2.7 WATER QUALITY
Objectives and Key Questions

The purpose of this module is to describe water quality in the Sol Duc watershed. Assessment of water quality is often viewed from two perspectives. The first centers on setting objectives. This involves describing the aquatic resources (i.e. streams, lakes, etc.), the beneficial uses associated with these resources, and a set of indicators which reflect conditions. The objectives set are usually reflected in State and Federal water quality standards. The second water quality assessment perspective relates to program implementation. Here, the focus is on how watershed processes and disturbance activities, through changes to input variables (e.g. sediment, water, wood, chemicals, etc.) affect beneficial uses as reflected through the same indicators used to assess conditions.

In conducting water quality evaluations associated with watershed analysis, the key is to focus on linkages. Much of the information needed is available from other core topic areas (or modules). For instance, core topics such as ***human uses*** and ***species & habitats*** also describe beneficial uses dependent on water resources. Likewise, watershed processes, such as ***vegetation***, ***hydrology***, and ***erosion***, are core topic areas in watershed analysis with information which relates to source inputs that affect water quality. Lastly, ***channel condition***, another core topic area, uses many of the same indicators associated with aquatic life uses in water quality assessments.

This is one of several tests of the water quality module ongoing in the State of Washington. It has been undertaken to refine proposed methods and to illustrate the utility of such an approach at the watershed scale. Currently, two very similar methodologies exist for assessing water quality in the Sol Duc watershed; Washington State Watershed Analysis and Federal Watershed Analysis as governed by the Northwest Forest Plan. Both approaches have proposed modules. The State of Washington's water quality module has not yet been officially adopted, while the Federal module is an extension of interim guidance issued in 1994. The analysis of water quality in the Sol Duc watershed is based on a composite of the two methodologies. Because water quality is best described in the context of how it affects a beneficial use, information from this watershed analysis will enhance the ability of the State water quality management agency, the Washington State Department of Ecology, in determining attainment of water quality standards.

The following key questions help frame the assessment of water quality in the Sol Duc watershed:

1. *What beneficial uses dependent on aquatic resources occur in the watershed and which water quality parameters are critical to these uses?*
2. *What are the current conditions and trends of beneficial uses and associated water quality parameters?*
3. *What were the historic water quality characteristics of the watershed?*
4. *What are the natural and human causes of change between historic and current water quality conditions?*
5. *What are the influences and relationships between water quality and other ecosystem processes in the watershed (e.g. mass wasting, fish habitat, stream channel, etc.)?*

Introduction

Water quality is an important characteristic which affects the value of aquatic resources. These resources include rivers, streams, lakes, reservoirs, estuaries, and wetlands. The value of aquatic resources is reflected by their ability to support a variety of uses. The public is interested in quality water to supply domestic, agricultural, and industrial needs. Quality water is also important to support recreational activities, such as swimming, boating, and fishing. Finally, aquatic life depends on suitable water quality for survival. Land management activities, combined with natural watershed processes, can affect water quality which in turn affects these beneficial uses.

Management of water quality is carried out through of the Federal Clean Water Act (CWA). The primary objective of the CWA is to *"restore and maintain the chemical, physical, and biological integrity of the Nation's waters."* Taken together, the interaction of chemical, physical, and biological conditions define the overall ecological integrity of an aquatic system over time. Characteristics addressed include indicators such as dissolved oxygen concentrations, temperature, and bacteria as well as habitat structure and processes, species composition, and diversity / abundance of aquatic dependent flora and fauna.

Approach

Water quality assessment within watershed analysis, under the Federal process, consists of three components. These include a ***characterization*** summary, a ***condition assessment***, and an ***interpretation***. The assessment attempts to identify, for waterbodies occurring in the watershed, those situations where beneficial uses dependent on water quality are, or are likely to be impaired as a result of disturbance activities. The approach taken in this module is to evaluate information on how water quality within the watershed is affected by the cumulative effects of disturbance activities.

CHARACTERIZATION

Overview

The Sol Duc River is located on the Olympic Peninsula of western Washington northeast of the community of Forks in Clallam County. The Sol Duc joins the Bogachiel River west of Forks to form the Quillayute River which enters the Pacific Ocean at LaPush. The Sol Duc drainage (226 square miles) contains 19 subwatersheds which have been aggregated into four watershed analysis units (WAUs). These WAUs include:

- North Fork Sol Duc
- Upper Sol Duc
- Sol Duc Valley
- Sol Duc Lowlands

Within the entire Sol Duc watershed, there are approximately 850 miles of streams, 740 of which are available to anadromous salmonids and resident fish. Chinook salmon, coho salmon, sockeye salmon, chum salmon, and steelhead trout all have self sustaining, native populations that utilize the Sol Duc River and its tributaries.

Surface waters in the Sol Duc watershed are the product of dynamic processes. Geology and geomorphology in the drainage interact with climatic events and vegetative succession. In addition, fire and land management activities also play a role. The headwaters of the Sol Duc watershed are formed in steeply sloping marine basalt and sedimentary rocks that have been modified extensively by glaciation *(see Sedimentation module for complete geologic history)* Previous cirque glaciers have left small basins in which alpine and sub-alpine lakes have formed. These lakes exhibit outflow streams that feed the upper north, main, and South Fork tributaries of the Sol Duc River.

The upper tributaries of the Sol Duc exhibit classic U-shaped valley cross-sections consistent with glacially modified terrain. The glacially influenced geomorphology in the upper Sol Duc has resulted in the formation of isolated wetlands in glacial depressions and riverine wetlands associated with abandoned channels and floodplains along main tributary channels. These wetlands provide a number of important watershed functions including watershed storage and routing, sediment storage, nutrient uptake and fish / wildlife habitat. The lower Sol Duc is a depositional area of mostly alluvial erosion deposits from glacial outwash.

The focus of ***Characterization*** is the question: ***"What beneficial uses dependent on aquatic resources occur in the watershed and which water quality parameters are critical to these uses?"*** In addressing this question, other subtopics could be considered which include:

Characterization — *Other Considerations*
What characteristics in the watershed are important to water quality? • What waterbodies and beneficial uses occur in the watershed and where are they located? • What water quality parameters are most critical to beneficial uses in the watershed? (e.g. how do stream temperature and dissolved oxygen fluctuations affect key fish species?)

Aquatic Resources

Aquatic resources in the Sol Duc drainage are summarized in Table 2.7-1. Streams in the Sol Duc watershed are classified by the State Department of Ecology as Class AA (exceptional) waters as defined in WAC 173-201A Waster Quality Standards for Surface Waters of the State of Washington. These have the most stringent water quality standards for streams. Lakes in the Sol Duc are classified as Lake Class. Wetlands are considered to be surface waters of the State of Washington, but have no numeric criteria associated with them in the context of State water quality standards. Therefore, wetlands have been classified according to dominant vegetative condition and hydrologic regime (Cowardin 1979).

The Washington State Department of Ecology (DOE) evaluates the status of surface water quality on a bi-annual basis and reports findings regarding water quality impairment as part of the Statewide Water Quality Assessment Section 305B Report (DOE 1992). Currently there are no water quality impaired waterbodies listed for the Sol Duc Watershed. In a similar report, the DOE maintains a list of surface waters which have been documented not to attain numeric and narrative State Water Quality Standards, the section 303D report (DOE 1994). Currently there are no surface waterbodies listed on the Section 303D report within the Sol Duc Watershed.

The distribution of surface waters in the Sol Duc watershed, including lakes, wetlands, and streams, is shown on Map 2.2A.

Table 2.7-1 Aquatic Resources Summary -- Sol Duc Watershed

ID	Subwatershed Name	Area (mi^2)	Waterbody Type		
			Streams (mi/mi^2)	Lakes & Ponds (acres)	Wetlands (acres)
North Fork Sol Duc					
7P	N.F. Sol Duc	30.75	3.87		65.6
Upper Sol Duc					
6F	Bonidu	1.72	NA		
7A	Sol Duc River	63.35	NA		1,577.7
7B	Alckee Creek	4.98	3.71		1.8
7C	S.F. Sol Duc	9.28	4.15		2.5
7D	Goodman Creek	8.62	3.81		0.0
7E	Camp Creek	4.30	4.99		0.7
7F	Kugel Creek	3.48	4.17		0.0
7M	Tom Creek		3.59		1.4
7O	Upper Sol Duc	35.70	NA	60.5	645.4
Sol Duc Valley					
7G	Upper Bear Creek	8.48	5.51		20.2
7H	Beaver Creek	14.26	4.31	33.5	357.5
7I	Lake Creek	11.13	3.27	457.1	529.7
7J	Bockman Creek	4.46	7.76		12.1
7N	South Bear Creek	3.15	5.51		0.0
7Q	Lower Bear Creek	6.47	5.51		35.8
Sol Duc Lowlands					
7K	Maxfield Creek	2.28	NA		3.4
7L	Tassel Creek	3.09	7.21		6.2
7S	Shuwah Creek	5.56	7.19		6.2
7T	Gunderson Creek	3.00	3.1		72.9

Beneficial Uses

The primary designated uses requiring protection in the Sol Duc drainage are anadromous fish habitat and domestic water supplies. The fish habitat module describes both anadromous and resident fisheries present in the Sol Duc. Anadromous fish of significant concern in the Sol Duc include Chinook, Coho, Steelhead, and Sockeye runs. There is little industrial usage and the limited agricultural & fish hatchery needs are met by the AA standards. Primary water supply facilities and fish hatcheries are shown on Map 2.2A.

A number of indicators are used in conjunction with beneficial use support evaluations. Several have been adopted as regulatory standards in the State of Washington (Table 2.7-2). Water quality criteria applicable to disturbance activities (urban development, agriculture, timber harvest, etc.) include temperature, turbidity, dissolved oxygen, pH, biological criteria, and fecal coliform bacteria. Characteristic water use designations and summaries of the Washington State Water Quality Standards and Drinking Water Standards are found in Appendix 2.7, Tables 2.7A-1 through 2.7A-7.

Table 2.7-2 State Water Quality Criteria – Summary of Key Parameters

Parameter	Criteria
Fecal Coliform	Shall not exceed a geometric mean of 50 colonies per 100ml, and not have more than 10% of all samples used to calculate the geometric mean exceeding 100 colonies per 100ml.
Dissolved Oxygen (D.O.)	Shall exceed 9.5 mg/L
Temperature	Shall not exceed 16°C due to human activities. When natural conditions exceed 16°C, no increases >0.3°C are allowed. Incremental increases resulting from NPS activities shall be <2.8°C.
pH	Between 6.5 and 8.5 +/-<0.2 units.
Turbidity	Not > 5 NTU over background when background is < 50 NTU, or have > 10% increase when background is > 50 NTU.
Aesthetic Values	Shall not be impaired by the presence of materials or their effects, excluding those of natural origin, which offend the senses of sight, smell, touch, or taste.

Assessments have been developed for forested watersheds which identify important parameters for each of these uses. MacDonald et al. (1991) have presented a qualitative evaluation of the effects of water quality parameters on the major designated uses of water for forested watersheds. This evaluation grouped parameters according to characteristics which include:

- **Water column**
- **Sediment**
- **Aquatic organisms**
- **Flow**
- **Channel characteristics**
- **Riparian**

This qualitative assessment provided ratings of each parameter within a group for each major use. A summary of each group (and common indicators) for significant beneficial use categories is summarized in Table 2.7-3. Key parameters for the Sol Duc which relate to anadromous and resident cold water fish include: temperature, dissolved oxygen, turbidity, bed material, pool parameters, large woody debris, and invertebrates.

Table 2.7-3 WQ Parameters / Beneficial Use Relationships

Water Quality Parameter	Water Supply	Recreation	Aquatic Life		
			Cold Water Fish	Warm Water Fish	Biological Integrity
Water Column					
Temperature	–	xx	nnnnnn	–	nnnnnn
Dissolved Oxygen	xx	xx	nnnnnn	nnnnnn	nnnnnn
Nutrients	xx	xx	–	–	xx
pH	nnnnnn	–	–	–	–
Toxic Contaminants	nnnnnn	xx	xx	xx	nnnnnn
Sediment					
Turbidity	nnnnnn	nnnnnn	nnnnnn	nnnnnn	nnnnnn
Sedimentation	nnnnnn	xx	nnnnnn	xx	nnnnnn
Aquatic Organisms					
Bacteria / Pathogens	nnnnnn	nnnnnn			–
Invertebrates		–	nnnnnn	nnnnnn	nnnnnn
Fish		nnnnnn			nnnnnn
Flow					
Peak Flows			xx	–	xx
Low Flows	nnnnnn		xx	xx	–
Channel Characteristics					
Width / depth			xx	xx	xx
Pool metrics			nnnnnn	nnnnnn	xx
Woody debris			nnnnnn	nnnnnn	xx

Key: nnnnnn Use is directly related & highly sensitive to the parameter in almost all cases
xx Use is closely related & somewhat sensitive to the parameter in most cases
-- Use is indirectly related & not very sensitive to the parameter in most cases
2 <blank> Use is largely unrelated to the parameter

CONDITION ASSESSMENT

The focus of ***Condition Assessment*** are the questions: ***"What are the current conditions and trends of beneficial uses and associated water quality parameters?"*** and ***"What were the historic water quality characteristics of the watershed?"*** In addressing this question, other subtopics could be considered which include:

Condition Assessment — *Other Considerations*
Are waterbodies within the watershed vulnerable based on current and past conditions? • How does water quality in the watershed compare to State Water Quality Standards? • What do current conditions or changes from past conditions indicate about the effect of input variables on the function of waterbodies? • What are the likely responses of waterbodies to potential changes in input variable s? (e.g. do situations exist that pose a moderate to high likelihood of adverse water quality in the watershed?) • What is the vulnerability of waterbodies and beneficial uses to potential changes in water quality?

Water Quality Assessment Terminology

Because water quality is best described in the context of how it affects a beneficial use, information from watershed analysis should enhance the ability of the State water quality management agency in determining attainment of water quality standards. Watershed analysis conducted using the State of Washington's procedures (Washington Forest Practices Board, November 1994) leads to an identification of resource vulnerability. Resource vulnerability is defined as the:*"Likelihood of material adverse effects on resource characteristics. Criteria may include (but are not limited to) current resource conditions"* Determination of vulnerability is quite similar to beneficial use support assessments conducted by States under CWA §305(b). Beneficial use support determinations under §305(b) fall into three categories: 1) fully supporting; 2) partially supporting; and 3) not supporting. Unless otherwise directed by the State water quality management agency, Table 2.7-4 can be used to equate these categories to vulnerability calls.

Table 2.7-4 Vulnerability Calls / CWA §305(b) Use Support Relationships

Vulnerability Call	Use Support Category [CWA §305(b) Guidance][1]
Low	Use Fully Supported
Medium	Use Partially Supported
High	Designated Use Not Supported

[1] *Reference:* "Guidelines for Preparation of the 1996 State Water Quality Assessments [§305(b) Reports]", Section 5: Making Use Support Determinations

The decision process for assigning a condition assessment or vulnerability call to various waterbodies needs to be clearly explained, including the use of monitored versus evaluative data. EPA has developed guidance which further describes use support categories and criteria for determining the status of water quality.

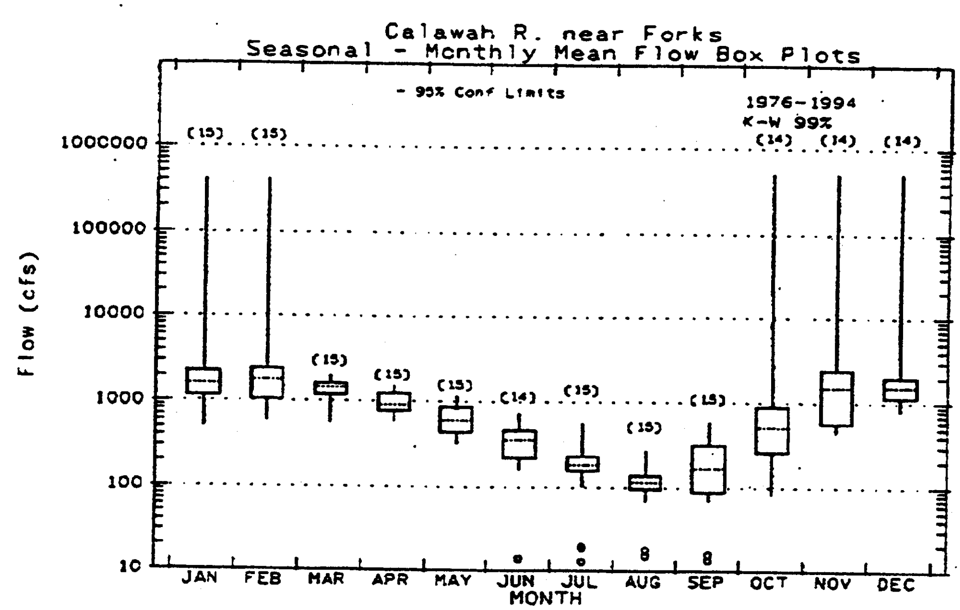
Current Conditions

Historical water quality data of limited scope is available (Fretwell 1984; QNR 1977). Some data is also available from the Sol Duc Hot Springs area (ONP 1994). In addition, the United States Forest Service, Sol Duc Ranger District completed an assessment of water quality within the Sol Duc Watershed as part of the 1995 Watershed Restoration Strategy contained in the Record of Decision for the Northwest Forest Plan (USDA and USDI 1994). Much of the information used in this assessment is a restatement of information summarized in the Sol Duc Restoration Watershed Analysis (USFS 1994). This assessment also relies on recent water quality sampling by the U.S. Forest Service and the Quileute Tribe. All suitable water quality data available is summarized in the Appendix 2.7.

Streams

The Sol Duc River ranges between 80 and 5,500 feet in elevation. Stream discharge measurements have been published for a number of locations within the Sol Duc watershed *(see Hydrology module report)*. Figure 2.7-1 depicts seasonal flow patterns typical of streams in the Quillayute River system. The seasonal flow pattern of streams in the Sol Duc drainage closely follows the normal precipitation pattern. Stream discharge increases with the onset of fall rains, peaks in early winter, and decreases to late summer low flows.

Figure 2.7-1 Seasonal Flow Patterns of Quillayute River System

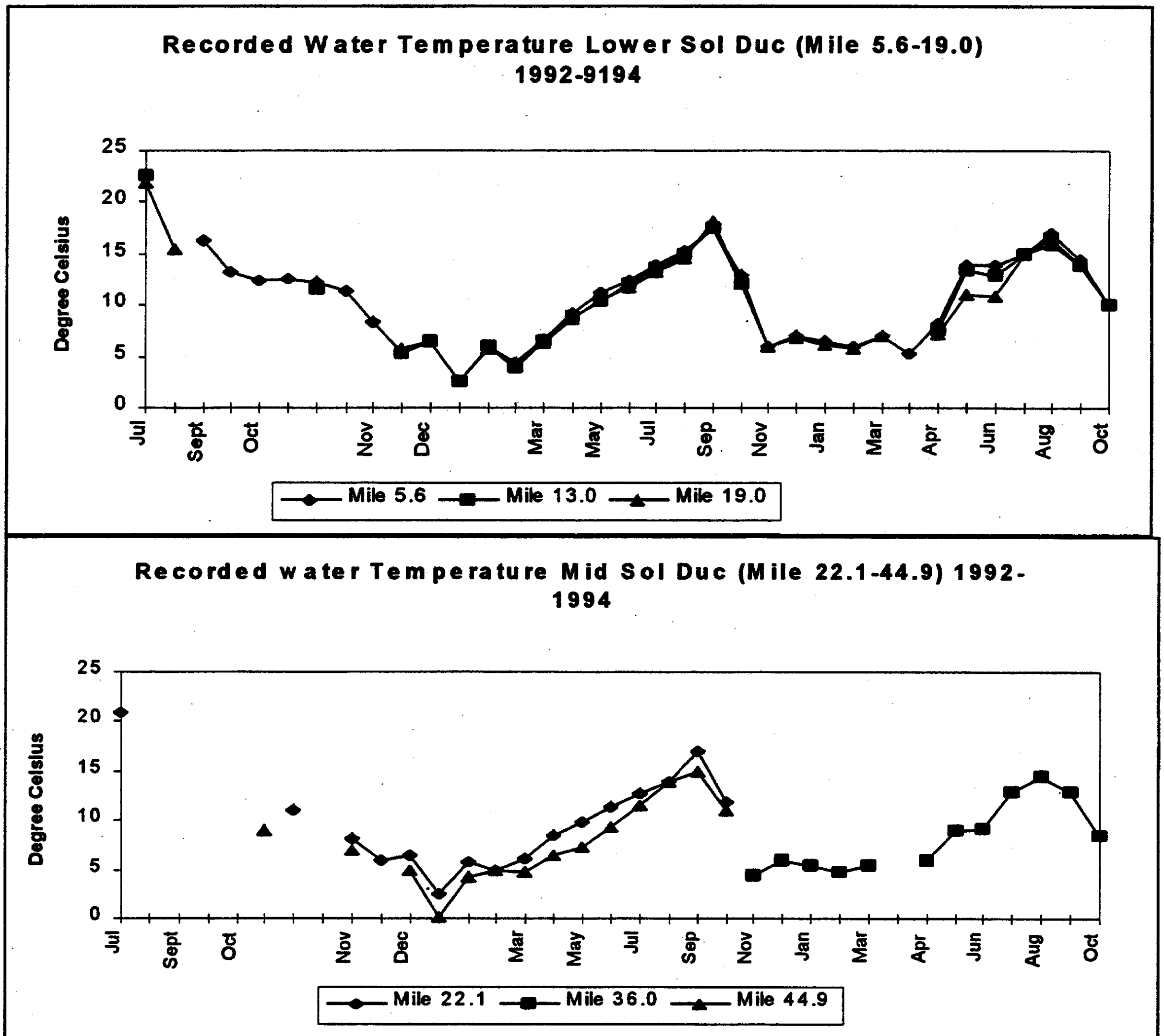


Many of the important coho and steelhead producing streams in this system experience very low summer flows that potentially reduce the productivity of this fishery by stranding fry in isolated pools, reducing total available habitat, and creating a greater potential for elevated temperatures. The Hydrology module describes streams that experience low flow problems in the drainage. These include Gunderson Creek, Maxfield Creek, Shuwah Creek, Bockman Creek, Lake Creek, and Kugel Creek. All of these streams have common structural characteristics: they flow out of the hills in bedrock or till-controlled channels and then flow long distances across the coarse, unconsolidated glacial fill material of the Sol Duc Valley before emptying into the Sol Duc River. The sections of stream flowing across the valley fill material experience low flow and drying problems. The coarse valley fill material features high infiltration rates and high permeability, so streams lose water in this material when the water table drops in the summer.

Temperature

A number of recording thermographs maintained by the U.S. Forest Service and the Quileute Tribe provide the most comprehensive information on stream temperatures in the Sol Duc. Figure 2.7-2 depicts the seasonal variation in water temperature in the Mainstem Sol Duc River at six sites based on monthly sampling. Annual maximum water temperatures, which exceed 20 degrees Celsius in some locations, occur between July and September, while annual minimums of approximately 5 degrees Celsius occur between November and March.

Figure 2.7-2 Sol Duc Water Temperature by Month .



Quileute Natural Resources data

Water temperature data for several tributary streams are depicted in Figures 2.7-3 and 2.7-4. Based on the frequency and magnitude of water quality standards violations under §305(b) water quality assessment guidelines, Beaver Creek and Bockman Creek do not support the anadromous fisheries use designation with respect to temperature under State water quality standards. Fish may be able to use these streams to some degree, but under suboptimal conditions when water temperatures exceed the State standard.

Figure 2.7-3 Water Temperature Data for Sol Duc Tributaries.

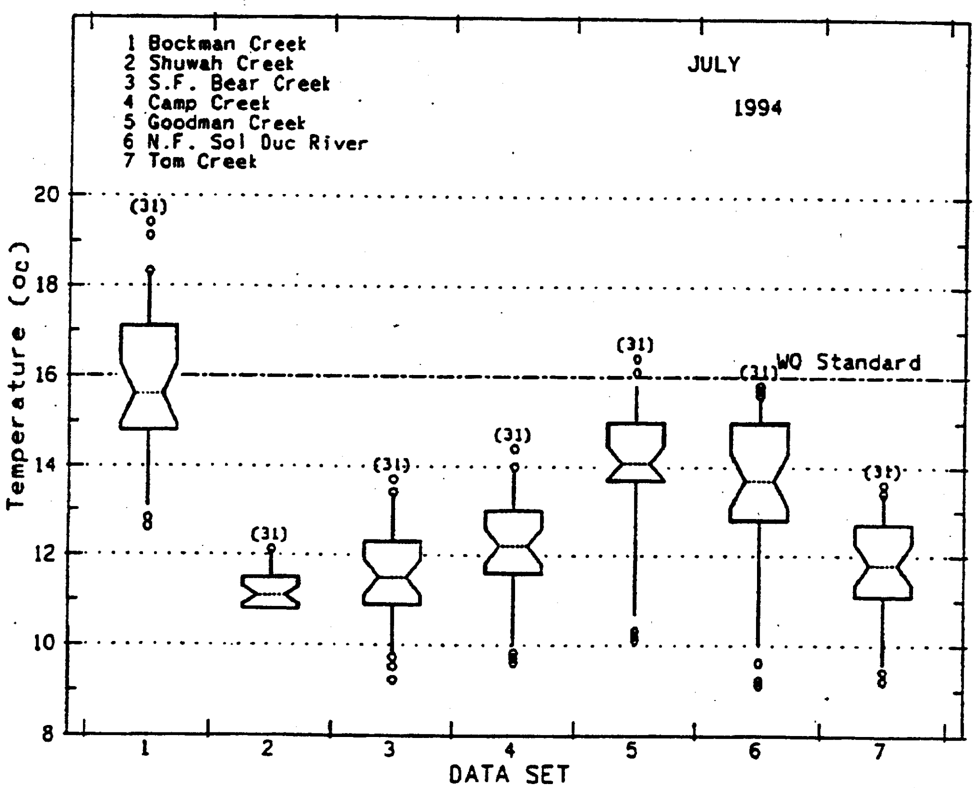
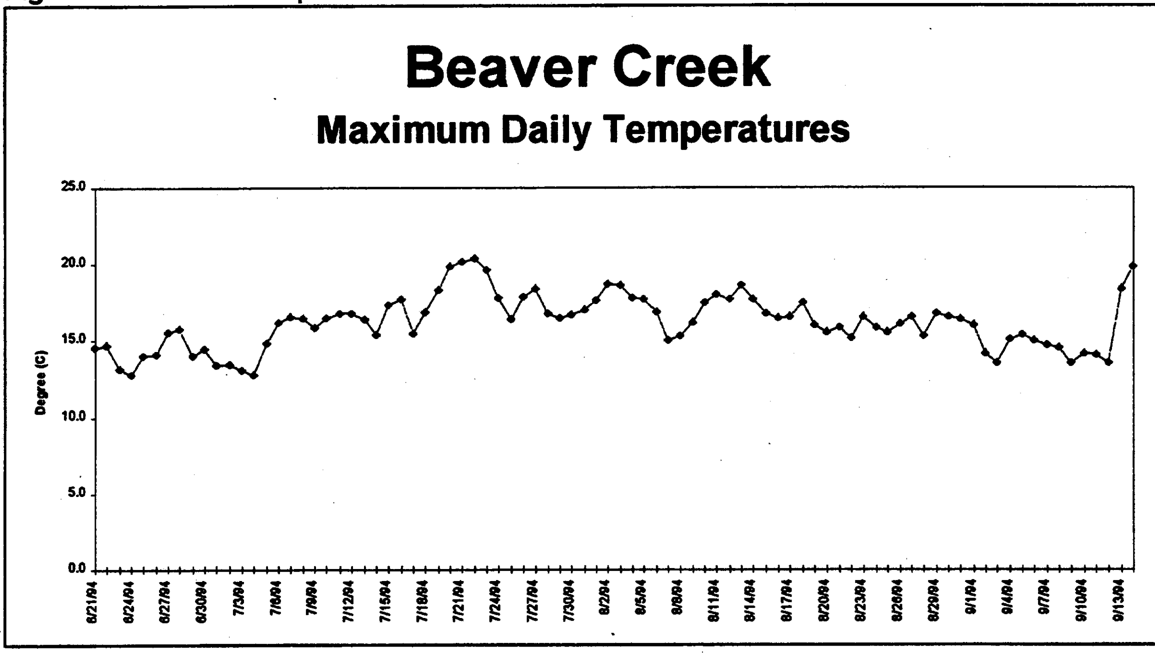


Figure 2.7-4 Water Temperature in Beaver Creek

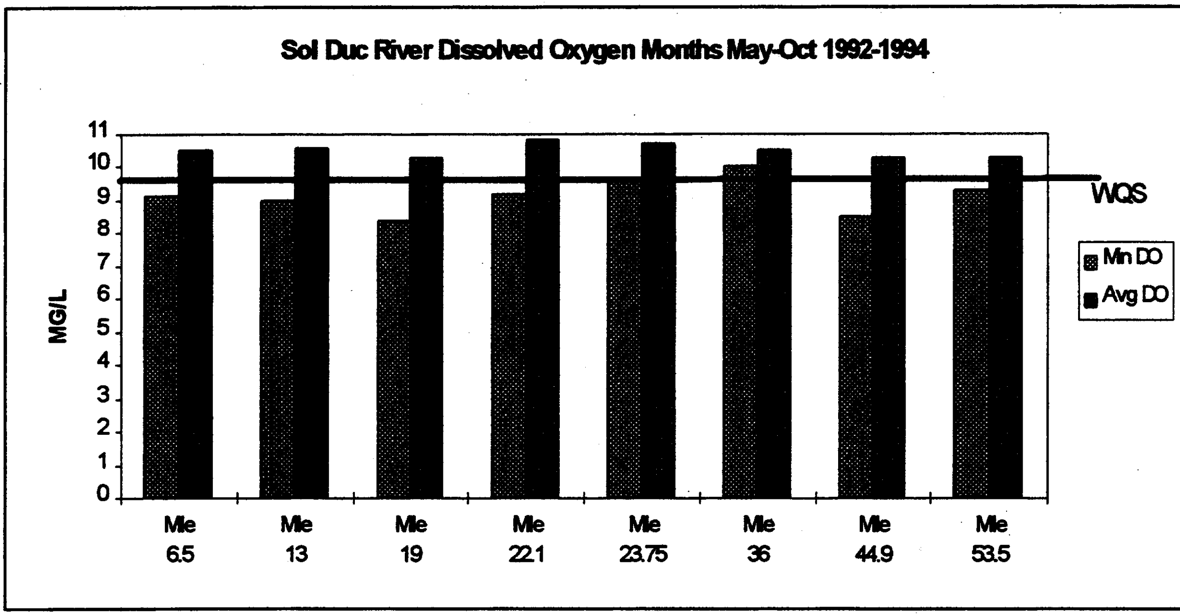


While the actual physical effects of elevated temperatures in these streams are unknown, past research (Reynolds and Casterlin 1979) suggests there is a negative effectAdditional time series plots of water temperature in tributary streams of the Sol Duc River are presented in Appendix 2.7 (Figures 2.7A-1 to 2.7A-10) These data indicate that the majority of the tributary streams in which water temperatures were measured did not exceed the State Water Quality Standard of 16.0°C.

Dissolved Oxygen

Limited sampling of dissolved oxygen was conducted in the Sol Duc River (Figure 2.7-5). Data is reported in Appendix 2.7. Most observations met State water quality standards. Instances where values fell below water quality criteria for dissolved oxygen (9.5 mg/L) occurred during periods of seasonally high air temperatures and low streamflows. Despite the depressed dissolved oxygen levels, no observed problems with aquatic life (e.g. fish kills) were reported. In summary, aquatic life uses appear to be supported in the Sol Duc watershed relative to dissolved oxygen.

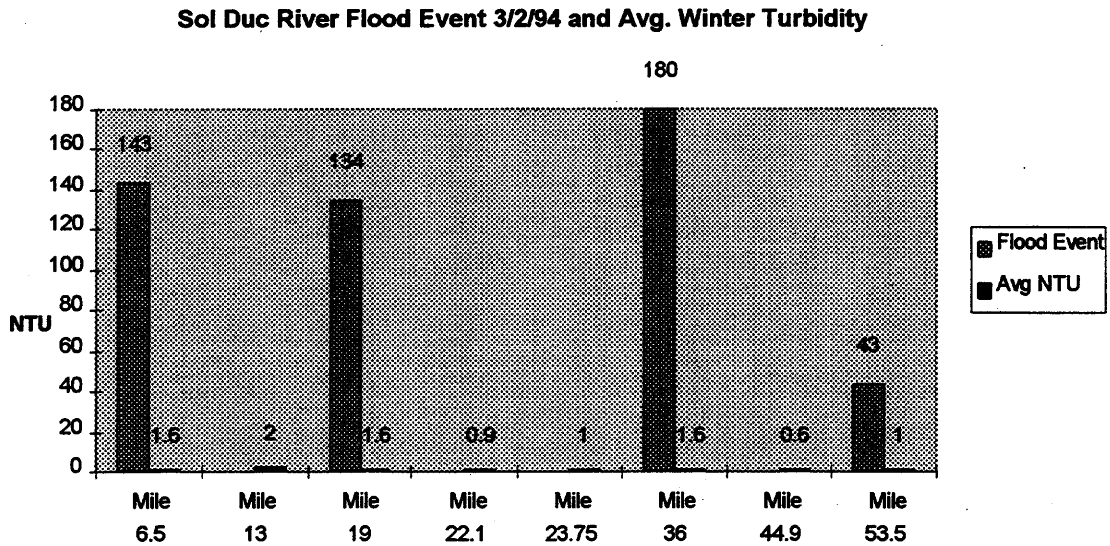
Figure 2.7-5 Seasonal Dissolved Oxygen Values in Mainstem Sol Duc River.



Turbidity

Turbidity data recorded in the Mainstem Sol Duc River indicates that on average, turbidity is quite low (2 NTU or less) except for periods of elevated discharge during storm events (Figure 2.7-6). Turbidity data recorded in Sol Duc River tributary streams are more variable, ranging from 0.05 NTU to 87.8 NTU (Appendix 2.7, Table 27A-15). These data were recorded as instantaneous grab-samples at a variety of locations throughout the watershed and do not represent continuous time-series records.

Figure 2.7-6 Mainstem Sol Duc River Winter Turbidity.



pH

Data recorded from grab samples at three locations on the Mainstem Sol Duc River indicate that pH falls well within the water quality standard. Of the 276 data points recorded, only 3 exceeded the water quality standard for pH. The data that exceeded the standard were collected near the Sol Duc Hot Springs Resort. The Olympic National Park has documented the extent of the effect on stream pH caused by the influence of hydrothermal water and the discharge from the resort pools (Appendix 2.7, Table 2.7A-16-21; 36, 37, 38), and found that within 30 meters downstream of the discharge point, water quality standards for pH were achieved. pH data recorded in Sol Duc River tributaries yields similar results as those found in the Mainstem Sol Duc. All pH samples collected in tributary streams fell within the State Water Quality Standard for pH with the exception of Lake Creek, which exceeded the standard in one sample (Appendix 2.7, Table 2.7A-14 & 15).

Lakes

Water quality data concerning lakes is extremely limited in the Sol Duc Watershed. Although there are many lakes within Olympic National Park which contribute to the Sol Duc River system, there is currently no water quality data associated with these waterbodies. In the lower Sol Duc River watershed there are two lakes of concern; Beaver Lake and Lake Pleasant.

Water quality data for Beaver Lake and Lake Pleasant have been published by the United States Geological Survey (U.S.G.S.) (Fretwell 1984) (Appendix 2.7 Table 2.7A-8 & 9 Figures 2.7A-16 & 17). This study, conducted in the summer, suggests that both lakes are thermally stratified and based on Secchi disk and total nitrogen measurements, are oligotrophic with low nutrient values and relatively stable dissolved oxygen concentrations. These conditions suggest that water quality in both lakes favors aquatic fauna over flora (Vollenveider 1979). Water quality data (Secchi, dissolved oxygen, and temperature) collected in Lake Pleasant by the Quileute Tribe in 1992, suggest similar conditions as reported by the U.S.G.S. study cited above. The temperature profile of Lake Pleasant in 1992 is almost exactly the same as was recorded by

Fretwell in 1984. Dissolved oxygen values while similar near the surface of the lake, are drastically different at a depth of 40 feet in 1992 (6.1 mg/L) compared with the 1974 (1.0 mg/L) values. While the cause of increased dissolved oxygen values at depth in Lake Pleasant is unknown, this increase is seen as an improvement in the context of the applicable water quality standard for dissolved oxygen.

Water temperatures in Beaver Lake (17.3° C) and Lake Pleasant (20-22° C) during summer months are well above the water quality standard for Class AA streams (16.0°C). Since both lakes provide discharge to streams, there is an obvious temperature effect likely to be observed downstream of both lakes during summer months.

Wetlands

The Sol Duc River watershed supports a great variety of wetland types which are distributed unevenly throughout the watershed. Wetlands mapped and inventoried in the Sol Duc watershed by the U.S. Fish and Wildlife Service as part of the National Wetlands Inventory (NWI) are shown on Map 2.2A. Wetland mapping and inventories have also been completed for portions of the Sol Duc watershed (Sheldon and Klein 1994).

Overall, the area occupied by wetlands within the Sol Duc River watershed is relatively small, with less than 3 percent of the land area occupied by wetlands. However, on a subwatershed scale, wetlands begin to become a more dominant landform. Lake Creek, Beaver Creek, Sol Duc River, Gunderson Creek, and Upper Sol Duc River, respectively, display wetland area percentages greater than the Sol Duc River watershed average (Appendix 2.7, Table 2.7A-10). Subwatersheds with relatively high wetland area percentages are typically low gradient drainages with extensive areas comprised of lakes (Lake Creek, Beaver Creek) or low lying areas associated with the Sol Duc River floodplain (Upper Sol Duc River, Sol Duc River, Gunderson Creek). The area and distribution of wetlands based on vegetation classification (Cowardin 1979) by subwatershed are shown in Table 2.7A-11 (Appendix 2.7).

In addition to mapped wetlands in the watershed, there is a significant portion of the watershed occupied by hydric soils (Map 2.2 A) (Appendix 2.7, Table 2.7A-12). These areas of wet soils are likely to have wetlands that have not been documented by the NWI mapping or other wetland inventories. Field examinations of hydric soils in Bear Creek, Sol Duc Valley, and Kugel Creek identified wetlands not indicated on the NWI maps.

A dominant factor resulting in long term changes to wetlands throughout the Sol Duc River watershed has been the placement of fill material within wetlands for the construction of forest access roads. An analysis of fill material placed in wetlands by construction of the current transportation network indicates that a relatively small area (4 acres) of wetlands within the watershed have been directly displaced by filling (Appendix 2.7, Table 2.7A-13).

Another important disturbance effect on wetlands within the Sol Duc River Watershed has been the logging of forested wetlands. Timber removal from forested wetlands can result in chemical, hydrologic and vegetation community changes which can in turn affect the type and availability of aquatic and terrestrial habitat (Richardson 1994; Shepard 1994) . The historic harvest of forested wetlands and associated riparian zones in the North Fork of Bear Creek and in tributaries flowing into the east side of Lake Pleasant (Map 2.2A), appear to have removed shade and promoted the establishment of deciduous trees and shrubs along the edges of wetland areas. These previously forested wetlands have been exploited by beaver populations which are utilizing the deciduous vegetation for food and material for dam construction. This process has not been systematically assessed within the Sol Duc River Watershed and so it is not currently possible to report the extent of forested wetlands affected by timber removal or the extent of aquatic habitat created or modified by beaver populations.

INTERPRETATION

The focus of ***Interpretation*** is the question: ***"What are the influences and relationships between water quality and other ecosystem processes in the watershed (e.g. mass wasting, fish habitat, stream channel, etc.)?*** In addressing this question, other subtopics could be considered which include:

Interpretation — *Other Considerations*

What watershed processes contribute or could potentially contribute input variables to waterbodies vulnerable to specific water quality parameters?

- What potential sources of input variables (e.g. sediment, water, solar radiation, or chemicals) could enter vulnerable waterbodies?
- Do land use practices or natural processes contribute input variables?
- What is the potential for delivery of adverse levels of input variables to vulnerable waterbodies?

Note: If potential sources of input variables to vulnerable waterbodies are not evaluated in other core topic areas (e.g. Vegetation, Hydrology, Erosion, Stream Channel), the water quality analyst will need to address an additional set of critical questions to determine sources and likely effects of land management activities on water quality.

In interpreting conditions, the focus of the assessment shifts to the relationship between the array of water quality parameters and associated input variables (e.g. sediment, energy, and chemicals) that can potentially be influenced by disturbance activities. Sensitivity of any given parameter to input variables depends on the type of waterbody (Table 2.7-5). As mentioned earlier, many of these input variables (hydrology, vegetation, erosion processes, stream channel, and fish habitat) are also considered in other module reports.

Assessment of water quality with respect to sedimentation must rely on integrating information from several other modules. Inputs which could affect beneficial uses are the result of interactions between vegetative, hydrologic, and erosion processes. The channel network and condition provides information on the conduits from sources, the transport potential of the system, and areas where responses would be observed. Finally, indicators used to evaluate fish habitat are often the same parameters utilized in water quality assessment. Thus, determination of beneficial use support must look at all pieces of the sediment picture.

Evaluation of water quality with respect to temperature must also consider the influence of multiple processes acting simultaneously. Seasonal variation in ambient air temperature, seasonal flow conditions and water consumption, streamchannel conditions, available riparian shade and groundwater contributions influence water temperature to some degree.

Additional considerations when interpreting water quality relationships include an evaluation of the frequency, magnitude, and duration of response by water quality parameters to input variables. This type of evaluation can then be related to the beneficial uses that exist in the waterbody under evaluation and a determination of the degree of influence that the input variables have on the beneficial use. When there are more that one or two input variables, water quality parameters, and beneficial uses involved in a specific waterbody, it may be necessary to prioritize beneficial uses and stratify input variables in terms of degree of influence.

Table 2.7-5 **Water Quality Parameters and Input Variables**

Water Quality Parameter	Input Variable	Waterbody Type			
		Streams	Lakes & Ponds	Wetlands	Nearshore Marine / Estuarine
Water Column					
Temperature	Heat energy	X	X		X
Dissolved Oxygen	Organic matter / Nutrients	X	X		X
Nutrients	Nitrogen / Phosphorus Fine sediment	X	X		X
pH	Acids / bases	X	X	X	X
Toxic Contaminants	Organic & synthetic chemicals	X	X	X	X
Sediment					
Turbidity	Fine sediment	X	X		X
Sedimentation	Coarse & fine sediment Bedload	X	X	X	X
Aquatic Organisms					
Bacteria / Pathogens	Fecal coliform / E. coli	X	X		X
Invertebrates	Sediment Toxic chemicals	X	X	X	X
Fish	Heat energy Sediment Toxic chemicals	X	X		X
Flow					
Peak Flows	Water yield	X			
Low Flows	Water yield	X			
Channel Characteristics					
Width / depth	Sediment	X			
Pool metrics	Sediment	X			
Woody debris	Riparian inputs	X			

Riparian Condition and Water Temperature

Shade is a major environmental factor influencing stream temperature. Its influence is likely to occur in nearly all streams except those that are too wide for mature trees to provide sufficient shade to influence temperature. Such streams typically occur 50-60 km (31-37 miles) downstream from the watershed divide in Western Washington (Sullivan et al. 1990). In glacial geology, wide, wet stream valleys may occur closer to the watershed divide. The degree of vulnerability of water temperature is determined by the relative role of shade in maintaining water temperature at or below the temperature criterion (Sullivan et. al. 1990).

Vulnerability of water temperature to increases resulting from shade removal varies with natural levels of shade which may in turn vary with stream width and elevation, as well as riparian tree height. When natural levels of shade are close to those required to maintain temperature based on the criteria, the stream has a high vulnerability to shade removal. If the required shade is low, and naturally occurring levels are high, the vulnerability to removal is moderate, especially considering shade protection measures in current forest practice regulations (WFPB 1993).

The Riparian Condition Assessment (Chapter 2.9) evaluates the condition of riparian zones with respect to shade and water temperature vulnerability (Map 2.9-C Riparian Shade and Water Temperature Vulnerability)
Table 2.7-6 summarizes the riparian shade assessment and recorded water temperature information by subwatershed.

Streams with naturally occurring low shade levels such as N.F. Sol Duc, S.F. Sol Duc, Goodman Creek and the Mainstem Sol Duc River, achieve maximum water temperatures at or above the water quality standard of 16°C, however the duration of temperatures at or above 16°C are short-term, lasting less than 7 days.

Streams such as Beaver Creek (Figure 2.7-4) and Lower Lake Creek do not have naturally low levels of shade, currently have stream segments with low riparian shade, and well exceed the water quality standard of 16°C for medium to long duration (weeks to months). These streams also receive discharge from warm lakes during summer months. Other streams such as Lower Bear, Swanson Creek, and Bockman Creek do not have naturally low levels of shade, do not receive warm runoff from lakes, currently have reduced riparian shade levels, and exceed the temperature standard of 16 °C for medium term duration greater than 1 week.

Table 2.7-6 Riparian Shade Condition and Water Temperature

Stream	Natural Low Shade	Low Shade	Recorded Temp. °C	Exceed 16°C
North Fork Sol Duc (7P)	Yes	Yes	15.8	No
South Fork Sol Duc (7C)	Yes	Yes	15.9	No
Tom Creek (7M)	No	Yes	13.6	No
Goodman Creek (7D)	Yes	Yes	16.4	Yes
Camp Creek (7E)	No	Yes	14.4	No
Upper Bear Creek (7G)	No	Yes	13.5	No
South Fork Bear (7N)	No	Yes	13.7	No
Lower Bear (7Q)	No	Yes	16.0	Yes
Cold Creek (7H)	No	Yes	14.4	No
Shuwah Creek (7S)	No	Yes	12.2	No
Lower Lake Creek (7I)	No	Yes	22.0	Yes
Mid-Upper Lake Creek (7I)	No	Yes	11.7	No
Mid-Swanson Creek (7A)	No	Yes	16.0	Yes
Mid-Gunderson (7T)	No	Yes	No Data	No Data
Mainstem Sol Duc River (7A)	Yes	Yes	22.7	Yes

Tom Creek, Camp Creek, Upper Bear Creek, South Fork Bear Creek, Cold Creek, Shuwah Creek, Upper Lake Creek Kugel Creek, and Tassel Creek, are well below the water quality standard for temperature despite varying degrees of reduced riparian shade levels. This suggests that water temperature in these streams is influenced to some degree by factors other than riparian shade during warm summer months.

North Fork Sol Duc, South Fork Sol Duc, Goodman Creek and the Mainstem Sol Duc River have naturally low levels of riparian shade and exceed the water quality standard for temperature. Water temperatures in these streams appear to have some dependence on riparian shade. The water quality standard for temperature in streams that naturally exceed 16°C is that no increase above 0.3°C is allowed from management activities (Appendix 2.7, Table 2.7A-2). It is unclear what effect removal of riparian shade in these streams would have on water temperatures.

Lower Lake Creek and Beaver Creek appear to have water temperatures that are highly vulnerable to removal of riparian shade (Appendix 2.7, Table 2.7A-23, 25, 33-38). However this conclusion is confounded by the discharge of naturally occurring warm water from lakes during the summer months. Both stream systems have reduced levels of riparian shade, and both exceed the water quality standards for long duration, however it is unclear whether this condition is due to lack of shade or warm water contributed from upstream lakes or both. Lower Bear Creek, Swanson Creek, and Bockman Creek appear highly vulnerable to the removal of riparian shade.

Sedimentation and Turbidity

Turbidity, both lithic and organic, reduces light penetration into the water column which can reduce primary production. Reductions in primary production can affect fish production through reduction of prey availability. Lithic turbidity is the product of suspended soil particles delivered to streams through sedimentation processes. The Sedimentation Module (Chapter 2.4) has evaluated the effect of landuse on increasing erosion rates above the natural background level for each subwatershed. These data are summarized in Table 2.7-7 below.

Table 2.7-7 Erosion Rates and Observed Turbidity

Stream/Subwatershed	% over Natural Background	Recorded High Turbidity (NTU)
7A Sol Duc River	140%	180
7B Alckee Creek	56%	0.24
7C S.F. Sol Duc River	199%	NA
7D Goodman Creek	148%	NA
7E Camp Creek	113%	NA
7F Kugel Creek	72%	10.3
7G Upper Bear Creek	62%	NA
7N South Bear Creek	51%	NA
7Q Lower Bear Creek	49%	0.66
7H Beaver Creek	101%	0.97
7L Lake Creek	98%	87.8
7J Bockman Creek	100%	NA
7K Maxfield Creek	5%	NA
7L Tassel Creek	71%	NA
7M Tom Creek	117%	NA
7O Upper Sol Duc River	12%	NA
7P North Fork Sol Duc River	0%	NA
7S Shuwah Creek	25%	NA
7T Gunderson Creek	124%	180

There is no clear relationship between subwatersheds with elevated levels of erosion and observed turbidity in streams based on the data presented in Table 2.7-7. This is likely due to the limited and highly variable nature of the recorded turbidity data and is included to document an obvious data gap.

Water Withdrawal and Water Quality

The quality of surface water is inextricably linked to water quantity (McDonald et al. 1991). Reductions in streamflow from water withdrawal can affect water temperature, dissolved oxygen and habitat availability. The Hydrology Module (Chapter 2.3) has identified low streamflows as a factor potentially affecting fish use of six streams (Gunderson, Maxfield, Shuwah, Bockman, Lake, Kugel) in the lower Sol Duc Watershed. The Hydrology Module further identified water withdrawals from the Mainstem Sol Duc River as potentially reducing streamflows by 40% in average years and 68% in dry years. Currently the State Department of Ecology (DOE) permits 135 cfs to be withdrawn from the Mainstem Sol Duc River and 16.7 cfs from the Lake Pleasant/Lake Creek watershed. The actual volume of water withdrawn from these streams during critical summer months when low flows are a problem is not currently known. Determination of sufficient instream flow volumes for the Sol Duc and its tributaries would allow a more reasonable interpretation of other factors influencing water quality in these streams.

Nutrient Inputs and Water Quality

Nutrients, in the form of nitrogen and phosphorus can effect water quality parameters such as dissolved oxygen, turbidity, and temperature, by changing the biological oxygen demand of the aquatic environment through increased production of algae and other vegetation. Sources of nitrogen and phosphorus inputs into the Sol Duc watershed include forestry inputs, agricultural inputs, and aquaculture or fish-hatching and rearing facilities.

Forestry inputs of nitrogen and phosphorous can occur when fertilizers are applied to forest lands in the form of pellets or sludge. These fertilizers are broken down by rainfall and soil microbial activity and processed by plants. A portion of the fertilizer may be directly applied to flowing waters by misapplication or by transport from runoff processes. Typically, where surface waters are well oxygenated, nutrient inputs from forestry are not sufficiently concentrated to cause measurable changes in primary production, biological oxygen demand, or dissolved oxygen (Bisson et al., 1992; Fredricksen et al., 1975). Streams that are low gradient (1% or less) and poorly oxygenated are more susceptible to nutrient inputs, and are more likely to exhibit depressed dissolved oxygen levels given increased nutrient inputs.

Agricultural sources of nitrogen and phosphorus include direct application of fertilizers to fields and surface waters, indirect inputs from agricultural runoff from fertilized areas, and inputs of animal fecal waste, direct or indirect, to surface waters. No systematic evaluation of nutrient inputs from agricultural lands in the Sol Duc watershed has been completed.

Fish hatching and rearing facilities can be sources of nitrogen and phosphorous through the discharge of fish food and fish fecal material. In the Sol Duc there are two fish hatching facilities, the Sol Duc and Bear Springs Hatchery, and one rearing facility, Snider Creek Rearing Pond (See Public Works Module for locations of these facilities). According to Bill Ward, Permit Manager, Water Quality Program, Washington State Department of Ecology, both the Bear Springs and Sol Duc hatcheries must meet the discharge requirements as stated in WAC 173-221A-100 which requires that upland fish facilities attain water quality standards at their point of discharge. Both the Bear Springs and Sol Duc hatcheries have been required to monitor their effluent and submit discharge monitoring reports to the Department of Ecology. The Snider Creek rearing pond because it is a federal facility sited on federal land, does not fall under the permitting authority of the Department of Ecology. The Snider Creek rearing pond is not required to monitor effluent discharges by the E.P.A., and is considered a minimus discharger. The Quileute Tribe has conducted limited monitoring at the outfall of the Snider Creek Rearing Pond (Appendix 2.7, Table 2.7A-15).

Watershed Summary

Historically, the primary beneficial uses in the Sol Duc watershed have been anadromous and resident fish habitat, wildlife habitat, and domestic water supply for human consumption. With the increased population in the basin over the last 120 years, the variety of beneficial uses existing within the basin has increased to include water supply to fish production facilities, agricultural and industrial uses, and recreation.

There are very few data that can be used to evaluate the historic condition of water quality in the Sol Duc Watershed before European settlement. Prior to widespread land management activities such as logging, and agriculture, the primary controls of water quality within the basin were the natural variability of climate and fire which influenced the spatial and temporal occurrence of floods and low flows, sedimentation processes and riparian vegetation succession.

European settlement of the watershed brought a new array of disturbance processes to play in the basin. Logging and road building which have been and are currently the most widespread landuses in the basin, altered fire, sedimentation, and hydrologic cycles as well as the riparian vegetation succession. Agricultural uses, while less prevalent in spatial extent, brought changes in the form of wetland alteration and nutrient inputs. Industrial and domestic water use increased within the basin, altering water availability in both the mainstem and tributaries of the Sol Duc River. These landuses fundamentally altered the disturbance regime within the basin from one of spatially limited, periodic, catastrophic disturbances, with relatively long recurrence intervals (See Vegetation Module) which allowed a period of recovery, to a more chronic disturbance regime which is more widely distributed across the watershed.

The interpretation of the current condition of water quality in the Sol Duc watershed must take into account the interaction of natural and human caused disturbance, the range of natural variability of water quality parameters, and the requirements of existing beneficial uses.

Confidence Assessment

The confidence in this assessment is low for fully addressing the key questions presented at the beginning of this report. While confidence about ambient water quality conditions at points where data were collected is generally high (See Appendix 2.7; Reliability of Data), our limited ability to interpret the data in the context of watershed conditions resulting from land management activities or natural disturbance processes reduces the confidence in the assessment. Further water quality monitoring efforts in the Sol Duc watershed should be designed so that specific cause and effect questions regarding watershed processes and their influences on water quality can be answered more definitely.

Conclusion

Available data suggests that water quality in the Sol Duc watershed is generally good. Data indicates pH, conductivity, temperature, dissolved oxygen are mostly within State water quality standards. However, there are some recorded exceptions to this general pattern. Information on tributary streams to the mainstem Sol Duc is limited and poorly understood. With increased population growth pressures and a maturing forest base, care must be taken to ensure the protection of riparian areas. Good riparian management now, and in the future, will help the overall prospects for the watershed. In addition, monitoring of low flow conditions needs to be undertaken along with monitoring of aquatic biological parameters. With these safeguards, the Sol Duc watershed could have good water quality in the years to come.

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