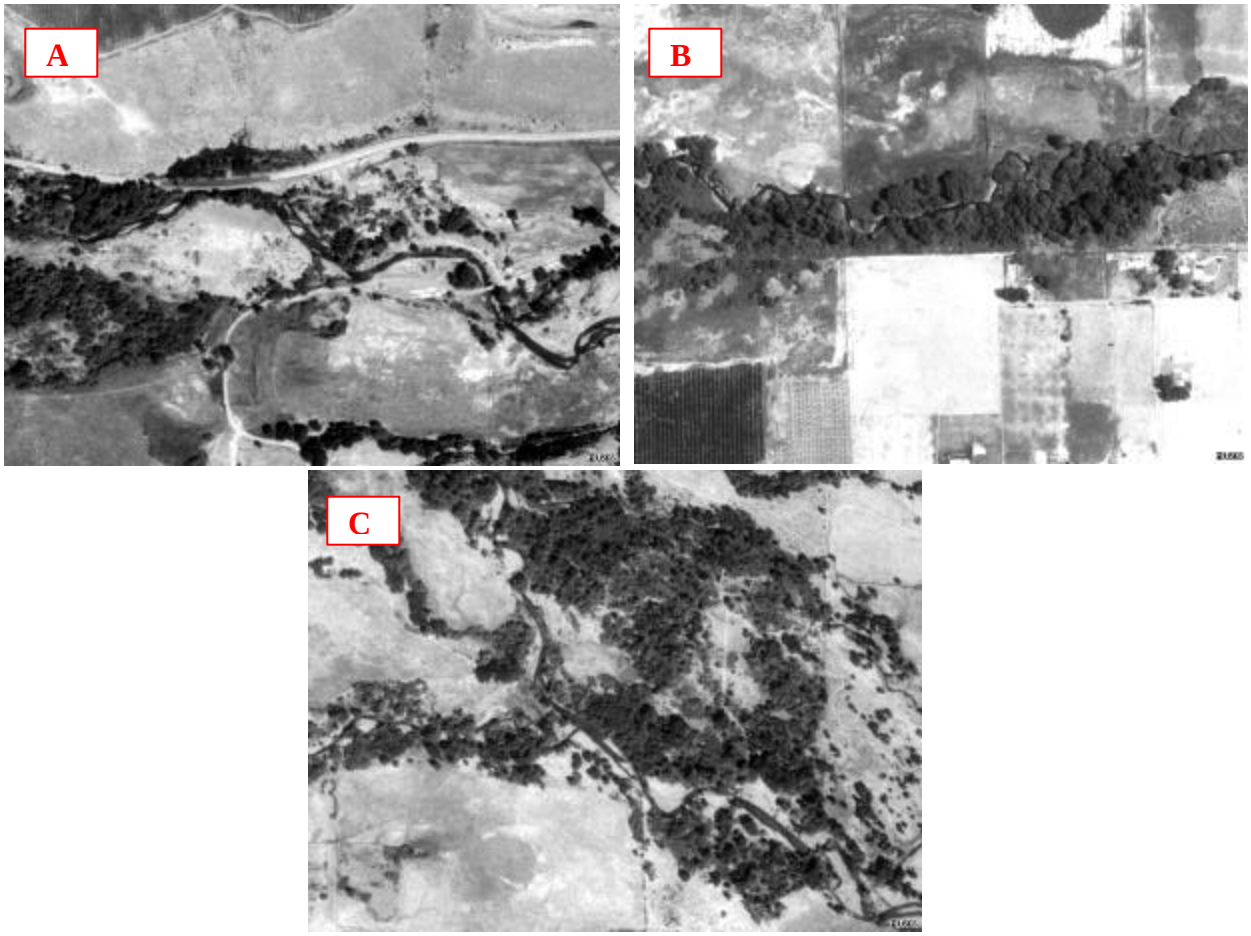


Figure 5. Aerial photographs of portions of the benchmark reach in middle Ahtanum Cr. (A), and of comparison reaches in lower Ahtanum Creek (B) and the lowermost reach of the North Fork of Ahtanum Creek (C).

Table 10. Comparison of reference and comparison reaches with respect to environmental factors associated with habitat type composition.

Reach	Gradient	LWD Loading	Natural Confinement	Artificial Confinement	Other factors
Benchmark	1.4%	very low	Unconfined	10-40% confinement	Moderate sinuosity, some bank sloughing, embedded; pool-riffle alluvial; benthic community unimpaired
Comparison 1	0.3%	very low	Unconfined	40-80% confinement	Very sinuous, substantial bank sloughing; heavily embedded; meandering alluvial; benthic community unimpaired
Comparison 2	1.6%	very low	Unconfined	40-80% confinement	Moderate sinuosity, frequent landslides, bed scour, 20-30% large rubble; plane-bed alluvial; benthic community unimpaired

is severe in the comparison reaches, and aerial photos reveal few side channels in Comparison 2, none in Comparison 1, and no off-channel habitat in either. These observations were combined and assessed, as shown in Table 11.

Table 11. Results of reference/comparison estimate of habitat type composition in Ahtanum Creek example.

Reach	Backwater pools	Beaver Ponds	Glides	Large Cobble Boulder Riffles	Pools	Pool Tail-outs[a]	Small Cobble Gravel Riffles	Side Channels
Benchmark	0%	0%	10%	10%	9%	3%	60%	8%
Comparison 1 (lower mainstem)	0%	0%	50%	0%	15%	4%	31%	0%
Comparison 2 (NF Ahtanum)	0%	0%	45%	22%	5%	1%	26%	1%

a. Pool tail-outs are always assumed to represent 25% of pool area.

It should be noted that there were a number of lower-Ahtanum reaches that were very similar to Comparison 1 in terms of gradient, LWD, bank/bed stability, side channels, and so on. The same was true of the North Fork of Ahtanum Creek and Comparison 2. Therefore, with only minor differences, habitat types were allocated to these comparable reaches in the same manner as for Comparisons 1 and 2.

Template Habitat Type

The magnitude and nature of the issues confronting a planner when attempting to reconstruct historic habitat types can best be illustrated by presenting a specific case from the Yakima River: the structural, hydrological, and vegetational transformation of the *Wapato reach*, the mainstem Yakima from Union Gap to the confluence with Toppenish Creek. Figure 6 documents some of these changes. Figure 6A shows the Yakima River in the Wapato reach as it existed in 1909 when it was surveyed by the U.S. Indian Irrigation Service (the area to the west of the main Yakima River channels now includes the most productive agricultural lands on the Yakama Indian Reservation). The historic Yakima River in this reach consisted of at least 50 substantial channels flowing north to south and hundreds of connecting channels. From the western to the eastern boundary, this anastomosis was as much as eight miles wide. The topography of the floodplain was exceedingly flat, and the extensive areas of alkaline soils shown on the map indicated it flooded frequently—perhaps annually. This supposition is supported by the fact that *mean* monthly flow historically reached a maximum of about 12,400 cfs in May (Snyder and Stanford 2001), and the current flood stage of the (diked) river just below Union Gap is ~15,000 cfs (USBOR 2001). Early residents (diary of R.U. Goode 1883; J.D. Cooper, U.S. Senate Ex. Doc. 1860) reported that this area was a treeless prairie covered with “long rank grass” in the valley bottoms, and cottonwoods, willows, and occasional pines on the riverbanks. The lower 20 miles of what is now called Toppenish Creek was historically a portion of the Yakima River, which collected discharge from the numerous distributary channels as they impinged on Toppenish Ridge and funneled it back to the main channel.

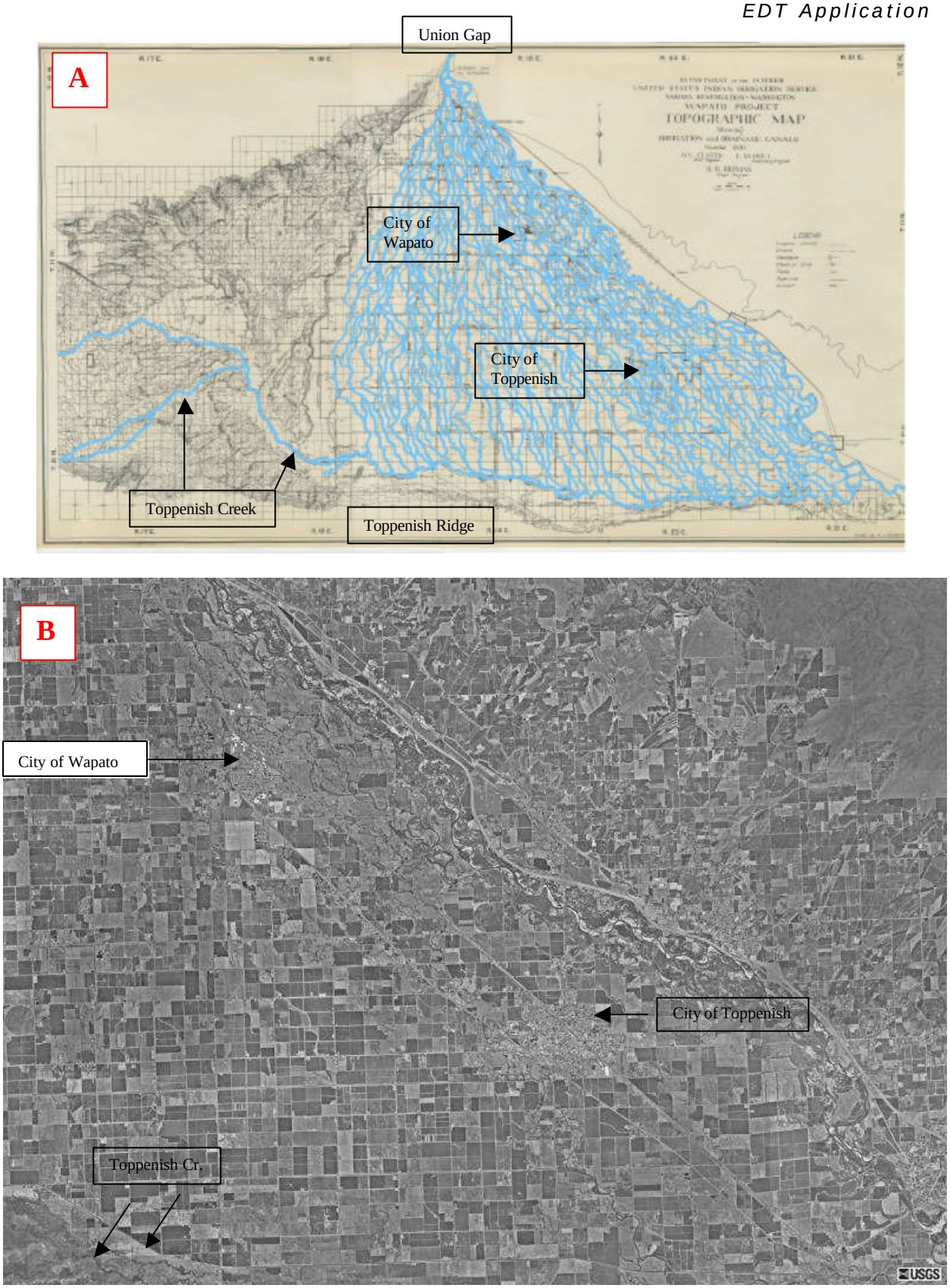


Figure 6. The "Wapato Reach" historically (A) and today (B).

Figure 6B is an aerial photograph (Terraserver) of the Wapato reach in 1996. Clearly, virtually all of the distributary channels were filled when the historic floodplain was converted to cropland. The few distributary channels that remain have been transformed into irrigation canals, and 20 additional miles have effectively been added to lower Toppenish Creek by eliminating its complex connections to Yakima River distributaries. The hydrograph in the reach has also been radically altered. Because of heavy irrigation diversions at the upstream end of the reach and the impoundment of the spring freshet in headwater storage reservoirs, maximum mean monthly flow is now 4,250 cfs, and occurs in February instead of May (USBOR Hydromet data for 1981 – 2000). The remaining channels of the Yakima River are still covered with a dense cottonwood/willow gallery, but the historic distributaries have either been converted to hop or asparagus fields or irrigation ditches; in either case, trees and even large shrubs are scarce or wholly lacking.

Given the absence of historic photographs or written descriptions of stream habitat, Yakima planners realized it would be possible to reconstruct habitat types in this area only approximately and with a substantial number of qualifications. But as hopeless as the task might seem at first glance, a reasonable description was created by a consideration of the reach as it exists today and general principles relating to LWD, substrate, sediment transport capacity, changes in the hydrograph, and channel gradient.

The general approach we used in the Yakima for estimating Template habitat consisted of the following steps. We first determined if there were any reasons to consider that the reach had changed from its normative state—whether it was essentially pristine. Some reaches did in fact fall into this category (e.g., those in wilderness areas), and for them Current and Template habitat types were identical or nearly identical.

For significantly altered reaches, such as the Wapato reach, we then considered the impact of channel slope, channel width, channel type, historic flow, and probable LWD loading on main channel habitat types, *at first concentrating only on pools, riffles, and glides in the main channel*. Width, slope, LWD loading, and channel type are the main determinants of pool spacing and pool area (Montgomery et al. 1995; Beechie and Sibley 1999), as well as pool/riffle ratios, where *pools* are generally understood to include all *non-riffle* habitat types. Pool/riffle ratios for large (5th order or greater), low gradient (< 1.5% slope), pool-riffle channel types with good LWD loading and balanced sediment supply/transport capacity ratios can be expected to be on the order of at least 50% (WDFW-Tribal Wild Salmonid Policy 1997; Peterson 1992; ODFW 1998). In such pristine main channel areas, glides other than pool tail-outs should be relatively rare; *non-tail-out glides* often represent sediment-filled pools. In light of the foregoing considerations, we have assumed that optimal, large river pool-riffle habitat should contain roughly 40% pools and 10% pool-tail-outs (sum ~50%), and 40% riffles and 10% non-tail-out glides.

Parenthetically, the planner should note that we have also developed *optimal case* pool/riffle/glide ratios for other channel types (step-pool, plane bed, pool-riffle and dune-ripple) and slope ranges. Other planners are encouraged to do the same. We have decided, however, not to present the ratios we employed in the Yakima analysis because

they are inherently basin-specific and might therefore bias proper relationships for other subbasins.

Returning to the Yakima example, we concluded that the historic reach from Union Gap to Toppenish did in fact represent optimal, large river habitat. To be more specific, we concluded that the main channels would have consisted of about 40% pools, 10% pool-tail-outs, 40% riffles (all small cobble/gravel), and 10% glides. The reach was and is clearly a cobble/gravel pool-riffle channel type; it has an appropriate gradient (0.2%), and the main channels were and are clearly *large* (mean width ~180 ft). Substantial recruitment of LWD from riparian cottonwood galleries would be expected, and the width, shallowness, and high sinuosity of both main and secondary channels would also have served to trap imported coniferous LWD carried downstream on relatively frequent floods (Nakamura and Swanson 1994; Palik et al. 1998). We envisioned a network of channels flowing through a patchwork of braids and stable tree-lined islands in which a moderately high density of LWD was clumped in a series of large log jams. The jams served both to increase main channel pool area and, more importantly, to create and maintain the network of secondary channels in the flat, unconfined floodplain to the west (Nakamura et al. 1993).

The following description is, however, incomplete: it remains to factor in the overall proportion of the wetted area made up of side channels, backwater pools, beaver ponds, and off-channel habitat (primarily *alcoves* and *sloughs* of various types). The general way in which this was done was as follows: assume that the cumulative area of backwater pools, beaver ponds, and side channels amounted to 15% of the total wetted area of the reach. [Ignore off-channel habitat for the moment; it is not part of the active channel and is accounted for separately.] In this hypothetical case, we would have reduced the proportion of pools, tail-outs, glides, and riffles in the main channels by 15%, so that the sum over all habitat types in the active channel was still 100%.

We used the Indian Irrigation Service map in Figure 6A and assumptions about side channel width and the proportion of braids in the reach to estimate the proportion of total wetted area consisting of side channels. Although the added shading in Figure 6A makes it difficult to tell, the level of detail in Figure 6A was actually quite high (the original map was roughly 3 ft by 2 ft in size). Careful measurements indicated channel widths down to about 20 ft were reflected on the map; widths less than about 20 ft could not be distinguished from a single line. We therefore assumed that all channels indicated by a single line were about 20 ft wide and that these smallest channels fell within the size criterion for side channels. Over 20 random transects, the proportion of total wetted width made up of such channels was ~40%. We did not, however, consider that all of the channels in this 40% were true side channels, because many would have actually been in the floodway of a larger channel and would therefore have been classified as *braids* (part of the main channel). We then examined topographic maps of the existing mainstem Yakima in the Wapato reach and determined that about 50% of the current mainstem consists of braids: multi-channel segments not separated by permanent vegetation. Assuming this ratio applied to the historic system, we finally concluded that 20% of the historic Wapato reach consisted of side channels.

The basis for estimating backwater pool and beaver dam area was somewhat more speculative. As to beaver dams, we reasoned that they should have been present in some

of the side channels (some exist even today) but that the regular occurrence of high flows and the very large total area of the reach would preclude their representing more than a small fraction of the total area. Somewhat arbitrarily, we assumed beaver dams comprised 2% of the total area. We also reasoned that much of the reach was braided, with frequent channel shifting and, therefore, that a substantial number of channels were actually sloughs or alcoves. Again somewhat arbitrarily, we assumed that perhaps 10% of the total wetted area would consist of off-channel habitat, half of which would occur in the braided regions mentioned earlier. We therefore estimated backwater pools at 5% of the total area.

Table 12 summarizes our conclusions as to the historic habitat type composition for the Wapato reach. As previously mentioned, the proportional areas of pools, tail-outs, riffles, and glides were estimating by reducing the proportions of these main channel habitat types by 27%—the sum of the contributions of side channels, beaver ponds, and backwater pools.

Table 12. Estimated habitat type composition of the Template Wapato reach expressed as a percent of the total wetted area of the reach.

Pools	Pool Tail-outs	Cobble Boulder Riffles	Cobble Gravel Riffles	Glides	Side Channels	Beaver Ponds	Backwater Pools	TOTAL
29.2%	7.3%	0%	29.2%	7.3%	20%	2%	5%	100%

A number of final points should be made with regard to this example. First, habitat type is not broken down within side channels. Side channels are considered small, complex, shallow, low velocity nursery areas for which further subdivision is unnecessary. Second, this habitat type analysis was in fact used as a very important reference reach for eight other similar reaches—unconfined, wide, anastomosing alluvial reaches distributed throughout the mainstem Yakima and Naches Rivers. The starting point for classifying Template habitat in these comparison reaches was the proportions listed in Table 12. These values were then modified by means of the same considerations and relationships described above. Finally, most readers will undoubtedly have noticed a problem with the process just described: habitat types are not estimated on a month- or flow-specific basis. It is clear that the habitat composition of a reach varies with flow, such that the pool/riffle ratio decreases as flow increases (Hilderbrand et al. 1999). Moreover, the example of the historic Wapato reach suggests that the contribution of side channels would be much smaller during base flow than during the spring freshet: many of the higher elevation, peripheral channels would dry up or become isolated pools in the late summer or fall.

D. Baseline Runs and Initial Evaluation

After the subbasin has been subdivided into appropriate reaches and described in terms of the environmental attributes, an initial or baseline model run should be made. These runs should be made for each independently modeled population. The outputs of these runs will consist of population performance parameters (productivity, capacity, equilibrium abundance, and life history diversity) for both the Current and the Template

conditions. While these figures have some importance in themselves, their main value lies in the light they cast on the *reasonableness* and utility of the way the populations and their habitat have been described.

Table 13 and Figure 7 summarize the results of the baseline EDT run for the three populations of Yakima spring chinook, as well as estimates of performance parameters based on observations. The real significance of these graphics will become apparent in the discussion below.

Table 13. Summary of EDT-based and observed adult Yakima spring chinook performance parameters for Current and Template conditions, and EDT-based performance parameters for Template conditions.

CURRENT												
	Life history Diversity[a]			Productivity[b]			Capacity[c]			Equilibrium Abundance[d]		
	Upper Yakima	Naches	Amer.	Upper Yakima	Naches	Amer.	Upper Yakima	Naches	Amer.	Upper Yakima	Naches	Amer.
EDT	33%	44%	66%	3.7	3.5	4.9	4,325	2,139	451	3,140	1,526	358
OBS	--	--	--	1.5	3.5	2.9	--	--	--	2,187	1,574	469
TEMPLATE												
EDT	99%	99%	100%	32.6	39.2	37.9	101,026	58,546	6,539	97,926	57,052	6,366

a. Expressed in terms of the percent of biologically possible life histories for which adult recruitment rate is > 1.0
b. Expressed both as the number of adult progeny (on the spawning grounds) per spawner and smolts per spawner.
c. Asymptotic maximal number of smolts or adults for a subbasin under average conditions.
d. Mean abundance of adults or smolts – analytically, the intersection of the replacement line with the production function curve.

Upper Yakima Spring Chinook Baseline 7/12/02					
Population	**Scenario**	**Diversity index**	**Productivity**	**Capacity**	**Abundance**
Yakima Spr Chin 7/11/02	Current without harvest	34%	3.8	4,641	3,429
	Current with harvest	33%	3.7	4,325	3,140
	Historic potential	99%	32.6	101,026	97,926

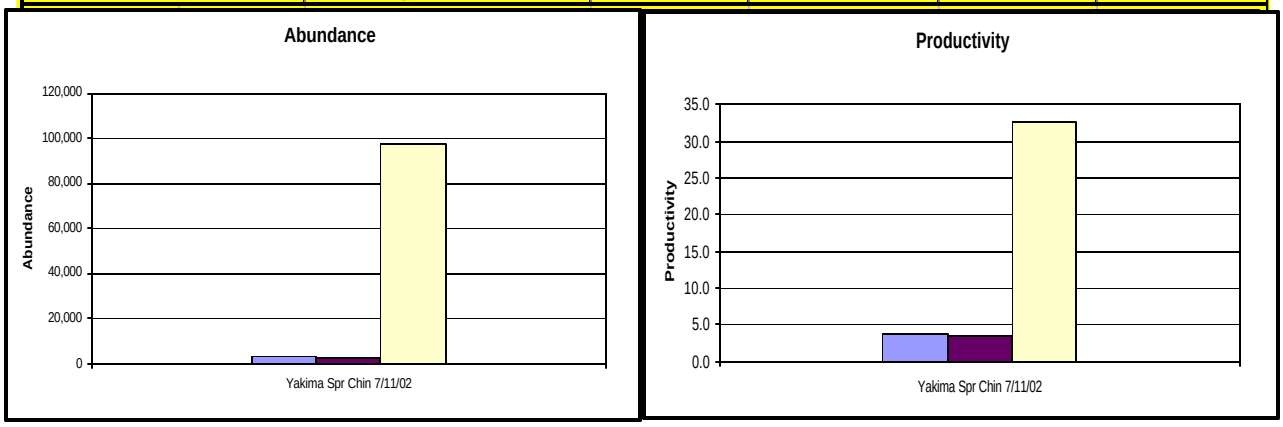


Figure 7. Summary of EDT-based performance parameters for the upper Yakima spring chinook population. Blue bars represent the Current without harvest, red the Current with harvest, and yellow the unharvested Template.

There are at least two, and sometimes three, aspects to this initial evaluation. The first is to determine whether the spatial resolution of the subbasin is fine-grained enough to reflect locally significant environmental processes and impacts. The second is to determine whether the performance parameters estimated by the model are reasonable. Depending on the answer to the second question, a third purpose is possible: identifying the erroneous input data or *troubleshooting.*

1. Resolution

There are, unfortunately, no clear-cut answers for the issue of resolution. Resolution depends on how faithfully reach definitions reflect several issues:

- boundaries of distinct geomorphic features and habitat maintenance processes
- confluences of fish-bearing streams
- *points of anthropogenic impact* imposed on the normative geomorphic structure
- spatially distinct spawning populations
- areas previously selected for development or environmental restoration.

Although the primary considerations in reach definition are geomorphic and hydrographic, there is no end to the number of reaches that might be defined strictly from this perspective. On the other hand, finer and finer reach subdivisions clearly become pointless when analyzed from the perspective of a fish.

The question a fish would ask is, "where are the boundaries between areas of different survival probabilities for adults or eggs or juveniles?" If it is impossible to state a clear rationale for meaningful differences in survival between two adjacent areas, the areas probably should not be split.

The existence of local spawning populations should also factor into the resolution issue. Long, structurally homogeneous glide–riffle sections are common in the lower portion of many rivers. While there might be no compelling (or obvious) geomorphic reason for subdividing such a reach, there could be a biological reason if spawning were clumped in one or more areas within it.

Another consideration is whether the existing reach structure reflects the points of environmental impacts faithfully. The impacts referred to here are anthropogenic—e.g., a sewage treatment plant outfall, a diversion dam, a heavily urbanized area, a poorly designed culvert, and so on. If such features can be expected to have a detectable impact on the survival of any life stage, they should be defined as a distinct reach.

Finally, most subbasins include areas that have become firmly targeted for specific restoration projects or for other kinds of development with adverse impacts on fish production. For example, many habitat restoration and water quality actions were identified in the Yakima subbasin during the Washington State's on-going Watershed Planning Process (Waldo 2001). It is well to include reaches that closely match the footprint of such proposed projects because it simplifies the assignment of new, post-implementation Environmental Attributes. The absence of project-based reaches

necessitates the estimation of an average effect over an entire reach, even though the actual impacts might be much more restricted.

All of these points were made during the earlier discussion on reach definition. Although no methods of assessing resolution can be described here that have not already been discussed, it is instructive to illustrate the process by describing a number of reaches in the Yakima that were subsequently split because of considerations like those described above.

At one point, the lower 70 miles of the Yakima River were subdivided into just four reaches: from the mouth to Horn Rapids Dam, from the dam to Snipes Creek, from Snipes Creek to Prosser Dam, and from Prosser Dam to Satus Creek. This breakdown was based on the fact that the entire lower river is low gradient, very warm in the summertime, heavily populated with native and exotic predators, and either mostly unconfined or confined within shallow canyons. There seemed little reason to subdivide these reaches further except to incorporate Prosser and Horn Rapids Dams, which impact outmigrant survival, and the two fish-bearing streams (Satus and Snipes Cr) that subdivide the mainstem canyon and floodplain reaches.

Subsequent investigation disclosed a number of reasons why the lower Yakima should in fact be subdivided. As is apparent in Table 14, the reasons for doing so touch on all of the issues motioned above.

2. Reasonableness of Output

It should be clearly understood that the issue of determining whether EDT-based performance parameters are reasonable is not the same as demonstrating no significant difference between observed and *predicted* (EDT-based) recruitment estimates. EDT was not developed with the intention of predicting annual fluctuations in production. Rather, EDT presents a quantitative working hypothesis of the average performance of a population given average environmental conditions. How then is one to evaluate the reasonableness of EDT output? The answer to this question is found in the fundamental purpose of EDT: to estimate the long-term impact on performance of the average quality and quantity of habitat in the reach network of the subbasin.

Perhaps the most appropriate performance parameter for assessing output accuracy is equilibrium abundance, because it integrates productivity and capacity and is explicitly a mean. Accordingly, one should expect a reasonable congruence between EDT-based equilibrium abundance and observed mean abundance over periods of relative environmental stability. Moreover, because the model derives equilibrium abundance from habitat quantity and quality, EDT estimates of the *relative* abundance of spatially separated populations (of the same species) should also compare well with observations. Similarly, when EDT is applied to the same population during two different time periods with significantly different environmental conditions, EDT estimates of relative abundance over time should compare well with observations. The most obvious example of the latter type of comparison is the relative abundance of the Current and Template conditions, which is critical to many aspects of an EDT diagnosis and a subbasin assessment. One's confidence in the essential accuracy of an EDT analysis would be considerably strengthened if both EDT and observations indicated historic

Table 14. Original reaches proposed for lower Yakima mainstem, subdivided reaches subsequently defined, and reasons for subdividing original reaches.

Original Reach	Subsequent Subdivisions	Reasons for Subdivision
Satus Cr. to Prosser Dam (RM 69.6 to 47.1)	Satus Cr. to Sulphur Cr. (RM 69.6 to 61.0)	Sulphur Creek, a tributary with substantial inputs of cool groundwater near its mouth, has been heavy modified to serve as an irrigation return. It is also a major point source of sediment and pesticide/herbicide runoff from the agricultural lands it drains. Moreover, a number of fisheries/water quality programs targeting Sulphur Creek have recently been proposed.
	Sulphur Cr to Mabton Bridge (RM 61.0 to 55.0)	Mabton Bridge marks the downstream end of a low gradient, naturally unconfined reach with abundant off-channel habitat. The Mabton-Prosser Dam reach is a moderately confined backwater with very little off-channel habitat and a sand/silt substrate.
	Mabton Bridge to Prosser Dam (RM 55.0 to 47.1)	Low gradient, confined backwater with silt/sand substrate.
Prosser Dam and Chandler Canal Diversion	Not subdivided	
Prosser Dam to Snipes Cr. (RM 47.1 to 41.8)	Not subdivided	
Snipes Cr. to Horn Rapids Dam (RM 41.8 to 18.0)	Snipes Cr. to Chandler Hydro-electric Powerplant Outfall (RM 41.8 to 35.8)	Flows in the Chandler Canal bypass reach (Prosser Dam to Powerplant Outfall) can be significantly reduced by hydro-electric & irrigation diversions at Prosser Dam. About half the diverted water is returned to the Yakima River at the Powerplant after running through turbines (the remainder is used for irrigation). The Bureau of Reclamation has proposed to increase instream flows in the bypass reach by foregoing power production and pumping Columbia River water to lower Yakima irrigators so that diversions at Prosser Dam can be radically reduced.
	Powerplant outfall to Corral Canyon Cr. (RM 35.8 to 33.5)	Corral Canyon Creek is a small tributary that has more production potential than was formerly recognized and has been targeted for several restoration projects.
	Corral Canyon Cr. to Benton City Bridge (RM 33.5 to 29.8)	Benton City Br. is the downstream boundary of a confined, boulder-bedrock reach and the approximate upstream boundary of a major fall chinook spawning area.
	Benton City Bridge to Horn Rapids Dam (RM 29.8 to 18.0)	Major fall chinook spawning reach with gravel/cobble substrate.
Horn Rapids Dam	Not subdivided	
Horn Rapids Dam to mouth (RM 18.0 to 0.0)	Horn Rapids Dam to upstream end of McNary Pool and "Yakima delta" area (RM 18.0 to 2.1)	Much of the reach from the dam to the Yakima delta area was historically unconfined and complex and is now a secondary spawning area for fall chinook.
	Upstream end of McNary Pool to mouth (RM 2.1 to 0.0).	Historically and currently different in structure from rest of lower river; considerably warmer than other lower river locations; much wider than any other portion of lower river.

mean abundance was, say, between 80 and 100 times greater than current abundance. Similarly, one's confidence in the reasonableness of output should increased if mean abundances for a population during two distinct but more recent time periods—say before and after construction of a major unladdered dam in the subbasin—were quite similar.

Another *indicator of reasonableness* is the degree to which EDT output reflects plausible density-dependent mortality. Consider a plot of observed recruits by brood year—either adults or smolts. If EDT has been properly *parameterized*, it should have estimated carrying capacity well enough that the observed trends in recruitment would be mirrored by estimates based on EDT—by recruitment estimates generated by applying EDT-based productivity and carrying capacity parameters to known brood year escapements. This congruence might be better for smolts than adults because the latter are affected by a greater number of confounding, out-of-subbasin environmental fluctuations.

Two final indices of reasonableness should be mentioned: the *general appearance* and the basic *red-face test*. The general appearance criterion consists simply of plotting the observed stock-recruitment scatter diagram (for smolts, adults, or both), and superimposing EDT-based recruitment values (again, generated by applying EDT production function parameters to known escapements). This test is passed if the EDT line seems to fit the scatter plot reasonably well. Obviously, this is not a stringent test; it is subject to a multitude of errors (Chapter 6 in Hillborn and Walters 1992) but is useful as an early indication that something is seriously amiss. The red-face test is even more basic: do EDT estimates match reality at all? Obvious examples of this index include known fish-bearing streams that are estimated to be barren (and vice versa); highly productive populations estimated to be barely viable (and vice versa); radically skewed relative abundance indices; and widely divergent EDT and empirical productivity measures.

Table 15 summarizes the various indices of reasonableness that were discussed above and provides commentary on their computation and interpretation.

3. Assessment of Reasonableness of Yakima Spring Chinook Output[3]

By all of the measures described in the previous section, baseline EDT output for Yakima spring chinook is reasonable. Baseline results pass the red face test as well as the general appearance test (Figure 8). Mean abundance observations of the three stocks of Yakima spring chinook (upper Yakima, Naches and American River) over the period 1981–2001 also compare reasonably well with EDT estimates. Mean adult abundance observed at Prosser Dam from 1981-2001 is estimated at 2,197, 1,574 and 469 for the upper Yakima, Naches and American stocks, respectively. Comparable EDT figures are 2,187, 1,526 and 358 (upper Yakima, Naches, and American rivers, respectively).

[3] All estimates are based on largely unpublished data provided by the Yakama Nation.

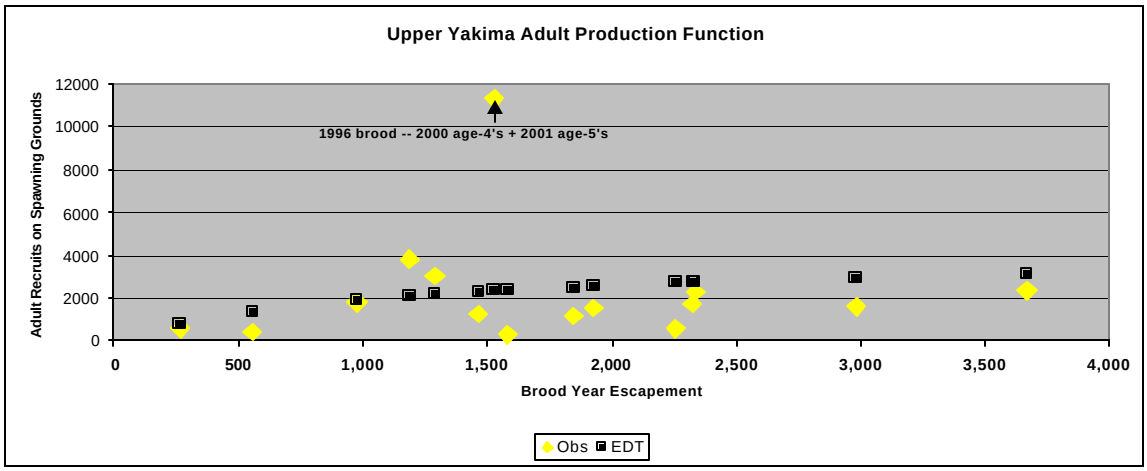
Table 15. Summary of *Indices of Reasonableness* for EDT output and a commentary on application. Note: application of any of these indices presupposes the baseline run has passed the *general appearance* and *red face* tests.

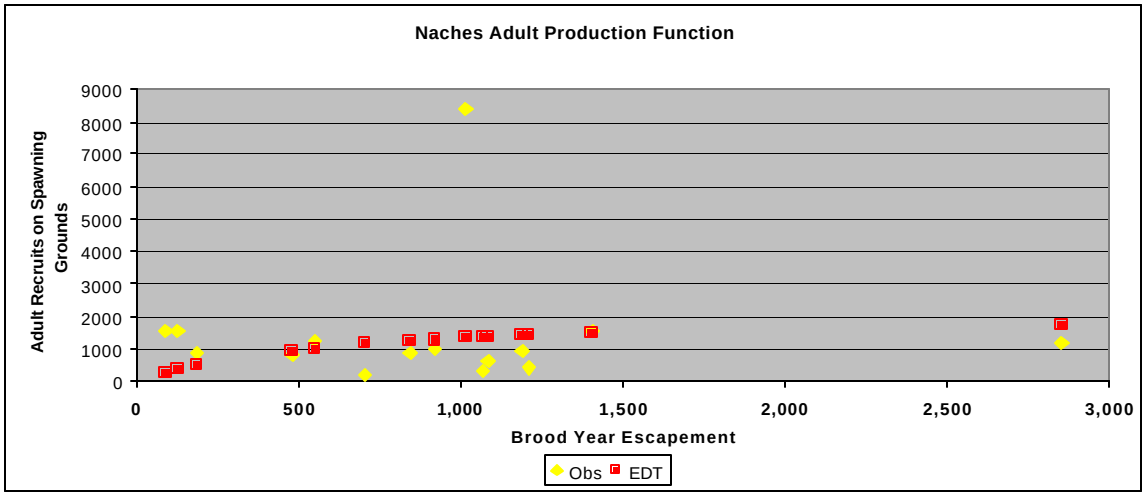
Index	Comment
Mean abundance	Compare observed mean abundance of a population with the "Equilibrium abundance" (Neq) estimated by EDT. Abundance observations must cover only the period for which habitat conditions were evaluated for the model.
Relative mean abundance: spatial	Compare observed mean abundances of two or more nonspecific populations with their respective EDT Neq's. The ratio of mean abundances and Neq's should compare well. Subject to the same conditions as mean abundance generally.
Relative mean abundance: temporal	Procedure and conditions identical to comparison of mean abundance for spatially segregated population.
Recruitment trends	Compare observed and EDT-based recruitment by brood year. Observational fluctuations that appear to be primarily density-dependent and are clearly not affected by unusual environmental conditions should be mirrored by EDT-based values. [EDT values are generated by applying the appropriate production function parameters to successive brood year escapements.]
Mean productivity values	Compare means of observed smolts per spawner, and/or smolt-to-adult survival and/or adult recruitment rate to comparable figures based on EDT. Special considerations are as follows: Smolts per spawner: estimated directly by EDT model with smolts counted at the mouth of the subbasin and spawners on the spawning grounds. Some adjustment of EDT- or observation-based values may be necessary if smolt counts were made far enough upstream to assume significant smolt losses between the observation point and the mouth[4]. Smolt-to-adult survival: estimated as the ratio of Neq's for smolts and returning adults at the mouth of the subbasin. (The same considerations for monitoring point apply here as for the smolts per spawner comparison.) Adult recruitment rate: estimated directly by EDT model over all spawning reaches. EDT- or Observation-based values may have to be adjusted if the monitoring station is well downstream of spawning areas and significant pre-spawning mortality is known to occur[5].

Relative abundance and abundance trends also compare reasonably well. The mean distribution of spawning escapement by stock is 52% upper Yakima, 37% Naches, and 11% American River for brood years 1981–2001. EDT estimates for the same stocks are 63%, 30%, and 7%, respectively. EDT-based relative Current/Template abundance also compares reasonably well with values estimated by other means. EDT estimates the sum of the equilibrium abundances of the three stocks under historic conditions at 162, 652 adults, over 30 times the average production for the last 20 years. This figure is bracketed by high and low estimates of historic spring chinook production in the Yakima, which range from about 43,000 (McNaeil and Kreeger 1993) to 202,000 (anonymous 1990). Figures 9 and 10 show that adult and smolt abundance trends based on EDT production function parameters mirror observed trends reasonably well, particularly for smolts. The smolt comparison is actually rather impressive as the

[4] Note that the off-line EDT model can estimate smolt passage and adult return at any defined reach in the subbasin. If a particular comparison is considered critical by planners, the Watershed Technical Administrator should be informed that a special run is needed.

[5] The same point can be made here: a special run can be requested at the actual monitoring point. This run will generate adult production parameters, which can then be used to estimate recruitment for specific brood year escapements.





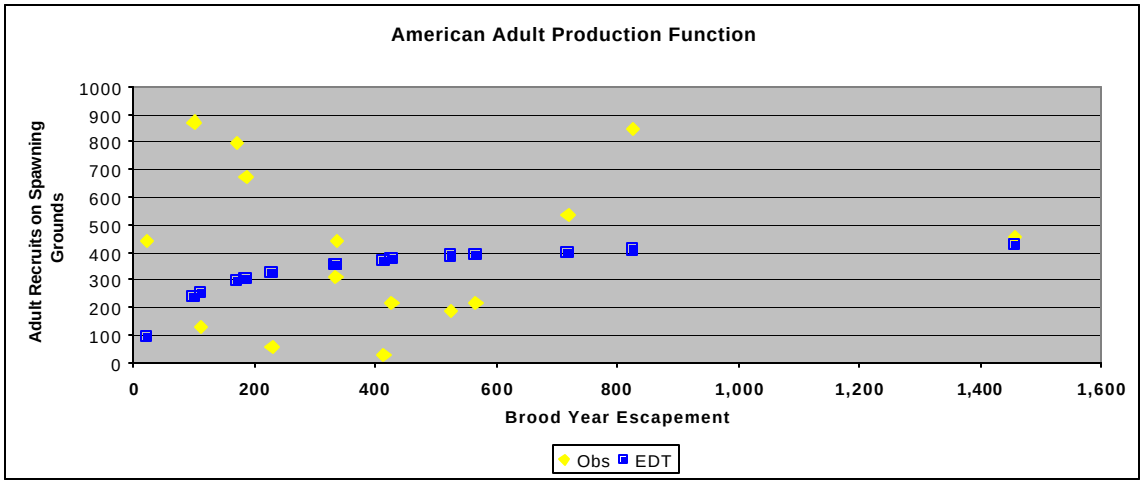


Figure 8. Adult recruitment as observed and as predicted by EDT for the upper Yakima, Naches, and American River stocks of spring chinook in the Yakima subbasin. Brood years 1981–1996.

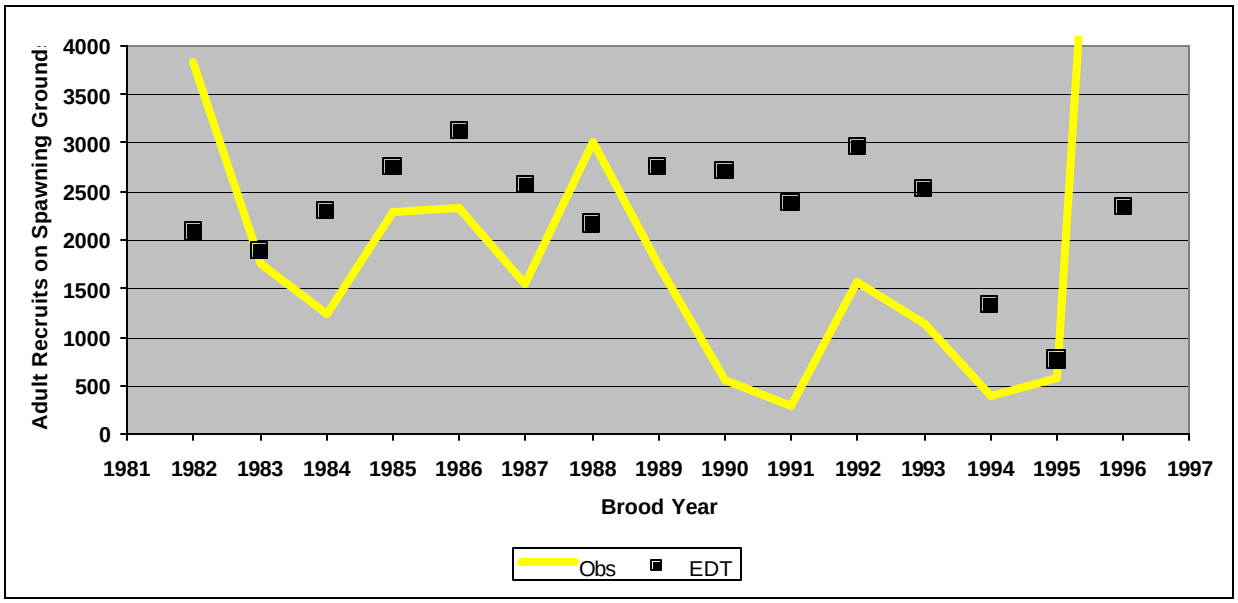


Figure 9. Comparison of observed and EDT-based estimates of adult recruitment by brood year, upper Yakima spring chinook.

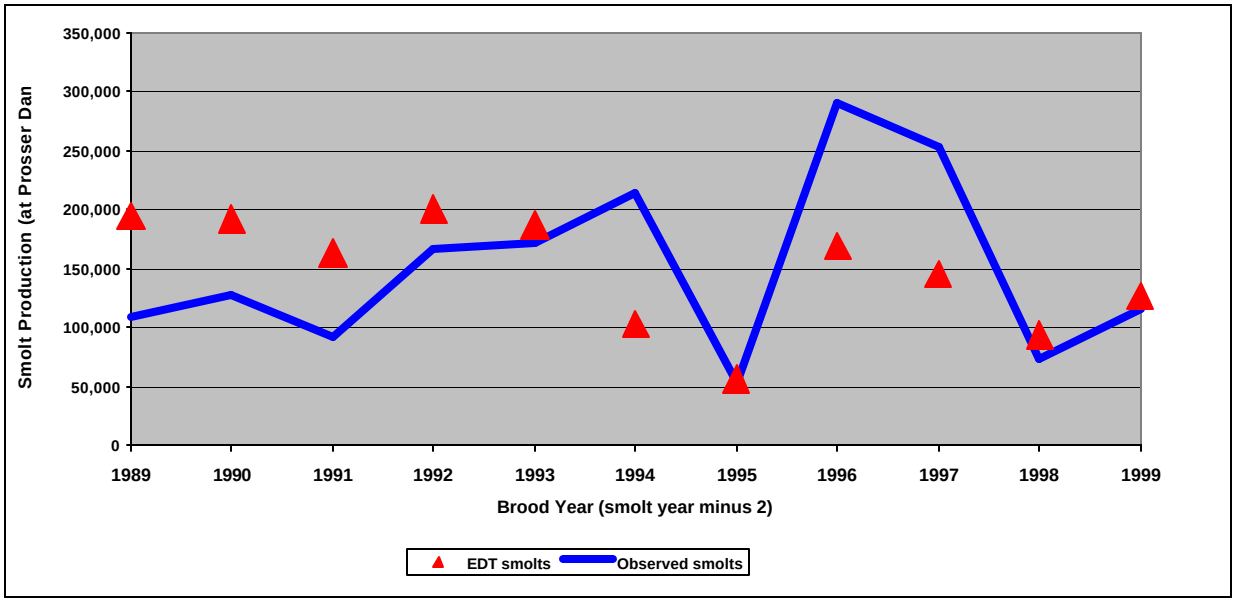


Figure 10. Comparison of observed and EDT-based estimates of smolt production of all stocks of Yakima spring chinook. Smolt production is estimated at Prosser Dam and is restricted to brood years 1989 – 1999, the years for which smolt passage based on PIT-tagged fish are available. EDT estimates represent the sum of estimates for smolt production for the American River, Naches, and upper Yakima stocks.

observed values represent a composite mixture of smolts from all three stocks, while the EDT-based values are the *sum* of independent estimates based on production function parameters for each stock.

Finally, observed and EDT-based productivity estimates also compare reasonably well. The mean smolt production rate (expressed as smolts per spawner) for brood years 1981 –1999 is 104. This figure is based on known spawning escapements and smolt passage estimates of a composite mixture of all stocks at Prosser Dam. The EDT model estimated smolt production rates for the upper Yakima, Naches, and American River stocks at 126, 133, and 164, respectively. These figures are not so different from the figures based on observations in light of the fact that the American River stock is so much smaller than the other stocks. A comparison of observed and EDT-based smolt-to-adult survival rates produced similar results. The mean of estimates based on observations is 2.8% with a 95% confidence interval of 1.8 – 3.8%. Again, these figures refer to a composite mixture of all three stocks. EDT-based estimates of smolt-to-adult survival are 3.5%, 3.1%, and 3.2% for the upper Yakima, Naches, and American River stocks, respectively.

Before leaving the topic of assessing the reasonableness of baseline EDT runs, it is again necessary to emphasize that it is easy to lose sight of the main objective of an EDT analysis. The importance of discrepancies between observations and EDT output should not be overemphasized. It is important not to lose track of *habitat* in an EDT analysis. EDT is useful to the degree that it accurately identifies beneficial quantities, qualities and distributions of habitat for a particular population. The precise degree of impact of a change in habitat on a population may not be as important as knowing the *relative impact* (compared to other environmental alterations) and the *manner of impact*—the kinds of environmental changes necessary to improve (or degrade) performance to some specified degree. We use EDT to guide land and water use management for the benefit of fish, not to manage fish populations.

4. Troubleshooting

Planners may find themselves confronted by discrepancies between EDT output and observations/estimates. Unless the discrepancies are large—off by a factor of two or more—or the output fails the red face test, planners should resist the temptation to revise attribute ratings unless new data support such revisions. However, whenever troubleshooting *is* warranted, emphasis should first be placed on the important but uncertain or imperfectly described attributes discussed earlier.

It is important in this context to retain a healthy measure of skepticism about the precision of both the EDT results and the empirical observations and not expect a perfect match[6].

Even so, troubleshooting will occasionally be necessary. When it is, what should a planner do?

[6] Although the initial baseline run of Yakima spring chinook compared reasonably well to available empirical data, the similarities were not always so close as might have been desired. Nevertheless, the input parameters were not tampered with. Troubleshooting was passed over entirely in the interest of preserving the clearest possible environmental picture.

Based on our experience and the many analyses we have performed over the past several years, we recommend the following steps:

- Review important but imperfectly understood environmental attributes first. For instance, reach lengths and widths are always important attributes and are often estimated from maps—a process which frequently leads to significant underestimates.
- Consider the most likely errors that might have contributed to discrepancies between observations and model output. Then revise the selected environmental attributes if warranted by further investigation.
- Review life history and demographic parameters embedded in the model. Although these parameters cannot be routinely altered by planners, they can be reviewed and if necessary revised with the assistance of the Watershed Technical Coordinator. Erroneous sex ratios (certain fall chinook populations) or life history assumptions (certain steelhead populations) have confounded EDT output in the past.
- As a next-to-last resort, simply review the environmental attribute ratings reach by reach, always asking the question, "are they consistent with existing data and local knowledge about the reach?" This might be especially fruitful in the case of derived ratings, such as many of those in the coarse screening datasets.

E. Subbasin Assessment – *Diagnostic Phase*

There are two elements to a Subbasin Plan: a Subbasin Assessment and a Management plan based on the Assessment. Our discussion is now approaching the concluding phase of a Subbasin Assessment, and it is appropriate for a moment to step back for an overview.

A Subbasin Assessment consists of the following elements:

- Estimates of current and historic production potential for target populations;
- Identification of specific reaches for protection and/or restoration; and
- Identification of the specific environmental attributes that are most responsible for depressed production in high priority restoration reaches.

Importantly, an Assessment also includes estimates of the level of proof for each modeled environmental attribute. These estimates can become critical to the evaluation of alternative Management plans when there is a substantial difference in the level of proof among the attributes that appear to limit production.

Looking ahead, there can also be such a thing as a *post implementation Subbasin Assessment,* in which a partially restored subbasin is re-analyzed for what remains to be accomplished. Under this scenario, new reaches would become high priority preservation and restoration candidates, and different environmental attributes would have to be restored for further improvement.

Two of the most useful products of an EDT-based Subbasin Assessment are lists of reaches prioritized by *preservation value* and *restoration potential.* Preservation value is the degree to which the performance parameters of a population are supported by a specific reach or group of reaches. Restoration potential is the increase in performance a population would experience if a single reach or group of reaches were restored to historic conditions. The significance of preservation value is revealed by the way in which it is estimated: as the percent decrease in performance that would result if the reaches were thoroughly degraded. Therefore, reaches with a high preservation value are prime candidates for protection because their degradation would have a disproportionately severe impact on production. The significance of a reach with a high restoration potential is that a given degree of restoration there would result in considerably more benefit to the population as a whole than if the same effort were to be applied elsewhere.

A Management Plan consists of a group of strategies intended to protect reaches with high preservation value and to restore environmental attributes in key restoration reaches to some degree of their normative character. One of the most valuable aspects of EDT as an ecological planning tool is that it is able to identify cumulative effects including hidden synergistic benefits among diverse actions. Thus, implicit in the development of a restoration management plan is the evaluation of various combinations of actions in an attempt to discover a package with maximum synergistic impact.

A Management Plan also includes a monitoring program with two major goals:

- To compare *realized* impact on targeted environmental attributes with the *intended* impact, and
- To compare the *eventual* response of the focus population to the *expected* response.

Thus, a good EDT-based Subbasin Plan has three essential features:

1. It is strategic—it identifies the places and kinds of actions that produce the largest benefits for a given level of effort.
2. It fosters accountability—its rationale is transparent.
3. It manages risk due to uncertainty by means of an effective monitoring plan. An effective monitoring plan should address at least three issues: (1) increasing the confidence in our knowledge of key limiting environmental attributes in key reaches, (2) evaluating the effectiveness of action elements in improving these key attributes, and (3) evaluating the impact of attribute changes on the performance of the focus population.

Returning to the final diagnostic phase of a Subbasin Assessment, many of the critical insights found in an Assessment are summarized in the *ladder diagram* (sometimes called *tornado diagram*). Figure 11 is a ladder diagram for the upper Yakima spring chinook stock. The *rungs* on the ladder represent diagnostic areas: groups of adjacent reaches consolidated into a larger unit for management purposes and for ease of presentation. The three ladders in Figure 11 represent (from left to right) preservation value and restoration potential for equilibrium abundance, productivity, and life history diversity.

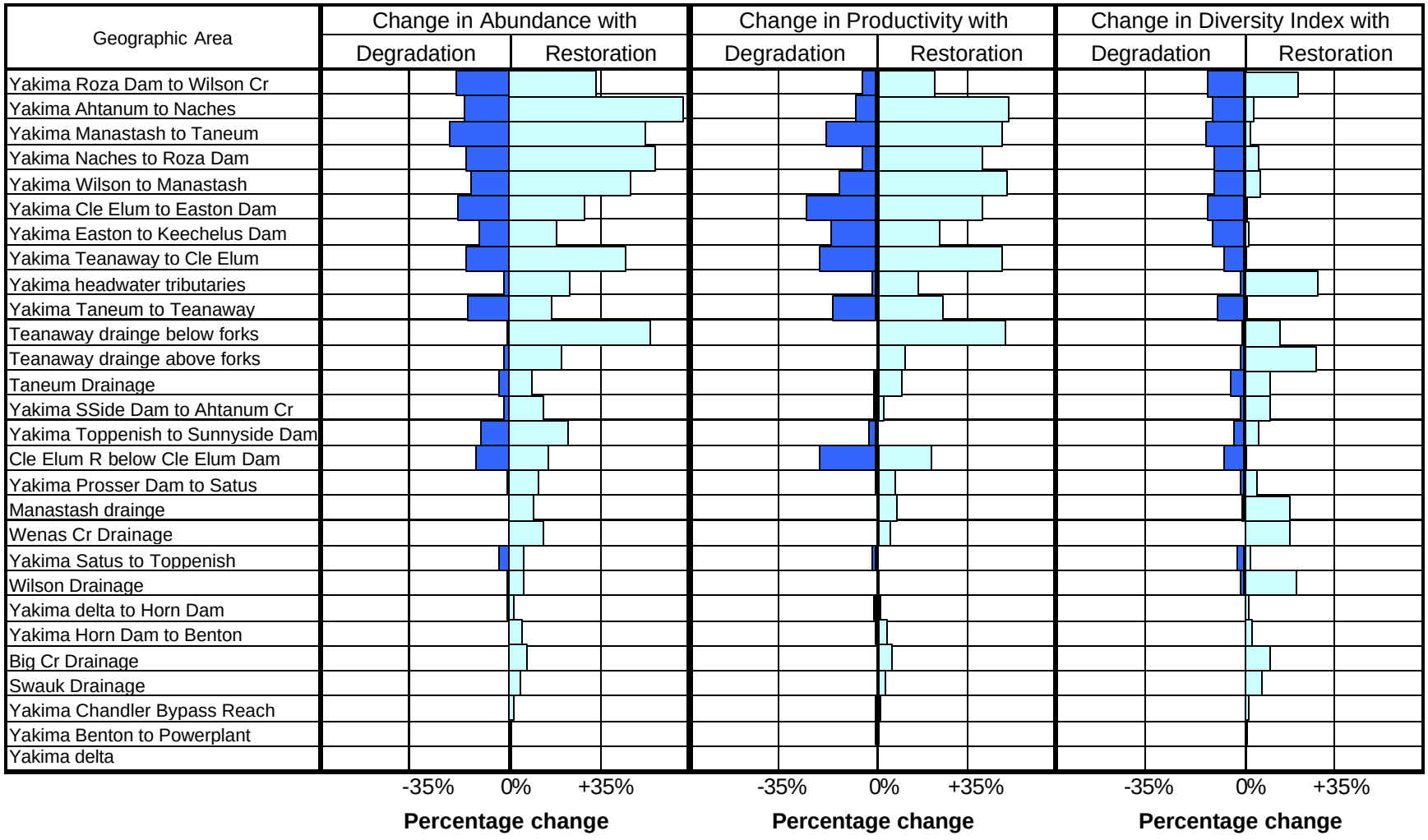


Figure 11. ***Tornado or ladder*** **diagram from the Subbasin Assessment of upper Yakima spring chinook.**

Consider just the abundance diagram for a moment. The dark blue (left) portion of each rung represents preservation value, and the lighter blue (right) portion represents restoration potential. The units in which each portion of the rung is expressed are *percent change from current population abundance*. Thus, the preservation value of the Yakima River from Ahtanum Creek to the confluence of the Naches River is approximately 15%. This means that the abundance of upper Yakima spring chinook would be expected to *decline* by about 15% if the reach were to be severely degraded from its Current condition. [*Degradation* is applied in a standardized way to each diagnostic area in an EDT analysis.] An approximate alternative interpretation is that the Ahtanum to Naches portion of the Yakima mainstem currently supports about 15% of the abundance of upper Yakima spring chinook.

For the same diagnostic unit, the Yakima from Ahtanum to Naches, the light blue portion of the rung indicates that the abundance of upper Yakima spring chinook would *increase* by nearly 70% from the current mean if environmental conditions were to be fully restored to historic conditions.

The arrangement of data is intended to graphically indicate the importance of a diagnostic area: the wider the rung, the more important the area.

Looking at rung width from bottom to top in each of the ladder diagrams, it is obvious that the bulk of the more promising candidate areas for protection and restoration are in the upper half of the basin; most of the narrower rungs at the bottom of the figures are lower river areas. To some degree, this simply reflects the life history of the species. Spring chinook do not usually spawn in the lower portions of a major river, and their migratory characteristics are such that rearing juveniles are unlikely to move more than a hundred miles or so downstream before smolting and quickly leaving the subbasin.

The preservation value side of the productivity diagram is also interesting, in that no area below Ahtanum Creek—approximately the mid-point of the mainstem Yakima and the reach bordering the city of Yakima—makes an appreciable contribution to sustaining current productivity. To a large degree, this simply reflects the fact that no spring chinook spawning occurs below Ahtanum Creek. However, it also indicates that, from the perspective of upper Yakima spring chinook, initial candidate areas for protection should be in the upper half of the basin.

The restoration potential side of the life history diversity diagram is interesting in that certain areas with modest restoration potential for abundance or productivity, and little or no preservation value, nevertheless have surprisingly large restoration potentials for life history diversity. This is mainly due to the definition of life history diversity as the percent of biologically possible trajectories that are viable—i.e., that have a productivity greater than 1.0.

A small drainage like Manastash Creek, for instance, which currently is almost totally blocked to adult access, could nevertheless support a small number of fish after appreciable restoration. Each of these viable new life histories, regardless of their abundance, would contribute to the diversity index proportion and would represent a valuable hedge against catastrophic losses in mainstem areas.

One final point should be made regarding the utility and implications of these ladder diagrams. The degree of coincidence of areas of high preservation value and restoration potential allows a planner to focus enhancement actions in a relatively narrow area. *The degree of overlap of high priority protection and restoration areas for other populations of spring chinook, and for other targeted species (steelhead, coho, etc.), will allow "strategic enhancement targeting" to be sharpened even more.*

Figure 12 tells another part of the story—not so much where attention should be focused as *what* should be addressed—the habitat factors that must be improved. This figure shows the relative degree to which production is constrained by various *habitat factors* across the same set of diagnostic areas shown in the ladder diagrams. A black dot indicates a habitat factor acting to depress production potential relative to historic values. The larger the size of the black dot, the larger the negative impact. These reach-by-attribute relationships represent the single most depressing factor affecting all life stages in a number of reaches.

Again, Figure 12 is an index of the habitat factors affecting production of the upper Yakima spring chinook population. Dominant habitat factors will differ for other spring chinook populations sharing downstream areas and will differ even more for fall chinook and other species.

Two things are immediately apparent in Figure 12. First, the most significant impacts on upper Yakima spring chinook occur in the upper half of the basin: no habit attribute has an *extreme impact* below Roza Dam. Only about 8 or 9 of the habitat survival factors have a substantial impact over the entire basin, and these are channel stability, flow, food, habitat diversity, obstructions, predation, sediment, temperature, and key habitat, with habitat diversity, sediment, temperature, and key habitat perhaps playing the largest role. With a number of caveats, the previous two Figures indicate that initial enhancement programs targeting upper Yakima spring chinook should generally focus on the upper half of the basin, and should generally address issues related to these nine habitat factors, and especially habitat diversity, sediment, temperature, and key habitat.

Figure 13 examines the issue of specific habitat problems more precisely but much more narrowly—specifically, for a single reach. Figure 13 shows that major habitat attributes impact production in the single reach of the Yakima River from Wide Hollow Creek to the Roza Powerplant outfall.

It shows additional detail, indicating the life stages most severely impacted relative to historic conditions, as well as the relative impact of various habitat factors by life stage (again, relative to historic conditions). This reach is also one of three in the 'Ahtanum to Naches' diagnostic area, which is one of the top candidates in the entire subbasin for either protection or restoration.

The blue-shaded rows in Figure 13 represent the four most severely impacted life stages (in descending order): incubating eggs, summer parr, holding adults, and overwintering pre-smolts. The yellow-shaded columns represent the habitat factors most responsible for depressing production in this reach: habitat diversity, predation, temperature, (lack of) key habitat and, at least for the most severely depressed life stage, sediment.

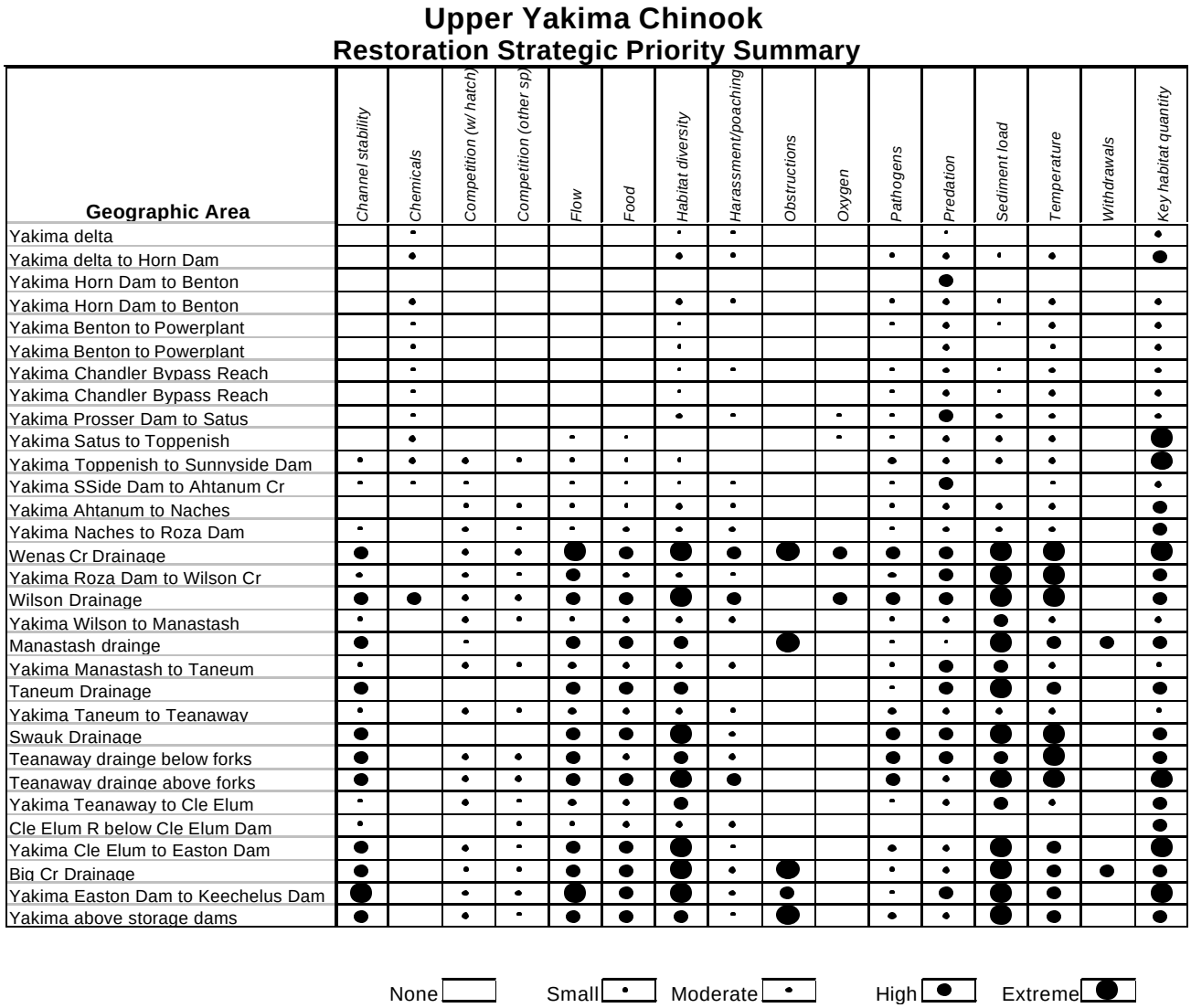


Figure 12. Diagram showing the relative severity of impacts of various habitat factors on all life stages of upper Yakima spring chinook in diagnostic areas from the mouth to the headwaters of the Yakima River.

It is with this kind of information and at this scale that alternative management plans should be focused. Previous EDT analyses, as well as other analyses not based on EDT, have identified the Yakima from Ahtanum Cr to the Naches as very high priority both for restoration and protection. The Bureau of Reclamation is in fact implementing a very ambitious program to purchase and protect as much of the high value habitat in this area as possible. Yakima subbasin planners will be evaluating complementary restoration programs targeting the same area in the very near future.

It is appropriate at this point to identify a subtle change in the nature of the environmental variables alluded to in Figures 12 and 13. These Figures no longer refer

Life stage	% Trajectories Affected	Productivity change (%)	Life Stage Rank	Change in attribute impact on survival															
				Channel stability	Chemicals	Competition (hatchery fish)	Competition (other spp)	Flow	Food	Habitat diversity	Harassment and poaching	Obstructions	Oxygen	Pathogens	Predation	Sediment load	Temperature	Withdrawals	Key habitat quantity
Spawning	1.6%	-8.8%	7								•				•		•		
Egg incubation	1.6%	-42.3%	1								•					●	•		
Fry colonization	2.0%	-6.8%	8					•	•	•					•				•
0-age active rearing	9.3%	-4.8%	2			•			•	•				•	●		•		●
0-age migrant	7.1%	-2.4%	5							•					●				•
0,1-age inactive	3.8%	-6.4%	4					•	•	•					•		•		•
1-age migrant	89.2%	-0.2%	6							•					●		•		⬤
1-age resident rearing	3.8%	-2.0%	9			•													•
1-age transient rearing																			
2+-age transient rearing																			
Prespawning migrant	99.6%	0.0%	10								•								⬤
Prespawning holding	1.6%	-24.2%	3							●	•				•		●		•
All Stages Combined	99.6%																		

KEY

NA = Not applicable

	Loss	Gain
None		
Small	•	∘
Moderate	●	○
High	⬤	◯
Extreme	⬤	◯

Figure 13. A "consumer report diagram" for the Yakima River reach from Wide Hollow Creek to the Roza Powerplant outfall. This diagram summarizes the relative impact of various degraded habitat factors on the survival of all life stages of upper Yakima spring chinook. The size of the black dots in the diagram indicate the relative severity of impacts of various habitat attributes on each life stage of the focal species. The most severely affected life stages are also ranked with 1 representing the most severe impact. Ranking is in terms of the percent of time a given life stage resides in the reach as well as the degree to which survival is reduced relative to historic conditions. Specifically, ranking is based on the product of these two factors.

to *environmental attributes* but to *habitat survival factors.* The change is more than semantic, reflecting a transformation or *evaluation* of one or more related habitat attributes. Specifically, habitat survival factors represent the species- and life-stage-specific survival rates that would be expected from the impact of related complexes of such environmental attributes as *sediment* (turbidity, percent fines in substrate, and embeddedness). This shift is significant, because often different combinations of environmental attribute values can have the same impact on survival (i.e., have the same habitat survival factor value). This means that planners will often have the opportunity to develop restoration actions that address general habitat issues like sediment by attacking the component environmental attributes most easily changed.

Consumer report diagrams like Figure 13 will be generated for every reach in the subbasin during the diagnosis phase of a subbasin assessment. Ladder diagrams like Figure 11 will be generated for every independently analyzed population and will include whatever number of diagnostic areas planners may define. Summaries of baseline output like Figure 7 will also be produced, for smolts as well as adults. This information summarizes the most important reaches for preservation and restoration and identifies the habitat factors and environmental attributes most needing improvement. A written summary and explanation of the relationships in graphic summaries like Figures 11, 12 and 13 (plus the graphics themselves) concludes the subbasin assessment portion of the subbasin plan.

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