Volume VI, Chapter 4
Integrated Watershed Assessment

TABLE OF CONTENTS

4.0 Integrated Watershed Assessment (IWA): GIS Based Screening of Watershed Process Conditions for Salmon Recovery Planning

4.1 Abstract

The Lower Columbia Region (LCR) includes several major river basins comprising 5,300 square miles (3.4 million acres) in southwest Washington. State, local, tribal and federal entities in the LCR are working cooperatively to develop recovery plans for Pacific salmon and steelhead listed under the Endangered Species Act (ESA). A key objective of this effort is to identify priority areas for preservation and restoration of key habitats. This requires an understanding of the existing and probable future status of fish populations and associated habitats, and the watershed and fluvial processes that influence them. We developed a GIS-based watershed screening and prioritization approach, referred to as Integrated Watershed Assessment (IWA), that explicitly considers three processes known to affect the quality and quantity of fish habitat: hydrology, sediment delivery, and LWD recruitment potential (as inferred from riparian condition). We used the IWA to evaluate existing and probable future conditions in 545 planning subwatersheds (3,000 to 12,000 acres) covering the entire LCR. Results of the IWA, in combination with outputs from the Ecosystem Diagnosis and Treatment (EDT) model, provide a 'top down' view of factors affecting instream habitat conditions, and a 'bottom up' view of the effects of these limiting factors on the performance of fish populations. This assessment tool enables identification and prioritization of specific management actions at appropriate temporal and spatial scales.

4.2 Integrated Watershed Assessment – Rationale, Methodology, and Application

Over the past decade, several population segments of salmon and steelhead (*Oncorhynchus* spp.) and native char (*Salvelinus* spp.) in the Pacific Northwest region of the United States have been listed as threatened or endangered under the Endangered Species Act (ESA). Currently, federal, state, tribal and local agencies and stakeholders are responding to ESA to develop comprehensive recovery plans for listed species. Recovery planning intersects with regional subbasin planning efforts also currently underway in the region. Ongoing recovery planning efforts are organized by planning units based on jurisdictions, previously defined sub-basin basin boundaries, and the geographic range of newly defined population segments. One such planning unit is the Lower Columbia Region of Washington State (LCR), comprised of five planning subbasins and covering several major river drainages, covering a total of 5,300 square miles (3.4 million acres). The LCR is further divided into 545 3,000 to 12,000 acre planning subwatersheds.

One element of recovery planning in the LCR is the synthesis of several complex sources of information to describe habitat conditions and identify factors that contribute to the decline of the listed species, or that limit their recovery. Consideration of watershed processes is acknowledged to be a necessary component of recovery planning. Measures of instream habitat conditions, which can be used to estimate the productivity of salmonid populations, provide an instantaneous 'snapshot' that are not reliable for describing trends in habitat quality when used alone, or for identifying management actions. Watershed processes (e.g., hydrology, sediment supply and transport, woody debris) are fundamental determinants of instream habitat conditions. The functionality or impairment of these processes is in turn suggestive of trends in habitat conditions over time, and of the potential as well as limitations of mitigation and restoration measures (Barinaga 1996, Beamer et al. 2000, Booth and Jackson 1997, Featherston et al. 1995, Gregory and Bisson 1997, Naiman et al. 1992, Ralph et al. 1994, Roper et al. 1998, Stanford and Ward 1992, Stanford et al. 1996). It is further recognized that many regional stream restoration projects have not performed as expected because the influence of degraded watershed processes was not adequately considered during the design process (Bisson et al. 1992, Doppelt et al. 1993, Roper et al. 1998). Therefore, an understanding of the condition of watershed processes is critical information both from the standpoint of planning restoration projects, and for developing a strategic understanding of the likely future contribution of a given subwatershed to recovery planning efforts.

There are several watershed processes that directly or indirectly affect the quality and quantity of salmon habitat in Pacific Northwest watersheds. For example, heat flux is a determinant of the temperature regime of surface waters, which in turn affects the suitability of habitats for various stages of salmonid life history. Sediment delivery and transport is a critical watershed process, which fundamentally affects channel morphology, substrate stability, and the structural diversity of available salmonid habitats. While multiple watershed processes important to salmonid habitat can be identified, the delivery and routing of sediment, water, and woody debris into and through the stream channel are viewed to be the fundamental determinants of watershed health (Beamer et al. 2000, Bisson et al. 1987, Gregory and Bisson 1997, Naiman et al. 1992). The condition of these watershed processes can be described by measures of sediment supply, hydrology, and riparian condition.

Watershed processes occur over a range of scales, from local (e.g., riparian zone condition and large woody debris recruitment) to basin levels (e.g., watershed level hydrologic condition). The scale and complexity over which these processes operate has resulted in a variety of modeling or predictive approaches used to estimate present, future and historical conditions. For example, sophisticated hydrologic models such as the Distributed Hydrology Soil-Vegetation Model (Wigmosta et al. 1994, Wigmosta and Perkins 2001), or the HEC-GeoHMS (USACE 2000) can be used to estimate hydrologic conditions in Pacific Northwest watersheds based on widely available GIS data. In comparison to hydrology, modeling of sediment delivery to stream channels is in its relative infancy (UCCCWE 2001). Empirical and stochastic models of sediment delivery have been applied in watershed management practices, but these models are typically data and calculation intensive. In general, computational requirements and data limitations do not allow for these and other more sophisticated modeling approaches to be applied systematically across large areas being considered in regional subbasin and salmon recovery planning.

For the purpose of recovery planning in the LCR, it was desirable to develop a screening level, GIS based modeling approach that can be used to evaluate the likely condition of sediment, hydrologic and riparian processes at subwatershed scales across the region. These three measures form the core of the modeling approach for the following reasons:

- They are fundamental drivers of watershed health
- Their condition could be inferred from synoptically available GIS data in the LCR
- Additional natural and human-derived factors affecting these processes, readily derived from available GIS data sets, can be rated against generally accepted effects thresholds

The value of the process-based approach to subwatershed categorization is that the processes examined are linked either directly or indirectly to habitat conditions that directly or indirectly affect the viability of fish populations. The focus on watershed processes allows for both an understanding of likely current conditions, as well as the ability to project likely future trends. Because the condition of watershed processes and associated trend factors are identified at subwatershed and watershed scales, the results of the analysis are suggestive of the general categories of habitat protection and restoration measures that could be included in salmon recovery planning.

4.2.1 General Approach

As discussed above, the IWA analysis examines hydrologic, sediment, and riparian conditions as fundamental drivers of watershed health. The approach relies on spatial analysis of landscape level GIS data against generally accepted or newly derived effects thresholds to determine the condition of these processes. IWA results are developed at local levels for sediment, hydrology, and riparian conditions, and at watershed levels for sediment and hydrology in all subwatersheds. The local level results describe the condition of factors affecting watershed processes within each subwatershed (i.e., not including upstream effects). The watershed level results describe the condition of watershed processes in the subwatershed including the influence of upstream areas (e.g., the entire drainage area).

The development of both local and watershed level results for each subwatershed provides two benefits for recovery planning purposes. The watershed level results provide an indication of the probable condition of watershed processes within each subwatershed because they include the influence of upstream effects. The local level results, because they are based solely on conditions within each subwatershed, can be used to identify which subwatersheds are probable source areas for degraded watershed processes having adverse downstream effects.

4.3 Applications for Identifying Likely Future Trends & Categories of Appropriate Management Actions

For recovery planning purposes, it is desirable to identify the likely future trends in process conditions in Key Subwatersheds over the next 20 years. This helps to further focus the direction of potential recovery planning Efforts. Given an understanding of current conditions and likely trends, it is then possible to identify general categories of appropriate watershed level management actions that can be used to maintain and improve conditions that advance recovery planning goals.

IWA results, in combination with additional sources of information on current and future land use and other landscape scale data, can be used to develop qualitative predictions of future trends and to identify appropriate categories of management measures. This approach is based on some general assumptions. For example, it is assumed that in subwatersheds where areas zoned for development exhibit a high proportion of currently undeveloped land, hydrologic and riparian conditions are likely to deteriorate over the next 10 to 20 years as development proceeds. In such areas, it would be appropriate to limit development where practical, protect riparian zones to the greatest extent possible, and invest in storm water management infrastructure to mitigate these effects. In contrast, it is assumed that hydrologic, sediment and riparian conditions in timber harvest watersheds under public ownership or subject to Habitat Conservation Plans would be expected to remain stable or to improve gradually over time.

Appropriate management measures would include promoting vegetation recovery, retiring forest roads where practicable, and managing the road drainage network to minimize sediment and hydrologic impacts.

The approach used to identify future trends and categories of management actions is described in Section 5.2.2.

4.4 IWA Methodology

The IWA methodology includes three primary elements: 1) analysis of the condition of watershed processes; 2) the prediction of likely future trends; and 3) the identification of appropriate categories of management actions to maintain or improve the condition of watershed processes. These elements are described in the following sections.

4.4.1 Watershed Process Condition Analysis

Evaluation of the condition of watershed processes is based primarily on available GIS data on describing landscape characteristics such as vegetation, geology and slope class, and other landscape scale factors such as road density, and zoning and development. These data sources describe landscape conditions that determine the condition of watershed processes, which are described in terms of functionality or degrees of impairment. A subwatershed with landscape conditions lying within natural ranges would be considered to have functional process conditions. Landscape conditions outside of natural ranges are indicative of varying degrees of impaired process conditions.

For example, a given subwatershed will have a natural sediment supply rate determined by its geology, topography, climate, soils, and vegetation. Subwatersheds of a similar type (e.g., high gradient mountainous headwaters) will have similar characteristics and would be expected to have similar sediment supply rates within a natural range. If a subwatershed of this type has perturbing factors leading to an estimated sediment supply rate outside of this range, then it would be considered impaired.

This approach requires a three-step analytical process:

1. Stratification of subwatersheds: Partitioning of subwatersheds into strata based on drainage area, elevation, geology, and hydrograph
2. Assessment of current subwatershed and watershed conditions based on GIS-derived, indicator-based estimates of sediment supply rates, hydrology, and riparian condition.
3. Classification of subwatersheds by level of process impairment, determined by comparison with impairment threshold values derived from the scientific literature or from observed distributions of subwatershed estimates.

Subwatershed stratification involves grouping subwatersheds based on natural characteristics that cause variation in watershed process conditions. Different combinations of landscape characteristics were used to create nine distinct subwatershed strata (Table 4-4.). To facilitate assessment of natural process conditions, subwatersheds that are relatively homogeneous with respect to these characteristics will be assigned to the same strata. The result is a more efficient and discriminating evaluation of subwatershed condition.

The action and influence of hydrologic, sediment and riparian processes are, by nature, broadly distributed within downstream and in some cases upstream gradients. Degraded process conditions in headwaters areas can have wide reaching effects in downstream areas. For these reasons, it is desirable to model the downstream influences of degraded process conditions to more fully capture the potential effects on instream habitat conditions. Subwatersheds are spatially linked in the IWA model to capture the influence of upstream drainage area on conditions within each subwatershed. In this way, the condition of factors affecting watershed processes in a subwatershed can be evaluated at both local (i.e., within that subwatershed) and watershed scales (i.e., incorporating conditions in upstream subwatersheds). The result of this process is two different types of information about each individual subwatershed. The local level results describe the condition of factors affecting watershed processes within the subwatershed boundary, while the watershed level effects describe the condition of watershed processes within the entire drainage area affecting that subwatershed.

Methods for assessment and classification of hydrologic, sediment and riparian conditions are described in the following sections. Subwatershed strata, and local and watershed level results for sediment, hydrologic and riparian conditions for all 545 subwatersheds in the LCR are listed by Subbasin and recovery planning watershed in Volume IV, Chapter 6.

Table 4-1. Subwatershed stratification matrix

	Topography/Hydrology/Geology		
Drainage Area	**Lowland/Rain Dominated/ Low to Moderate Erodability**	**Lowland/Rain Dominated/ High Erodability**	**High Elevation/Snow Dominated/ Low Erodability**
Small (>15,000 acres)	Strata 1 Lowland Tributaries	Strata 2 Lowland Tributaries	Strata 3 Headwater Streams
Medium (15,000-75,000 acres)	Strata 4 Lowland Watersheds	Strata 5 Lowland Watersheds	Strata 6 High Elevation Mainstems
Large (>75,000 acres)	Strata 7 Low Gradient Large River Mainstems	Strata 8 Low Gradient Large River Mainstems	Strata 9 High Elevation Large River Mainstems

Sediment Assessment and Classification Methods

Excessive instream sedimentation has been recognized as a substantial cause of degraded salmonid habitat throughout the Pacific Northwest (Reiser, 1998). This sedimentation resulted from increased rates of sediment delivery from hill slopes to stream channels, typically linked to land management activities (e.g., Salo and Cundy, 1987). For this reason, URS determined that evaluating relative sediment delivery rates could aid in the screening of watersheds within the study area for purposes of salmon recovery planning.

Our evaluation of sediment delivery rates rests on three important assumptions:

- Over the long term (from a human planning perspective), sediment delivery is controlled by geology and related physiographic properties of the landscape (i.e., slope). Locally, sediment delivery occurs from a range of active erosional processes, generally not including surface erosion.
- Over the short and intermediate term, climate (as measured by precipitation volume and intensity patterns) is effectively constant, varying within a defined range.

- Over the short term, removal of substantial vegetation and other drainage alterations result in a rapid increase in sediment delivery rates from a range of active erosional practices, including but not limited to surface erosion.
- Measured sediment delivery rates are quite variable in time and space, and locally sensitive to the specific nature of the landscape perturbations and the timing of these perturbations with regard to climatic events.

This sediment-screening tool needed to be able to distinguish the effects of landscape management practices on sediment delivery from natural sediment delivery rates. Several potential proxies for landscape management practices were considered. The Skagit System Cooperative (Beamer et al. 2002) developed a approach for calculating sediment delivery rates from different geology types based on the extent of vegetation coverage and slope. This approach was found to be impractical in the LCR, because the extent of vegetation coverage based on geology type could not be clearly correlated to sediment delivery rates.

Whole-landscape models of sediment delivery, such as the Forest Service's Water Erosion Prediction Project (WEPP) model, are not sufficiently well developed to account for erosional processes other than surface erosion. Yet, watershed analyses conducted in southwestern Washington have noted the relative importance of mass wasting and, less commonly, gullying or streambank erosion, as major contributors to sediment delivery. These include watershed analyses in the Kosmos, Upper Skookumchuck, and Panakanic drainages (Murray-Pacific 1997, Western Watershed Analysts 1997, Weyco n.d.). At the same time, these analyses do not quantify sediment delivery except for that predicted from the surface erosion of roads. This is due to the fact that the effort and complexity of such quantification does not serve the purpose of the watershed analyses, which is to understand watershed processes at a level of detail sufficient to identify probable sources of habitat limiting factors. However, the density of unsurfaced forest roads can serve as a useful proxy for the effect of landscape management practices on sediment delivery. This approach has precident in the surface erosion component of Washington State's watershed analyses guidance. The sediment component of Washington State's watershed analysis manual is based on detailed studies of road-related sediment delivery rates and habitat effects by Cederholm and Reid (1987) by the type of road and use patterns in the Clearwater River basin of the Olympic Peninsula. Road density is arguably a useful proxy measure of the intensity of land use at the landscape scale.

There are no watershed assessments or other comprehensive investigations within the LCR with sufficient information to quantify sediment delivery rates for processes other than surface erosion, and, as mentioned, surface erosion appears to play a less important role in the delivery of sediment to stream channels. However, the general agreement that forest roads are an important factor in the delivery of sediment to stream channels, and the fact road density is readily applied in a modeling context suggests that forest road density can be combined with other factors to provide a reasonable screening level evaluation of the condition of sediment processes.

Therefore, rather than explicitly calculating sediment delivery rates, we have developed an ***index of erodability*** that can be used to predict the relative magnitude of sediment delivery from a watershed over short and intermediate time scales. The index of erodability is calibrated to account for the observed non-linear relationship between measured erosion and sediment delivery to stream channels. While this non-linear relationship cannot be fully quantitatively established, there are several observations of soil erosion and sediment delivery that are suggestive of the relative magnitude of sediment delivery resulting from erosion of differing geology types by slope class. These include compilation of sediment yield rates in experimental (i.e., instrumented) basins by Swanson et al. (1987) for the western Oregon Cascades (equivalent to the southern Washington Cascades) and the Coast Range (equivalent to the Willapa Hills area), and inventoried sediment delivery volumes from older forest roads in four watersheds in western Washington (Veldhuisen and Russel 1999). Sediment delivery in this study was partitioned by source (gully vs. landslides) vs. land surface slope, as described by Veldhuisen and Russell (1999).

The experimental work by Swanson et al. (1987) and Velduisen and Russel (1999) was conducted in watersheds with generally steeper terrain. While much of the LCR is comparable to the watersheds examined in these studies, a significant proportion of the LCR has relatively flat terrain that would be expected to have less natural erodability. To account for this variability, K-factors for soil associations mapped in Lewis County are used to scale the index for areas of the LCR with shallower terrain (Evans and Fibich 1987). The "K" factor is the soil erodability factor used in the Universal Soil Loss Equation and its decedents, including the soil erosion component of WEPP. Soil associations were matched to the slope and rock types on which they formed, which allowed for the use of geology data as a proxy for soil type.

The erodability index was calculated for subwatersheds in the LCR using the following sources of synoptically available GIS data:

- Geology (WDNR 1:100,000 scale coverage)
- Slope class (WDNR 1:100,000 scale coverage)
- Unsurfaced road density (Class 0, 4 and 5 roads, WDNR 1:24,000 scale coverage)
- Subwatershed attributes (total area, upstream subwatersheds)

This GIS data was used to develop the following parameters, which are combined and the results averaged on an area-weighted basis for each subwatershed:

- The relative erodability of the underlying bedrock, divided into three erodability classes:
  - Low for massive igneous and sedimentary rocks
  - Moderate for thinly bedded sedimentary rocks and pyroclastic deposits (i.e., volcanic materials not related to lava flows)
  - High for unconsolidated sediments of alluvial, glacial, or volcanic origin.
- The land surface slope, defined by three slope classes as provided by the source data:
  - <35% slope
  - 35-65% slope
  - >65% slope
- Road density of unsurfaced roads, divided into three classes related to the log-normal mean density of unsurfaced roads (WDNR class 0, 4 and 5) within each unique polygon combination of slope and erodability class:
  - High road density: > +1 standard deviation from the mean (>8.3 miles/mile^2)
  - Moderately high road density: 0 to + 1 standard deviations from the mean (3.3 to 8.3 miles/mile^2)

- Moderately low road density: 0 to – 1 standard deviations from the mean (2 to 3.3 miles/mile^2)
- Low road density: < – 1 standard deviations from the mean (<2 miles/mile^2)

These four data themes and parameters described above were intersected to identify the area in each subwatershed in each unique combination of slope and erodability class, and the unsurfaced road density in each of these combinations. The road density thresholds cited apply to the geology and slope class polygons, rather than the subwatershed or watershed level road density. These data were then used to calculate natural and currently existing subwatershed erodability ratings using the following three step methodology:

First, a background sediment delivery index value, referred to as the GeoSlope Sediment Delivery (GSSD) index, was developed for each GIS polygon representing a unique combination of slope and geology type. The GSSD provides an estimate of the relative sediment delivery rates to the watershed under natural conditions. The GSSD is calculated by summing the area weighted erodability ratings for each unique combination of slope and erodability classes found at local and watershed levels. Erodability ratings by geologic erodability and slope classes are shown in Table 4-2. These arbitrary index values were developed from data reported by Swanson et al. (1987) and the Lewis County soil survey (Evans and Fibich 1987).

Next, an estimate of the effect on sediment delivery from managed lands was calculated for each polygon, using unsurfaced road density as a proxy for land use activities, referred to as the Road Susceptibility to Sediment Delivery (R) index. The presence of unsurfaced forest roads is widely recognized as the major cause of accelerated sediment delivery for forestlands, but can also a major contributor to sediment delivery from agricultural or other cleared lands. The R index was scaled to account for the estimated acceleration in sediment delivery based on results of Reid and Cederholm (1987) and Veldhuisen and Russell (1999). Veldhuisen and Russell (1999) reported their data on a land-slope basis only, and found that inventoried sites with both low and high slopes had the highest rate of gully erosion, while only sites in the highest slope class were found to have mass wasting features. While recent modeling suggests that road density is less important than road location and use in predicting sediment delivery (Kahklen, 2001), road density is used here because it can be reliably calculated at the scale of each slope and geology type polygon across the LCR.

Finally, the GSSD and R indices were combined to arrive at a Managed Condition Sediment Delivery (MCSD) index. The average unsurfaced road density in the study area was calculated as 5.8 mi/mi^2, with a standard deviation of 2.5 mi/mi^2 (log-normal distribution). For low road density values (2 to 3.3 mi/mi^2), the MCSD was calculated as the average of the GSSD and R values. For intermediate road density values, the MCSD was set equal to the R value. For high road density values, the MCSD was set equal to 3 times the R value. MCSD index values by erodability, slope and R class are shown in Table 4-3.

It is important to note that relative road density thresholds rather than absolute thresholds for watershed scale road density from the literature because the individual area of analysis is not the drainage, but individual spatial polygons representing a combination of a single erodability class and slope category. The data set used to develop this relative rating represents several thousand distinct GIS polygons with a broad range of road densities ranging from zero to tens of miles per square mile of area, suggesting a representative range of effects. It is interesting to note that the resulting thresholds are comparable to existing literature values for drainage scale road densities (Wade 2000, 2001).

Table 4-2. Natural erodability ratings used to calculate GeoSlope Sediment Delivery (GSSD) index values

Geology Type*	Geology Type Erodability Class**	Natural Erodability Rating Based on Slope Class***		
		Slope < 30%	Slope 30-65%	Slope >65%
ice	NONE	0	0	0
water				
acidic intrusive rocks	LOW	1	5	10
andesite flows				
basalt flows				
basalt flows (Frenchman Springs Member [CRB, WB])				
basalt flows (Grande Ronde Basalt, undivided [CRB])				
basalt flows (GrandeRondeBasalt,upper flows of norm.mag.pol.)				
basalt flows (GrandeRondeBasalt,upper flows of rev.mag.pol.)				
basalt flows (Pomona Member [CRB, SMB])				
basalt flows, invasive (CRBG, undivided)				
basalt flows, invasive (Grande Ronde Basalt,undiv.[CRB])				
basalt flows, invasive (Pomona Member [CRB, SMB])				
basic intrusive rocks				
dacite flows				
diorite				
gabbro				
granite				
granodiorite				
intrusive andesite				
intrusive andesite and dacite				
intrusive basaltic andesite				
intrusive dacite				
intrusive rhyolite				
intrusive rocks, undivided				
quartz diorite				
rhyolite flows				
argillic alteration	MODERATE	25	50	75
basalt flows and flow breccias, Crescent Formation				
continental sedimentary deposits or rocks				
continental sedimentary deposits or rocks, conglomerate				
marine sedimentary rocks				
nearshore sedimentary rocks				
pyroclastic flows				
quartz monzonite				
talus deposits				

Geology Type*	Geology Type Erodability Class**	Natural Erodability Rating Based on Slope Class***		
		Slope < 30%	Slope 30-65%	Slope >65%
tuffs and tuff breccias				
volcanic and sedimentary rocks				
volcanic rocks				
volcaniclastic deposits or rocks				
alluvial fan deposits	HIGH	50	75	150
alluvium				
alluvium, older				
alpine glacial drift, pre-Fraser				
alpine glacial outwash, Fraser-age				
alpine glacial till, Fraser-age				
artificial fill, including modified land				
glacial drift, undivided				
lahars				
mass-wasting deposits, mostly landslides				
outburst flood deposits, gravel, late Wisconsin				
outburst flood deposits, sand and silt, late Wisconsin				
peat deposits				
pebble breccia				
terraced deposits				

* Washington Department of Natural Resources (WDNR) lithological term (LITH_TERM) used in the State of Washington geology 1:100,000 GIS coverage.

** Relative erodability of geology class based on observed regional relationships

*** Natural erodability rating for each polygon having the defined geology and slope class combination

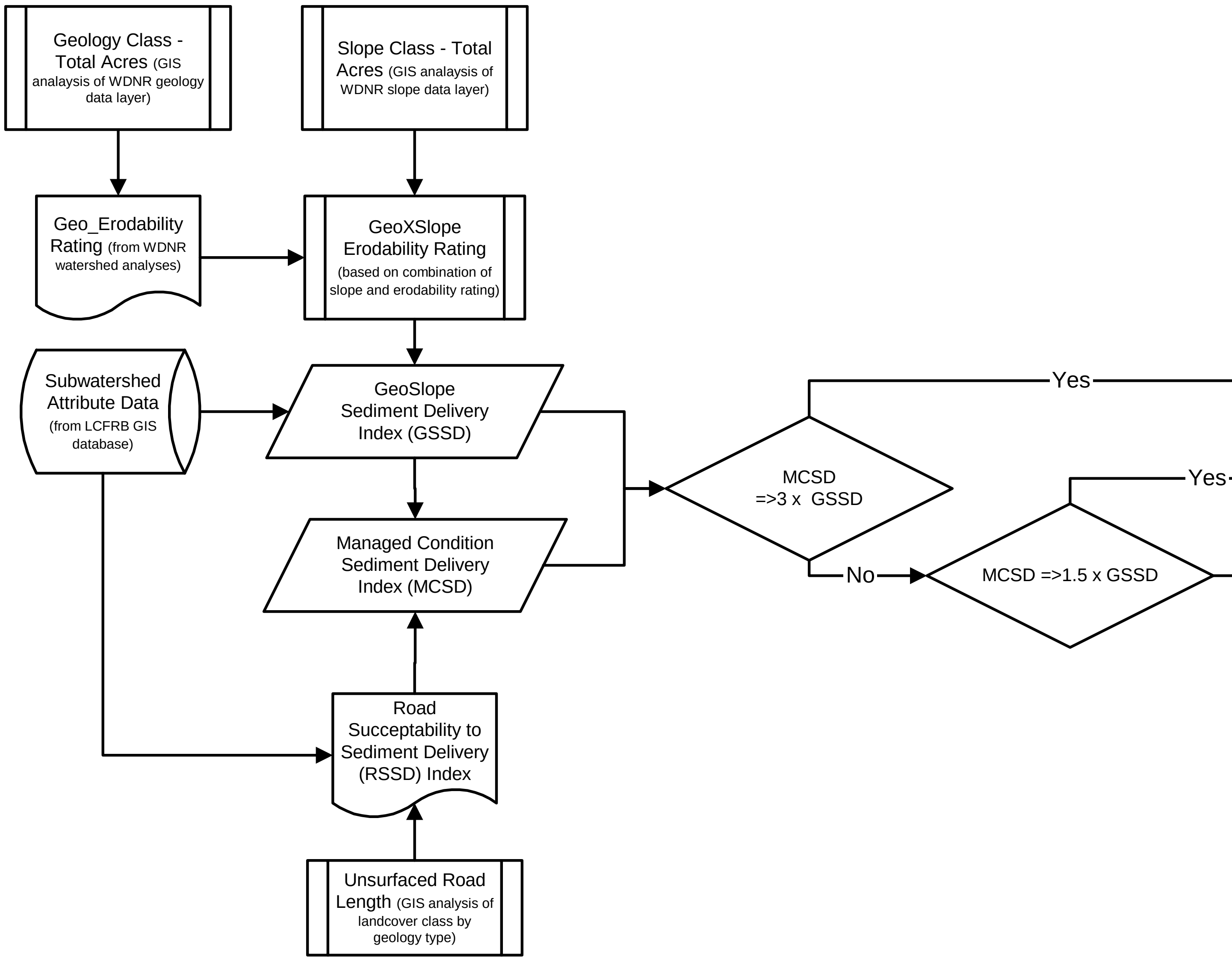
Table 4-3. Road Susceptibility to Sediment Delivery (R) index values used to calculate the Managed Condition Sediment Delivery (MCSD) index

Erodability Class	Slope Class	Natural Erodability Rating*	R Index Value**			
			Road Density $< 2\ m/m^2$	Road Density $2 - 3.3\ m/m^2$	Road Density $3.3 - 8.3\ m/m^2$	Road Density $>8.3\ m/m^2$
Low	<30%	1	1	1.5	2	5
	30-65%	5	5	5	5	15
	>65%	10	10	30	50	150
Moderate	<30%	25	25	38	50	150
	30-65%	50	50	50	50	150
	>65%	75	75	288	500	1500
High	<30%	50	50	75	100	300
	30-65%	75	75	75	75	225
	>65%	150	150	575	1000	3000

* From Table 5-3

** Road Susceptibility to Sediment Delivery index values reflect non-linear relationship between road density and the Natural Erodability Rating

The attribute information in GIS derived polygons based on the intersection of slope class, geology type and forest roads were used to calculate the GSSD and MCSD index values. GSSD and MCSD for each individual polygon are aggregated to derive local ($GSSD_{sws}$, $MCSD_{sws}$) and watershed level ($GSSD_{ws}$, $MCSD_{ws}$) index values for each subwatershed. A conceptual diagram of this analytical process is shown in



Geology Class - Total Acres (GIS analaysis of WDNR geology data layer)
Slope Class - Total Acres (GIS analaysis of WDNR slope data layer)
Geo_Erodability Rating (from WDNR watershed analyses)
GeoXSlope Erodability Rating (based on combination of slope and erodability rating)
Subwatershed Attribute Data (from LCFRB GIS database)
GeoSlope Sediment Delivery Index (GSSD)
Managed Condition Sediment Delivery Index (MCSD)
Road Succeptability to Sediment Delivery (RSSD) Index
Unsurfaced Road Length (GIS analysis of landcover class by geology type)
MCSD =>3 x GSSD
Yes
No
MCSD =>1.5 x GSSD
Yes

Figure 4-1.

The natural (or background) watershed level $GSSD_{ws}$ for subwatershed *j* is calculated as:

Eq. (1n) $$GSSD_{ws} = \frac{\sum_{j=1}^{m} P_i G_i}{\sum_{j=1}^{m} A_{sws}}$$

---

and the natural local level $GSSD_{sws}$ for subwatershed *j* is defined as:

Eq. (2n) $$GSSD_{sws} = \frac{\sum_{i=1}^{n} P_i G_i}{A_{sws}}$$

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based on subwatershed area A_{sws}:

Eq. (3) $$A_{sws} = \sum_{i=1}^{n} P_i$$

---

where:

$GSSD_{ws}$ = Watershed level natural erodability rating

$GSSD_{sws}$ = Subwatershed level erodability rating; $j = 1, 2, \ldots, m$

A_{sws} = Area of contributing polygons(s) within subwatershed; $j = 1, 2, \ldots, m$

n = number of polygons

m = number of subwatersheds

P_i = Total area of polygons with unique GSSD erodability and slope class combinations area (acres); $i = 1, 2, \ldots, n$

G_i = The natural erodability rating each combination of P_i; $i = 1, 2, \ldots, n$ (see Table 4-2)

Current erodability index values at the watershed level $MCSD_{ws}$ are calculated similarly, substituting R_{sws} for G_{sws}. Eq. (1n) and Eq. (2n) are replaced with:

Eq. (1c) $$MCSD_{ws} = \frac{\sum_{j=1}^{m} P_i R_i}{\sum_{j=1}^{m} A_{sws}}$$

---

and:

Eq. (2c) $$MCSD_{sws} = \frac{\sum_{i=1}^{n} P_i R_i}{A_{sws}}$$

respectively, where:

$MCSD_{sws}$ = The erodability index value for the subwatershed under current managed conditions

R_i = The R index value for the polygons slope, geologic erodability and unsurfaced road density combination; $i = 1, 2, \ldots, n$ (seeTable 4-3)

The condition of sediment processes in each subwatershed is determined at the local and watershed levels by comparing the current condition ($MCSD_{sws}$ or $MCSD_{ws}$) to the background condition ($GSSD_{sws}$ or $GSSD_{ws}$) at the appropriate scale. At the local level, only the areas within the subwatershed boundary that contribute sediment are examined. At the watershed level, all upstream areas contributing sediment to the subwatershed are examined. GSSD and MCSD values vary significantly between subwatersheds, reflecting differences in geology, slope and intensity of land use.

The following threshold values have been established based on calibration of results to conditions observed in existing watershed assessments (Veldhuisen and Russel 1999):

Functional: $GSSD < 1.5 \times MCSD$

Moderately Impaired: $1.5 \times GSSD \leq MCSD < 3 \times GSSD$

Impaired: $MCSD \geq 3 \times GSSD$

In addition to the impairment rating, the natural erodability index values (GSSDsws, GSSDws) also provide useful information on the likelihood of sediment problems occurring in a subwatershed. Those areas with high natural erodability index values are more likely to suffer from high levels of sediment supply and the subsequent effects on stream channel conditions. In contrast, those areas with very low erodability index values are more likely to suffer from sediment starved conditions, particularly in locations below dams where upstream recruitment of sediment is limited.

It is important to note that these thresholds and the ratings values presented in Tables 5-3 and 5-4 are derived from the described watershed assessment studies and information about the erodability of various geology types. While these values are quantitative, they should not be viewed as quantitative rates of erosion resulting from a given combination of slope and geology type under varying management conditions. Rather, they are an aggregate scale of relative erodability which has been calibrated against available information.

The semiquantitative nature of these index values, and potential data accuracy issues contribute to uncertainty in this analysis. This uncertainty should be considered when interpreting the results of this analysis. The nature and implications of this uncertainty are described in Section 5.3.

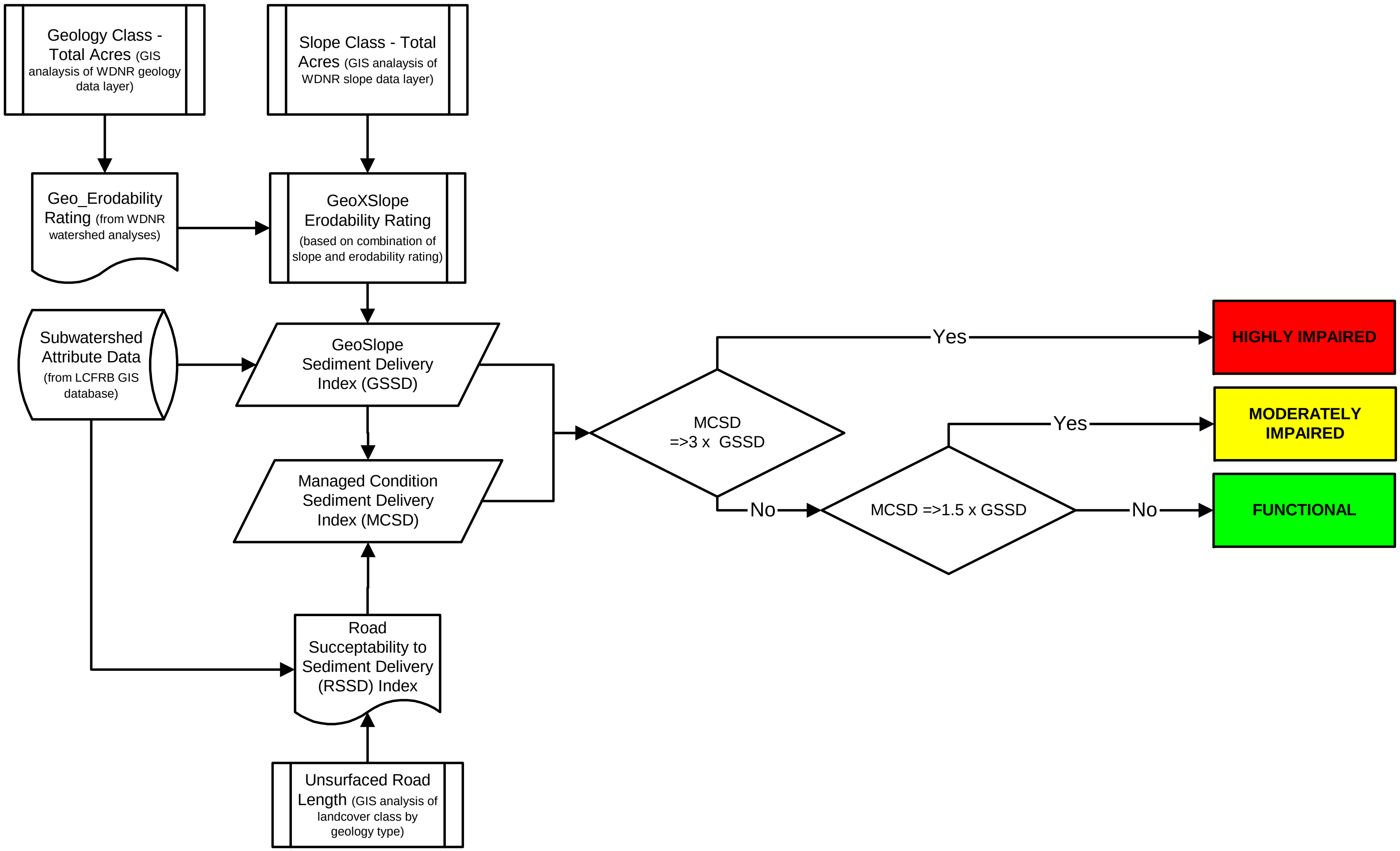

Figure 4-1. Conceptual diagram of subwatershed process condition analysis methodology for sediment supply, and selected additional

factors.

Hydrology Assessment and Classification Methods

Several well developed hydrologic models are in existence. For example, sophisticated hydrologic models such as the Distributed Hydrology Soil-Vegetation Model (Wigmosta et al. 1994, Wigmosta and Perkins 2001), or the HEC-GeoHMS (USACE 2000) can be used to estimate hydrologic conditions in Pacific Northwest watersheds based on widely available GIS data. However, computational requirements and data limitations do not allow for these and other more sophisticated modeling approaches to be applied systematically across the entire LCR. For these reasons, it is desirable to develop a screening level tool to evaluate the condition of hydrologic processes in recovery planning subwatersheds. A simplified approach to evaluating the condition of hydrologic processes was developed following the example provided by the Skagit System Cooperative (Beamer et al. 2002).

Like sediment supply, watershed hydrologic conditions can significantly affect channel conditions, instream habitat parameters, and the overall quality and quantity of available habitat for focal species. Again like sediment supply, the condition of hydrologic processes in recovery planning subwatershed can be degraded by either local or watershed levels factors. Following the guidance provided by Beamer et al. (2002), the condition of subwatershed hydrologic processes is calculated based on the intersection of the following GIS themes and calculated values:

- Impervious surface (calculated from GIS zoning coverages for Clark County and effective impervious surface (EIS) values).
- Subwatershed attributes (total area, upstream subwatersheds)
- Land cover (vegetation, 1:100,000 scale 1993 LANDSAT coverage)
- Road density (WDNR road coverage)

These data themes are intersected using a two-stage analysis process to determine hydrologic functionality or impairment in urbanizing and undeveloped lands based on effective impervious surface and vegetative cover (Beamer et al. 2000). These data sources are used to calculate the hydrologic condition in the subject subwatershed, and in upstream subwatersheds. A conceptual diagram of the analysis method is shown in . Stage 1 involves the calculation of acres of effective impervious surface (EIS), calculated for each subwatershed zoning class polygon based on zoning specific EIS values (Beamer et al. 2000). EIS for each subwatershed is calculated using the following formula:

Effective impervious surface (I_{ws}) for a given watershed is calculated as:

Eq. (4)
$$I_{ws} = \frac{\sum_{j=1}^{m} I_{sws} A_{sws}}{\sum_{j=1}^{m} A_{sws}}$$

where subwatershed area A_{sws} is calculated as Eq. (3) above and subwatershed EIS (I_{sws}) is defined as:

Eq. (5)
$$I_{sws} = \frac{\sum_{i=1}^{n} P_i E_i}{A_{sws}}$$

And:

I_{ws} = Effective watershed impervious surface area (%)

I_{sws} = Subwatershed impervious surface area (%); $j = 1, 2, \ldots, m$

A_{sws} = Area of contributing subwatersheds (acres); $j = 1, 2, \ldots, m$

n = number of polygons

m = number of subwatersheds

P_i = Polygon area (acres); $i = 1, 2, \ldots, n$

E_i = Effective impervious surface area for zoning class x (%); $i = 1, 2, \ldots, n$

Subwatershed and watershed hydrologic impairment is determined by comparing EIS values to the following provisional threshold values. If EIS exceeds 10 percent at the local or watershed levels, the subwatershed is considered to be hydrologically impaired. If EIS is between 3 and 10 percent at the local or watershed levels, the subwatershed is considered to be moderately impaired. If the subwatershed has less than 3 percent impervious surface, Stage 2 of the hydrologic analysis is conducted.

Stage 2 of the hydrologic condition involves analysis of land cover and road density at local and contributing watershed scales. Vegetation class is calculated using existing land cover data using the following formulas:

Land cover for a given watershed (LC_{ws}) is calculated as:

Eq. (6)
$$LC_{ws} = \frac{\sum_{j=1}^{m} LC_{sws}}{\sum_{j=1}^{m} A_{sws}} \times 100\%$$

where subwatershed area A_{sws} is calculated as Eq. (3) above, and percent of subwatershed land cover LC_{sws} in vegetation classes 3, 4 or 15 is defined as:

Eq. (7)
$$LC_{sws} = \frac{\sum_{i=1}^{n} (F_3 + F_4 + F_{15})_i}{A_{sws}} \times 100\%$$

and:

LC_{ws} = Watershed land cover in vegetation classes 3, 4 and 15 (%); (from Lunetta et al. 1997)

LC_{sws} = Subwatershed land cover in vegetation class 3, 4,or 15 (%)j = 1, 2, …, m

A_{sws} = Area of contributing subwatersheds, j = 1, 2, …, m

N = number of polygons

M = number of subwatersheds

F_3 = Polygon area in vegetation class 3, early-seral (acres)

F_4 = Polygon area in vegetation class 4, other forest (acres)

F_{15} = Polygon area in vegetation class 15, non-forest (acres)

Subwatershed or watershed road densities are calculated by dividing the miles of total road per square mile of subwatershed or contributing watershed area. The combination of these two factors is used to categorize unclassified subwatersheds as hydrologically impaired, likely to be impaired, or functional. A conceptual diagram of the analysis methodology with impairment thresholds is shown in Figure 4-2.

The effects thresholds used in the hydrologic analysis include:

- Percent hydrologically mature vegetation: >50% vegetation class 3, 4 or 15
- Road density: >3 miles/mile^2
- Impervious surface area: 3% and 10%

As shown in Figure 5-4, the interaction of these thresholds within a given subwatershed and its drainage area are used to determine its impairment rating. The 50 percent threshold for hydrologically mature vegetation is a conservative (i.e., allowing for less mature vegetation) threshold derived from several sources, including US Forest Serivce watershed assessments (USFS 1996, 2001), and the Skagit System Cooperative watershed screening approach for the Skagit River basin (Beamer et al. 2002). It relies on the percentage of immature to mature forest present in a watershed, as measured by the watershed area not in vegetation classes 3, 4, or 15 in the GIS vegetation coverage (Lunetta et al. 1997). These data classes represent immature forest, clearcut areas, rock and ice, urbanization, or other unvegetated open ground. The remaining vegetation classes, data values 1 and 2, are representative of late seral forest, and mid-seral forest classes, respectively.

The road density threshold of 3 miles per square mile is derived from the Skagit System Cooperative watershed screening approach (Beamer et al. 2002). This includes roads of all classes. Road densities exceeding this threshold value have been observed to correlate with changes in subwatershed level hydrologic regime.

Finally, the impervious surface thresholds are similarly based on empirical evidence of changes in hydrologic conditions with adverse effects on instream habitats. These thresholds were applied by the Skagit System Cooperative (Beamer et al. 2002), and are derived from ongoing research on urbanization effects in Western Washington.

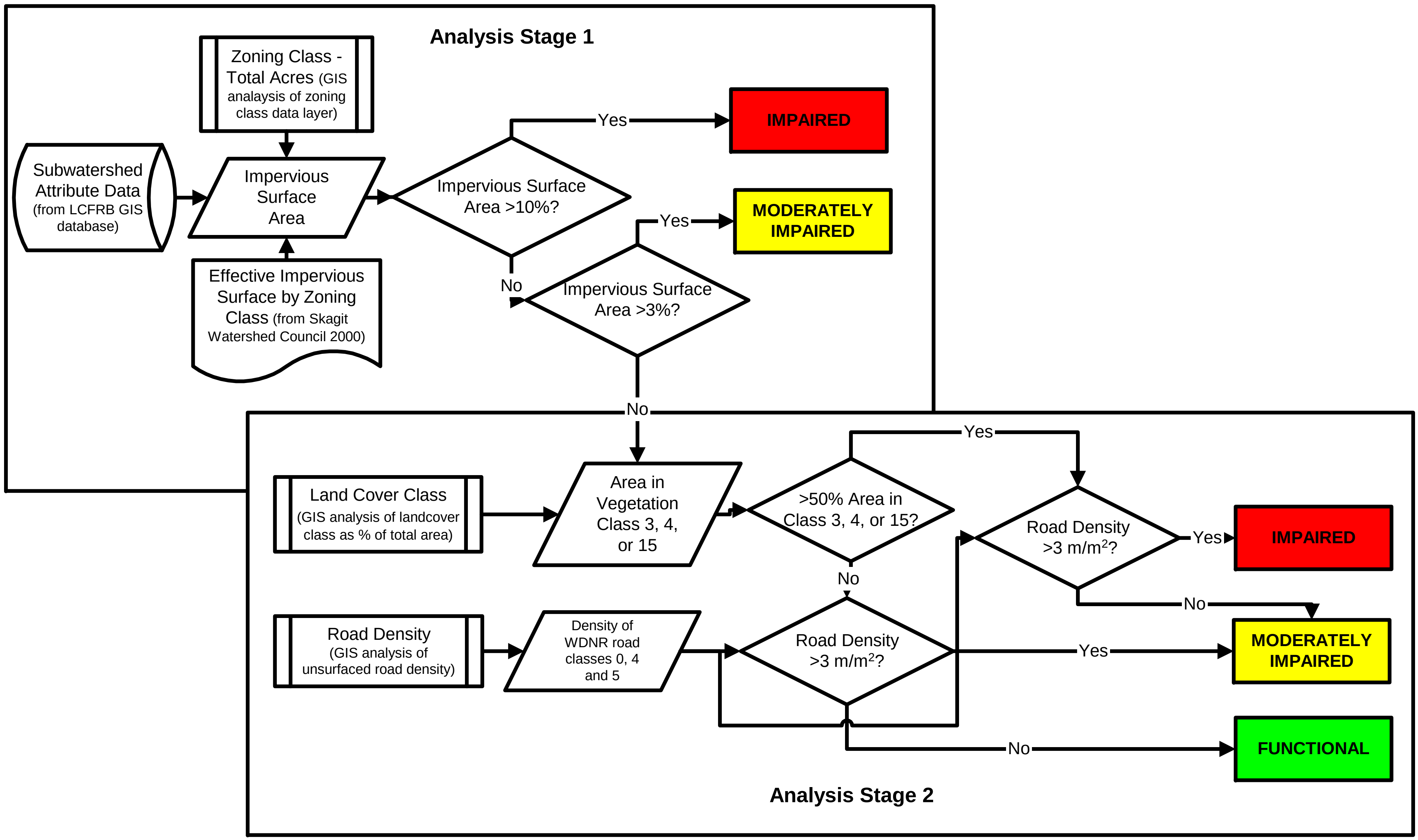

Figure 4-2. Conceptual diagram of subwatershed process condition analysis methodology for hydrology, and selected additional factors

Riparian Assessment and Classification Methods

Riparian condition and LWD recruitment directly affect channel morphology, substrate conditions, nutrient cycling, stream temperature, and the structural diversity of available habitats for focal species. Riparian condition is selected as a proxy measure of these watershed processes. The IWA approach to riparian condition relies on previous GIS based analyses and data developed by Lunetta et al. (1997), and further refined by Beamer et al. (2002). Beamer et al. (2002) conducted ground truthing of the Lunetta et al. (1997) data set, which was developed for all areas of Western Washington, including the majority of the LCR.

Unlike the sediment and hydrologic analysis, no feasible analytical approach could be developed for routing of riparian functions between subwatersheds. Analyses of watershed level sediment and hydrologic conditions incorporate additive effects based on drainage area as a primary calculation tool. The riparian analysis does not include this type of calculation, and a detailed analysis of the transport capacity of woody materials between subwatersheds based on other factors is beyond the scope of this analysis. Therefore, the riparian condition analysis applies only at the local level, no watershed level (i.e., incorporating riparian conditions in upstream subwatersheds) analysis is conducted. The implications of this are expected to be minor however because riparian influence on large woody debris recruitment is expected to be limited primarily to subwatershed scales. Only the larger mainstem rivers (i.e., subwatershed strata 7 and 8) are capable of ongoing transport of large woody materials over distances that would regularly cross subwatershed boundaries. This does however limit the ability to evaluate transport of smaller woody material and organic debris between subwatersheds.

Riparian zone condition is evaluated using the following data sources:

- Land cover (LANDAT TM 1993 GIS data coverage)
- Streams (SSHIAP 1:24,000 scale GIS hydrology coverage)

These data themes are merged to estimate the proportion of intact versus degraded riparian zone condition, based on total stream length. These proportions are then compared to derived threshold values to determine functionality or the degree of impairment, as described below.

Riparian zone condition is evaluated using a data layer developed following the methods of Lunetta et al. 1997. The data layer describes the proportion of streamside buffer acreage by vegetation class, based on the intersection of the LANDSAT TM 1993 data layer with a 30 meter buffer polygon around 1:24,000 SSHIAP stream segments.

Functionality or impairment of riparian vegetation is based on the proportion of total buffer area in five vegetation classes: class 1, late seral vegetation, including old growth and mature second growth riparian forests; class 2, mid seral vegetation, including maturing second and third growth coniferous forests; class 3, early seral vegetation, including a mix of young coniferous and/or primarily deciduous vegetation types; class 4, ‘other forested’ lands, clear cuts, brush, young deciduous forest, and; class 5, ‘non-forested’ lands, including rock, snowfield, urban areas, agricultural land, etc. Based on field observations, each of these vegetation classes has been observed to correspond to a proportion of area in functional versus impaired condition. These observations were used to develop a functionality modifier for each vegetation class (Beamer et al. 2000). A conceptual diagram of the riparian process analysis methodology is shown in **Error! Reference source not found.**.

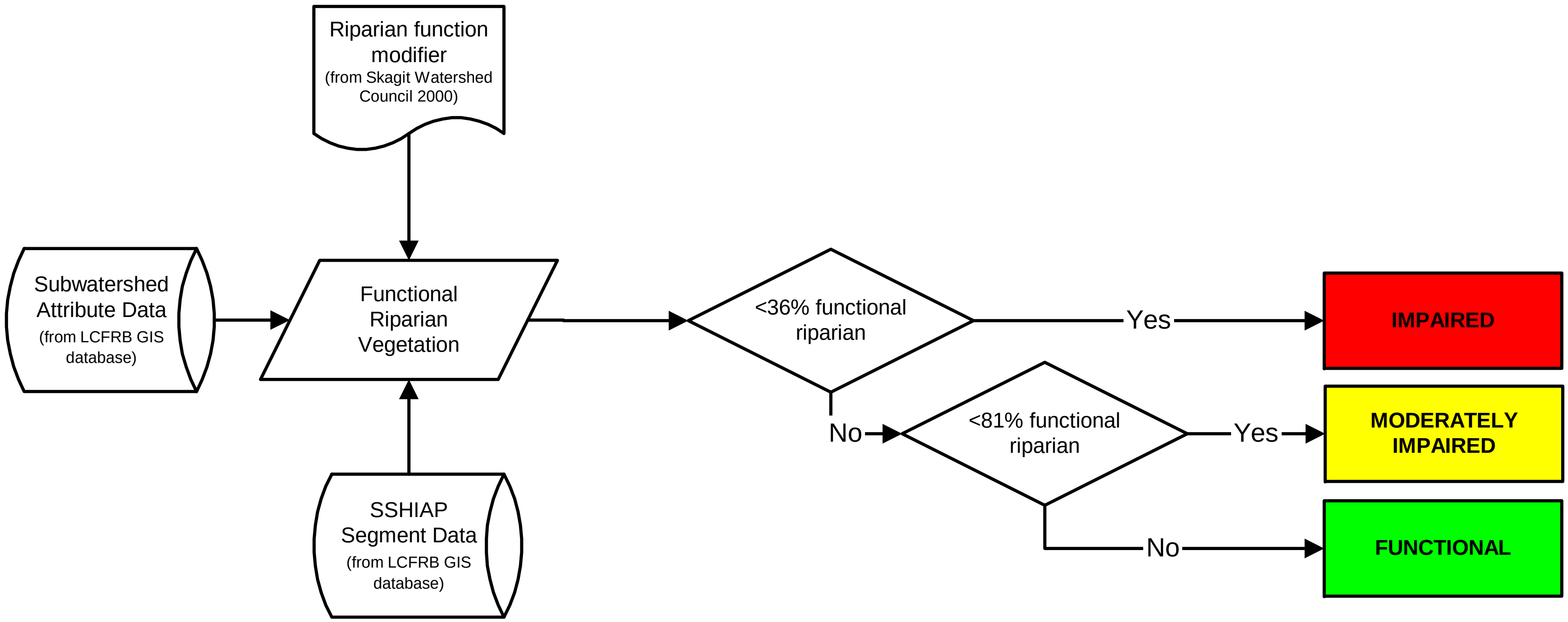

Figure 4-3. Conceptual diagram of subwatershed process condition analysis methodology for riparian function, and selected additional factors

Percent of functional riparian area is calculated from vegetation class and functionality modifiers using the following formula:

$$\text{Eq. (8)} \qquad R_{sws} = \frac{C_1M_1 + C_2M_2 + C_3M_3 + C_4M_4 + C_{15}M_{15}}{B_{sws}} \times 100\%$$

Where:

R_{sws} = Percent functional riparian zone vegetation (%)
B_{sws} = Total buffer area (acres)
C_1 = Buffer area in vegetation class 1, late-seral (acres)
C_2 = Buffer area in vegetation class 2, mid-seral (acres)
C_3 = Buffer area in vegetation class 3, early-seral (acres)
C_4 = Buffer area in vegetation class 4, other forest (acres)
C_{15} = Buffer area in vegetation class 15, non-forest (acres)
M_1 = Vegetation class 1 functionality modifier (100%)
M_2 = Vegetation class 2 functionality modifier (92%)
M_3 = Vegetation class 3 functionality modifier (88%)
M_4 = Vegetation class 4 functionality modifier (43%)
M_{15} = Vegetation class 15 functionality modifier (4%)

Functionality and degree of impairment is determined by comparing R_{sws} for each subwatershed to selected threshold values for riparian condition. The threshold values applied were derived from a relative ranking of riparian functions across the Lower Columbia region. Using untransformed riparian condition data, the mean and, resulting in the following values:

- Functional (>1 standard deviations above mean): ≥ 81% functional riparian zone
- Moderately impaired (± 1 standard deviation from mean): 36% ≤ functional riparian zone <81%
- Impaired (>1 standard deviation below mean): < 36% functional riparian conditions

This relative rating is difficult to compare to other existing thresholds for riparian conditions, because these thresholds are typically based on different units of measurement. For example, the Environmental Protection Agency's Rapid Bioassessment Protocol (Barbour et al. 1999), and the Washington Conservation Commission salmonid habitat condition ratings (Wade 2001) are based on the average riparian zone width containing appropriate vegetation for the habitat type at the reach level. However, because these thresholds are believed to be valid because they are based on a large data set representing riparian conditions ranging from intact and nearly pristine to highly impaired across a broad range of habitats.

4.4.2 Predicting Future Trends & Developing Management Recommendations

As mentioned in the introduction to this chapter, the IWA analysis includes a quantitative analysis of watershed process conditions, described previously, and a qualitative assessment of likely future trends in these conditions and potential management options for protecting or improving these conditions. This qualitative assessment is based on the results of the quantitative analysis, and consideration of additional factors which are likely to influence watershed process conditions in the future.

Characteristics such as land cover, road density and impervious surface are related to land use patterns that have generally predictable patterns. These characteristics, in combination with additional factors that are measurable at landscape scales are suggestive of likely future trends in watershed process conditions. In turn, the extent and nature of these characteristics and the predicted future trends are suggestive of management options appropriate for maintaining or improving the condition of these watershed processes.

Landscape level characteristics and additional factors used to predict future trends and identify appropriate management actions are defined below. The approach to the Future Trends and Management Recommendations analyses are described in the following sections.

Additional Factors

Additional factors include the data sets used in the IWA analyses, and other GIS data sets describing additional landscape scale characteristics which influence watershed process conditions. These additional factors include:

- Erodability Index: Subwatershed specific indices of natural (GSSD) and current (MCSD) erodability ratings from the IWA analysis
- Floodplains: Percentage of total area defined as FEMA floodplains
- Land ownership: Percentage of subwatershed area in federal, state, or other land ownership.
- Rain on snow: Percentage of total subwatershed and drainage area in the rain on snow zone.
- Wetlands: Percentage of total subwatershed area defined as wetlands in the National Wetlands Inventory
- Land cover: Percentage of subwatershed area in hydrologically mature forest, Class 1, Class 2 and/or Class 3 from Lunetta et al. (1997)
- Currently zoned but vacant lands: Percent of subwatershed area zoned for development but currently vacant
- Road density: Subwatershed road density, miles/mile^2
- Stream crossing density: Number of road stream crossings per mile of defined streams (1:24,000)
- Streamside road density: Subwatershed density of roads within 100 feet of a defined stream (1:24,000 scale)

The first three of these characteristics are interpreted qualitatively in the evaluation of future trends and management recommendations. The remaining additional factors are used in the same fashion, further informed by threshold values describing a relative range of conditions for these characteristics. These threshold values are described in **Error! Reference source not found.**.

Additional Factors values for all 545 subwatersheds in the LCR are listed by Subbasin and recovery planning watershed in Chapter 6.

Future Trends

The future trends analysis is a qualitative exercise, using best professional judgement to predict likely trends based on the quantitative analysis results, qualitative evaluation of additional data on subwatershed characteristics (additional factors), and the predominant likely future land uses. Whether the hydrologic condition, sediment supply and transport, or riparian condition of a subwatershed is likely to change in the foreseeable future depends on its current status and the prevalence of factors that predispose the process dynamics to change. Predicted changes in impervious surface, land cover and road density, the primary indicators used in analysis of hydrologic conditions, can be used to directly calculate future hydrologic conditions. The prevalence of other extenuating factors, such as percent of area in urban growth reserve and streamside road density can change in ways that increase or decrease the likelihood of impaired hydrologic conditions. In the case of sediment, land cover, and road density and streamside road density can change in ways that increase or decrease the likelihood of impaired sediment supply conditions. Predicted changes in land cover values can be used to directly calculate future sediment supply conditions in the same way that current conditions are calculated. Predicted changes in road density can be measured against existing thresholds to determine the likelihood of improving or degrading sediment supply conditions. Similarly, for riparian conditions predicted changes in land cover over time can be used to predict natural recovery. The prevalence of other extenuating factors, such as percent of area in urban growth reserve and streamside road density can change in ways that increase or decrease the likelihood of impaired riparian conditions.

A set of basic assumptions was used to guide the future trends analysis. These assumptions are detailed in Table 4-4.

Table 4-4. Process trend factor characteristics, metric thresholds, and general metric rating thresholds

		Metric Thresholds/Rating Criteria				
Characteristic	**Metric**	**Low/Poor**	**Moderate Low/Fair**	**Moderate High/Good**	**High/Excellent**	**Data Source**
Wetlands	Acreage of palustrine or littoral lacustrine wetlands directly associated with habitat channel (within 200 feet of channel less than 4% gradient	<1 acres total in SWS	1-20 acres total in SWS	>20 to 100 acres total in SWS	>100 acres total in SWS	Derived from NWI and SSHIAP data sets (see Ch. 6 for description). Thresholds derived from relative rating for subwatersheds in the LCR
Subwatershed area with hydrologically mature vegetation	% of subwatershed area in vegetation class 1, 2 or 3	<25% class 1, 2, or 3	25 to 50% class 1, 2, or 3	>50 - 75% class 1, 2, or 3	>75% class 1, 2, or 3	Derived from Lunetta et. al (1997) data set provided by Lewis County GIS. Thresholds derived from Beamer et al. (2002)
Urbanization potential	% of SWS area with currently zoned but vacant lands	>15% zoned but vacant	>7.5 to 15% zoned but vacant	>4.5 to 7.5% zoned but vacant	0 to 4.5% zoned but vacant	Derived from Clark County zoning data and thresholds from Beamer et al. (2000). Thresholds derived from a relative rating of zoned LCR subwatersheds.
Future development potential	% of SWS area with potential to be impervious surface based on currently vacant lands zoned industrial, commercial, or residential	>10% effective impervious surface	>5 to 10% effective impervious surface	>3 to 5% effective impervious surface	0-3% effective impervious surface	Derived from available GIS zoning coverages. Threshold values from Beamer et al. (2000).
Road density	Road density in miles/mile^2 (m/m^2) of SWS area	Road density >6 m/m^2	Road density >3-6 m/m^2	Road density >2-3 m/m^2	Road density 0 to 2 (m/m^2)	WSDOT/USFS/DNR GIS data. Thresholds derived from Wade (2001).

		Metric Thresholds/Rating Criteria				
Characteristic	**Metric**	**Low/Poor**	**Moderate Low/Fair**	**Moderate High/Good**	**High/Excellent**	**Data Source**
Streamside road density	Miles of streamside road per mile of stream	>0.71 miles of road/mile of stream	>0.37 to 0.71 miles of road/mile of stream	>0.04 to 0.37 miles of road/mile of stream	0 to 0.04 miles of road/mile of stream	WCC GIS coverage developed for LFA report. Thresholds derived from a relative rating of LCR subwatersheds.
Stream crossing density	Number of stream crossings per mile of stream	>3.9 stream crossings/mile	>2.7 to 3.9 stream crossings/mile	>1.4 to 2.7 stream crossings/mile	0 to 1.4 stream crossings/mile	Relative rating of stream crossing densities across the LCR. Thresholds derived from a relative rating of LCR subwatersheds.

Table 4-5. General assumptions used for prediction of future trends

Process Conditions	Predominant Land Use Urban/Residential	Forestry	Agriculture*	Recreation
Sediment	Trend towards increasing degradation as development increases	Trend stable on private lands where continuing timber harvest is expected. Trend towards gradual improvement on public lands where timber harvest is expected to decline	Trend stable with some gradual improvement as incentive programs for sediment best management practices progress	Trend stable or towards improvement on public recreational lands.
Hydrology	Trend towards increasing degradation as development increases	Trend stable on private timber lands where ongoing harvest is expected. Trend towards gradual improvement on public lands where harvest is expected to decline.	Trend stable (assuming that lands remain in agriculture)	Trend stable or towards improvement on public recreational lands.
Riparian	Trend stable with gradual degradation as development increases	Trend towards gradual improvement on both public and private timber lands.	Trend towards gradual improvement as incentive programs for riparian protection/restoration progress	Trend stable or towards improvement on public recreational lands.

* For the purpose of future trends analysis, agricultural lands are expected to remain in agriculture unless they are inside an urban growth boundary or urban growth reserve.

Future trends assumptions do not include impacts on watershed process conditions from significant natural events, such as wildfire or volcanisms.

Categories of Management Actions

The IWA methodology is dependent on landscape scale data to determine the condition of watershed processes, and factors that contribute to impaired conditions. Categories of appropriate management actions are suggested by the landscape conditions (e.g., extent of vegetative cover) and the Additional Factors affecting that contribute to current conditions. For example:

> *Subwatershed condition:* Hydrologic conditions are moderately impaired due to vegetation cover high road density.
>
> *Management options:* Promote recovery of vegetation where possible, examine road drainage network and maintain or make improvements where necessary.
>
> *Subwatershed condition:* watershed level sediment conditions highly impaired.
>
> *Management options:* Identify key contributing upstream subwatersheds, promote vegetation recovery in these subwatersheds and manage Additional factors that can exacerbate degradation such as the road network and streamside road drainage where possible and appropriate.
>
> *Subwatershed condition:* Hydrologic and riparian conditions are highly impaired due to urban development and high impervious surface levels.
>
> *Management options:* Design and implement or improve existing stormwater management infrastructure, promote programs to protect and restore riparian vegetation where possible and appropriate.

Several possible permutations of management actions exist. The management recommendations will be tailored to the general sources of impairment and additional contributing factors that are indicated by available data. In addition, specific recommendations related to major watershed-specific problems will be developed based on available information.

4.5 Uncertainty Analysis

The IWA is a screening level tool for evaluating the condition of watershed processes and identifying likely future trends and management options. There are several potential sources of uncertainty that must be considered when interpreting and applying IWA results, and developing recovery planning scenarios. These sources of uncertainty fall into the following categories:

- Input data reliability: Is the scale of the data used appropriate for the application, and do the data accurately represent current conditions?
- Methodological uncertainty: How accurately do the quantitative methods reflect the condition of the processes they attempt to describe?
- Subjectivity: How greatly do subjective elements of the analysis affect the results of the IWA analysis?

These sources of uncertainty apply in varying degrees to the quantitative and qualitative aspects of the IWA. The extent to which each of these sources of uncertainty impacts the quantitative and qualitative components of the IWA analysis is discussed below.

4.6 Quantitative Sediment Analysis

The quantitative sediment analysis relies on the combination of GIS data at different scales and newly derived and arbitrary ratings describing the relative erodability of different geology types. The rating thresholds are calibrated against available field assessments of erosion and sediment delivery to stream channels in the LCR. Sources of uncertainty inherent to this approach include the combination of input data with different scales, and the arbitrary nature of the arbitrarily derived erodability rating scales, and the thresholds used to determine impairment ratings.

The GIS data sets used in the sediment analysis represent a range of scales, from 1:24,000 to 1:250,000 scale. Stream and road data are more detailed 1:24,000 scale data. In contrast, slope data are 1:100,000 scale, and soils and geology data are at the coarse 1:250,000 scale. Because the scale of the input data used in an analysis limits the scale at which one can infer the accuracy of results, the sediment analysis results should be considered relatively accurate at the 1:250,000 scale, with decreasing accuracy at finer scales. For this analysis, the scale of the input data are appropriate for interpreting results at the subwatershed scale, with decreasing accuracy as the results are applied at finer scales (e.g., individual 1:24,000 scale stream reach level).

There is a moderate degree of uncertainty associated with the quantitative methodology used in the sediment analysis because it is based on arbitrarily derived rating scales for the erodability of different geology types. As noted, these erodability rating scales were derived from available literature sources and calibrated using available studies and data, but this approach is inherently subjective. The level of uncertainty associated with this approach could be reduced by ground truthing the analysis and using the results to calibrate the methodology.

The sediment analysis results determine the degree of impairment by how many times the value of MSCD exceeds GSSD. Under this approach, subwatersheds with low erodability are treated the same as those with high erodability for the purpose of determining degree of impairment. The logical basis for this approach is that channel conditions and sediment storage and transport capacity in each subwatershed have formed based on the natural sediment regime. However, this approach may lead to identification of less degraded conditions in subwatersheds where absolute sediment input has increased far more than subwatersheds rated more highly degraded. An alternative approach would be to develop threshold values based on the absolute difference in the GSSD and MSCD ratings in future analyses.

In the aggregate, the level of uncertainty associated with the sediment condition results should be considered moderate. The results of this analysis are considered relatively accurate at the subwatershed level, with progressively decreasing accuracy at the reach level.

4.7 Quantitative Hydrologic Analysis

Like the sediment analysis, the quantitative hydrologic analysis relies on the combination of GIS data sets at different scales. In contrast however, the analytical approach is simpler and depends on thresholds that have been broadly applied for determining hydrologic impacts using GIS based lanscape scale data . Sources of uncertainty inherent to this approach include the accuracy of the input data, and of the impact thresholds.

The input data include GIS land cover (or vegetation) data at 1:100,000 scale, and roads and zoning data at 1:24,000 scale, and effective impervious surface area percentages for different zoning categories. Several factors affect the accuracy of these input data, leading to uncertainty regarding the results of the analysis.

First, the land cover data used in the IWA analysis is based on the 1992 LANDSAT Thematic Mapper imaging data set, which is derived from images taken in 1990. This data is now 13 years out of date and may not accurately represent the landcover conditions existing in 2003. This will lead to overestimation of degraded conditions in subwatersheds with large areas of vegetation that have become hydrologically mature over the past decade, and underestimation of degraded conditions that have been recently harvested. The extent of potential error is currently unknown. However, a LANDSAT data set from year 2000 has recently come available for use in future analyses. These two data sets can be compared and the IWA results updated to more accurately reflect current conditions.

In addition, the land cover data set is cagegorized in such a way that subwatersheds with large areas of naturally treeless vegetation (e.g., praire or meadow) cannot be readily differentiated from developed areas. This will lead to overestimation of degraded conditions. This tendency is mitigated in developed areas by the reliance on zoning data to determine EIS. The tendency to overestimate degradation is also mitigated by the reliance on road density information to determine hydrologic condition. Road density and zoning information is believed to be relatively accurate at the subwatershed scale. However, these data may not reflect recent road construction and development. In smaller subwatersheds where development is ongoing, these data may not fully represent current conditions.

In contrast, there is considerable uncertainty associated with the EIS values used. EIS values were based on zoning data for Skagit and Whatcom Counties used by Beamer et al. (2000). The zoning categories provided by Beamer et al. (2000) are generally comparable to those used by Clark County and portions of Lewis County (the only counties for zoning data is available), but are not necessarily a one to one match. This may lead to over- or underestimation of EIS associated with a given zoning category. There is additional uncertainty associated with EIS on zoned but currently vacant lands. Zoned but vacant lands are considered to have zero EIS for the purpose of this analysis. However, this assumption is believed to lead to underestimation of EIS on lands that have been cleared or developed in the past but are not currently built up. This will in turn lead to potential underestimation of hydrologic impacts in subwatersheds with large areas of zoned but currently vacant lands. In addition the uncertainty in assignment of EIS values, the IWA analysis does not account for the influence of stormwater controls that can mitigate the effect of impervious surface area on hydrologic condition. This will lead to overestimation of degraded conditions in urbanized areas.

The relatively crude methodology used in the hydrologic analysis is also a source of uncertainty, primarily because it relies on absolute thresholds to describe what is in reality a gradual and progressive progression in impairment. For example, the analysis relies on threshold values of 50 percent of subwatershed area in hydrologically mature vegetation and 3 miles/mile^2 to determine degree of impairment. As a result, a subwatershed with 49.9 percent impervious surface and road density of 2.9 miles/mile^2 would be rated hydrologically functional, while a neighboring subwatershed with 50.1 percent mature vegetation and 3.1 miles/mile^2 of roads would be rated as impaired. In reality, these two subwatersheds are quite similar in condition but they are rated quite differently by the IWA approach. This effect leads to a relatively high degree of uncertainty in the hydrology results. However, it is useful to recognize that the thresholds chosen have been broadly applied by USFS and other entities for screening level watershed assessments. Further, the use of three distinct data sets (EIS, hydrologically mature vegetation, and road density) mitigates the uncertainty that would result from reliance on any one subwatershed characteristic to determine hydrologic condition.

In the aggregate, the level of uncertainty associated with the hydrologic condition results should be considered moderate. Uncertainty in the results for subwatersheds in urbanizing areas or areas zoned for development, there is a lesser degree of uncertainty due to greater confidence in the influence of EIS on hydrologic conditions.

4.8 Quantitative Riparian Analysis

The riparian condition analysis has several inherent sources of uncertainty which affect the interpretation of results. The analytical approach is relatively simple, relying on combination of two GIS data sets and a modifier based on ground truthing of the data set to describe current conditions. Sources of uncertainty inherent to this approach include input data accuracy, and methodological limitations.

The riparian condition analysis mixes 1:24,000 scale hydrography with 1:100,000 scale vegetation coverages to arrive at a interim reach specific 1:24,000 scale rating. The individual 1:24,000 scale ratings are then aggregated at the subwatershed level to rate the riparian conditions in each subwatershed as a whole. The individual reach level ratings have limited accuracy because of the mixing of finer scale hydrography with coarser scale land cover data. This effect is mitigated by aggregation of reach level data to the subwatershed level.

In addition to the scale issue, the vegetation data used is the same 1992 LANDSAT TM set used in the hydrologic analysis. This suggests a similar uncertainty related to input data accuracy. This effect is expected to result in greater uncertainty in riparian results for lowland subwatersheds with increasing residential development. Riparian zones in higher elevation forested subwatersheds are generally well protected by the broad implementation of riparian protection zones in forestlands.

Methodological issues also lead to uncertainty in the riparian condition results. Specifically, the analytical approach assumes that vegetation types outside of the selected ‘functional’ vegetation classes do not provide adequate riparian function. This is an issue particularly for subwatersheds with extensive floodplain area with different natural vegetation types from forested drainages. While the application of groundtruthed riparian function modifiers mitigate this effect, there is a bias towards an impairment rating for these subwatersheds in the analysis. This leads to a potential overestimation of degraded conditions in lowland subwatersheds.

The riparian analysis methodology also relies on thresholds derived from a relative rating of the percent of functional riparian vegetation across all LCR subwatersheds with vegetation data. This approach was necessary because existing literature derived thresholds for determining riparian condition are not compatible with the model outputs. The use of relative ratings introduces an unknown level of uncertainty in the results. However, the thresholds used are intuitively logical for a screening level approach (for example, a subwatershed must have greater than 81 percent of stream length with ‘functional’ riparian vegetation to be rated functional overall). Moreover, a relative rating resulting in the logical separation of planning subwatersheds into best, intermediate and worst condition is useful for the purpose of prioritizing subwatersheds for recovery actions.

Similar to the sediment and hydrologic analyses, the aggregate the level of uncertainty associated with the riparian results is considered moderate. Results in lowlying subwatersheds with a high percentage of area in floodplain should be viewed as less accurate overall than results in higher elevation, forested subwatersheds.

4.9 Qualitative Prediction of Future Trends

The future trends analysis is a qualitative exercise, using best professional judgement to predict likely trends based on the quantitative analysis results, qualitative evaluation of additional data on subwatershed characteristics (additional factors), and the predominant likely future land uses. The basic assumptions used to inform this analysis are presented in Table 5-6. Being an inherently subjective process, there is a relative degree of uncertainty associated with these projections. The degree of uncertainty associated with these predictions is presumed to be high.

4.10 Summary

In summary, the IWA analysis is a combined quantitative and qualitative method for evaluating the condition of key watershed processes that are fundamental drivers of instream habitat condition, and the likely future trends in these conditions. The IWA should be considered a screening level evaluation of watershed conditions, useful for preliminary identification of priority areas, and probable sources of some important habitat limiting factors. Collectively, this information informs the identification of categories of management options for preserving and restoring watershed processes. Together with EDT results, the results of the IWA analysis can be used as lines of evidence for identifying areas important for recovery planning.

There are several sources of uncertainty associated with the IWA analysis. While the extent of these sources of uncertainty remains to be tested with ground truthing, the collective uncertainty associated with the sediment, hydrology, and riparian analysis is tentatively classified as moderate. The prediction of future trends is a more qualitative and subjective process, with a higher associated degree of uncertainty. While the uncertainty regarding future trends is relatively high, these predictions can serve as a point of discussion around which recovery planning scenario development can proceed.

4.11 References

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