



State of Oregon  
Department of  
Environmental  
Quality

*DRAFT*

# TECHNICAL BASIS FOR REVISING TURBIDITY CRITERIA

Water Quality Division  
The Oregon Department of Environmental Quality

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# 1 Introduction

The federal Environmental Protection Agency (EPA) has delegated the Oregon Department of Environmental Quality (DEQ) to administer sections of the Clean Water Act. Section 303 of the Act requires that DEQ review Oregon's water quality standards regularly in order to use the latest scientific information and consider the state's latest needs. This document provides the technical basis for a turbidity criteria revision undertaken to better address the protection of beneficial uses.

## 1.1 Background on Oregon's Turbidity Criteria

Oregon's turbidity standard was first adopted in the 1970's and last revised in 1990. The turbidity criterion has been based largely on EPA's 1976 criteria for Solids (Suspended, Settleable) and Turbidity criterion developed to protect freshwater fish and other aquatic life. The USEPA turbidity guidance states that: "Settleable and suspended solids should not reduce the depth of the compensation point for photosynthetic activity by more than 10 percent from the seasonally established norm for aquatic life" (USEPA, 1976).

The only substantive change to Oregon's turbidity criteria in 1990 was a shift from measurement using Jackson Turbidity Units (JTUs) to Nephelometric Turbidity Units (NTU). According to standards methods for the examination of water and wastewater the turbidity units read as JTUs are similar to NTUs (Clesceri, 1989). The Nephelometric methods, however, provides greater reliability over a wider turbidity range especially at the lower ranges of turbidity (below 25 NTUs).

Primary productivity was presumably the most sensitive aquatic life use considered in the 1990 criteria review, although this was not explicitly stated (ODEQ, 1990). Photosynthesis and the EPA 1976 criteria were key considerations, resulting in the retention of the (current) 10% turbidity increase allowance (Section 1.2.2.2); however with different turbidity units. Public comment recommended additional and separate reviews on turbidity, suspended sediments, settleable solids, and accumulated fines to resolve remaining issues.

Remaining questions from the 1990 turbidity criteria review included:

- Scientific questions regarding:
  - Seasonal norms: natural turbidity variability and whether natural conditions might violate the 10% increase allowance.
  - The relationship of the percent NTU increase (allowance) to a percent reduction in the compensation point depth. Would a 10% reduction in turbidity equate to a 10% change in the compensation point?
- Which permits would have to contain limits? It was initially assumed that some point sources should not have limits. However, the planned review process to make that determination did not take place.
- How monitoring parameters would be addressed.

### 1.1.1 Past implementation

Implementation of the turbidity criteria has been inconsistent. During development of the turbidity criteria, representatives of point sources noted that the greater precision afforded by using NTUs, and

being able to measure below 25 NTUs, might mean that some dischargers would not be able to meet turbidity limits.

Oregon's turbidity criteria have routinely been implemented for activities permitted under Section 404 of the Clean Water Act and certified under DEQ's CWA 401 certification program. Changing to NTUs in the early 1990's had allowed greater accuracy in measuring turbidity at low levels. Under clear background water conditions (< 5 NTUs), meeting the criteria was achieved by implementing the narrative limited duration exceedance allowance.

Non-point sources such as agricultural and forestry activities have also implemented turbidity criteria. With few exceptions to date, DEQ has referenced turbidity criteria in NPDES stormwater-only permits, but has not applied the criteria to most other industrial or municipal sources, in part because the agency had not determined how the criteria should be applied.

### **1.1.2 Initiation of the Current Review**

The re-visitation of the turbidity criteria occurred in 2001, in part due to turbidity becoming a permit issue for the first time as backlogged permits were reviewed for compliance of water quality standards. There were also concerns with the perceived 'over-stringency' of the '10% allowance', as well as with the open-ended narrative allowing potentially unfettered turbidity discharges authorized through a permit or 401 certification.

DEQ lacked staff resources to initiate the revisions until receipts authority funding was offered by the Northwest Pulp and Paper Association (NWPPA). With funding to pay for staff to make revisions to the criteria, DEQ decided to go forward with the process.

### **1.1.3 Purpose of the Review**

The purpose of this evaluation is to develop water quality criteria that better address the effects of turbidity on beneficial uses, including the most sensitive beneficial uses. Revising the current criteria to more closely align with the protection of beneficial uses will provide stronger rationale for a more defensible standard, will improve credibility with the regulated community and the public, and will better protect water quality. Basing turbidity criteria on effects to beneficial uses would better meet the intent of the standard to protect uses, particularly for low ambient turbidity levels, where the current ten percent increase in turbidity may be negligible in relation to natural (or background) levels.

## **1.2 Overview of the Draft Proposal**

### **1.2.1 Information Sources**

Information was obtained using available DEQ materials, state library resources, and computer database searches, as well as by contacting representatives from other states regarding their approaches to developing turbidity criteria. Primary journal articles were used to evaluate aquatic life effects, and human-related visual and aesthetic effects. Qualifying studies for this evaluation included turbidity effects relative to control or background levels, and those that identified statistically significant effects directly attributable to turbidity (light and visual) influences. Some information regarding physical sedimentation effects are cited, but distinguished from turbidity effects. Additional information regarding drinking water suitability, and treatment was gathered from drinking water treatment facility personnel. [see Section 3.3.1]

## 1.2.2 Policy Issues, Rationale, and Choices Supporting the Proposal

### 1.2.2.1 EPA Guidance

Section 131.11 of CFR Title 40 requires that “States must adopt those water quality criteria that protect the designated beneficial use. Such criteria must be based on sound scientific rationale and must contain sufficient parameters or constituents to protect the beneficial use. For waters with multiple use designations, the criteria shall support the most sensitive use.” EPA’s “Water Quality Handbook: Second Edition” says that “States are encouraged to adopt both numeric and narrative criteria. Aquatic life criteria should protect against both short-term (acute) and long-term (chronic) effects” (USEPA, 1994).

Until recently, the only turbidity criteria suggested by EPA came from “Quality Criteria for Water” (USEPA, 1986) with the following numeric and narrative criteria having been adopted in part, or at least conceptually, by Oregon:

*“Solids (Suspended, Settleable) and Turbidity - Freshwater fish and other aquatic life: Settleable and suspended solids should not reduce the depth of the compensation point for photosynthetic activity by more than 10 percent from the seasonally established norm for aquatic life.”*

*“Aesthetic Qualities - All waters shall be free from substances attributable to wastewater or other discharges that: settle to form objectionable deposits; float as debris, scum, oil, or other matter to form nuisances; produce objectionable color, odor, taste or turbidity; injure or are toxic or produce adverse physiological response in humans, animals, or plants; [or] produce undesirable or nuisance aquatic life.”*

Within the last five years EPA has developed recommendations for nutrient criteria based on reference site conditions of Ecoregion-designated areas of Oregon. These criteria include secchi depth in lakes and reservoirs, and turbidity for rivers and streams, to be used as response variables and starting points in developing nutrient criteria. This approach includes the following ‘critical elements’ in developing criteria, excerpted from the nutrient criteria development documents (USEPA, 2001):

- Historical and recent *nutrient* data
- Reference sites/reference conditions
- Models employed for prediction or validation
- Expert review and consensus (from RTAG: Regional Technical Assistance Groups)
- Downstream effects of criteria

While Oregon (and most other states) are not employing a reference condition approach for turbidity criteria development, our approach does contain similar considerations in developing numeric criteria such as evaluating seasonal norms, employing models, facilitating expert review, and considering downstream effects (see Section 1.2.3.1).

### 1.2.2.2 Oregon’s Current Turbidity Criteria

*Oar 340-041-0036: Turbidity (Nephelometric Turbidity Units, NTU): No more than a ten percent cumulative increase in natural stream turbidities shall be allowed, as measured relative to a control point immediately upstream of the turbidity causing activity. However, limited duration activities necessary to address an emergency or to accommodate essential dredging, construction or other legitimate activities and which cause the standard to be exceeded may be authorized provided all practicable turbidity control techniques have been applied and one of the following has been granted:*

(a) *Emergency Activities: Approval coordinated by DEQ with the Department of Fish and Wildlife under conditions they may prescribe to accommodate response to emergencies or to protect public health and welfare;*

(b) *Dredging, Construction or other Legitimate Activities: Permit or certification authorized under terms of Section 401 or 404 (Permits and Licenses, Federal Water Pollution Control Act) or OAR141-085-0100 et seq. (Removal and Fill Permits, Division of State Lands), with limitations and conditions governing the activity set forth in the permit or certificate.*

### 1.2.2.3 Other States Turbidity Criteria

Numeric turbidity criteria have been developed by 30 States out of the 52 states, territories, and the District of Columbia. Roughly two thirds of these states employ a relative criteria, allowing an increase above background conditions either with an established NTU increase such as “no more than 5 NTUs above background” or as a percent increase such as “no more than a 10% increase above background (similar to Oregon’s current criteria). Little rationale or justification was found for state’s criteria levels.

No states other than Idaho currently distinguish between acute or chronic turbidity levels in their turbidity criteria approach. Idaho has both an instantaneous criteria (50 NTUs), and a 10 day criteria (not to exceed 25 NTUs). British Columbia employs a 30-day average aquatic life criteria allowing an average of 2 NTUs above background turbidity levels of 0-8 NTUs, 8 NTU when background is between 8 - 80 NTU, 10% when background is  $\geq$  80 NTUs.

Seven states, including five western states (Washington, Idaho, Alaska, Montana, and California) have ‘maximum’ turbidity increase allowances of 5 NTUs above background for their highest class waters that may include drinking water sources, salmonid habitat, or recreational waters.

Four of the five western states also have higher allowances (10 NTUs) for lower class waters which may include cold water aquatic life, secondary recreation, salmonid habitat, marginal salmonid habitat, non-salmonid habitat, or non-drinking water.

Montana’s narrative criteria allow ‘no increase’ above naturally occurring turbidity for conventional water treatment reaches or pristine reaches. The Central Valley region of California has the most conservative criteria overall, currently allowing a 1 NTU increase above backgrounds of 0-5 NTUs; though they may raise the criteria from 1 to 2 NTUs for measurability.

Seven other regions of California allow percent increases of 20% above lower background conditions, with many going to a 10% increase allowance at higher background levels ( $\geq$ 50 NTUs or JTUs). One California region allows only 10% increase above natural levels, similar to Oregon’s current criteria, which can be very conservative in clear water conditions. All of the western states except Montana go to a percent increase allowance (10 - 20%) at higher background levels, also proposed in the draft Oregon criteria. Going to a ‘percent increase’ at higher background levels as proposed in the Oregon turbidity criteria is done to allow certainty in determining a *measurable difference* between background and activity-related turbidity increase due to higher variability in measurements known to occur at higher turbidity levels. [Appendix I contains additional information]

## 1.2.3 Proposed Criteria

### 1.2.3.1 Overview of Criteria Approach and Rationale

Criteria levels and narrative in the draft turbidity rule are designed to protect aquatic life and other beneficial uses including drinking water treatment, safety, aesthetics, recreation, and agricultural and industrial water use. For most Oregon waters aquatic life will be the most sensitive use. Other uses are considered to be important in setting turbidity criteria, but tend to be more site-specific or value-orientated such as aesthetics, and don't lend themselves to being drivers for developing state-wide turbidity criteria to as great an extent as aquatic life.

Three types of information were considered in developing draft criteria with respect to aquatic life: 1) Scientific literature describing turbidity effects on plants, macroinvertebrates, and fish, including fish behavioral data that can be reasonably connected to a physiological endpoint. The effects of solids are considered in a peripheral context since monitoring turbidity can indicate both turbidity and sedimentation impacts. Sediment in water directly affects fish health and population (e.g. gill abrasion and egg smothering; 2) Meta data analysis including regression modeling is utilized to help bridge information gaps in the literature, especially in estimating potential magnitude versus duration thresholds; and 3) ambient water quality monitoring data that characterizes current turbidity conditions or reference-site conditions presented in summaries or analysis.

Oregon's approach to protecting beneficial uses from turbidity impacts is essentially source control of turbidity-causing activities, with numeric and narrative criteria allowing small increases above background conditions per each activity. In part, this is a self-monitoring program, with emphasis on using monitoring to insure that best management practices (BMPs) are functioning properly. Criteria levels are designed to be applied state-wide in order to provide adequate protection from all identified sources of anthropogenic turbidity. Site-specific allowances for short-duration pulses or additional flexibility for channel restoration projects, emergencies, and essential channel dredging are provided in the rule through CWA 401 certification reviews or NPDES permits. The criteria also provide more stringent protections where special concerns are identified, also to be applied on a site-specific basis through the same review process.

There does not exist a standard formula for developing turbidity criteria as there is for toxic parameters where there is a common endpoint such as lethality. Nor is there a single set of studies which everyone can agree on for setting thresholds.

The EPA recommends that turbidity criteria (and other criteria) should "reflect local conditions" (USEPA, 2001). The Independent Multidisciplinary Science Team (IMST) recommended that recovery of wild salmonids required a management and policy goal of emulating "natural processes within their historic range", and with respect to fine sediment production, to "emulate historical patterns of disturbance" with respect to the quality (coarseness), extent, and frequency of sediment inputs (IMST, 1999). The IMST, an independent scientific peer review panel appointed by the governor serves state agencies responsible for developing and implementing the Oregon Plan and other salmon or stream enhancement programs throughout this state.

While Oregon is not taking a reference site approach, we are taking an approach that takes into consideration the water clarity conditions that exist in the state and ones that will protect the sensitive uses, and types of species, such as salmonids that survive in many state waters. The protection of these conditions is weighed in along with the protection levels and information from specific laboratory and field studies, and also meta analysis, such as Newcombe's (2003) clear water fishes model.

Since we are not proposing an absolute criteria it is important to consider how turbidity impacts uses with respect to the magnitude and duration of exposure. It has been fairly well documented in the

literature that high magnitude turbidity may not be harmful if it occurs over short time-frames. Conversely, chronic inputs of low-level turbidity must also be considered in developing protective criteria. (Newcombe, 2003)

Long-term turbidity increases may cause chronic behavioral changes in fish that reduce net energy gains (and growth) either from photosynthetic food chain reductions, or from fishes reduced ability to identify and consume prey. High-magnitude pulses of turbidity may disorientate fish, reduce habitat access, or result in physical sedimentation impacts in the water column or to spawning beds. In general, long-term turbidity discharges should be lower than short-term discharges because they have the potential to influence the same local environment over long periods of time, producing a chronic affect on migration routes, habitat quality and access, and shoreline environments.

### **1.2.3.2 Level of Protection**

The turbidity criteria are intended to provide a level of resource protection that reflects DEQ's interpretation of protecting beneficial uses. Aquatic life endpoints consistent with other standards can be characterized as behavioral endpoints that lead to a physiological responses such as reduced growth in fish or may lead to impairment at the population level.

In order to provide some direction through the uncertainty regarding behavioral effects on fish growth, and habitat suitability, an impact assessment model was developed and presented in Newcombe (2003). This model addresses impacts relative to an optimal condition for clear water fish (0 NTUs). Since we are proposing a relative increase above background conditions and not an absolute criteria to be protected, interpretation of the model must also be considerate of shifting level of protection in applying the criteria increase allowances to different background levels. Section 4.1 discusses the setting of 'relative criteria' with respect to high variability in state waters, acclimation, and adaptability of aquatic species with respect to turbidity level increases.

The level of protection proposed for all activities and across the state is high, protecting all of the beneficial uses described above including the most sensitive aquatic life uses, and fish behavioral effects leading to physiological changes. While information regarding fish suggests that clear water conditions are preferable or 'ideal' overall, it also suggests that behavioral effects that occur at very small turbidity increases, such as a slight change in reaction distance to prey, can be compensated for and are not important to fish growth or population level effects.

Where additional review through a CWA 401 certification or NPDES permit can occur for specific sites, the turbidity increase allowance levels can be raised for short durations while keeping both the short and long-term levels of protection high. Where short-term pulses of increased turbidity might cause impairment to other beneficial uses, such as drinking water treatment, or might cause suspended sediment or sedimentation impacts, provisions are included in the criteria to address these concerns.

### **1.2.3.3 Proposed Turbidity Criteria**

The general turbidity criteria include maximum allowances and monthly average allowances above background turbidity levels, as well as a visual contrast criteria (Table 1.1; see Flow Chart for rule application in Appendix J). Limitations on visible plumes is included as part of the criteria to be applied in lieu of turbidity meter measurements. 'Background turbidity' would be defined as follows:

"Background turbidity" means turbidity in the immediate vicinity of and outside the area of influence of the discharge or discharges from the source or sources under consideration. For establishing NPDES permit limits, background turbidity may be calculated as the up-stream historical turbidity associated with low flows, excluding episodic run-off events, for the season(s) or period(s) for which the turbidity

discharge limit is established. If background data are unavailable, 1 NTU may be used as a default value.

Limited duration criteria include a specific set of allowances approvable through a CWA 401 certification review, an NPDES permit, or some other appropriate regulatory agency as stated in the table below. Additional flexibility could be obtained through a CWA 401 certification for channel restoration projects, emergencies, or essential navigation channel dredging with increased attention and monitoring of best management practices and consideration of potential sediment or sedimentation impacts.

The criteria allow for compliance to be measured or calculated to be met at the edge of properly designed mixing zone or within a specified distance downstream or away from the activity-related turbidity input. Compliance is determined by comparing background turbidity against turbidity measured at the compliance point described below. A visible plume should not extend past the compliance point, measured as a distance from the origin of the activity. If the plume originates or exists at depths below the visual field, a turbidity meter should be used to determine compliance at the depth of the plume.

<b>Table 1.1 Turbidity Criteria</b>			
<b>Maximum Allowable Increases in Turbidity</b>			
<b>OAR 340-041-0036(2)</b>			
<i>(a) Maximum Criteria</i>		<i>(b) Monthly Average Criteria</i>	
<i>Background Turbidity</i>	<i>Allowable Increases (above bckgrd)</i>	<i>Background Turbidity</i>	<i>Allowable Increases (above bckgrd)</i>
≤ 33 NTUs	5 NTUs	≤ 30 NTUs	3 NTUs
> 33 NTUs	15%	> 30 NTUs	10%
(c) Visual Criteria. A conspicuous plume must not extend further than the compliance point distances in section (3), except as consistent with the numeric or other applicable criteria stated in this rule.			

<b>Limited Duration Criteria</b>
<b>OAR 340-041-0336(2)</b>
<p>(d) If specifically authorized by NPDES permit, CWA §401 water quality certification, or other regulatory mechanism, a person may exceed the maximum turbidity criteria in subsection (2)(a) as described below:</p> <p>(A) Turbidity may exceed an increase of 5 NTUs above background during a single period of not greater than eight hours for each calendar day allowed. During that period, turbidity increases above background may exceed 30 NTUs for no more than two hours and must not exceed 50 NTUs above background turbidity; and</p> <p>(B) Limited duration criteria under paragraph (2)(d)(A) are allowed for no more than 6 calendar days out of any consecutive 30-day period, unless turbidity monitoring or existing relevant data demonstrate compliance with the monthly average turbidity criteria in subsection (2)(b).</p> <p>(e) In a CWA §401 water quality certification, the Department may authorize ecological restoration, emergency, or essential dredging activities to exceed the criteria in subsections (2)(a) through (2)(d) for a period defined in the certification, and in accordance with the following:</p>

- (A) The Department finds that the source cannot practicably comply with criteria in subsections (2)(a) through (2)(d).
- (B) The Department finds for channel restoration or essential dredging that the activity will achieve long-term gains in the protection of beneficial uses that outweigh its potential adverse impacts to beneficial uses, or will offset or mitigate negative impacts to beneficial uses by achieving positive gains on the site or elsewhere in the basin.
- (C) The Department finds that there will be no permanent impairment to any beneficial use from the activity due to or as a result of turbidity, sediment, or sedimentation impacts; and
- (D) The Department coordinates with the Department of Fish and Wildlife regarding water quality and resource protection before authorizing exceedances under this section.
- (f) The Department may establish criteria for limited duration exceedances more stringent than the criteria in subsection (2)(d) to protect beneficial uses from activities that occur in areas or situations such as:
  - (A) In scenic waterways;
  - (B) In waters listed under §303(d) of Clean Water Act for turbidity or sedimentation;
  - (C) Upstream of public drinking water intakes;
  - (D) Upstream of redds or active spawning areas;
  - (E) Activities occurring outside the in-water work period as defined by ODFW; or
  - (F) At any location where special circumstances, cumulative impacts, or other conditions require additional protection.
- (g) Persons using authorizations granted under subsections 2(d) through 2(f) must:
  - (A) Utilize all reasonable and practicable measures to maintain activity-related turbidity at the lowest achievable level;
  - (B) Monitor best management practices and other control measures to demonstrate that the conditions allowing for the exceedance have been met; and
  - (C) Document and monitor turbidity to demonstrate BMP effectiveness and/or compliance with allowed turbidity levels.

<b>Turbidity Criteria Points of Compliance</b> for activities not subject to an OAR 340-041-0053 mixing zone
<b>OAR 340-041-0036(3)</b>
(a) For wetted stream widths no greater than 30 feet at the discharge point: 50 feet.
(b) For wetted stream widths greater than 30 feet but not greater than 100 feet at the discharge point: 100 feet.
(c) For wetted stream widths greater than 100 feet but not greater than 200 feet at the discharge point: 200 feet.
(d) For wetted stream widths greater than 200 feet at the discharge point: 300 feet.
(e) For ponded systems such as lakes, reservoirs, ponds, wetlands, backwater systems, and similar waterbodies: 100 feet, or the maximum surface dimension of the water body, which ever is less.

The 3 and 5 NTU allowances provide a high level of protection to long-term exposure. The 5 NTU maximum provides some flexibility and a constraint on the monthly average criteria (3 NTUs), as well as enforcement capability. For short-term projects, these criteria may be more strict than needed to assure use protection. For this reason limited duration criteria were developed allowing higher magnitude pulses of turbidity estimated to also provide a similar high level of protection if limited to the shorter time frames, as prescribed. The allowance of higher magnitude pulses of turbidity is also considered in the turbidity rule with requirements of increased monitoring and evaluation of potential sedimentation impacts to occur through increased permit or 401 certification processes.

## **2 Understanding Turbidity**

### **2.1 Overview**

Turbidity is a measure used to represent the clarity, or in real terms, the 'lack of clarity' in water. Turbidity is defined by the American Society for Testing and Materials International (2003) as, "an expression of the optical properties of a liquid that cause light rays to be scattered and absorbed rather than transmitted in straight lines through a sample." Nephelometry commonly incorporates nephelometric units (NTUs) that increase with increased light scattering associated with increased particle concentrations, ranging from 0 to 2000 NTUs, or greater. Direct turbidity effects are those associated with light transmittance in the water column (see Section 3). Turbidity can shade out light that supports photosynthesis, primary productivity, and the food chain. Turbidity can also limit visibility important to prey identification and capture, and social interaction by visually-orientated species such as salmonids.

#### **2.1.1 Turbidity as a Surrogate for Total Suspended Solids**

Turbidity can be an indirect measure for total suspended solids concentration in the water column. Turbidity provides a surrogate for measuring suspended solids and for controlling a wide array of beneficial use impacts associated with suspended and settleable solids. However, the relationship between turbidity and solids is site specific, dependent on the size and shape of suspended particles, preventing universal comparisons or translations. While the rule focuses on the direct impacts from turbidity, the effects of solids are considered in a peripheral context since monitoring turbidity can indicate both turbidity and sedimentation impacts. Sediment in water directly affects fish health and population (e.g. gill abrasion and egg smothering). Sediments can also be important transporters of bacteria and toxic metals and/or organic compounds.

## **2.2 Methods of Water Clarity Measurement**

### **2.2.1 Nephelometry (Turbidity NTU Measurement)**

Turbidity is not an inherent property of water, like temperature, but rather an expression of how its constituents interact with light. The size and shape of turbidity-causing particles range widely in field measurements may result in different responses among different types of nephelometers, even when they are calibrated to the same standards (Davies-Colley and Smith, 2001). Since the criteria being proposed is a relative-based criteria allowing relative increases in turbidity above a measured background turbidity level, accurately determining the relative difference between background turbidity levels and activity-related turbidity levels should not pose a problem if the same instrument is used for both measurements (see Appendix G for more regarding uncertainties in measurement)

Nephelometric turbidity meters normally measure light scattered at a 90° angle, or, in the case of ratio Nephelometric turbidity meters, at more than just a 90° angle which may include forward and back scatter detection as well as transmitted light. Ratio turbidimeters "yielded reasonably accurate and precise results on effluent samples, as indicated by spike recoveries ranging from 89 to 105% and replicate relative standard deviations of 0.5 to 5.7%" according to NCASI (2002). Ratio nephelometer measure turbidity more accurately in cases where dissolved color (which absorbs light) is present (NCASI, 2002). The same study estimated relative standard deviations for receiving water samples ranging from 0.3 to 7.9%, indicating "reasonably precise" measurement.

Nephelometric turbidity meters accurately readout zero in clear water and respond with high sensitivity to increasing turbidity. Different methodologies and instruments have been used to measure ‘turbidity’ over the years, involving a wide range of light sources, light attenuation techniques, and calibration standards. An important consideration in making relative comparisons for turbidity criteria compliance: the same instrument should be used to measure ‘background’ and ‘activity-related’ samples (see Appendix G).

## **2.2.2 The Utility of Turbidity and NTUs for Water Quality Criteria**

Turbidity measurement is useful for its relative ease and practicality, especially when compared to other types of water clarity and suspended sediment measurement. The use of on-site turbidity monitoring by activities that may discharge to State waters provides a tool for quick assessment and timely on-site modifications of turbidity control measures in order to protect water quality. Most of the studies to date, and those reviewed for this evaluation, have measured and reported water clarity impacts to organisms in terms of turbidity units [NTUs, JTUs, FTUs (Formazin Turbidity Units), etc.]; with NTUs being the most commonly used units. DEQ has compiled NTU data from more than 10 years of ambient turbidity monitoring around the State. This turbidity data provides a description of seasonal and reach-specific trends in water clarity.

Utilizing nephelometric methods and NTUs as criteria units of measure was chosen for the following reasons:

- 1) A high degree of sensitivity of NTU measurement over a full range ( $\geq 0$ ) of water clarity levels;
- 2) Aquatic life impact studies predominantly rely on NTUs to characterize water clarity effects;
- 3) DEQ and many others who monitor for water quality, measure turbidity in NTUs;
- 4) DEQ has collected at least ten years of NTU data from many waterbodies around the State;
- 5) The regulated community has traditionally applied NTU monitoring;
- 6) Translating existing NTU data to other method units may be problematic; and
- 7) Turbidity monitoring using a nephelometer is easy and relatively inexpensive either in the field or in the plant, with respect to other comparable water clarity measurement methods.

EPA Method 180.1 (Determination of Turbidity by Nephelometry) describes a method for determining turbidity in drinking, ground, surface, and saline waters, and for domestic and industrial wastes for turbidities up to 40 NTUs, with the use of dilution recommended for higher values (USEPA, 1982).

## **2.2.3 Other Water Clarity Measurement Methods**

Recent studies have suggested that alternative methods, such as Secchi disk, or transmissometry (beam attenuation), that measure light transmittance (or percent transmittance) as opposed to light scattering may be more relevant to assessing the water clarity effects on visually orientated aquatic species (Davies-Colley and Smith, 2001). However, universal relationships are not always apparent between turbidity and percent light transmittance method units across the full range of NTU levels reported in the literature. As methods continue to improve, opportunities may exist that allow more useful translation between different types of measurement. Where a reasonable correlation to NTUs can be made at the reach or basin level using surrogates such as suspended solids or other methods, those methods could also be used to measure turbidity criteria compliance.

## **2.3 Causes of turbidity**

Turbidity results from natural and anthropogenic inputs of sediments, organic matter, dissolved matter, or other turbidity causing materials (such as algae or algae promoting nutrients) into the water column. Major controlling factors of turbidity magnitude, duration, frequency, and composition include

precipitation, gradient, geology, natural disturbance, and land use, all of which can be highly variable, creating highly variable turbidity conditions through out the state and over seasonal cycles .

Once in the system, turbidity causing materials may be conserved in the water column, deposited in the channel, washed out into the flood plain, or transported downstream. Turbidity causing sediments that have been deposited in stream channels may be re-suspended during subsequent high flow events. Larger, heavier particles tend to settle first, while smaller clay particles may remain suspended, continuing contributions to downstream turbidity levels.

### **2.3.1 Natural Sources of Turbidity**

Natural turbidity contributions occur from gully, and channel erosion and mass wasting (landslides), the deposition of organic materials or dust into waterways, and groundwater (nutrient) influences. Vegetation absence or loss from natural attrition, windthrow, fire, and/or seismic events, along with precipitation (or wind) events can increase soil erosion and contribute to hydraulic (or airborne) transport of turbidity-causing sediments into waterways.

The quality of landslide (or debris-flow) materials from steeper, un-harvested headwater areas tends to be a mix of wood, rock, and soil. The wood and rock in the system can create sediment traps, and build channel complexity that reduces hydraulic impacts to the channel bottom and walls, and attenuate or prevent downstream effects from sediments that might otherwise cause increasing turbidity and further erosion.

'Natural' levels of sedimentation and turbidity may be increased from historic times in channels where systems have been modified such that wood and complexity have been removed from channels or prevented from entering channels, or where wetlands and channel-adjacent braided channels and have been filled or cut off from the main channel. Flow connectivity with the floodplain and wetlands is also important in removing or filtering sediments and turbidity from the main channel. Turbidity levels may be decreased below dams that have trapped sediment movement from higher elevation streams.

### **2.3.2 Anthropogenic Sources of Turbidity**

Anthropogenic turbidity originates from both non-point and point sources as defined in OAR 340-041-0001:

(40) "Nonpoint Sources" means any source of water pollution other than a point source. Generally, a nonpoint source is a diffuse or unconfined source of pollution where wastes can either enter into or be conveyed by the movement of water to waters of the state.

(44) "Point Source" means a discernable, confined, and discrete conveyance, including but not limited to a pipe, ditch, channel, tunnel, conduit, well, discrete fissure, container, rolling stock, concentrated animal feeding operation, vessel or other floating craft, or leachate collection system from which pollutants are or may be discharged. Point source does not include agricultural storm water discharges and return flows from irrigated agriculture.

Most non-manufacturing or non-municipal sources of turbidity would be defined as nonpoint sources and include: agriculture, mining, forestry, transportation (roads and stream crossings), and channel modifying activities that remove vegetation or disturb slopes or channels, allowing increased erosion into or within waterways. Others include reservoir or dam releases of algal-laden waters, or other hydrology modifying activities. Sources that have traditionally been difficult to manage for sedimentation and turbidity include:

- Irrigation return flows

- Channel dredging and channel dredging return flows
- Poorly constructed dirt and gravel roads
- Wet-weather hauling on dirt or poorly armored roads
- Stream crossings
- Vegetation removal from unstable slopes or channel banks
- Dam releases of sediment or algal-laden turbidity

Manufacturing or municipal point sources of turbidity include: industrial and municipal treated waste discharges, and industrial and urban stormwater. Treated waste is important because it is usually highly suspendable (traveling far downstream), often continuous, and thus potentially affecting the same locale over a long time period. Sources that may present difficulties in turbidity control include:

- Those manufacturing and municipal sources that have not specifically controlled turbidity discharges in the past, including:
  - Older sewage lagoon sewage treatment systems, especially those that discharge highly suspended solids into receiving water with low dilution. Lagoon systems may also yield high solids due to algal growth.
  - Other industrial sources that are without current turbidity limits and little data regarding potential turbidity discharge levels, such as fish processors discharging wastewater into receiving streams that provide little dilution.
- NPDES permitted industrial and urban stormwater discharges.

## **2.4 Ambient Conditions**

### **2.4.1 Oregon Rivers**

Several rivers around the state were inventoried for turbidity monitoring data collected by the Department of Environmental Quality between 1992 and 2002. Turbidity sampling frequency was approximately one sample measurement every two months during that period. Four years of turbidity data was paired with coinciding USGS flow data for 17 stations around the state (1998 – 2002). The following listed tables and figures containing this information are included in the appendices.

- Appendix B. Summary statistics (ave, med, min, max) for turbidity monitoring data (1992-2002)
- Appendix C. Frequency statistics (% 0-5 NTUs, etc.) for turbidity monitoring data (1992-2002)
- Appendix D. Comparison of 10-year data to 2-year daily measurements in Umatilla Basin.
- Appendix E. Figures: Turbidity and flow for 17 monitoring stations (1998-2002)
- Appendix F. Figures: Turbidity and flow regressions: Willamette R.

Although turbidity would be expected to vary at times throughout the state, streams are typically relatively clear. In general higher turbidity would be expected during the winter and associated with higher flows. Measured turbidity levels ranged widely among 20 routine monitoring stations (0.3 to >700 NTUs) between 1992 and 2002.

The statewide median turbidities (averaged across stations) were 4.6, 2.9 and 7.6 NTUs for the annual, low flow, and high flow periods, respectively (Table 2.1; additional information in Appendix B). The Owyhee station results were not included in the annual and low flow statistics since its highest flows occurred during the summer (opposite of other sites) due to dam releases immediately upstream of the monitoring station. Nearly 60% of the inventoried stations achieved turbidity levels of 5 NTUs or less 95% or more of the time during low flow periods. Approximately 80% of all measurements taken during the low flow period were 5 NTUs or less, while 43% of all measurements taken during the high flow period were 5 NTUs or less (Table 2.2; additional information in Appendix C). Less than 4% of all measurements taken during the low flow period were greater than 20 NTUs, while 17% of all measurements taken during the high flow period were greater than 20 NTUs.

**Table 2.1** Turbidity summary data (~NTUs) from 20 OR DEQ ambient monitoring stations (1992 – 2002). **[See Appendix B for additional data and information]**

NTUs	Ave.	Med.	Min.	Max.	Std. Dev.	N (Stations)
<b>Annual Cycles</b> 8/01/92 – 7/31/02	11	5	0.3	700	19.6	19
<b>High Flow Periods:</b> 10/06 – 5/25	14	8	0.4	700	23.0	20
<b>Low Flow Periods:</b> 5/26 – 10/05	4	3	0.3	80	3.9	19

**Table 2.2** Turbidity summary data: NTU magnitude % frequencies; 20 OR DEQ ambient monitoring stations (1992 -2002). **[See Appendix C for additional data and information]**

NTUs	0-5	>5-10	>10-20	>20-50	>50-100	>100-150	>150
<b>Annual</b> 8/01/92 – 7/31/02	56.4	18.6	12.6	8.6	2.3	0.5	1.1
<b>High Flows</b> 10/06 – 5/25	43.2	22.3	17.2	12.8	2.6	0.6	1.2
<b>Low Flows</b> 5/26 – 10/05	79.1	12.1	4.5	1.2	1.7	0.5	1.0

A comparison of the ‘daily measurements’ (1998 – 1999) to the ‘one measurement per two months’ data from which the above statistics are drawn, was made for the Umatilla River at Westland Road monitoring station, with results contained in Appendix D. Results reveal that the two data sets are comparable with respect to average, median, minimum, standard deviation, and frequency statistics. The daily measurements captured higher magnitude peaks, or maximum events. Due to data availability, this was the only comparison of this type made.

#### 2.4.1.1 Oregon Rivers: Turbidity and Flow

Higher turbidity is often related to increased stream discharge (Appendix F). Data from the Willamette River at Hawthorne Bridge (Portland) obtained from monitoring between 1998 and 2002 is used to illustrate that turbidity at this monitoring location was correlated with flow; for the high flow period (~Oct 1 – May 31) and the for flows at or above 50,000 cfs:  $R^2= 0.89$ , and  $0.78$  respectively (Appendix F1 and F2) The correlation was less pronounced when considering the low flow period (~June1 – Sept.30) or flows below 50,000 cfs ( $R^2= 0.35$  and  $0.28$ , respectively) and as shown in Appendix F3. The turbidity never exceeded 10 NTUs during the low flow period, or when the river flow was below 50,000 cfs except during one monitoring event (Feb 21, 2002: 21 NTUs at 32,000 cfs), and was never observed below 15 NTUs when the river flow was above 50,000 cfs.

## 2.4.2 Smaller Oregon streams

A six year DEQ ambient monitoring study completed in 2002 inventoried small wadeable stream sites (June through September) in eight ecoregions around the state, including: Blue Mountains; Cascades; Coast Range; Columbia; Eastern Cascades Slope; Klamath; Snake River High Desert; and Willamette Valley ecoregion. Of the approximately 375 different stream sites monitored, approximately 100 were defined as reference sites, corresponding to grade A, B, or C sites as represented in Table 2.3, and described in the key for Table 2.3. Non-reference sites (approximately 275) correspond to grades C, D, E, or F. The reference site determination for sites classified as “C” was made on a case by case basis, with all reference sites classified in accordance with DEQ protocol (Drake, 2004).

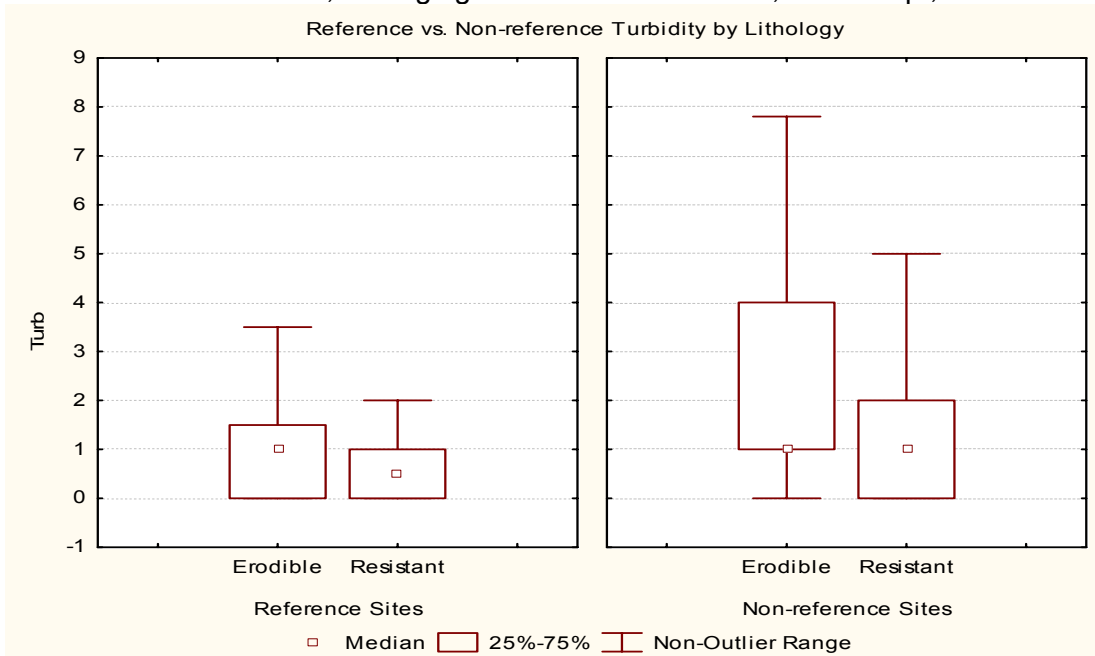
HDI code	Ave.	Med.	Min.	Max.	Std. Dev.	N (Samplings)
<b>A</b>	1.0	1.0	0.5	1	0.2	10
<b>B</b>	1.5	1.0	1.0	13	2.1	33
<b>C</b>	1.9	1.0	0.6	33	3.8	154
<b>D</b>	2.4	1.0	0.3	78	5.8	233
<b>E</b>	16.2	2.0	1.0	263	48.3	36
<b>F</b>	10.6	8.0	1.0	28	10.5	8
(not specified)	4.1	2.0	0.4	29	6.4	27
<b>All</b>	3.4	1.0	0.3	263	14.2	501
<b>Erodable</b>	3.8	1	1	78	8.9	186
<b>Resistant</b>	1.5	1	0.6	22	2.4	95

<b>KEY for Table 2.3</b>	
<b>Human Disturbance Index (HDI) Site Grading Descriptions</b>	
<b>Grade</b>	<b>Description – Reference sites</b>
<b>A</b>	Site represents <u>ideal</u> watershed and stream conditions, a <b>wilderness</b> area or watershed with <b>virtually no human disturbance</b> . These sites represent “natural” conditions and characterize biological integrity.
<b>B</b>	Site represents <u>good</u> watershed and stream conditions; <b>some human disturbances but not extensive</b> , and/or best management practices are well implemented. These sites represent “minimally disturbed” conditions and may characterize biological integrity.
<b>C</b>	Sites represent <u>marginal</u> watershed and stream conditions for a reference site. Human disturbance is present, but the site was the <b>best available for the basin/region</b> . These sites represent “least disturbed” conditions, and generally do not characterize biological integrity.
	<b>Description - Non-reference sites</b>
<b>D</b>	Site represents <u>sub-marginal</u> stream and watershed conditions. <b>Considerable human disturbance</b> is present at <b>reach or</b> in large portions of the <b>watershed</b> .
<b>E</b>	Site represents <u>poor</u> stream and watershed conditions. <b>Considerable human disturbance</b> is present at <b>reach and</b> in large portions of the <b>watershed</b> .
<b>F</b>	Site represents <u>very poor</u> stream and watershed conditions. <b>Human disturbance</b> is <b>extensive throughout stream and watershed</b> .

Overall median levels were ~1 NTU, regardless of lithology (resistant or erodable), or the degree of human disturbance. Median levels for human influenced non-reference sites E and F were 2.0 and 8.0, respectively. Reference site medians for level III subcoregions monitored (Blue Mountains, Cascades, E. Cascade Slope, Coast Range, Klamath Mountains, Snake River and High Desert, and Willamette

Valley) were all 1 NTU, except for the Willamette Valley subecoregion with a median of 2 NTUs. The highest average and maximum turbidities for smaller streams were recorded for the reaches most disturbed by human activity (Table 2.3, and Figure 2.1).

**Figure 2.1** Small OR streams, averaging ~6 feet in wetted width, June-Sept, 1997 – 2002.



### 2.4.3 EPA Reference Site Conditions

EPA calculated medians of the lower 25<sup>th</sup> percentiles of turbidity values from monitoring data for several ‘Nutrient Ecoregions’ of Oregon in order to estimate reference site turbidity levels (Table 2.4). These levels are intended for use as turbidity ‘response variables’ if state’s choose to use a reference site approach to developing nutrient criteria (USEPA, 2001). Author’s of this approach state that using the 25<sup>th</sup> percentile approach “roughly approximates the 75<sup>th</sup> percentile for a reference population”. The study relies on several different units for turbidity, including NTUs, FTUs, and JCU, which are not interchangeable. EPA’s data generally agrees with DEQ’s ambient data evaluation which indicates low (or clear) turbidity water conditions in the state.

**Table 2.4** Reference Conditions for Turbidity (U.S. EPA, 2000 -2001)

	25 <sup>th</sup> percentile
<b>Ecoregion I</b> subcoregion 3 (Willamette Valley)	4.66 NTUs
<b>Ecoregion II</b> subcoregion 1 (Coast) subcoregion 4 (W. Cascades) subcoregion 9 (E. Cascade Slopes and Foothills) subcoregion 11 (Blue Mountains) subcoregion 77 (North Cascades) subcoregion 78 (Klamath Mountains)	1.08 NTUs
	0.25 NTUs
	1.5 NTUs
	0.8 NTUs
	0.76 NTUs
<b>Ecoregion III</b> subcoregion 10 (Columbia Plateau) subcoregion 12 (Snake River Basin) subcoregion 18 (Wyoming Basin) subcoregion 80 (Northern Basin and range)	5.5 NTUs
	1.45 NTUs
	1.54 NTUs
	4.2 FTUs 2.33 NTUs

## 2.4.4 Variability between turbidity measurements and between sites

Historically the turbidity standard relied on background measurements taken immediately above the turbidity causing event because some variability in turbidity is expected over time (see Rivers and Streams Sections 2.4.1 and 2.4.2) as well as between sampling locations. Data developed by the National Council for Air and Stream Improvement (NCASI, 2002) provides an indication of sample variability in the Willamette River.

The NCASI (2002) data from the Willamette suggest that average turbidities generally increased in the downstream direction between Harrisburg and Corvallis monitoring sites. Turbidity increased an average of 0.9 NTUs (based on 45 paired measurements) between the Harrisburg monitoring site and the Cartney site located 6.4 kms downstream. The overall increasing turbidity trend continued between all four mainstem monitoring sites with average annual turbidities increasing by as much as ~5 NTUs between Harrisburg and Corvallis (~40 kms apart) during a relatively wet/high flow period (1999-2000) and less than ~1 NTU increase during a relatively dry/low flow period (2000-2001). The NCASI (2002) study observed positive relationships ( $P > 0.05$ ) between precipitation, river flow, and turbidity.

The range and variability between sites also increased in the downstream direction. The NCASI (2002) study also observed that each study site exhibited ranges of turbidity varying more than 10% between levels measured throughout the year. While the study did not conclude a cause or suggest generalizing the trend as applicable to other sections of the Willamette or other water bodies, it did make the point that downstream turbidity increases between study sites could exceed the current 10% increase criteria.

The 10 % criteria would occasionally be exceeded due to variation in stream turbidity or due to monitoring accuracy. The Department routinely performs quality assurance and control checks

	Absolute Difference	% Difference
Median	0.0	0.0
75	1.0	11.8
90	2.0	40.0
95	4.0	66.7
Average	1.7	11.7

(QA/QC) on ambient sampling data. As part of the QA/QC procedures a replicate sample is often taken. For field samples a second aliquot is collected and tested immediately following the original samples. This process provides pairs of data that represent data collected at the same location at nearly the same time. The DEQ turbidity QA pairs for all stations over the last 10 years shows that typically there is very little difference between the paired samples (median difference = 0), but that over 25% of the time the paired samples exceed 10%.

## **3 Literature and Information Review of Impacts to Uses**

### **3.1 Overview**

This section of the report describes the data sources and data quality incorporated into this report, and the evaluated relationship between the measured effects (or endpoints) to the beneficial uses that are protected under Oregon Administrative Rules (OARs). The findings are summarized in tables and conclusions to provide an important part of the rationale for the proposed criteria numbers.

#### **3.1.1 Types and Quality of Information Used in the Evaluation**

*Data sources.* Literature was obtained using available DEQ materials, state library resources, computer database searches, as well as citations.

*Data quality.* Primary journal articles were used to evaluate aquatic life effects, and human-related visual and aesthetic effects. Qualifying studies for this evaluation included turbidity effects relative to control or background levels, and those that identified statistically significant effects directly attributable to turbidity (light and visual) influences. Studies characterizing physical (particle) effects are not included in this evaluation. Additional information regarding drinking water suitability, and treatment was gathered from drinking water treatment facility personnel.

Information in the literature regarding turbidity effects on aquatic life is most extensive for fish species, with less data regarding plants and macro-invertebrates. Both laboratory studies and field studies were evaluated. Most studies compared effects of elevated turbidity levels to a clear-water (low turbidity) control condition, as opposed to reporting the effects of turbidity measured as an increase above a range of turbidity levels in which test animals were intentionally acclimated. Meta analysis, such as the clear water fish assessment model (Newcombe, 2003), helps bridge some of the gaps in the overall literature.

Data regarding turbidity effects on drinking water treatment were obtained from written reports as well as information submitted by Oregon drinking water treatment facilities. There are approximately 375 surface water intakes for drinking water on rivers and reservoirs in the state that each serve at least 10 people (or involve more than 3 hookups).

Data regarding aquatic aesthetic and safety considerations and turbidity were obtained through the available literature. These are important considerations for recreation and tourism, as well as any commercial or resource management activities that are affected by water clarity conditions.

#### **3.1.2 Effects Endpoints and Beneficial Uses Considered in the Report**

Endpoints used in this evaluation represent biological or behavioral responses to turbidity by aquatic organisms in laboratory or field tests. Turbidity is also important to human beings with respect to drinking water, aesthetics, safety, and recreation. Table 3.1 lists the beneficial uses affected by turbidity and their potential adverse effects, along with the measured endpoints from laboratory and field studies considered in this report.

Turbidity endpoints were organized into three general categories: 1) impacts to aquatic life; 2) impacts to treatment processes such as drinking water treatment, or industrial-use treatment; and 3) aquatic aesthetic and safety considerations.

**Table 3.1** Endpoints used in determining adverse effects to beneficial uses

<b>Beneficial Use:</b>	<b>Endpoint:</b>	<b>Adverse Effect to:</b>
Resident Fish and Aquatic Life:		
<i>Plants</i>	Whole-stream respiration Photosynthesis, Productivity, Percent cover, Growth rate, Cell density	Growth  Survival
<i>Invertebrates</i>	Species density, Species richness	Reproduction
<i>Fish or other aquatic animals</i>	Reactive distance, Avoidance, Feeding behavior, Predator/prey interactions Growth rate	Ecological integrity
Water supply (and Aesthetics)	Treat-ability, Aesthetic acceptability	Treatment Cost Aesthetic quality
Water contact recreation Fishing Boating Aesthetics	Aesthetic acceptability, Visual recognition	Hazard identification and safety Aesthetic quality

### 3.1.3 Information Use in Evaluating Turbidity Effects and Developing Criteria

Effects from turbidity to aquatic life are summarized in Table 3.4. Effects levels from individual studies are characterized in order to develop water quality criteria that protect the most sensitive uses. A final summary table (Table 3.6) includes effects summaries from individual aquatic life studies, meta-analysis results, ambient turbidity level statistics, as well as optimal turbidity levels for other beneficial uses including water supply, safety, aesthetics, and recreation.

Studies regarding fish, invertebrates, and plants provided two types of turbidity effects information for review in this analysis. From many studies, a single turbidity value could be drawn indicating a statistically significant difference between a turbidity effect level based on a specific endpoint and a control, or in a few cases to a lower test level. In nearly all cases, the control level is “clear water” or approximately 0 NTUs. Where the lowest value tested shows a significant difference compared to the control, it is not certain precisely where the NOEL occurs. Data showing significance between test levels and higher level controls which might be interpreted to indicate acclimation capability in aquatic biota was limited.

What might be thought to be acute effects regarding turbidity were tested and observed with fish only, and pertain to behavioral changes such as reactive distance, avoidance, or feeding rates observed after five test days or less. Chronic effects for fish generally pertain to growth, or other biological responses observed after more than five test days. However, since acute effects data characterizes non-lethal endpoints that may be symptoms of long-term effects like growth, survival, and reproduction, most of the fish data (except alarm and avoidance effects) may be characterized as chronic. Invertebrate and plant endpoint data may also be characterized as chronic effects, with all data resulting from a two month test period or longer.

Characterizing the effects data as chronic should not imply that the duration of turbidity exposure is not important. Information reviewed for this evaluation considers long term (or continuous) exposures from anthropogenic sources in establishing criteria, as well as shorter term exposures, considering duration and magnitude of turbidity in providing guidance for anthropogenic inputs to be allowed under the rule.

Lowest observed effects levels (LOELs) were the lowest observed adverse effects levels observed in each study where a turbidity effect was manifested and statistically significant. NOELs (no observed effects level) are defined as the highest turbidity test level used in studies where no effects were observed. Effect levels,  $EL_{50}$ s and  $EL_{25}$ s, were calculated using regression curves, denoting turbidity levels with an effect that was estimated using an appropriate regression model as being 50% and 25% respectively, greater than that of the control (or lowest turbidity level tested). For example, the turbidity level at which the density of invertebrates is one half of the density for the control may be denoted as an  $EL_{50}$ .

While the terms like  $EL_{50}$  and  $EL_{25}$  are used to represent data in this analysis, this concept is not used in the traditional EPA approach to developing criteria, such as that outlined for toxics criteria in Stephen et al. (1985). That is because many endpoints regarding turbidity include behavioral effects that are not comparable or combinable in the way that lethal endpoints are used in determining toxics criteria. Therefore, the overall approach, as described above, weighs all of the evidence including single LOELs,  $EL_{50}$ s,  $EL_{25}$ s and other relationships from regression equations, and modeling. Potential protection levels for aquatic life are then compared to protection levels for other beneficial uses in developing the overall criteria.

Turbidity effects on both native Oregon fish and non-native species were evaluated in this report, with native species given more weight in proposed criteria where information is available. Flowing water species and tests were considered separately from non-flowing (lake) species and tests.

It should be noted that turbidity can also be an indicator (or surrogate) of potential physical sedimentation impacts to aquatic organisms and habitat. While this is not the primary factor considered in developing turbidity criterion alternatives, opportunities for protecting against severe sedimentation effects exist through the implementation of a turbidity criteria. [see Section 3.2.5.1 and Appendix H]

## **3.2 Aquatic life effects**

### **3.2.1 Stream Productivity**

Primary production is an important component of the food chain influencing food available for invertebrates and fish. Turbidity can decrease available light to plants. The USEPA based its 1976 turbidity criteria (same as the current EPA criteria) for 'freshwater aquatic life' on primary productivity: "Combined effect of color and turbidity should not change the compensation point more than 10 percent from its seasonally established norm, nor should such a change place more than 10% of the biomass of photosynthetic organisms below the compensation point".

### 3.2.1.1 Light Attenuation

The penetration of light through water is generally represented by the Beer-Lambert law:  $I_d = I_0 e^{-Kd}$ ; where  $I_0$  is the irradiance at the water surface,  $I_d$  is the irradiance with a penetration of light at depth =  $d$ , and where the light attenuation with depth is related to a constant ( $k$ ). The proportion of light making it through water is dependent on the constant attenuation ( $k$ ) rate which is dependent on turbidity. The relationship between light penetration and turbidity can be viewed as a curvilinear relationship; i.e., a 10% increase in turbidity is not equivalent with a 10% reduction in compensation depth (Figure 3.1; From Lloyd et al, 1987 ).

Lloyd et al (1987) observed that when turbidity in Alaskan lakes increased to above 5 NTUs, the 1% light compensation level decreased markedly in deeper waters, and continued to decrease but to a lesser degree as the turbidity increased to 25 NTUs and above. A seasonal 5 NTU increase in turbidity above clear water conditions reduced the productive euphotic volume (or volume of photosynthetically available radiation) of naturally clear lakes by as much as 80%. Biological systems and reduction in primary productivity does not necessarily follow a similar predictive cause and effect relationship with turbidity or the reduction of light, as discussed below. Primary productivity in shallow systems does not necessarily respond in the same way because light may still be available for growth throughout the water column.

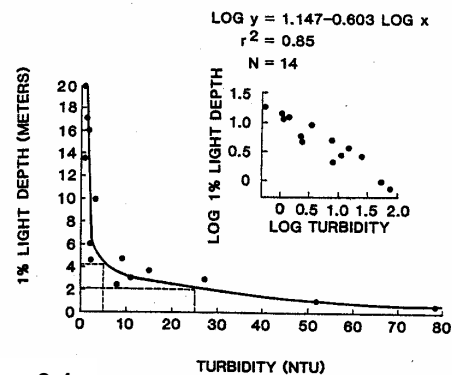


Figure 3.1 — Compensation (1% light) depth versus turbidity for several Alaskan lakes; NTU is nephelometric turbidity unit.

### 3.2.1.2 The Utility of and Light Compensation Depth as an Endpoint

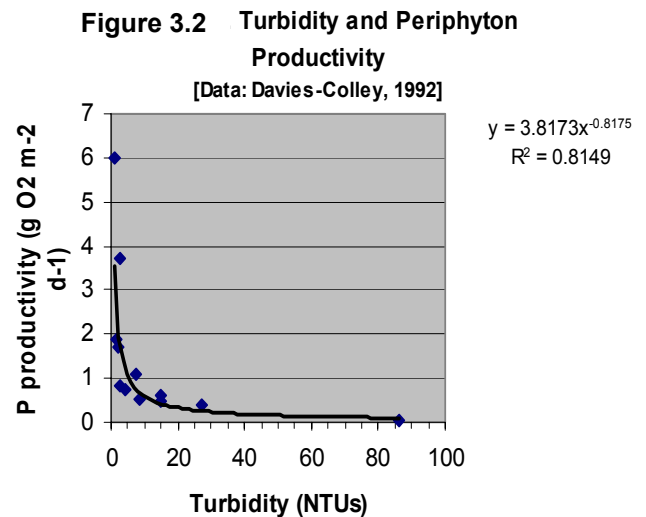
Recent research has discovered cases in which plants have shown an ability to grow under more turbid conditions than previously thought; with respect to suspended particles that have low absorption coefficients (Davies-Colley and Smith, 2001). A study by Parkhill and Gulliver (2002) showed that overall photosynthetic efficiency compensated for decreased irradiance on shallow systems (~0.2 meters) that they evaluated. Due to 'exceptions', Newcombe (2003) does not use light compensation depth as key variable in modeling for clear water fish protection. Fish reactive distance, a high trophic level indicator, was chosen instead. This is not to say that the effect of turbidity on primary productivity is not important. Rather, there do not exist universal relationships between light compensation depth (or turbidity) and primary productivity. There may exist relationships predictive of local turbidity condition effects on primary productivity, such as that developed with the data from the Davies-Colley et al. (1992) study, described below.

### 3.2.1.3 Effects of Turbidity on Primary Productivity

Increased turbidity has been shown to influence aquatic primary production. Some of the initial work describing these effects was done by Lloyd (1987) regarding streams in Alaska, with information gathered for the study indicating that a 5 NTU increase in turbidity (above clear water conditions ~0 NTUs) could potentially decrease primary productivity in clear streams by 3-13%, and a 25 NTU increase could decrease primary productivity in clear streams by 13-50 %, with negative effects on primary production in streams predicted to be even larger at depths of greater than 0.5 meters. A 5 NTU increase in turbidity reduced the productive euphotic volume of naturally clear lakes by as much

as 80%, and chlorophyll-a concentration decreased significantly in glacially turbid lakes with decreased euphotic volume. This suggests that clear water lakes (<5 NTUs) are potentially susceptible to the high impacts on primary productivity from low level turbidity increases. Lloyd (1987) concluded that moderate levels of protection would be approximately 25 NTUs and 5 NTUs above natural conditions in streams and lakes, respectively. A high level of protection would be 5 NTUs above natural conditions in streams and lakes.

A field study by Davies-Colley et al. (1992) on a stream receiving seasonal long increases in turbidity where primary production was limited by available light showed reduced proclivity related to turbidity. Significant downstream decreases at all six study sites in periphyton productivity (g O<sub>2</sub>/m/day), and biomass (mg/m<sup>2</sup>) which correlated strongly with maximum gross photosynthetic production; pairing 5 upstream sites (low turbidity) with 5 high turbidity downstream sites (R<sup>2</sup>=0.99). Increases in turbidity were thought by the authors to be responsible for both parameter decreases due to light shading. The stream waters were also highly colored from organic material (humic), but color (as well as nutrient levels and other sources of shading) was ruled out as a factor affecting periphyton productivity and biomass.



When all of the data from Davies-Colley et al. (1992) was pooled for this review the periphyton primary productivity was correlated with turbidity ( $r^2=0.815$ ) with an estimated EL<sub>50</sub> of 2.6 NTUs and an EL<sub>25</sub> of 1.6 NTUs (Figure 3.2), and with periphyton biomass productivity (R<sup>2</sup>=0.703) with an estimated EL<sub>50</sub> of 3.5 NTUs; with all values representing long-term effects. These observations indicate that low level increases in turbidity that occurred for an extended period can have a large impact on primary productivity on streams where production is light limited.

Although the observed relationship reflect the site specific conditions observed during the study and at the study site the authors note that their results may be comparable to Alaskan streams >0.5 meters in depth based on findings reported in Lloyd et al. (1987). Plant production versus turbidity levels in waters of depths of 0.5 meters or less are depicted in Figure 3.3 from Lloyd et al. (1987).

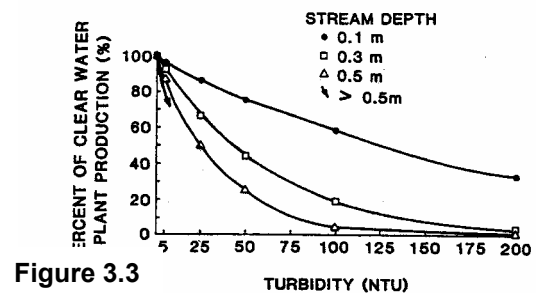


FIGURE 5.—Reduction in plant production with increased turbidity in artificially turbid streams of various depths in interior Alaska (derived from equation 7); NTU is nephelometric turbidity unit.

The Parkhill and Gulliver (2002) study produced a mix of results regarding effects of suspended sediments on aquatic communities. They concluded that daily photosynthetic production was not significantly different between treatments of up to 35 NTUs compared to controls of 5 to 10 NTUs, probably due to increased photosynthetic efficiency at higher turbidity levels. According to the authors, this disagrees with one of Lloyd's hypothesis basically saying the opposite, but agrees with several other authors cited in the report. While autotrophic productivity might be less affected due to increased photosynthetic efficiency, the authors did state that the whole-stream metabolism in the test streams confirmed that even small loads of sediment in the system decreased overall biological activity in streams. The study did show periphyton biomass (chl a) and percent cover of macrophytes was significantly decreased in higher turbidity treatments compared to controls. The authors suggested that several factors influence the relationship between light and photosynthesis including photosynthetic

efficiency, nutrients associated with suspended solids, photo-inhibition, and changes in plant location or species distribution, among other factors.

### 3.2.2 Invertebrates

Increased turbidity could influence the presence and diversity of invertebrate species directly or through indirect impact on primary productivity. The limited data reviewed for this report suggests that Oregon water bodies are represented by macro invertebrates that rely on algal or primary production to survive (Mochan, 2000; and Hubler, 2000).

A substantial body of literature addresses the influence of sediment and sedimentation on invertebrates. There is less literature addressing the influence of turbidity. The effect of turbidity or suspended sediments on the magnitude of drift (macro-invertebrate movement in the current) has been documented. Waters (1995) and Birtwell et al. (1984) found that invertebrate drift increased with increasing turbidity. Culp et al. (1986) showed increasing macroinvertebrate drift with increasing fine sediments with results also indicating that benthic macroinvertebrate density and diversity in the benthos was reduced. Increased drift and its influence on fish feeding are discussed in the Fish Behavioral Effects section (see Reactive Distance).

One study was reviewed that evaluated the direct impacts of long-term turbidity exposure on macro-invertebrates. Quinn et al (1992) determined that invertebrate densities and taxonomic richness decreased at higher turbidity (downstream) sites. Invertebrate density decreased significantly between all downstream sites with median turbidities of from 7 to 154 NTUs higher than upstream sites (median 0.9 – 4 NTUs).

Invertebrate taxonomic richness decreased significantly between all but two downstream sites with median turbidities of from 23 to 154 NTUs higher than upstream sites. Since the sites with the lowest downstream increases in turbidity exhibited significant declines in densities (>55% decrease), the negative effects could potentially occur at lower turbidity level increases. Study test animal bodies and gills were clean of sediments, ruling out direct sedimentation effects. It was surmised by the authors that lower epilithon biomass and productivity, and degraded food quality, all potentially affected by turbidity, was the likely explanation for the decreased invertebrate densities. Other factors, including nutrient levels, color, or other sources of shade were ruled out as causing the effect.

Figure 3.4

Turbidity and Benthic Invertebrate Densities [Data: Quinn et al, 1992]

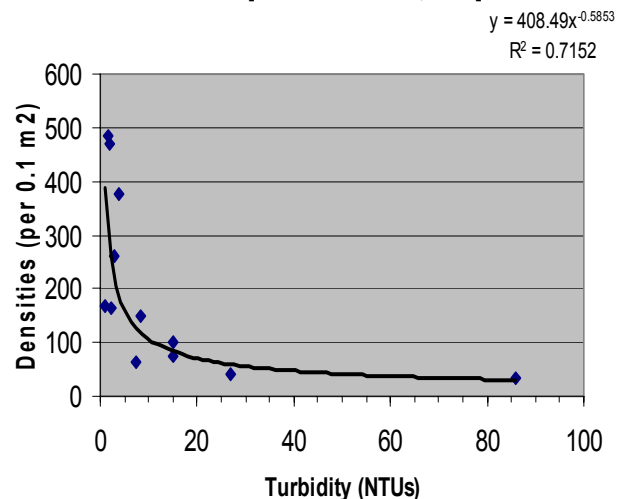
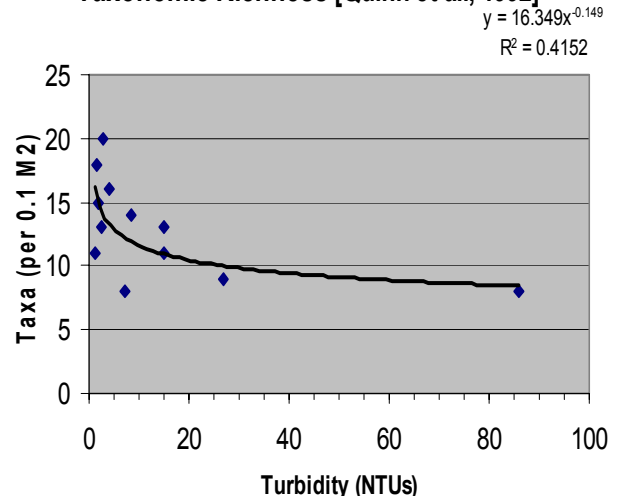


Figure 3.5

Turbidity and Benthic Invertebrate Taxonomic Richness [Quinn et al., 1992]



When all the data from Quinn’s test and control studies were pooled for this report, turbidity was found to be correlated with both invertebrate density (Figure 3.4;  $r^2=0.72$ ) and richness (Figure 3.5;  $r^2=0.415$ ). As turbidity increased from 1.1 to 3.7 NTUs invertebrate densities decreased by approximately one half, resulting in an estimated  $EL_{50}$  of 3.7 ( $EL_{25} = 1.8$ ).

Taxonomic richness (Figure 3.5) was also decreased at higher turbidity levels with approximately half of the species eliminated at around 25 NTUs, and approximately 25% gone at a turbidity level of 3 NTUs ( $EL_{50} = 25$  NTUs;  $EL_{25} = 3$  NTUs). The streams studies were shallow streams (0.2 – 0.4 meters), so turbidity effects could be different in deeper waters or systems with different plant communities adapted to lower light conditions prevail and provide adequate food base for macroinvertebrates. The authors also suggested that overall shading effects may be greater in humic colored waters, such as those in the study site, than in non-humic colored waters.

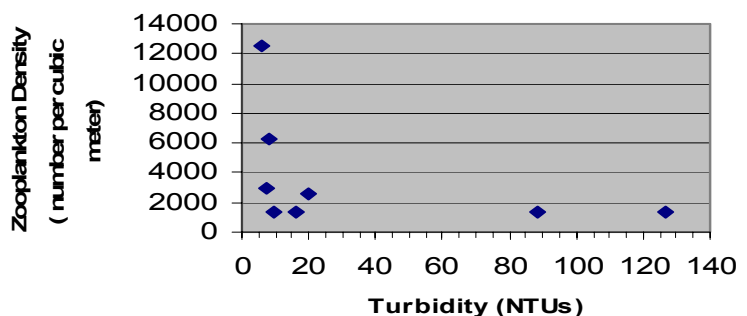
The Oregon Department of Environmental Quality (DEQ) compared observed biotic integrity measurement with observed winter turbidity measurement in a study completed in 1997 (Mulvey and Hamel, 1998). North and Mid Coast streams with high maximum turbidities in the winter (> 60 NTUs) showed lower biological integrity (density and richness of species) for macro invertebrates and fish compared to minimally impaired reference sites. Turbidity versus direct sedimentation impacts were not separated in this field study.

A preliminary evaluation by DEQ comparing turbidity levels to biotic indices in small Oregon streams indicates that ‘poor’ conditions for invertebrates occurred at turbidity levels of approximately 10 NTUs and greater (Doug Drake’s (DEQ) personal communication). “Poor” denotes biologically impaired conditions and was established as the 25<sup>th</sup> percentile of the distribution of indices data from reference sites. The 25<sup>th</sup> percentile was used because the reference site conditions were considered to be impacted by human disturbance; i.e. not pristine sites. This relationship may not be assumed to be a direct causal relationship with turbidity since other variables were also associated with declines in vertebrate conditions; the most important being channel-bottom fines and total suspended solids, both potentially related to turbidity levels.

Lloyd et al. (1985) concluded that the lack of aquatic insects found in the stomachs of Arctic grayling in turbid waters, discussed in the *Fish* section of this report, was probably the result of a lack of macro invertebrates resulting from turbidity, or an inability of the fish to locate prey in turbid waters, or both.

Lloyd et al. (1987) studying lakes in Alaska noted that data indicated that zooplankton densities and turbidity were strongly linked. The turbidity and zooplankton relationship was extrapolated from comparisons to the 1% light compensation depth data presented in Figure 3.6. Turbid lakes exhibited as little as 5% of the zooplankton densities often associated with clear lakes.

**Figure 3.6 Turbidity and Zooplankton Density [Data: Loyd et al., 1987]**



### 3.2.3 Fish

Direct turbidity effects to fish are mostly visibility-related, causing behavioral changes with respect to maneuverability or migration, feeding, predation, and/or escape. Behavioral effects could lead to use impairment through physiological or population effects by reduced or less efficient feeding leading to

reduced growth, avoidance and habitat abandonment, interspecific competition, or other effects. Indirect effects to fish include food-chain impacts discussed above with respect to reductions in primary and secondary productivity including macro-invertebrate densities.

### 3.2.3.1 Fish Behavioral Effects

**Reactive(Reaction) Distance and Contrast Degradation theory.** Turbidity may influence fish behavior by reducing the ability of visually oriented fish to see and capture prey. The behavioral effects could reduce feeding ability, influence feeding mechanism, reduce growth and thereby degrade beneficial uses.

The term contrast degradation theory has been used to describe the relationship between available light and the reaction distance at which fish perceive and react to potential prey items. The importance of contrast between the prey and its background with respect to prey recognition and capture under various light and turbidity conditions was studied by Vogel and Beauchamp (1999). They determined that reaction distances in lake trout were maximized under relatively low light conditions that roughly corresponded to ambient midday light intensities occurring at 10-40 meters below the water surface. Light intensities at or above this condition ( $\geq 17.8$  lx) caused a decrease in reaction distances at 3.18 and 7.40 NTUs but not at the lowest turbidity level tested (0.9 NTUs). The decrease in reaction distance was thought to result from increased backscatter from increasing light on turbidity causing particles that reduced the contrast between the prey and its background.

De Robertis et al (2003) state that “contrast degradation theory predicts that increased turbidity decreases the visibility of objects at longer distances more than that of objects that are visible at short distances. Consequently, turbidity should disproportionately decrease feeding rates of piscivorous fish, which feed on larger and more visible prey than particle-feeding planctivorous fish”. Utne-Palm (2002) suggest that the positive effect of turbidity is pronounced for larval fish due to a short field of vision and fewer particles scattering light between them and their prey, and that this positive effect of prey contrast is dependent on “the optical properties, scattering properties of suspended particles and the visual sensitivity of the predator”. This, along with decreased predation from larger fish may help explain the positive effects of turbidity on juvenile species (see **Foraging** subsection, below).

Several authors suggest that reactive distance, the distance at fish visually recognize and respond to a particular prey item provides an important, if not a key variable in fish predator-prey interactions (Newcombe, 2003). Sweka and Hartman (2001a) developed a model based on the measured reaction distance of *Salvelinus fontinalis* (Brook trout) decreasing exponentially with increasing turbidity (Figure 3.7), indicating that the prey density would have to increase exponentially as reactive distance decreased in order to maintain a constant encounter rate. While drifting invertebrate densities may increase with increasing turbidity as discussed in the invertebrate section above, the authors concluded that the densities would have to increase exponentially as reactive distance decreased in order to maintain a constant encounter rate. While drifting invertebrate densities may increase with increasing turbidity as discussed in the invertebrate section above, the authors concluded that the densities would have to increase by a factor of 16 at 20 NTUs to compensate for the reduction in

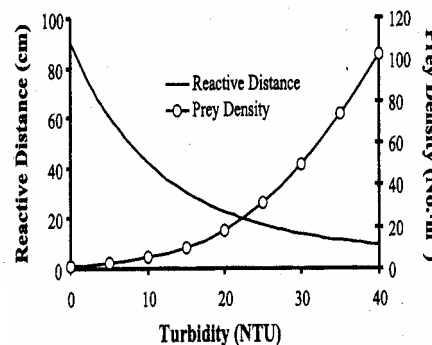
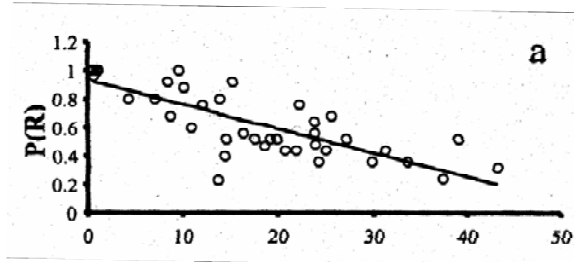


Figure 3.7

FIGURE 2.—Relationships between (1) turbidity and the reactive distance of brook trout and (2) turbidity and the prey density necessary to maintain a constant encounter rate between predator and prey if the predator does not increase swimming activity. Density is that needed to maintain a mean ( $\pm 95\%$  confidence interval) encounter rate of  $0.18 \pm 0.02$  prey/s, as calculated for brook trout in clear water ( $< 5$  nephelometric turbidity units).

reactive distance, field of view, and encounter rates. They stated it would be unlikely that these increases would occur to enable the same feeding capability observed under clear water conditions.

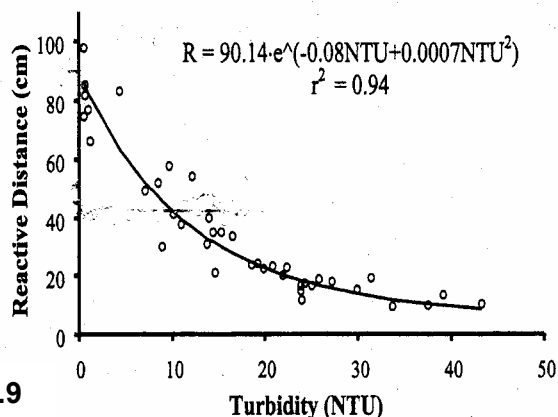
The Sweka and Hartman (2001a) study indicated that the probability of reacting to prey decreased linearly with turbidity as shown in Figure 3.8 (ANOVA:  $F_{1,33} = 121.36$ ;  $P < 0.01$ ) from Sweka and Hartman (2001a). Turbidity did not influence the probability of an attack once prey were within reaction distance, the probability of a capture once the prey item was attacked, or the probability of ingesting a captured item. The authors used groups of three fish in each trial in order to prompt the most immediate, and thus most accurate reaction distance response, assuming that a single fish might wait longer after initial recognition of prey before eliciting a noticeable reaction, and that competition for prey may lessen the lag-period. The appearance of the test tank background was darkened in order to provide enough contrast for visual recognition under low turbidity conditions.



**Figure 3.8** Turbidity and the probability of a brook trout reacting to a prey item (Sweka and Hartman, 2001a)

Sweka and Hartman (2001a) stated that if prey density is not increased proportionally to increased turbidity, then the feeding strategy of the fish must change from drift feeding which is low energy intensive, to an active feeding strategy which is high energy intensive, reducing the net energy gain from each prey item consumed.

Brook trout reactive distance decreased significantly at 10 NTUs, the lowest test level, compared to the control (0 NTUs), and with regressed data presented in Figure 3.9 (Sweka and Hartman, 2001a). Brook trout are an introduced cold-water species related to native *Salvelinus confluentus* (Bull trout) for which no 'reactive distance' data was available. An EL50 of ~10 NTUs for reactive distance was estimated from the study data and Figure 3.9.



**Figure 3.9**

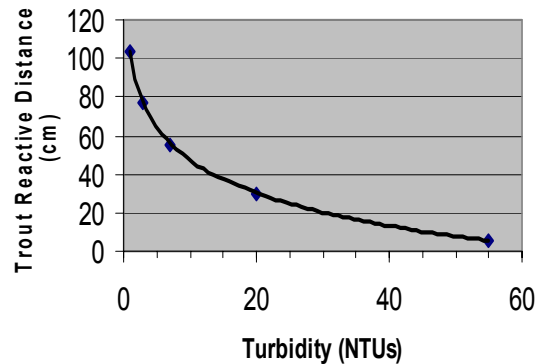
FIGURE 1.—Model describing the reactive distance of brook trout at turbidity levels ranging from 0 to 43 nephelometric turbidity units (NTU). Data from two depths (15 and 25 cm) and all turbidity levels were pooled for model estimation ( $N = 39$ ).

Rainbow Trout (*Oncorhynchus mykiss*) showed reduced reactive distance the lowest levels tested (15 NTUs and 30 NTUs), with 20% and 55% reductions (each statistically significant) in reactive distance, respectively, compared to the ambient turbidity (or control: 4-6 NTUs) Barrett et al. (1992); observed *Oncorhynchus kisutch* (Coho salmon), having a statistically significant decrease in reactive distance at 20 NTUs, the lowest level tested compared to the control, 0 NTUs (Berg and Northcote, 1985); *Oncorhynchus tshawytscha* (Chinook salmon), authors developed the relationship:  $RD = 31.64 - 13.31 (\log T)$ ,  $r^2 = 0.98$  using 14 treatment medians, where RD is the reactive distance, and T in the turbidity in NTUs, testing 0.5 to 243 NTUs (Gregory and Northcote, 1993). An EL50 of 10 NTUs was estimated for this report from the log-linear relationship developed by the authors. In all of these tests the fish responded to reactive distance at the lowest turbidity levels tested suggesting that even low level increases in turbidity may reduce reactive distance under appropriate light conditions.

Newcombe (2003) developed the following relationship between turbidity and reactive distance, based on available data pooled from Brook trout and Lake trout (both introduced chars), and rainbow trout (native salmonid): reactive distance =  $103.7342 - 24.7067 \log_e \text{NTUs}$  ( $R^2 = 0.86$ ). A turbidity increase from 1 NTU to 7 NTUs decreases the reactive distance by approximately one half, resulting in an estimated EL50 of ~7 NTUs (Figure 3.10).

**Figure 3.10** Turbidity and Trout Reactive Distance

[data: Newcombe (2003)]

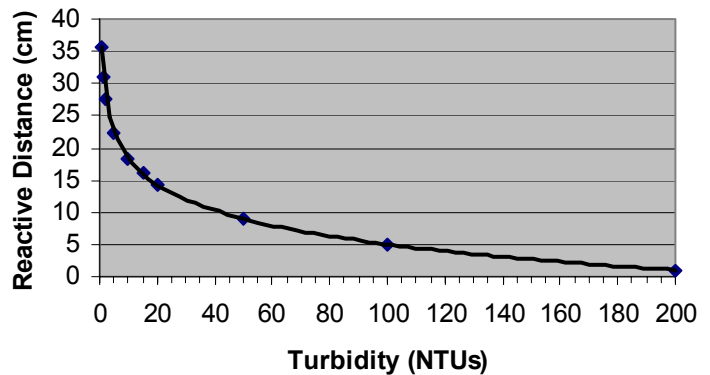


Similar information regarding turbidity and the reactive distance of juvenile Chinook salmon from Gregory and Northcote (1993) is illustrated in Figure 3.11. At 10 NTUs, the reactive distance is approximately 18 cm, or about one half of the reactive distance observed at 0.5 NTUs.

**Figure 3.11**

**Turbidity and Juvenile Chinook Salmon**

**Reactive Distance** [data: Gregory and Northcote, 1993;  $RD = 31.64 - \log T$ ,  $r^2 = 0.98$ ]



Vogel and Beauchamp (1999) observed that *Salvelinus namaycush* (Lake trout) reactive distance LOEL was 3 NTUs. Lake trout are an introduced species in Oregon, and related to other Oregon *Salvelinus*: Brook trout (introduced) and Bull trout (native).

**Foraging Behavior.** Reactive distance studies indicate that during low turbidity background conditions, small increases in turbidity can decrease reaction distance, and that reaction distance may influence other behaviors affecting predator/prey interactions. For example, turbidity can reduce feeding rates of visually oriented fish, or result in a shift in feeding strategies. These strategies may be less efficient resulting in reduced success and reduced growth rates. However, some fish, especially juveniles may experience positive effects of increased turbidity on their ability to feed and also escape predation.

*Oncorhynchus kisutch* (Coho Salmon) saw a significant decrease in prey capture success, and a significant decrease in feeding rate (~20%), at the lowest level tested (20 NTUs) compared to the control, 0 NTUs (Berg and Northcote 1985). The reactive distance data from the same study showed a significant decrease in reactive distance at the lowest NTU level tested, 20 NTUs, ~50% of reactive distance at 0 NTUs. At 30 NTUs, the decrease in feeding rate was approximately 40%, as compared to the control.

Surface and benthic feeding rates of juvenile chinook salmon (all size categories combined) on prey (*Drosophila*, 10-minute test; and *Tubifex*, 5-minute test) increased significantly at turbidity levels of 35-150 NTUs compared to rates at <1 NTU and 810 NTUs (Gregory and Northcote, 1993). In both cases, a large proportion (>60%) of fish at the <1 and 810 NTUs did not feed at all. The authors suggested that higher turbidity levels afforded a reduced perception of potential risk by both predators and prey. Planktonic foraging on *Artemia* was highest at all low treatment levels (<1 – 70 NTUs) but not significantly decreased (compared to low levels) until the turbidity reached 350 NTUs (1 minute test). Percent feeding was fairly even (~ 100%) for all turbidity level treatments regarding planktonic feeding.

In a follow-up study, illustrated in Figure 3.12 juvenile Chinook salmon were evaluated according to the size of the fish (divided into three categories based on the mean fork length), the results did not vary greatly between size categories regarding planktonic feeding on *Artemia* (Gregory, 1994). However, fish in the two smallest size categories surface feeding on *Drosophila* behaved differently than as described in the earlier publication, with the greatest feeding rate observed at the lowest turbidity level (<1 NTU) with the feeding rate declining with increasing turbidity [ NTUs tested: <1, 18, 35, 70, 150, 370, and 810] . Benthic foraging on *Tubifex* resulted in the highest feeding rates for all size categories occurring between 18 and 150 NTUs, but without the pronounced dome-shaped curve relationship for the two smaller fish groups that was seen for the largest fish group (the dome-shaped curve depicts low foraging at the extremes, the low and high turbidity levels, with the greatest foraging rates occurring in the intermediate turbidity levels, as described above). Gregory (1994) discussed many factors regarding predator-prey relationships and turbidity including acclimation to water clarity conditions, fish size, feeding ability, and visual ability, and the use of turbid waters as cover. Foraging rate was thought to be controlled by two main factors, visual ability and perceived risk. Visual ability is fairly straightforward and can be measured as reactive distance. However, perceived risk is much more complicated and may change over the life of a fish, and depend on its role as prey or predator.

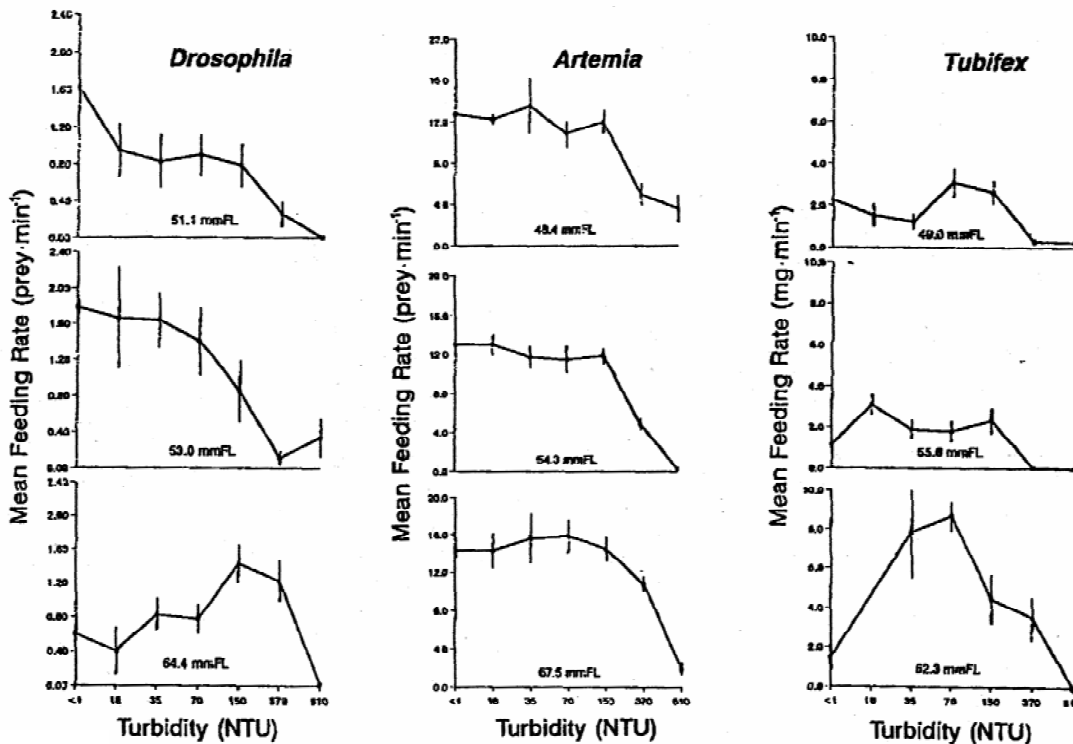


Figure 3.12

Figure 2. The effect of turbidity on the mean feeding rate of juvenile chinook salmon on surface, planktonic, and benthic prey in 70-l aquaria, in trials representing three forager sizes (n = 8 for each treatment in each trial; bars denote standard error [SE]; chinook sizes are trial means).

*Salvelinus fontinalis* (Brook trout; non-native) exhibited a “transition from a typical drift-feeding strategy to an active searching strategy” at between 10 and 20 NTUs (Sweka and Hartman, 2001b). This change in activity was thought to cause the observed reduction in fish growth; shifting to a high energy intensive feeding method reducing the net energy gain from each prey item consumed. Changes in feeding rates may also influence beneficial uses by influencing intraspecific competition. Native *Oncorhynchus clarki henshawi* (Lahontan Cutthroat Trout), and *Richardsonius egregius* (Lahontan redbay shiner) feeding rate(s) decreased significantly from low levels (3.5, 6, and 10 NTUs) compared

to levels of 20 NTUs and greater in Summit Lake, Nevada (Vinyard and Yuan,1996). Predation rates decreased by 80% between the 3.5 NTU and 25 NTU test levels (multiple regression:  $F=35.1$ ,  $P<0.001$ ). While the difference between 3, 6, and 10 NTUs was not tested for statistical significance, the following relationship between turbidity and predation rate was noted: At 3.5 NTUs, 80 to 100 % of potential prey were consumed; at 6 NTUs, 75 to 95% of prey were consumed; and at 10 NTUs, 65 to 90 % of prey were consumed. Feeding rates were greater for the shiner than for trout at all turbidity levels tested, with shiner consumption of large prey items greater than trout at the highest turbidity levels tested (25 NTUs); which was thought to help explain why the shiner has been more successful than the trout in 'recent' times.

The mean feeding rate of non-native *Galaxius fasciatus* (Banded kokopu), decreased significantly at 10 NTUs (~25%), the lowest level tested ( $p<0.05$ ) and at 20 NTUs (~36%;  $p<0.001$ ) compared to the control, 0 NTUs (Rowe and Dean 1998). The authors have suggested that the reduction of feeding at 20 NTUs was 'ecologically significant'. Results regarding four other species tested indicated that feeding was reduced with increasing turbidity levels; but only for the Banded kokopu and inanga (at 640 NTUs) were differences significant compared to the control. The red-finned bully exhibited a significantly increased feeding rate at 40 NTUs compared to the control, followed by a decline in the feeding rate as the turbidity continued to increase.

The behavioral response of fish, especially juveniles, to turbidity may be dependent on whether they perceive themselves as prey or predators. Favorable responses to turbidity reported in the literature, mostly involve reduced predation on larval or other developmental stages of fish species including suckers, fathead minnows, and salmonids are shown in Table 3.2. Observed increase in feeding rates may be due to reduced perception of predation.

**Table 3.2** Favorable responses by fish to elevated turbidity levels reported in the literature.

Fish species	Native	Response and NTU level reported	Reference
<i>Oncorhynchus spp.</i> (Salmon)	Y	Juvenile salmon (age-0) were less likely to be preyed upon and consumed in more turbid Frazier River waters (27-108 NTUs) compared to clearer Harrison River (<1 NTUs) and Nicomen Slough waters (1-6 NTUs)	Gregory and Levings, 1998
<i>Oncorhynchus tshawytscha</i> (Chinook Salmon)	Y	Juvenile Chinook salmon (all size categories combined) had significantly higher foraging rates on surface prey ( <i>Drosophila</i> ) at 35-150 NTUs compared to the clear water control (<1 NTU).	Gregory and Northcote, 1993
<i>Oncorhynchus tshawytscha</i> (Chinook Salmon)	Y	Juvenile Chinook salmon (all size categories combined) had significantly higher foraging rates on benthic prey ( <i>Tubifex</i> ) at 35-150 NTUs compared to the clear water control (<1 NTU).	Gregory and Northcote, 1993
<i>Oncorhynchus tshawytscha</i> (Chinook Salmon)	Y	Juvenile Chinook salmon occupying a turbid water treatment (~22 NTUs) had a lower magnitude and duration of response to perceived predator exposure (birds) than in clear water (<1 NTU).	Gregory, 1993
<i>Pimphales promelas</i> (Fathead Minnow)	N	No measurable change in predation at 11 NTUs (turbid condition) of minnows by <i>perca flavescens</i> (yellow perch) compared to the clear water control. However, the proportion of smaller prey captured in the clear water condition did increase significantly compared to the 11 NTU treatment.	Abrahams and Kattenfeld, 1997
<i>Pimphales promelas</i> (Fathead Minnow)	N	Anti-predator behavior, assumed to be costly to growth, was observed to be less in the turbid water condition (13 NTUs) compared to the clear water control.	Abrahams and Kattenfeld, 1997
<i>Xyrauchen texanus</i> (Razorback Sucker)	N	Predation by sunfish and squawfish was less at 68 NTUs compared to clear waters.	Johnson and Hines, 1999

**Avoidance/alarm/social organization effects:** *Oncorhynchus tshawytscha* (Chinook salmon) changed their location(s) and distribution in an experimental tank, and reacted "less markedly" and for a shorter duration to predation risks in the more turbid test environment of 23 NTUs (23 NTUs was the lowest turbidity level tested compared to the control, <1 NTU (Gregory, 1993). Juvenile *Oncorhynchus kisutch* (Coho salmon) that were acclimated to clear water conditions (< 0.3 NTUs) exhibited significant

avoidance response to suspended sediment introduction into an experimental tank at ~ 70 NTUs, while similar test fish that were acclimated to more turbid water conditions (2 - 15 NTUs) exhibited significant avoidance response at ~ 100 NTUs (Bisson and Bilby 1982). The authors also concluded that juvenile cohos did not prefer more turbid water condition (10-20 NTUs) over clear conditions (~0 NTUs) even if they had been acclimated to more turbid conditions (2-15 NTUs).

Laboratory studies involving non-native species exhibited avoidance response at the lowest NTU levels tested, based on available information: migratory *Galaxius fasciatus* (Banded kokopu) and *Galaxius brevipinnis* (koaro) each had LOELs of approximately 13 NTUs (Boubee et al. 1997). The authors estimated EL<sub>25</sub>s and EL<sub>50</sub>s of 6.7 and 17-24.6 (~20) NTUs, respectively, for Banded kokopu, and 6.5 and 69.2 (±6.11) NTUs, respectively, for koaro.

As turbidity increases and the reactive distance approaches zero, normal clear water behavior patterns tend to break down (Berg and Northcote, 1985; Sweka and Hartman, 2001). Coho salmon dominance hierarchies broke down when fish were subjected to 30 – 60 NTUs for at least one day, and re-established when turbidity was returned to 0 – 20 NTUs (Berg and Northcote, 1985). The authors stated, “The fitness of salmonid populations exposed to short-term pulses of suspended sediments may be impaired”. A sudden pulse of turbidity that quickly introduced 60 NTUs to an otherwise clear arena caused fish to initially swim upstream toward the pulse to investigate, and then drift downstream to remain in clear water as long as possible, then exhibiting alarmed behavior with some fish entering the gravel for several hours.

### 3.2.3.2 Fish Physiological Effects

Reduced growth is often used as a measure of when potential impacts result in a physiological impact that may influence beneficial uses. Increased turbidity may influence growth through changes in feeding behavior, stress, or other behaviors.

In a study conducted by Sweka and Hartman (2001b), growth rates in Brook trout decreased significantly with increasing turbidity in five-day tests, exhibiting a 62% decrease in growth rates between the highest level tested (40 NTUs) and the clear water control. Growth did not appear to be affected by mean daily consumption or encounter rates. The authors concluded that a transition to active feeding which was observed between 10 and 20 NTUs caused growth rates to decrease with increasing turbidity. Active feeding is more energy intensive than drift feeding, resulting in less energy gained per prey item. An EL<sub>50</sub> of 25 NTUs was estimated for this report from the author's regression equation: specific growth rate = 0.051 – 0.001(NTUs); R<sup>2</sup> = 0.48. Observed growth rates were less than those predicted by the model, with increasing differences at increasing turbidity test levels, highlighting the importance of the effect of turbidity increases on abiotic factors such as activity rates and feeding strategies.

In two separate laboratory tests, one using straight 'raceway' channels and one using oval channels, weight and length of *Oncorhynchus kisutch* (Coho Salmon) were significantly decreased at the lowest turbidity test levels, compared to clear test waters (Sigler et al., 1984). In raceway channels at 11-32 NTUs, the length and weight increases were decreased by approximately 22-33% (upper-lower channel), and 50-65% (upper-lower channel), respectively, in a 14-day study, as compared to the clear water control. In Oval channels the length and weight increases were decreased by approximately 55% and 45% at 22 NTUs, respectively, in an 11-day study, and by approximately 58% and 90% at 23 NTUs, respectively, in a 15 day study, as compared to the clear water control. While fewer fish were observed in 9 out of 10 tests across a range of turbidity levels (11-86 NTUs) compared to the clear water control for both test types, results were not statistically significant. However, in raceway channels, the biomass, in grams per meter, was significantly reduced across the range of test levels (11-49 NTUs), compared to the clear water control. In the same study, laboratory tests using straight 'raceway' channels, weight and length increases of *Oncorhynchus mykiss* (Steelhead Trout) were

significantly decreased in turbid waters (38 NTUs, the lowest test level) compared to clear test waters; the length and weight increases were decreased by approximately 46-42% (upper-lower channel), and 61-62% (upper-lower channel), respectively, in a 19-day study, as compared to the clear water control. Sigler et al. (1984) observed that more steelheads stayed in clear water channels than in turbid channels in all tests.

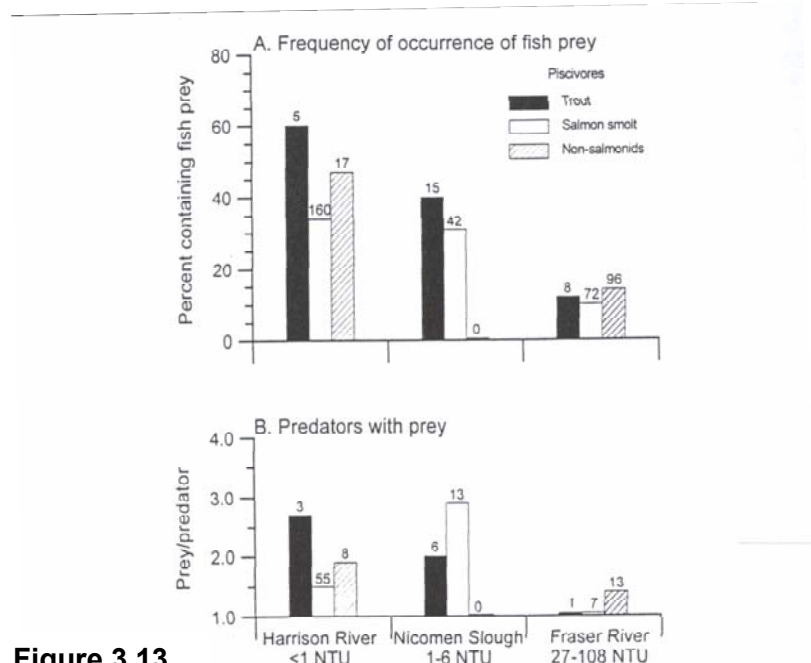
### 3.2.3.3 Fish Survival: Large Scale Ecosystem Findings

Field studies may be used to help describe when behavioral or physiological impacts observed in laboratory studies exhibit demonstrable impairment to beneficial uses. Field studies have documented reduced primary production leading to reduced fish populations, or from changes in predation.

Only a few studies have connected turbidity to food chain dynamics and fish productivity. Lloyd et al. (1987) observed in Alaskan lakes that euphotic volume (water body surface area \*the depth to which 1% of the subsurface light penetrates) is related to total phytoplankton production (chlorophyll a), which in turn influences zooplankton density, and then can limit smolt production (juvenile *Oncorhynchus nerka nerka*, sockeye salmon) over a long-term or seasonal time period. Juvenile smolt production in lakes decreased significantly with decreasing

euphotic volume (linear equation:  $R^2=0.99$ ). A 5 NTU increase in turbidity reduced the productive euphotic volume of naturally clear lakes by as much as 80%. Chlorophyll-a concentrations in glacially turbid lakes with decreased euphotic volume were significantly less than clear lakes. Zooplankton densities in turbid glacially fed lakes were as little as 5% of those in clear lakes (also, see Figure 3.6). Lloyd et al. (1987) also reported that in streams where euphotic volume and primary productivity are also strongly influenced by turbidity, arctic grayling were absent from reaches below mines (with average turbidities ranging from 75 to 727 NTUs). Un-mined reaches (averaging from 1.3 to 2.7 NTUs) had 0.5 to 8.7 grayling per haul.

[See the Plant and Invertebrate sections]



**Figure 3.13**

FIGURE 3.—(A) Percentage of adult trout, salmon smolts, and nonsalmonid piscivores that consumed fish prey in the Harrison River, Fraser River, and Nicomen Slough areas, British Columbia, 25 April and 15 May 1991. (B) Number of prey consumed per predator among those with at least one fish prey in the stomach. Numbers above bars indicate the number of predators examined: NTU = nephelometric turbidity units.

The studies done in Alaska on both flowing systems and lakes are important in that they trace the effect of turbidity in autochthonous systems through the food chain hierarchy. Oregon stream systems are variable and may rely on both autochthonous and allochthonous contributions to the food chain, with the emphasis shifting between the two contributions throughout the year due to seasonal stream conditions (see more above under **Plants**). Studies have shown that the reduction of stream shade and the increase of sunlight to streams can increase salmonid production due to increases in primary productivity (Holtby, 1988; Tschaplinski, 1999). Gregory and Levings (1998) study conducted in British Columbia found that predation by fish species, including salmonids [*Oncorhynchus clarki* (Cutthroat trout), *Oncorhynchus mykiss* (Rainbow trout), *Oncorhynchus tshawytscha* (Chinook salmon), and *Oncorhynchus kisutch* (Coho salmon)], was significantly less in the most turbid study, the Fraser River,

SW British Columbia (27 to 108 NTUs) than predation in a clear water site, the Harrison River (<1 NTU), and a low turbidity site, the Nicomen Slough (1-6 NTUs) as depicted in Figure 3.13 from Gregory and Levings (1998). Predation by salmonids at the Fraser River site remained consistently low (relative to the two other study sites) during the period when turbidity was ~27 NTUs; i.e. no temporal or spatial differences in predation rates. *Ptychocheilus oregonensis* (Northern Squawfish), a native Oregon species, was the most successful predator in turbid waters, probably due to the use of olfaction, as well as vision, to locate prey.

Significant results were measured in two ways: first, of the 491 fish caught for the survey, the percentage of adult trout, salmon smolts and non-salmonid piscivores (89% salmonids overall) that had at least one prey item in their gut from each site was compared; and second, of those with at least one ingested prey item, the number of prey items per predator for each site was compared (Figure 3.12). The percentage of prey-containing salmonids from the two clearest water sites was approximately 3-5 times greater than from the high-turbidity Fraser River site. Of the fish with at least one ingested prey item, the numbers of ingested prey in salmonids were approximately 1.5 to 3 times greater than from the Fraser River site. Of the more than 35,000 fish caught (75% salmonids) for the study survey, the greatest numbers of juvenile salmon came from the clearest water site, the Harrison River, with up to 300 fish per set (mean catch). The highest number of juvenile salmon caught at either the Fraser River or Nicomen Slough sites was approximately 20 fish per set during the same period, April and May, 1991.

A preliminary evaluation by DEQ compared turbidity levels to biotic indices from monitoring data collected from 375 small Oregon streams (from June – Sept, 1996 – 2002) representing eight ecoregions around the state, including: Blue Mountains; Cascades; Coast Range; Columbia; Eastern Cascades Slope; Klamath; Snake River High Desert; and Willamette Valley ecoregion. The analysis indicated that ‘poor’ conditions for vertebrates (fish) were associated with long-term turbidity levels of at least 25 NTUs and above with declines beginning above 10 NTUs (Doug Drake’s personal communication). This cannot be assumed to be a direct correlation relationship since other variables were also associated with declines in vertebrate conditions. However the most important of these variables were channel-bottom fines and total suspended solids, both potentially related to turbidity levels. The 25 NTU threshold is near the lower end of the turbidity range of the Frazier River turbidity levels (~27 NTUs). This does not suggest that the Frazier River site would be equally ‘poor’, but is not out of line with Frazier River results, considering substantially lower salmonid presence in the Frazier River compared to clearer water conditions. As a meta analysis, this evaluation is also discussed below with respect to Newcombes’s (2003) impact assessment model.

#### **3.2.3.4 Meta Analysis**

Newcombe (2003) developed an empirical model for relating potential fish impairment to turbidity level and duration thresholds. Results regarding turbidity (NTU) from Newcombe’s model are summarized in Table 3.3, below. While much of the model values with respect to fish reactive distance originated with turbidity (NTU) response data, the primary model calibration is based on black disk sighting range(s), which relate directly to water clarity. Therefore a degree of caution regarding ‘NTU’ levels must be taken.

The modeling approach is well supported and qualified, with elements originating from past and current research, and based on extensive peer consultation and limited meta analysis of peer reviewed reports. Turbidity effects considered for the model include fish reactive distance, predator prey dynamics, egg and larval development growth rates, and habitat alteration effects. The model was developed for application in marine, estuarine, and inland water systems where sediment plumes can be transported through otherwise relatively clear water environments. Applications suggested by the author include “dredging operations for navigation in rivers, ocean dumping of dredge spoils, cleaning spawning

channels beside large streams, in-stream works, placer mining, land use planning, and enforcement of environmental and fisheries legislation”.

The Newcombe (2003) model implies that the impact of turbidity on fish is related to both duration and the turbidity level. The levels of impairment are described in both narrative and numeric ranges, each resulting from the same data, with comparable effect categories. Numeric (semi-quantitative) ranges of ‘severity-of-ill-effect scores’ (0-14.5) were established as follows, along with the narrative categories (italics):

*slightly impaired* denotes ‘feeding and other behaviors begin to change’, with **0.5 ≤** a minor impact **<3.5**;

*significantly impaired* denotes a ‘marked increase in water cloudiness could reduce fish growth rate, habitat size, or both’, with **3.5 ≤** a moderate impact **<8.5**; and

*severely impaired* denotes ‘profound increases in water cloudiness could cause poor condition of habitat alienation’, with **8.5 ≤** severe impact **< 14.5**.

The semi-quantitative method allows for assigning values between categories and integrations of clear water intervals or recurrent events. The model provides a method to infer the potential risk of impairment over a range of turbidity conditions and durations of potential exposure effects to clear water fish. Figure 3.14 represents a subset of Newcombe’s model values providing a window on NTU levels that approach significant impairment over a 30-day period. Note the decreasing degree to which each additional NTU affects impairment in the model, conforming with information discussed in this section regarding light penetration and aquatic life effects that are strongly affected at low turbidity increases above clear water conditions, with the measurable affect increases diminishing as turbidity increases above 0 NTUs.

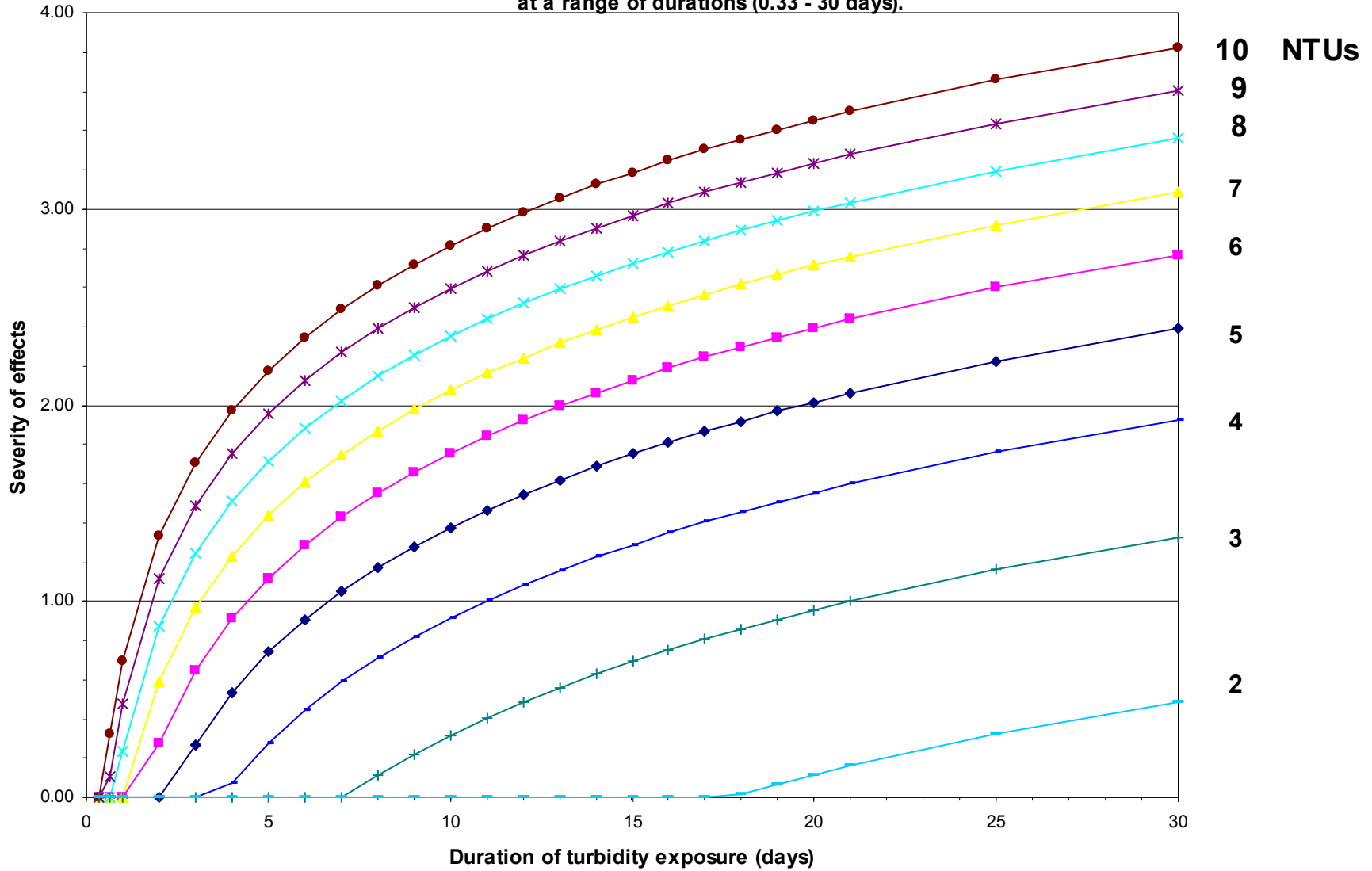
**Table 3.3** Modeled adverse turbidity level effects on clear water fish with respect to duration of exposure. [Data from Newcombe, 2003].

Duration	Turbidity Levels <i>at or above</i> which Adverse Effects are estimated to occur to Clear Water Fish (NTUs)		
	Slight impairment [behavioral effects]	Significant effects [to growth and habitat]	Severe impairment [habitat alienation]
1 hour	38	160	
2 hours	28	120	
3 hours	23	100	
8 hours	15	65	710
24 hours	10	39	440
5 days	5	19	215
3 weeks	3	10	115
>10 months		3	35

An analysis by DEQ regarding small (wadeable) streams discussed in the previous section indicated that ‘poor’ conditions for vertebrates (fish) were associated with low-flow seasonal turbidity levels of at least 25 NTUs and above with declines beginning above 10 NTUs (Doug Drake’s personal

Figure 3.14

Newcombe (2003) severity of effects scores (0 - 4) regarding clear water fishes predicted from turbidity increases (2-10 NTUs) above clear water conditions at a range of durations (0.33 - 30 days).



communication). This appears to be qualitatively similar to results of Newcombe's (2003) assessment model regarding clear water fishes which predicts that a long-term turbidity level of 25 NTUs would be at the threshold "severely impaired" or "poor" water quality conditions.

### 3.2.4 Summary of Aquatic Life Turbidity Effects

Effects to aquatic life caused by turbidity and discussed in this report are summarized in Table 3.4. The depicted turbidity levels, defined in this report as NOELs (no observed effect level) and LOELs (lowest observed effect level), provide upper and lower boundaries between which significant turbidity effects are expected to take place. EL50s and EL25s provide useful information on the relative magnitude of the turbidity effects compared to low turbidity level controls. Key findings below discuss the implications of this data set, as well as other information including modeling in establishing potential criteria levels.

**Key findings**, including those used to develop Table 3.4, illustrating turbidity aquatic life effects:

- Primary productivity and invertebrate densities supplying fish food, which can be affected at low turbidity levels (<4 NTUs) that occur over extended periods as shown from EL50 and EL25 estimates in Table 3.4; however the data would overestimate the effect in non-humic colored waters, or systems with substantial allochthonous inputs.
- Lakes appear to be the most susceptible to long-term turbidity exposure effects on primary productivity and the food chain. Lloyd et al. (1987) reported that a 5 NTU increase above clear water conditions resulted in an 80% reduction of the productive euphotic volume of lakes, whereas a 5 NTU increase above shallow clear water streams was reported to cause a 3 – 13% decrease in primary productivity, or a 25 NTU increase could decrease primary productivity by 13 – 50 %.
- Most of the plant and invertebrate data discussed in this report represent highly autochthonous systems driven by light and shading caused by turbidity. Limited information available indicates that Oregon stream systems are variable and may rely on both autochthonous and allochthonous contributions to the food chain, with the emphasis shifting between the two contributions throughout the year due to seasonal stream conditions. Therefore, the importance of turbidity on primary productivity in Oregon may be site and season-specific. A preliminary evaluation by DEQ comparing turbidity levels to biotic indices in small Oregon streams indicates that 'poor' conditions for invertebrates were associated with turbidity levels of approximately 10 NTUs and above (Doug Drake's (DEQ) personal communication).
- Recent research has discovered cases in which plants have shown an ability to grow under more turbid conditions than previously thought; with respect to suspended particles that have low absorption coefficients (Davies-Colley and Smith, 2001). Due to these 'exceptions', Newcombe (2003) did not use light compensation depth as key variable in modeling for clear water fish protection. Fish reactive distance, a high trophic level indicator, was chosen instead.
- Salmonids are visually orientated and suited to capture food most efficiently under clear water conditions (Sweka and Hartman, 2001a and b; Newcombe, 2003). While salmonids can survive and feed in non-clear water conditions, surveys have shown that their numbers may significantly decrease under more turbid conditions compared to clear water conditions, and that salmonids found in turbid waters feed less and are out-competed by other fish more suited to those conditions (Gregory and Levings, 1998; Lloyd et al, 1987). Social hierarchies break down under turbid conditions. As turbidity pulse levels increase, dominant salmonids lose feeding advantages to subordinate fish (Berg and Northcote, 1985). The authors stated, "the fitness of salmonid populations exposed to short-term pulses of suspended sediments may be impaired".

- Fish behavioral effects from turbidity, such as reactive distance, avoidance, or feeding rate, are believed to be important to fish growth, survival, and reproduction (Newcombe, 2003; Sweka and Hartman, 2000a and 2000b; Lloyd et al., 1987). The importance of behavioral effects may be small if occurrence is over a short-time frame with importance increasing with the duration of turbidity exposure (Newcombe, 2003).
- Fish reactive distance is a 'key variable in predator-prey interactions' (Newcombe, 2003). Growth of fish may be decreased by turbidity in a number of ways, or in combination, including reduced prey capture from decreased reactive distance and inability to locate prey, a shift from passive drift feeding in clearer waters to active feeding at higher turbidity levels resulting in less energy gained per prey item (Sweka and Hartman, 2000b), or a reduced food supply from turbidity limiting primary production affecting invertebrate productivity (Davies-Colley et al., 1992; Quinn et al., 1992).
- Reactive distance of fish (to prey items) was decreased by ~one half at 10 NTUs (or less) compared to clear water conditions (Sweka and Hartman, 2000a; Gregory and Northcote, 1993; Newcombe, 2003). This equates to an ~8-fold reduction in the volume of water available for identifying prey at 10 NTUs as compared to 0 NTUs.
- The Berg and Northcote (1985) study connected Coho salmon reactive distance, and prey consumption. At 20 NTUs, the lowest level tested, reactive distance and number of prey captured each decreased by more than one half (significantly different) compared to the control (0 NTUS).
- The limited data suggest a shift in feeding strategy at near 10 NTU above otherwise clear water. The non-native Brook trout shift in feeding strategy between 10 and 20 NTUs was thought to be responsible for growth declines in the fish (Sweka and Hartman, 2001b). Shifting from passive drift feeding to active energy intensive feeding is associated with trout reactive distance which is decreased by at least half at 10 NTUs or less, based on all of the data reviewed for this evaluation.
- Specific study data was not available to define clear relationships between turbidity and fish avoidance, foraging/predation, or growth, or other response variables reviewed for this evaluation; other than one study regarding non-native Brook trout which found some correlation ( $R^2 = 0.48$ ) between turbidity and growth rate (Sweka and Hartman, 2001b).
- Sigler et al. (1984) found that for both coho salmon and steelhead, weight and length decreased significantly at the lowest test levels, 22 NTUs for coho and 38 NTUs for steelhead, above the control (0 NTUs). Length and weight of coho salmon increased 22-58% and 45-90% less, respectively, at ~23 NTUs compared to clear water controls. Length and weight of steelheads increased ~45% and 62% less, respectively, at 38 NTUs compared to clear water controls.
- Fish growth rate and size (juvenile Coho salmon) has been correlated with fish survival; however the causal link between the two has not been clearly defined (Quinn and Peterson, 1996). Suttle et al. (2004) observed that steelhead growth and survival both decreased as the result to fine sediment deposition, citing lower prey availability and higher activity as potential factors.
- Fish production and presence was clearly linked through food chain data and information on light levels affected by turbidity in Alaskan waters showing strongest effects in deep lakes at low turbidity levels with a reduced effect on shallower streams (Lloyd et al., 1987).
- A field study conducted by Gregory and Levings (1998) concluded that salmonid presence and predation was significantly less in the most turbid study site, the Fraser River, in SW British Columbia (27 to 108 NTUs) than compared to a clear water site, the Harrison River (<1 NTU), and a low turbidity site, the Nicomen Slough (1-6 NTUs). Of the more than 35,000 fish caught (75% salmonids) for the study survey, the greatest numbers of juvenile salmon came from the clearest

water site, the Harrison River, with up to 300 fish per set (mean catch). The highest number of juvenile salmon caught at either the Fraser River or Nicomen Slough sites was approximately 20 fish per set during the same period, April and May, 1991.

- In order to provide some direction through the uncertainty regarding behavioral effects on fish growth, and habitat suitability, an impact assessment model was developed and presented in Newcombe (2003). Turbidity/duration thresholds in Table 3.3, resulting from Newcombe (2003) data, provide information for setting potential management levels above which clear water fish would be susceptible to harmful turbidity effects related to reactive distance, or other behavioral reactions affecting predator/prey interactions, alarm response, and upstream migration, as well as growth and habitat degradation. The model suggests an absolute turbidity level of 3 NTUs for long term protection, above which significant growth and habitat effects may be expected to take place, with a similar magnitude of protection occurring at 5 NTUs over 7 weeks, ranging up to 150 NTUs for 1 hour.
- An analysis by DEQ regarding small (wadeable) streams indicated that 'poor' conditions for vertebrates (fish) were associated with (but not directly correlated to) low-flow seasonal turbidity levels of at least 25 NTUs and above with declines beginning above 10 NTUs (Doug Drake's personal communication). This is not be out of line with Newcombe's (2003) assessment model regarding clear water fishes which predicts that a long-term turbidity level of 25 NTUs would be at the threshold "severely impaired" or "poor" water quality conditions.
- Turbidity effects on aquatic life systems may begin at low levels and follow along a response curve conforming to light interaction processes with turbidity causing particles in the water column. Similar relationships were noted for several related response variables with respect to turbidity increases from clear to turbid conditions. The 1% light compensation depth in deeper waters such as lakes, aquatic plant productivity ( $\text{g O}_2/\text{m}^2$ ) and biomass and invertebrate densities in autochthonous streams, zooplankton densities in lakes, and a behavioral effect, trout reactive distance, were all affected strongly at low turbidity increases above clear water conditions, and as the turbidity continued to increase, the measurable affects diminished or were saturated (Lloyd et al., 1987; Davies-Colley, 1992; Quinn et al., 1992; and Newcombe, 2003). For example, a turbidity increase from 1 NTU to 7 NTUs decreased the trout reactive distance by approximately one half (Newcombe, 2003). Other examples may be surmised from the  $\text{EL}_{50}$  and  $\text{EL}_{25}$  levels shown in Table 3.4 which denotes 50 % and 25%, of the negative response taking place at that turbidity level, respectively. The curvilinear relationships suggests that for normally clear background conditions, small increases in turbidity due to anthropogenic activities for extended periods can have an important effect on primary productivity which supports zooplankton, macro invertebrates and the food chain affecting salmonids and other aquatic species, as well as on salmonid predator/prey interactions, or other behaviors involving visibility and mobility.
- In considering the use of turbidity as a water quality standard, Lloyd (1987) suggested that the standard should protect freshwater habitats from decreased aquatic productivity due to decreased light penetration, as well as protect fish and other aquatic wildlife from lethal or sub-lethal (chronic) effects. The author concluded that moderate levels of protection would be approximately 25 NTUs and 5 NTUs above natural conditions in streams and lakes, respectively. A high level of protection would be 5 NTUs above natural conditions in streams and lakes. The author also stated that protecting extremely clear waters might require more stringent criteria "due to the dramatic initial impact of turbidity on light penetration". Lloyd's (1987) rationale for these protection levels stemmed from scientific literature studies indicating that turbidity levels as low as "10-25 NTUs" can have "deleterious effects on fish". This is not out of line with conclusions of this report, considering strong turbidity effects occurring above clear water conditions, shifts of fish feeding behavior above 10 NTUs, and growth impacts measured at ~23 NTUs.

**Table 3.4** Aquatic life: summary of significant turbidity effects level ranges. [See text or Appendix A for actual values]

		> = Control   > = NOEL   < = LOEL □ = EL25   ■ = EL50																				Citation	
<b>Fish: Flowing water</b>																							
<i>Native</i>																							
Reactive Dist:	Brook trout	N	>																			Sweka and Hartman 2001a	
	Rainbow Trout	Y		>																		Barrett et al. 1992	
	Chinook Salmon	Y																				Gregory and Northcote 1993	
	Coho Salmon	Y	>																			Berg and Northcote 1985	
Avoidance:	B. Kokopu	N																				Boubee et al. 1997	
	Koaro	N																				■70	
	Chinook Salmon	Y	>																			Gregory 1993	
	Coho Salmon	Y																				70-100	
Alarm:	Coho Salmon	Y																				60	
Social Order:	Coho Salmon	Y	Social order (SO) intact 0 – 20										SO out 30-60										Berg and Northcote 1985
Foraging:	Banded Kokopu	N	>																			Reduced feeding: 25% & 36% at 10 & 20 NTUs, respectively	Rowe and Dean 1998
	Brook trout	N																				Feeding shift: at 10-20 NTUs	Sweka and Hartman 2001b
	Chinook salmon	Y	Surface and Benthic feeding at 35-150 NTUs > at 1 and 810 NTU																				Gregory and Northcote 1993
	Chinook salmon	Y	Planktonic feeding reduced at 350 NTUs compared to 1-70 NTU																				Gregory and Northcote 1993
	Chinook salmon	Y	Smaller juveniles reduced surface feeding in turbid water (≥18 NTU)																				Gregory 1994
	Coho Salmon (prey capture)	Y	>																			Berg and Northcote 1985	
	Coho Salmon (feeding rate)	Y	>																			Berg and Northcote 1985	
	Cutthroat trout; Rainbow trout; Chinook salmon; Coho salmon	Y	Field predation by Salmon/char less at 27-108, compared to <1 NTU																				Gregory and Levings 1998
Growth:	Brook trout	N																				Sweka and Hartman 2001b	
	Coho Salmon	Y	>																				
	Coho Salmon	Y	Length & weight increases reduced 55-58% & 45-90%, respectively at 23 NTUs compared to the clear water control																				Sigler et al. 1984
	Steelhead Trout	Y	>																			<	
	Steelhead Trout	Y	Length & weight increases reduced 42-46% & 61-62%, respectively at 38 NTUs compared to the clear water control																				
<b>Fish: Lake Species</b>																							
Reactive Dist:	Lake trout	N	>	<																		Vogel and Beauchamp 1999	
Foraging:	Lah. Cutthroat Trout	Y																				Vinyard and Yuan 1996	
	Lahontan redbside shiner	Y																					
Productivity:	Sockeye salmon	N	>	<																		Lloyd et al. 1987	
<b>Invertebrates: Flowing water (shallow autotrophic systems &lt;0.55 meters):</b>																							
Density (number per unit area)			□	■																		Quinn et al. 1992	
Richness (taxa per unit area)																						■ 100	
<b>Invertebrates: Lakes</b>																							
			>	<																		Lloyd et al. 1987	
<b>Plants: Flowing water (shallow autotrophic systems &lt;0.55 meters):</b>																							
Periphyton productivity (O <sub>2</sub> )			□	■																		Davies-Colley et al. 1992	
Periphyton Biomass			□	■																			
% of clear water plant production																						■ For 0.5 m water depth	
Whole stream respiration																						> <	
<b>Plants: Lakes</b>																							
			>	<																		Lloyd et al. 1987	
<b>Turbidity NTUs</b>		0>	2	4	6	8	10	12	14	16	18	20	22	24	26	28	30	32	34	36	38	40	

### 3.2.5 Ancillary Considerations Regarding Aquatic Life Effects

While water clarity and the light and sight effects from turbidity are primary considerations for state turbidity criteria, the material constituents of turbidity may have additional important effects on aquatic life and habitat, and should be considered within the application of the turbidity criteria where information exists. Direct physical and biological effects of suspended and deposited sediment particles causing turbidity, such as gill abrasion and egg smothering, are discussed in the next section and Appendix I. Other parameters associated with turbidity or suspended sediments include temperature (seasonal tolerance), toxics transport, dissolved oxygen levels, nutrient and bacterial transport and increased stress on organisms that can occur through a combination of these and other factors (Servizi and Martens, 1991).

Tolerance to suspended sediment effects at 18°C, and at 0°C was estimated at 47%, and 33%, respectively, of that at 7°C (Servizi and Martens, 1991). The authors concluded that several factors affected by suspended sediments and/or temperature could be responsible for this, including: cough reflex, oxygen transfer, oxygen saturation levels, metabolic rates of fish, capacity for mobility and feeding. Newcombe and Jensen (1996), considering many of the same mechanisms, stated that seasonably warm water would increase negative effects of suspended sediments more so than seasonably cold water.

The transport of toxics including metals and halogenated organics via suspended sediments is discussed in Sorensen et al. (1977). Metals and organic compounds absent from the water column often show up in the micro-particle fraction of analysis tests. Adsorption to suspended solids is the mechanism by which toxics obtain an intimate association with suspended clay or solids with a high organic content. Ney (1990) provides information on chemical characteristics that may be conducive to adsorption. For example, high  $K_{ow}$  (octanol water partition coefficient),  $> 1000$ , is often used to indicate parameters associated with adsorbency with suspended particles: low  $K_{ow}$ ,  $>1000$  indicates that adsorption will not occur; and adsorption may or may not occur at  $K_{ow}$  of 500 - 1000, dependent on other properties. The release of adsorbed chemicals from suspended solids may result from changes in the water column such as salt content, acidity, oxygenation, or other mechanisms including uptake from aquatic biota (Sorensen et al., 1977). Sources of halogenated organics and metals have included agricultural irrigation waste water, channel dredging, industrial wastewater, and air deposition.

Nutrients such as phosphorus bind to soil particles and become bioavailable in aquatic systems after runoff events, for example, from animal feedlot operations and construction sites. Phosphorus, nitrogen, and ammonia may be released with dredged sediments. Algae and bacteria production dependent on nutrient loads may be a source of turbidity and also involved in de-oxygenation events in the water column. (Sorensen et al., 1977)

Turbidity as an inhibitor of ultra-violet treatment of bacteria in drinking water is discussed in the Drinking Water Supply section 3.3.1.

#### 3.2.5.1 Suspended Sediment (Physical Effects of Turbidity Constituents)

Suspended sediments (or solids) can be an important constituent of turbidity and thus many of the reported effects on fish and aquatic systems associated with suspended sediments are also the same effects attributed to water clarity already discussed in this report. Turbidity can also be a surrogate for estimating suspended sediment concentrations, and since turbidity monitoring is fairly easy to achieve in the field (compared to suspended sediment monitoring), and is required for many permitted or certified activities, it makes sense to consider potential sedimentation effects in conjunction with turbidity, particularly when considering site-specific limited duration turbidity criteria. Appendix H

provides information that may be useful in monitoring and assessing suspended sediment effects in association with turbidity assessments and monitoring.

### **3.2.5.2 Ambient Turbidity Conditions**

An additional approach and consideration for protecting aquatic life includes an understanding of ambient turbidity conditions under which aquatic species are currently surviving. Section 2.4 provides monitoring information on turbidity levels and trends regarding Oregon rivers and small streams. Looking at average and median turbidity levels around the state, as well as ranges of turbidity levels over the annual cycle, provides a useful insight into what conditions fish are currently being exposed to and to what extent those levels should be protected.

The EPA has recommended that turbidity criteria developed as an indicator of nutrient criteria leading to excess algal growth (and other criteria) should “reflect local conditions” (USEPA, 2001). The Independent Multidisciplinary Science Team (IMST) recommended that recovery of wild salmonids required a management and policy goal of emulating “natural processes within their historic range”, and with respect to fine sediment production, to “emulate historical patterns of disturbance” with regarding the quality (coarseness), extent, and frequency of sediment inputs (IMST, 1999). Sections 4.1 and 4.2 discuss ambient conditions with respect to setting relative criteria and in establishing protective turbidity levels.

## **3.3 Human Health and Community Effects**

### **3.3.1 Drinking Water Supply**

Turbidity influences drinking water treatment with respect to aesthetic acceptability for drinking, cooking, and bathing, as well as costs of preparing water for ultraviolet radiation disinfection processes.

Unfiltered treatment systems are the most susceptible to turbidity, and are therefore usually located in watersheds associated with very low turbidity, or which can rely on ground water sources during periods when surface water turbidity is high. The Bend, Oregon, unfiltered water treatment system can treat turbidity levels of 1.5 to 2.0 NTUs, but must shut down if the turbidity exceeds 2.0 NTUs. According to EPA drinking water regulations, turbidity cannot exceed 5 NTUs prior to unfiltered treatment, unless caused by an “unusual or unpredictable event”, with no more than 2 events allowed in 12 months or 5 events in 120 months.

Filtered water treatment systems can handle higher levels of turbidity, but with the normal associated costs of treatment. EPA recommends filtering water for treatment to 0.3 NTUs, depending on the type of treatment, in 95% of samples per month, and never to exceed 5 NTUs.

Medford, OR, filtered water treatment system reports difficulty treating water when the NTUs exceed 50. And according to Robert Noelle, Water Quality Superintendent for the Medford Water Commission (personal communication) turbidity increases of only 2 to 3 NTUs can have detrimental effects on there treatment process, especially with no advance warning, in part due to the 0.3 NTU treatment level now required by EPA to protect for *Crptosporidium*, *Giardia* and other protozoa, viruses, and pathogenic bacteria. Noelle also stated that free residual chlorination is the most common disinfection method used in Oregon, and it is also susceptible to turbidity increases. Ultraviolet (UV) light treatment processes may be inhibited by turbidity, especially if particles absorb UV light or if pathogens are imbedded in turbidity causing particles.

The Clackamas River, Oregon, filtered water treatment system must change its treatment at between 25 and 50 NTUs. Facility specialists of the Albany filtered water treatment system reported that costs

generally increase with increasing turbidity. A 1997 draft study by Dermont et al. estimated that on average, for each 1-percent reduction in turbidity, chemical costs (coagulation) would be reduced by \$0.20 per million gallons. Water supplies with lower turbidity can actually require more coagulant than water supplies that are more turbid. However, all of the Oregon treatment facilities contacted stated that reduced ambient turbidity would reduce their treatment costs.

For filtered drinking water facilities, turbidity is also a surrogate for suspended sediment and associated adsorbed chemical contaminants, so reducing turbidity and associated treatment costs often goes beyond simply improving the aesthetic quality or ultraviolet light inhibiting treatment processes. Therefore, cost models may not separate physical or chemical effects from suspended sediments from purely 'turbidity' effects.

Based on the above information, limiting turbidity level increases to 5 NTUs or less would be optimal for water treatment facilities, with treatment costs decreasing with decreasing turbidity. Water treatment facility operators in Oregon have expressed a desire for advanced warning of upstream source exceedences of turbidity criteria, in order to prepare for timely adjustments to their treatment processes (See draft rule language discussed in Section 4.2.5.3).

### 3.3.2 Safety, Aesthetics, Recreation, and Livelihood

Turbidity effects on hazard identification and aesthetic quality influence water contact recreation, fishing, boating, sightseeing, and aesthetic quality in general, all of which are important in Oregon to both residents and visitors of the State.

**Safety and identification.** The National Technical Advisory Committee (NTAC, 1968), and Guidelines for Canadian for Recreational Water Quality (Health and welfare Canada, 1992) both recommended a water clarity level for hazard identification and visibility yielding a visible secchi disc sighting range of 1.2 meters which corresponds to approximately 4.2 NTUs (based on correlation data from Newcombe, 2003)). A scientific rationale for choosing this value was not provided in either case. With no estimate of an acceptable level, the National Academy of Scientists concluded that the water clarity should allow for the detection of submerged hazards or bodies (NAS, 1973).

Lloyd (1987) stated that, "absolute turbidities of 4-8 NTUs and above may hamper efficient management of fisheries in Alaska because aerial observers cannot see into the streams and estimate returns of adult salmon". While this may not be directly applicable to Oregon fisheries management, it does provide further indication of water clarity potential for the ability to perceive objects or hazards in water bodies.

**Aesthetics and recreation.** For bathing in rivers or lakes, 60% of the people surveyed in New Zealand considered waters yielding a visible Secchi disc at a depth of 1.2 meters, corresponding to approximately 4.2 NTUs, to be suitable for bathing (Smith et al., 1991). In the same study, ninety percent of those surveyed considered waters yielding a visible Secchi disc at a depth of 2.75 meters, corresponding to approximately 1.5 NTUs, suitable for bathing. Smith and Davies-Colley (1992) surveyed 15 field parties of the Water Resource Survey in New Zealand with respect to recreational bathing and aesthetic suitability-for-use, with consensus recommendations shown in Table 3.5:

**Table 3.5** Bathing and aesthetic suitability for use. The black disc sighting ranges (m) and turbidity (NTU) ranges are overlapping, since the black disc values were presented only as partition markers between categories. [data from: Smith and Davies-Colley, 1992]

	Bathing Suitability		Aesthetic Suitability	
	Black disc sighting range (meters)	Turbidity (NTUs) [NTUs estimated from Newcombe, (2003)]	Black Disc sighting range (meters)	Turbidity (NTUs) [NTUs estimated from Newcombe, (2003)]
Eminently suitable	≥2.7	≤1	≥3.0	≤1
Suitable	<2.7 - 1.6	>1 - 2	<3.0 - 1.7	>1 - 2
Marginally suitable	<1.6 – 1.1	>2 - 3	<1.7 - 1.0	>2 - 3
Unsuitable	<1.1 – 0.5	>3 - 8	<1.0 – 0.4	>3 - 11
Totally unsuitable	< 0.5	> 8	< 0.4	>11

In laboratory tests, Smith and Perrone (1996) observed that the percent change in clarity required to present perceptible differences to surveyed viewers, decreased as the control condition for comparison increased in turbidity. A greater than 300% (or 15 NTU) increase above a turbidity sample of 5 NTUs was needed to reveal a ‘conspicuous’ difference between samples; with a similar response by those surveyed at approximately 16 NTUs (160%) above a control sample of 10 NTUs, and 70 NTUs (140%) above a control sample of 50 NTUs. ‘Somewhat of a noticeable difference’ was perceived at 8.5 NTUs (170%), 9 NTUs (90%), and 35 NTUs (70%) above 5, 10, and 50 NTU control levels, respectively. ‘Barely noticeable differences’ occurred at 3.4 NTUs (68%), 3.2 NTUs (32%), and 10 NTUs (20%) above 5, 10, and 50 NTU control levels, respectively. [also, see Figure 4.4] The appearance of disparity between these statistics and Table 3.5 results may be due to perceived differences above perfectly clear water (0 NTUs) and perceived differences above turbidity levels of 5 NTUs or greater.

**Recreation and livelihood.** Wildlife and fishing quality are directly influenced by processes affecting food chain dynamics. Caux et al. (1997) characterized primary production as a key variable in influencing wildlife presence and fishing opportunities. Primary productivity was found by Lloyd et al (1987) to be sensitive to low level turbidity increases (<5 NTUs) concluded that mining-affected turbidities of 8 – 50 NTUs “coincided with, and may have contributed to, a 55 % decline in sport fishing” on the Chatanika River, Alaska.

Overall, most of the data evaluated with respect to aesthetics, contact recreation, and safety, indicates that optimal turbidity levels in clear water streams would be low (2-4 NTUs) in order to protect for these values and uses.

### 3.4 Summarization

A summary of data and information regarding the effects of turbidity to beneficial uses, and discussed in Section 3, as well as ambient turbidity summary data are presented in Table 3.6.

**Table 3.6** Overview of turbidity levels and responses that may lead to adverse effects to aquatic life, and regarding other beneficial uses, summarized from information presented in this evaluation.

Beneficial Use		NTUs Turbidity Levels (absolute or above a clear water control): Response	
<p><b>Aquatic life:</b> ranges of important adverse effects reported in the literature and referenced in Table 3.4. [The '&lt;' symbol signifies the lowest test level used in a study and one that showed a significant difference with the control (0 NTUs in most cases). Data was insufficient to determine a NOEL (No observed effect level) for aquatic life.</p>	<p><i>Flowing waters</i></p> <p>&lt;3 - 25: Primary productivity, : dependent on water depth/color/nutrients. (for 0.5 m water depth; shallower water: less effect; deeper water: more effect)</p> <p>&lt;4 : Invert. densities, dependent on primary prod./allochthonous inputs</p> <p>≤10 : Fish reactive distance (visible range is decreased by approximately one-half, with potential change to active feeding strategy)</p> <p>10 - 20: Fish Foraging/feeding strategy (Brook trout ; non-native)</p> <p>&lt;22 : Coho salmon growth rate (Significant decrease at 22 NTUs, the lowest level tested above the control (0 NTUs))</p> <p>&lt;38 : Steelhead trout growth rate (Significant decrease at 38 NTUs, the lowest level tested above the control (0 NTUs))</p> <p>70-100 : Coho Salmon avoidance ( Significant avoidance at 70 and 100 NTUs compared to controls ~0 NTUs, and for similar test fish acclimated to &lt;0.3 and 2-15 NTUs, respectively)</p>		
	<p><i>Lake waters</i></p> <p>&lt;5 : Primary productivity</p> <p>&lt;5 : Zooplankton densities</p> <p>≤10: Fish reactive distance</p> <p>10 - 20: Fish foraging</p> <p>&lt;5 : Smolt production</p>		
<p><b>Aquatic life:</b> Turbidity levels at and above which significant turbidity effects are estimated to take place, based on Newcombe (2003) <b>Impact Assessment Model</b> for Clear Water Fish.</p>	<p>3 : 10.5 months (long duration)</p> <p>10 : 3 weeks</p> <p>120: 2 hours (short duration)</p>		
<p><b>Drinking water:</b></p>	<p>2 - 5 : For both filtered and un-filtered systems; filtered systems can withstand higher levels. Costs generally increase with increasing turbidity.</p>		
<p><b>Aesthetics and bathing</b></p>	<p>≤3.5 : Suitable for recreation, aesthetics and bathing (as perceived in comparison to 0 NTU background conditions). Note: the ability to notice a difference (which is key to suitability) decreases (occurs at higher NTUs) as background levels increase.</p>		
<p><b>Safety/Other</b></p>	<p>3.5: Only data available with no rationale given other than for safety and visibility.</p> <p>≤4 - 8 : Visibility for fisheries management and aerial observations.</p>		
<p>Ambient turbidity levels for rivers (1992 - 2002; 20 sites statewide).</p>	average	<p><b>10.7</b> (Annual); <b>14.9</b> (High flow (10/06 – 5/25)); <b>4.0</b> (Low flow (5/26 – 10/05))</p>	
	median	<p><b>5.0</b> (Annual); <b>8.0</b> (High flow (10/06 – 5/25)); <b>3.0</b> (Low flow (5/26 – 10/05))</p>	
	Frequencies high flow period (10/06 - 5/25)	<p>0 - 5: 43.2%</p> <p>&gt;5 - 10: 22.3%</p> <p>&gt;10: 34.5%</p>	<p>Oregon small wadeable streams (June – Sept) 1997 – 2002</p> <p style="text-align: center;"><u>NTUs</u></p> <p>average: 3.4</p> <p>std dev : 14.2</p> <p>median: 1.0</p>
	Frequencies low flow (5/26 – 10/05)	<p>0 - 5: 79.1%</p> <p>&gt;5 - 10: 12.1%</p> <p>&gt;10: 8.8%</p>	

## 4 Policy Considerations

Policy considerations include the selection of a turbidity criteria approach, the level of protection for beneficial uses, implementation parameters, and flexibility in implementing regulated activities.

### 4.1 Setting 'Relative Criteria'

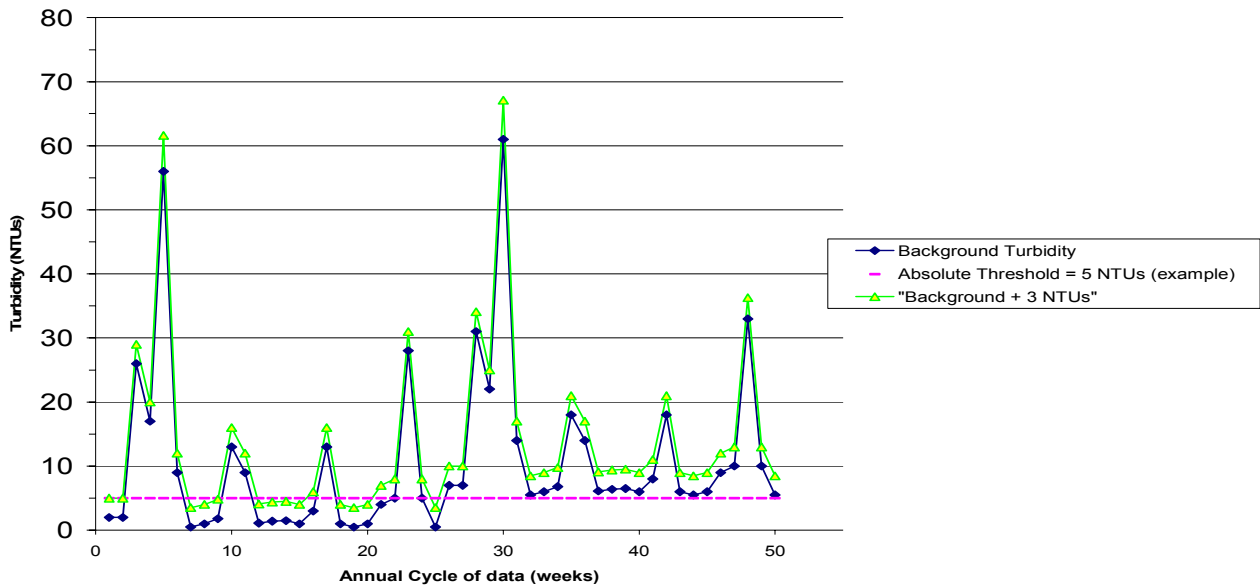
Oregon, and many other states, have established regulatory criteria for turbidity allowing increases above a 'background' or 'natural' condition that is either measured upstream or otherwise outside of the influence of the activity-related turbidity. This 'relative' approach is different from other water quality criteria that establish an 'absolute' ambient level or concentration restricting activity-related pollutant contributions.

The rationale for establishing a criteria relative to the background level:

- High variability in most state waters complicates the establishment of ambient criteria. The observed variability in ambient turbidity ranges from 0 to >800 NTUs (20+ monitoring station around the state evaluated) with increasing turbidity levels often, but not always, associated with increasing flow volumes and flow velocity. Clear waters prevail in most areas of the state, exemplified by a median of  $\leq 3$  NTUs in low flow periods, and  $\leq 8$  NTUs during high flow periods, with some streams, such as the Metolius River north of Camp Sherman with maximums that do not exceed  $\sim 5$  NTUs.
- Turbidity effects are usually sub-lethal, with the assumption that aquatic life (and other beneficial uses) are somewhat acclimated to variability, and can assimilate limited increases in turbidity, with the magnitude of acceptable increases dependent on the duration of exposure (Newcombe, 2003). Data suggest that:
  - Fish acclimated to higher turbidity levels are in turn alarmed at higher turbidity levels than non-acclimated fish.
  - Though 'clear water fish' prefer clear waters, fish presence and productivity under turbid conditions has been documented.
  - Primary productivity has been shown to be limited by turbidity but not to the extent that it was thought to be when EPA based its initial turbidity standard on a light compensation point. More recent information (discussed in section 3.2.1) has shown that plants may compensate for decreased irradiance caused by turbidity by increasing photosynthetic efficiency.
  - The aquatic food chain is based on both allochthonous and autochthonous contributions; i.e. macroinvertebrates (fish food) don't depend entirely on aquatic plants, but also utilize detrital inputs (fallen leaves, etc.).

An alternative to a relative standard would be an absolute criteria level (or levels) based on specific reference site conditions deemed protective of macro-invertebrate assemblages or other aquatic life (see Figure 4.1 below). However, this approach is data intensive and presents difficult management choices: too high of a turbidity threshold would be under-protective of clear water conditions; and too low of a threshold would restrict or prevent activities during 'naturally' higher turbidity conditions where small increases in turbidity would not adversely affect aquatic life. Under variable conditions, something in-between could still be problematic in either or both cases.

**Figure 4.1 Turbidity : Relative versus Absolute Criteria**



### 4.1.1 Allowing Increases Above Background Turbidity

Since ambient (background) turbidity levels usually vary seasonally throughout the state, a relative criteria, as is currently applied, and being proposed, will allow turbidity increases above the upstream (background) level. This presents three problems to be resolved in the new standard and with respect to the application of background turbidity. First, criteria will potentially produce different levels of protection varying with the background level. Second, there exists the potential to increase the upper and lower boundaries of 'natural conditions'; i.e., already high turbidity levels will be pushed higher, and clearest water conditions will be less clear. Third, there exists the opportunity for sources to elevate the background level used for downstream source monitoring, allowing, stair-stepping turbidity (cumulative) increases. Cumulative increases must be carefully considered since each individual activity, or group of activities, would be allowed the relative increase proposed in the criteria.

### 4.1.2 Cumulative Impact Potential

Ambient turbidity levels, and thus 'background' levels measured for purpose of making a relative comparison to induced turbidity, may contain a 'natural' erosional component, as well as an anthropogenic component, with either component usually being an unquantifiable proportion of the measured ambient turbidity level. Human activity may also have acted to reduce ambient turbidity, for example, regarding impoundments or reservoirs that act as sediment sinks preventing downstream sediment transport. Quantification of a 'natural' turbidity component may be least problematic near the headwaters where few sources exist (though information is limited for making determinations), and increasingly difficult downstream with additional anthropogenic and 'natural' sources; with further complication due to the re-suspension of previously settled turbidity-causing materials. The following include primary considerations regarding turbidity accumulating from anthropogenic sources:

- The 'background' turbidity level may be elevated due to anthropogenic source contributions upstream. Thus, further allowed turbidity increases, depending on the magnitude, may adversely affect beneficial uses by pushing turbidity levels to magnitudes outside the normal ranges in which species may be acclimated during the season of activity.

- The allowed activity-related increase above the ‘background’ turbidity level may inadvertently influence the background turbidity used at the next site downstream, causing a stair-step increase in ambient turbidity levels from anthropogenic sources.
- Distances between anthropogenic sources may be important regarding accumulating turbidity and increased level effects. Urban stormwater may be an accumulating source with multiple discharges to receiving streams. Other reaches may be subject to multiple turbidity sources from temporary upland or in-channel projects occurring in the same general area during the same time period; i.e. during a work window.
- Ponded systems may be susceptible to cumulative increases of turbidity that result in overall turbidity increases to the water body, and thus to the background level to which relative increases are made.

### 4.1.3 Defining Criteria Background

Defining background turbidity is important to the level of protection regarding single or multiple activities, and for practicality in monitoring, since the proposed criteria would allow a relative increase above ambient or background levels in the receiving water body:

“Background turbidity” means turbidity in the immediate vicinity of and outside the area of influence of the discharge or discharges from the source or sources under consideration. For establishing NPDES permit limits, background turbidity may be calculated as the up-stream historical turbidity associated with low flows, excluding episodic run-off events, for the season(s) or period(s) for which the turbidity discharge limit is established. If background data are unavailable, 1 NTU may be used as a default value.

For areas with multiple sources in close proximity, the rule would allow for the measurement of a single background level to be taken upstream of all of the sources; i.e., many sources would be treated as a single source with respect to turbidity criteria allowances. Since a goal of the rule is that no single activity could result in turbidity increases approaching significant impacts, then multiple-source discharges would also be protective under this scenario, by eliminating stair-step increases of turbidity above increasing background levels.

For compliance monitoring and relative comparisons, background turbidity measurements are to be taken at approximately the same time as the activity-related turbidity measurements. The background definition also allows for seasonal or periodic estimations of background turbidity to be used to make relative comparisons for sources with predictable or homogeneous turbidity discharges. It is assumed that discharges meeting the criteria during the lowest flows will also meet the criteria during higher flows that have more dilution and often with higher background turbidity levels. Where background levels cannot be measured or estimated, a 1 NTU default turbidity level may be used. One NTU is the median turbidity level for small wadeable streams, statewide. The default level may be useful at the top of the watershed where there is no ‘upstream’ to monitor background. It may also be useful for calculating limits in larger systems void of background turbidity data. In these cases, dilution volume of the receiving stream is the main driver of the limit level, not the background turbidity level.

## 4.2 Level of Protection

Criteria levels and narrative in the draft turbidity rule are designed to protect aquatic life and other beneficial uses including drinking water treatment, safety, aesthetics, recreation, and agricultural and industrial water use. For most Oregon waters aquatic life will be the most sensitive use. Other uses are considered to be important in setting turbidity criteria, but tend to be more site-specific or value-

orientated, and don't lend themselves to being drivers for developing state-wide turbidity criteria to as great an extent as aquatic life.

According to a consensus recommendation by the turbidity criteria Internal Review Team, the proposed criteria should provide a level of resource protection that reflects DEQ's interpretation of protecting beneficial uses. Aquatic life endpoints consistent with other standards can be characterized as behavioral or other endpoints that lead to physiological responses such as reduced growth or may lead to impairment at the population level. This would include behavioral effects on foraging capability and strategies used by salmonids that result in growth reductions. Since foraging capability is dependent on food supply, primary productivity is also an important endpoint in considering criteria development.

While measurable growth effects to fish are usually caused by chronic, or long-term turbidity increases to fish behavior, ability to identify prey, or impacts to the food supply, short-term high-level turbidity increases or pulses are also important, causing fish disorientation and stress, avoidance or habitat alienation, and/or potential sedimentation impacts (Newcombe, 2003; Newcombe and Jensen, 1996). The Internal Review Team recommended, by consensus, that criteria include duration and magnitude in the protection levels.

Another important consideration in developing protective criteria is ambient water quality data that characterizes current turbidity conditions. The EPA recommends that turbidity levels as response variables for measuring nutrient-related impairment should "reflect local conditions" (USEPA, 2001). The EPA approach includes estimating reference site conditions at the ecoregion or subcoregion scale to be used along with scientific literature and modeling tools to set protective levels. The Independent Multidisciplinary Science Team (IMST) recommended that recovery of wild salmonids required a management and policy goal of emulating "natural processes within their historic range", and with respect to fine sediment production, to "emulate historical patterns of disturbance" with respect to the quality (coarseness), extent, and frequency of sediment inputs (IMST, 1999). While this evaluation does not attempt to develop different criteria for specific basins or reach conditions, it does propose state-wide criteria that are protective of current ambient conditions across the state and in consideration of reference site conditions; based on data from approximately ten years of recent monitoring, including turbidity ranges, and central tendencies.

The Internal Review Team also recommended, by consensus, continuing to use 'relative' criteria, allowing activity-related increases of turbidity above background receiving water turbidity levels. Allowing increase above background levels must be considerate of the following:

- The level of protection changes with different background levels.
- Cumulative increases must be carefully considered since each individual activity, or group of activities, would be allowed the relative increase proposed in the criteria.

The level of protection proposed for all activities and across the state is high, protecting all of the beneficial uses described above including the most sensitive aquatic life uses. While information regarding fish suggests that clear water conditions are preferable or 'ideal' overall, it also suggests that behavioral effects that may occur at very small turbidity increases, such as a slight change in reaction distance to prey, can be compensated for if not extensive or frequent and may not be important to fish growth or population level effects.

## 4.2.1 Synthesis of information

There does not exist a standard process or formula for developing turbidity criteria such as EPA's recommendations regarding toxic parameters. Nor are there commonly agreed upon endpoints or a single set of studies which everyone can rely on for setting thresholds. In drafting criteria this evaluation utilized:

- Literature regarding laboratory and field (large-scale) studies.
- Meta analysis, incorporating literature or monitoring data into predictive models regarding effects to aquatic life or habitat.
- Recent monitoring data characterizing current ambient conditions across the state.

In order to provide some direction through the uncertainty regarding behavioral effects on fish growth, and habitat suitability, an impact assessment model was developed and presented in Newcombe (2003). The model addresses impacts relative to an optimal condition for clear water fish (0 NTUs). Since we are proposing a relative increase above background conditions, and not an absolute criteria to be protected, the model must be used carefully regarding the ambient conditions in which we are allowing turbidity increases. The model, and much of the literature, do not address acclimation of species to higher background level turbidities. Here, information pertaining to aquatic life acclimation to turbidity, as well as seasonal differences in species response to turbidity are also evaluated.

## 4.2.2 Practical considerations:

The draft rule's goal for the myriad of activities that cause turbid increases in state waters is to provide a simple, practical, and flexible approach for assessing and complying with turbidity criteria. Oregon's approach to protecting beneficial uses from turbidity impacts is essentially source control of turbidity-causing activities, with numeric and narrative criteria allowing small increases above background conditions. In part, this is a self-monitoring program, with emphasis on using monitoring to insure that best management practices (BMPs) are functioning properly.

Criteria levels are designed to be applied state-wide in order to provide adequate protection from all identified sources of anthropogenic turbidity. Site-specific allowances for short-duration pulses or additional flexibility for channel restoration projects, emergencies, and essential channel dredging are provided in the rule through CWA 401 certification reviews or NPDES permits. The criteria also provide more stringent protections where special concerns are identified, also to be applied on a site-specific basis through the same review process.

In developing criteria DEQ looked at monitoring capability and practicality for different types of discharges in order to allow flexibility in measuring compliance. For example, we incorporated the use of surrogates like suspended sediment data or a visual contrast methods into the draft rule (and guidance) providing less expensive or technically easier alternatives to using a turbidity meter. We also developed approaches allowing controlled and protective short-term pulses of turbidity while providing practical work period application and flexibility for specific projects. We worked with stakeholders on these approaches, many of which will be doing the monitoring, as well as DEQ staff involved in implementing the criteria through permits, 401 applications, or through other state or federal agencies.

### 4.2.3 Changes from current rule (Table 4.1):

The current rule allows a 10% increase above background per activity. The current criterion was designed to protect primary productivity in lakes by not changing the seasonal average depth in lakes where algae would grow by more than 10%. Reasons to review the current criteria include:

- The current criteria have not been consistently applied and would be unnecessarily restrictive especially at low background turbidity levels.
- While the emphasis in developing the current rule was on protecting primary productivity in lakes, fish protection in flowing systems with food chain considerations has become a greater focus of the scientific literature and in this rule revision. Negative effects to fish are indicated at turbidity levels as low as 10-25 NTUs, a conclusion of this study and Lloyd (1987).
- Duration versus magnitude effects were not considered regarding the current rule. Criteria have been applied as ‘instantaneous’ increase allowances, with little or no consideration of seasonal averages or long versus short-term effects.
- The existing rule provides narratives allowing temporary site-specific flexibility when the Department believes uses are protected. The proposed rule provides a more direct application of levels associated with use protection.

The draft rule would allow a monthly average increase of 3 NTUs above background, together with an allowed 5 NTU maximum increase above background per activity (or activities). The proposed rule incorporates a broader review of beneficial uses protections and retains flexibility by providing additional criteria based on both magnitude and duration as well as narratives providing site specific flexibility and describing how the Department will determine uses are protected. A visual criteria is also proposed for activities not using a turbidity meter, providing an inexpensive alternative to monitoring turbidity and BMP effectiveness. Compliance distances are also included as part of the criteria in order to establish consistent monitoring over a range of water body sizes.

**Table 4.1** Rule change overview.

<b>Concept</b>	<b>Current Rule</b>	<b>Draft Rule</b>
NTU increase applied to each source	Yes	Yes
Relative to control point upstream	Yes	Yes, and may group sources
Protection level	10% Increase	3 NTUs (monthly average) 5 NTU (maximum)
Limited duration exceedances	Yes	Yes
Specified magnitudes and duration for exceedances	No, full flexibility	Yes
Compliance distances specified	No, identified by permit or CWA water quality certification	Yes
Visual observation method	No, identified by permit or CWA water quality certification	Yes

## 4.2.4 Long-term Turbidity Increase Level Protection

Long-term protection levels, including the monthly average and maximum criteria, are the basic elements of the turbidity criteria. These levels are to be achieved by activities unless otherwise authorized through permits or 401 water quality certifications. The goal is to protect aquatic life and other beneficial uses from long-term turbidity discharges, and also provide a constraint on the magnitude and repetition of limited duration increases allowed through permits or 401s.

For projects causing turbidity increases for short periods, of three weeks or less, the proposed 5 NTU criteria is also adequate to meet the monthly average criteria (3 NTUs proposed). For longer projects, of more than three weeks, a greater effort would be required to achieve the proposed 3 NTU monthly average criteria, though 5 NTUs would still be the daily threshold. Where 5 NTUs cannot be met, limited duration criteria could be authorized to allow higher magnitude pulses of turbidity. The monthly average criteria would still have to be met, except under special conditions described in Section 4.2.5.2. Limited duration criteria require site-specific information and considerations, time frames, and monitoring and reporting requirements that are not implementable outside of authorizations like permits and 401 certifications that can address specific areas and types of projects.

### 4.2.4.1 Monthly Average Criteria

The purpose is to establish a criterion level that: 1) provides beneficial use protection from chronic or long-term sources, as discussed in Section 3.2.3.4; 2) to provide a constraint on the limited duration criteria in order to prevent negative effects from repeated pulses of higher level turbidities by controlling the overall average turbidity increases; and 3) to replace, in a large part, the current criteria that allows a 10% increase above background, with a similar goal of protecting ambient conditions in allowing conservative increases above background turbidity levels.

**Recommendation:** Allow each activity to increase background turbidity by no more than 3 NTUs as a monthly average for background turbidity levels up to 30 NTUs, and a 10% increase (monthly average) at backgrounds > 30 NTUs, not to be exceeded beyond a designated compliance point.

#### **Rationale:**

*Scientific literature* indicates that some aquatic life responses to turbidity occur at low turbidity levels (< 5 NTUs) due to decreases of light to plants and reduced visual recognition in fish with the potential negative effects increasing with increasing magnitudes and durations of turbidity exposure (see Table 3.4). While salmonid juveniles can take advantage of turbid conditions for cover in avoiding predators, salmonids in general are better adapted to clear water conditions for several reasons. Salmonids are visually orientated and suited to capture food under clear water conditions (Newcombe, 2003). While salmonids can survive and feed in non-clear water conditions, surveys have shown that their numbers significantly decrease under more turbid conditions compared to clear water conditions (Gregory and Levings, 1998; Lloyd et al, 1987). Salmonid social hierarchies break down under turbid conditions (Berg and Northcote, 1985).

*Food chain.* Primary productivity and invertebrate densities, both important to fish food supply, have been shown to be affected by turbidity at low levels <5 – 25 NTUs (and above) in flowing waters (Davies-Colley, 1992; Lloyd et al., 1987; Quinn et al., 1992; Parkhill and Gulliver, 2002). The NTU range spans data from studies with different types of trophic systems. The (Quinn et al., 1992) study had the only data available directly regarding macroinvertebrates and turbidity, and involved a highly autochthonous system (dependent mostly on in-stream primary productivity) and presenting a fairly extreme condition and response to turbidity, with declines in densities at seasonal averages of <5 NTUs; and with results dependent on conditions of the Davies-Colley study which showed significant declines in primary productivity at <5 NTUs. Lloyd et al. (1987) concluded that a 5 NTU increase

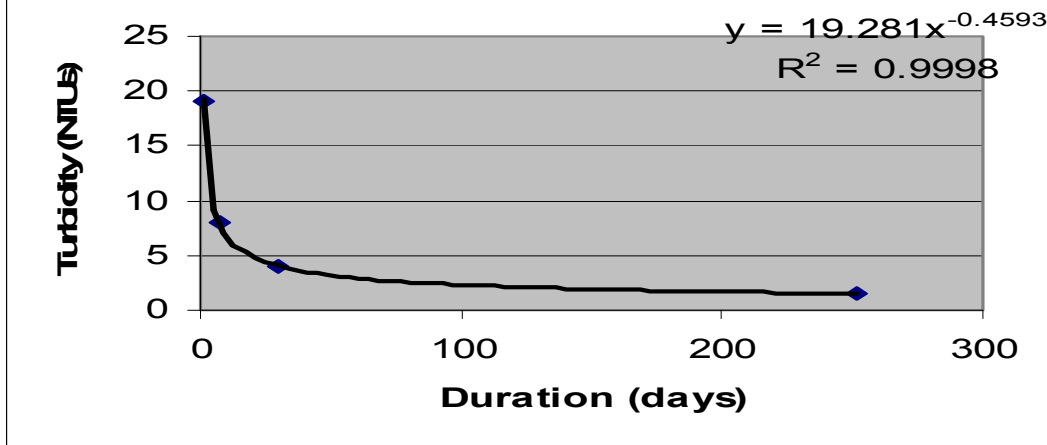
above shallow, flowing clear water conditions would result in a 3 – 13% decrease in primary productivity, while a similar increase to lakes could result in a much greater impact: ~ 80% decline in the euphotic zone. The importance of turbidity on primary productivity in Oregon is thought to be site and season-specific, though definitive information on the extent of effects is lacking. Because of these uncertainties along with recent studies showing plant acclimation to shade-causing turbidity (Davies-Colley and Smith, 2001), primary productivity was not a primary driver in this analysis (or Newcombe's (2003) meta analysis) but rather a conservative factor for consideration. The effects of seasonal turbidity are not well defined in the literature. However, information discussed in Section 3.2.5 indicates that warmer water temperatures increase negative sedimentation effects that may be associated with turbidity. The summer in-water work window also coincides with periods of clearest water conditions and the highest aquatic photosynthetic potential. The Meta-analysis section below describes some preliminary work on turbidity levels and associated macroinvertebrate indices around the state.

*Fish behavior/growth effects.* Fish behavioral effects from turbidity, such as reactive distance, avoidance, or feeding rate, are believed to be important to fish growth, survival, and reproduction (Newcombe, 2003; Sweka and Hartman, 2000a and 2000b; Lloyd et al., 1987). Reactive distance of fish (to prey items) was decreased by ~one half at 10 NTUs (or less) compared to clear water conditions (Sweka and Hartman, 2000a; Gregory and Northcote, 1993; Newcombe, 2003). Feeding strategy of fish, dependent on the reactive distance, shifts between 10 and 20 NTUs, from passive drift feeding to active energy intensive searching for food which results in a reduced net energy gain per prey item (Brook trout; Sweka and Hartman, 2000a and 2000b). Fish growth declines were observed at the lowest turbidity levels tested for coho salmon (~23 NTUs) and for steelheads (~38 NTUs) compared to clear water controls (Sigler et al. 1984). An additional factor discussed in the literature regards seasonal influence on suspended sediment effects (see section on Ancillary Considerations). Studies have indicated that seasonably warm water would increase negative effects of suspended sediments more so than seasonably cold water (Newcombe and Jensen, 1996; Servizi and Martens, 1991).

Lloyd (1987) suggested a moderate level of protection for freshwater stream and lake habitats of 25 and 5 NTUs, respectively, and a high level of protection of 5 NTUs for both types of systems, based on scientific studies indicating that turbidity levels as low as "10-25 NTUs" can have "deleterious effects on fish". This is not out of line with conclusions of this report, considering behavioral effects occurring quickly above clear water conditions, shifts of fish feeding behavior above 10 NTUs, and growth impacts measured above 20 NTUs.

*Meta analysis.* Newcombe's (2003) impact assessment model for clear water fish provides some direction through the uncertainty regarding duration and magnitudes of turbidity exposure and behavioral effects on fish growth, and habitat suitability, an impact assessment model was developed and presented in Newcombe (2003). The curve depicted in Figure 4.2 represents the thresholds at which impacts to clear water fish have been predicted to cause slight impairment with an index value of ~2 (Also see Tables 4.3 and 4.4). This would be considered a high level of protection.

**Figure 4.2 Turbidity increase above clear water conditions and Duration exposure that would result in a severity of ~2.00 (Data from Newcombe, 2003)**



At ~2 months, a 3 NTU increase above clear water conditions is predicted to have a severity index score of ~2, or cause slight impairment to clear water fish, such as salmonids. At ~11 months, (the extent of the models practical application) a 3 NTU increase above clear water conditions (~0 NTUs) would be at the threshold of causing significant effects to growth and habitat of clear water fish (salmon) resulting in a severity score of 3.5. An important consideration here regarding continuous activities that might discharge turbidity for 11 months or more, such as industrial or municipal wastewater facilities, is that compliance distances or mixing zones would limit turbidity increases from system level increases of this magnitude. These meta analysis results provide a check against available scientific information and give additional direction in selecting and refining long-term criteria.

An analysis by DEQ regarding small (wadeable) streams indicated that ‘poor’ conditions for invertebrates and vertebrates (fish) were associated with low-flow seasonal turbidity levels of approximately 10 NTUs and above, and 25 NTUs and above, respectively, with declines for fish indices beginning above 10 NTUs (Doug Drake’s personal communication). This information is not refuted by Lloyd’s (1987) study estimating a range for protection (10 -25 NTUs) discussed above (*Fish behavior/growth effects*) or Newcombe’s (2003) clear water fishes assessment model which predicts that a long-term turbidity level of 25 NTUs would be near the threshold of “severely impaired” or “poor” water quality conditions.

*Ambient monitoring data.* Rivers and streams in Oregon have been typically clear with respect to data collected over the last 15 years, with the statewide median turbidities for rivers (averaged across stations) of 4.6, 2.9 and 7.6 NTUs for the annual, low flow, and high flow periods, respectively. Median levels for smaller streams monitored around the state were 1 NTU, or less, regardless of lithology (resistant or erodable), or the degree of human disturbance. The highest average and maximum turbidities for smaller streams were recorded for the reaches most disturbed by human activity.

*Other States/countries* (also, see ‘Other states’ in Section 2). Oregon would be the first state to implement a ‘monthly average’ criteria. California has a criterion of 2 NTUs, but this is not specified for any averaging period. Most other western states have similar criteria (to California) but with lowest increase allowances of 5 NTU. British Columbia utilizes a 30-day average aquatic life criteria allowing a 2 NTU increase for background turbidity levels of 0-8 NTUs; 8 NTU when background is between 8 - 80 NTU; and 10% when background is  $\geq$  80.

**Summary:** As a relative increase above ambient conditions, a long-term NTU criteria should guard against fish growth reductions caused by behavioral foraging effects that may occur above 10 NTUs, and protect against potential food chain impacts. No single activity should increase turbidity to harmful levels; rather, a safety factor should be in place for additional protection since each activity can add to downstream background levels, and we are relying on data that mostly pertains to absolute levels of turbidity, and not increases to existing conditions.

- An increase of 3 NTUs above background turbidity levels should protect most clear water conditions. A 3 NTU increase would result in ambient turbidity levels at the edge of the mixing zone, or at the compliance point, of 3 to 6 NTUs more than half of the time during summer low flow periods (based a median of 3 NTUs), and from 3 to 11 NTUs more than half of the time during the winter high flow period ( based on a median of 8 NTUs).
- A 3 NTUs increase (at the edge of a mixing zone or compliance point) to clear water (0 NTUs) should have no substantive effect on the local reach, and little, if any, downstream (cumulative) effect, and while the 3 NTU increase may add some additional impact as background levels increase, proportionately it will have a less and less impact to the receiving stream and its uses as background levels increase.
- Long-term beneficial uses would be protected, including most primary productivity and the food chain, fish, and most recreational, aesthetic, and safety values, based on the literature reviewed for this study.
- The proposed 3 NTU criteria is slightly less stringent than California criteria (2 NTUs), and slightly more stringent than Washington state criteria (5 NTUs).
- For measurability of a relative difference between activity and background turbidity levels, it is recommended that the increase allowance shifts from NTUs to a percent base increases (10%) at backgrounds >30 NTUs (note: 3 NTUs is 10 % of 30 NTUs).

#### 4.2.4.2 Maximum Criteria

The purpose of the maximum criteria is to: 1) provide a constraint on the long-term protection level (or monthly average) while allowing some flexibility to occasionally exceed that level; and 2) provide a tool for compliance and enforcement that provides measurability and a clear threshold value that can be efficiently assessed.

Because the maximum criteria is applied as a single measurement to assess potential turbidity increases over very short time periods, there is a question as to whether it is always the appropriate level considering magnitude and duration curves, such as those depicted in Figure 3.13.

##### **Options:**

- Add another criteria (10 NTUs) to the rule for projects known to fit a shorter time frame.
- Allow a maximum criteria level of greater than 5NTUs and less than 10 NTUs.
- Allow 5 NTU increase; rely on the limited duration criteria available through a 401 certification or permit for higher allowances.

**Recommendation:** Allow each activity to increase background turbidity by no more than 5 NTUs for backgrounds of 0 to 33 NTUs, and a 15% increase above backgrounds > 33 NTUs. Rely on limited duration criteria for higher allowances.

## Rationale:

*Literature/studies.* As a constraint to the monthly average turbidity criteria, literature briefly summarized regarding the monthly average criteria is also largely applicable to the maximum criteria. This assumes that activities without permits or 401 certifications may occur for unlimited or unknown time periods.

*Meta data analysis.* Regression equations developed by Newcombe (2003) were used to develop curves in Figure 3.14 comparing a range of potential criteria showing duration versus magnitude effects on clear water fishes, including salmonids:

- A 5 NTU increase above clear water conditions (0 NTUs) results in severity of effects score of 1.00, the threshold for slight impairment, at ~11 days, and a score of 2.00, at ~20 days. From a qualitative respect, a score of 2.0 is in line with what the Internal review team has recommended for a level protecting aquatic life, or a high level of protection. Table 4.3 provides a key for effects scores (from Newcombe, 2003), and a range of potential criteria and severity of effects scores approaching 2.00.
- A 10 NTU increase above clear water conditions (0 NTUs) results threshold score of 2.0 at ~4 days, with significant effects estimated at durations beyond ~ 20 days.

*Other States.* Seven states, including five western states (Washington, Idaho, Alaska, Montana, and California) have 'maximum' turbidity increase allowances of 5 NTUs above background for their highest class waters that may include drinking water sources, salmonid habitat, or recreational waters. Four of the five western states also have higher allowances (10 NTUs) for lower class waters which may include cold water aquatic life, secondary recreation, salmonid habitat, marginal salmonid habitat, non-salmonid habitat, or non-drinking water. Idaho has both an instantaneous criteria (50 NTUs), and a 10 day criteria (not to exceed 25 NTUs).

**Summary:** The maximum turbidity criteria, rather than the monthly average criteria, will be the criteria paid the most attention by activities since it is the threshold to be applied and achieved at the time of monitoring. As a maximum criteria, it also provides a simple threshold test requiring action if it is not met. Literature indicates that long-term effects on fish foraging occur at levels at or above 10 NTUs (Sections 3.2.3.1 and 4.2.4.1), and the meta analysis discussed above indicates that 10 NTUs would not provide long-term protection at the level recommended for this evaluation (Newcombe effects score of ~2.00). While the proposed 5 NTU criteria may be too conservative for short time frames, it does meet the long term protection goal, and the proposed rule would allow the flexibility to exceed the 5 NTU level as discussed in the next sections.

- A 5 NTU increase could be allowed for 18 days (out of 30 days) and still meet the draft monthly average criteria (3 NTUs) if no additional turbidity were discharged from the activity.
- For continuous discharges, 5 NTU allowance should provide adequate flexibility in achieving the monthly average criteria, allowing a 67% discharge level increase above the 3 NTUs for part of the month.
- Where additional flexibility is needed by short-term or continuous dischargers, limited duration criteria allowing protective short-term increases in turbidity could be obtained through a CWA §401 or NPDES permit.
- *Other beneficial use considerations.* Information gathered for the technical basis suggests that overall, low level turbidity levels (<5 NTUs) are optimal for most beneficial uses (see Table 3.6).

- For measurability of a relative difference between activity and background turbidity levels, it is recommended that the increase allowance transitions from NTUs to a percent base increases (15%) at backgrounds >33 NTUs (note: 5 NTUs is 15 % of 33 NTUs).

#### **4.2.5 Limited duration criteria**

Many projects, especially in-water work, can release short-term pulses of turbidity into state waters. Literature discussed in this report indicate that if the magnitude and duration of turbidity increases are controlled within certain parameters, then the effects are minimal and temporary (Newcombe, 2003). The current rule allows limited duration exceedances of the 10% turbidity increase allowance, but with no magnitude or duration caps. The EPA has informed DEQ that open-ended criteria will no longer be acceptable. However, there is also a recognition that some projects involving channel reconstruction or dredging may not be capable of meeting proposed turbidity magnitude and duration caps. In order to allow necessary work to be done in channels, these types of projects would have to minimize and document turbidity NTUs and document BMP effectiveness, and either show long term gains in the protection of beneficial uses outweighing short-term impacts or mitigate for negative turbidity effects. There may also be cases where downstream turbidity and/or sedimentation from higher turbidity pulses can be detrimental to beneficial uses such as drinking water intakes, or salmonid spawning beds. In these cases, more stringent caps than those specified in the rule could be applied. Because higher magnitude pulses of turbidity can quickly harm aquatic life and habitat, all of these allowances require special control and oversight. For this reason they are applied only through permits, 401 water quality certifications, or in some cases through other agency regulatory mechanisms.

Limited duration criteria are divided into three categories in the draft rule: 1) specific magnitude and duration criteria authorized through a CWA 401 certification review, an NPDES permit, or other appropriate regulatory agency; 2) additional flexibility criteria authorized through a CWA 401 certification for ecological restoration projects, emergencies, or essential navigation channel dredging that can't meet the criteria in the first category; and 3) more stringent criteria authorized by the Department for waters of special concern.

In each category described above (corresponding to draft rule (2)(d) through (2) (f), the following would apply, as stated in the draft rule:

(2)(g) Persons using authorizations granted under subsections 2(d) through 2(f) must:

- (A) Utilize all reasonable and practicable measures to maintain activity-related turbidity at the lowest achievable level;
- (B) Monitor best management practices and other control measures to demonstrate that the conditions allowing for the exceedance have been met; and
- (C) Document and monitor turbidity to demonstrate BMP effectiveness and/or compliance with allowed turbidity levels.

Additional findings and documentation would be included for the second category, and are discussed below in Section 4.2.5.2.

##### **4.2.5.1 Specific magnitude and duration criteria**

The Purpose of these criteria is to 1) provide through 401 water quality certifications, NPDES permits, or other state agency water protection programs, a controlled and implementable monitoring process for allowing pulses of turbidity at specific magnitudes and durations deemed protective of aquatic life

and other beneficial uses; 2) be considerate of potential sedimentation effects; and 3) be used as a maximum criteria substituting for the 5 NTU maximum criteria.

There are many potential combinations of magnitude and duration for allowing periods of limited duration criteria. The choice should be practical and flexible with respect to potential activity types and work periods, and with respect to monitoring.

**Recommendation:** The following draft rule language is proposed:

(2)(d) If specifically authorized by an NPDES permit, CWA §401 water quality certification, or other regulatory mechanism, a person may exceed the instantaneous turbidity criteria in subsection (2)(a), as described below:

(A) Turbidity may exceed an increase of 5 NTUs above background during a single period of not greater than eight hours for each calendar day allowed. During that period, turbidity increases above background may exceed 30 NTUs for no more than two hours and must not exceed 50 NTUs above background turbidity; and

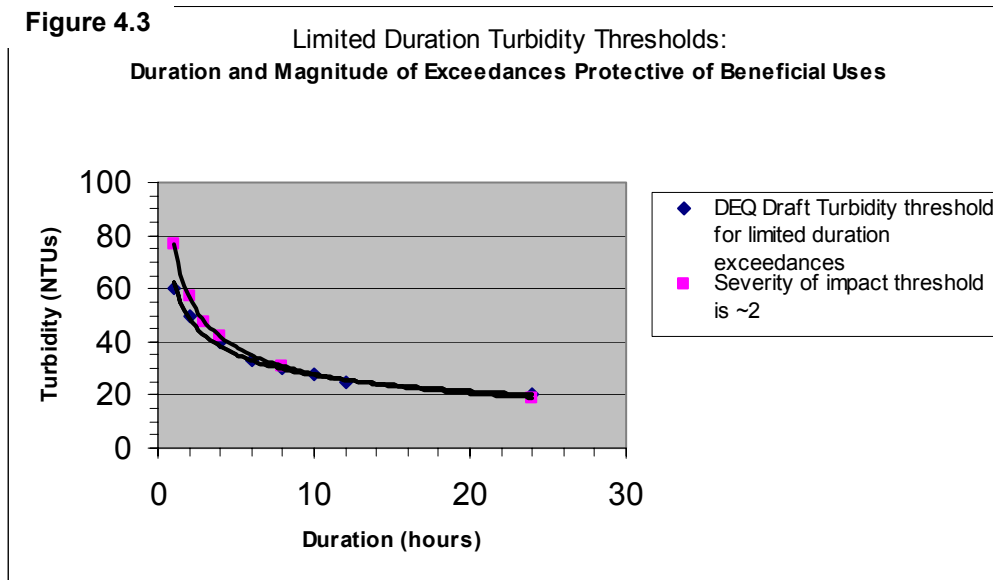
(B) Limited duration criteria under paragraph (2)(d)(A) are allowed for no more than 6 calendar days out of any consecutive 30-day period, unless turbidity monitoring or existing relevant data demonstrate compliance with the monthly average turbidity criteria in subsection (2)(b).

**Rationale:**

*Scientific literature:* Indicates short-term pulses of turbidity can be allowed at specific magnitudes that do not harm clear water fish. The importance of behavioral effects may be small if occurrence is over a short-time frame with importance increasing with the duration of turbidity exposure (Newcombe, 2003). A sudden pulse of turbidity that quickly introduced 60 NTUs to an otherwise clear test area caused fish to initially swim upstream toward the pulse to investigate, and then drift downstream to remain in clear water as long as possible, then exhibiting alarm behavior with some fish entering the gravel for several hours (Berg and Northcote, 1985). Juvenile *Oncorhynchus kisutch* (Coho salmon) that were acclimated to clear water conditions (< 0.3 NTUs) exhibited significant avoidance response to suspended sediment introduction into an experimental tank at ~ 70 NTUs, while similar test fish that were acclimated to more turbid water conditions (2 - 15 NTUs) exhibited significant avoidance response at ~ 100 NTUs (Bisson and Bilby, 1982). Acclimation to higher turbidity levels also supports the utility of a relative based standard, allowing increases above background levels.

*Meta analysis:* Figure 4.3 is provided to help evaluate protections provided in draft criteria with respect to limited duration exceedances. The upper curve represents the threshold at which impacts to clear water fish have been predicted (using linear regression; Newcombe, 2003) to be at an index value of ~2, which is at the middle of the slightly impaired (or minor impact) range (0.5 -3.5 severity) and less than the 'significantly impaired' threshold index of 3.5. The lower curve represents the draft limited duration criteria discussed above. The curves match fairly well at durations greater than 8 hours. The 2 to 8 hour section of the lower curve was developed because literature indicates significant avoidance by juvenile fish (when acclimated to 0 NTUs) at 70 NTUs occurring during short time intervals (30 minutes) (Bisson and Bilby, 1982). A less than 70 NTU threshold was chosen to protect fish from conditions which cause avoidance as discussed above and also provide a safety factor.

**Figure 4.3**



There exist many potential alternatives to the proposed rule language and parameters for specific magnitude and duration. Some of these are included below in Table 4.2. Another option for increased flexibility through a permit or 401 certification would be to base criteria on the equation in Figure 4.3 in order to establish a threshold line for the NTU magnitude for the specific number of activity hours in each day:

$Y = 62.52x^{-0.3566}$  Where  $Y$  would equal the turbidity threshold (not to be exceeded), and  $x$  would be the activity hours for the day or days of interest. The option would also have to meet the monthly average criteria (3 NTUs proposed), as do parameters in Table 4.2

**Table 4.2**

<b>Limited Duration Exceedances</b> (single exceedance period per 24-hour period); & may enlist only one category from the list below per day		
<b>Hrs per 24 hrs</b>	<b>Maximum NTUs</b>	<b>Exceedance Period Limit per 30-days (month)</b>
2	50	6
4	40	5
8	30	4
12	25	3
24	20	2 (non-consecutive)

*Ambient monitoring data:* According to data from ambient conditions under which salmonids currently exist in Oregon are highly variable, suggesting that species can survive during short-term turbidity increases; however streams are typically clear (see Tables 2.1 - 2.3 and Figure 2.1). In general higher turbidities occur during the winter and are often associated with higher flows. Measured turbidity levels ranged widely among 20 routine monitoring stations (0.3 to >700 NTUs) between 1992 and 2002. For low and high flow periods ambient river turbidity levels measured at greater than 20 NTUs occurred 4.4% and 17.2% of the time, respectively. For low and high flow periods ambient river turbidity levels measured at greater than 50 NTUs occurred 3.2% and 4.4% of the time, respectively.

*Other States:* Idaho has an instantaneous turbidity criteria of 50 NTUs for cold water aquatic life.

**Summary:** The proposed allowances would be protective to beneficial uses by limiting the magnitude and duration of turbidity pulses. Since the effect of repeated pulses are not addressed quantitatively in any model or the literature, the monthly average criteria was chosen as a constraint, resulting in a limitation of 6 periods at the specified durations and magnitudes of turbidity allowable in any consecutive 30-day period (Tables 4.3 and 4.4). For projects that do not fit well into this scenario, additional days may be added as long as the daily magnitude and duration limits are met, and as long as data can show that the monthly average criteria are achieved. The rule would also allow for the use of specific BMPs with reduced or no turbidity monitoring if reliable data shows that the BMPS will reliably limit turbidity to the above required levels.

**Table 4.3** Qualitative and Quantitative ill effects scores [Newcombe (2003)]

**\*Key**

Qualitative		Quantitative
0	Best for adult clear water fishes ( <i>Ideal</i> )	0 to ≤ 0.5
1 to 3	Feeding and other behaviors begin to change ( <i>Slightly impaired</i> )	0.5 to ≤ 3.5
4 to 8	Could reduce fish growth, habitat size, or both ( <i>Significantly impaired</i> )	3.5 to ≤ 8.5
9 to 14	Could cause poor condition or habitat alienation ( <i>Severely impaired</i> )	8.5 to ≤ 14.5

**Table 4.4** Potential severity of effects scores based on magnitude and duration of turbidity exposure.

Criterion (NTUs)	Duration	Effects Severity SCORE (Newcombe 2003)*
<b>Long-term effects</b>		
3	1 month (30 days)	1.3
3	2 months	2.0
3	3 months	2.3
3	4 months	2.6
3	11 months	3.5
4	1 month	1.9
7	1 month	3.1
<b>Short-term effects</b>		
5	1 day	0.0
5	3 weeks	2.0
11	1 day	1.0
19	1 day	2.0
30	6 hours	1.7
50	2 hours	1.7
30	8 hours	1.6
6 hrs @ 30 NTUs + 2 hrs@ 50 NTUs +16hrs@ 5 NTUs 15 = ave	1 day	1.5
	3 days	2.6
	6 days	3.2

#### 4.2.5.2 Additional Flexibility Criteria

The purpose of this criteria is to: 1) provide oversight and requirements to minimize and document turbidity increases through 401 water quality certifications for ecological restoration, essential dredging, and emergency activities that cannot achieve limited duration or other turbidity criteria; 2) make findings that long-term gains for ecological restoration projects outweigh short-term impacts to beneficial uses, or in the case of essential channel dredging, to mitigate or offset negative water quality impacts; and 3) prevent permanent turbidity, sediment, and sedimentation impacts.

**Recommendation:** The following draft rule language is proposed:

(2)(e) In a CWA §401 water quality certification, the Department may authorize ecological restoration, emergency, or essential dredging activities to exceed the criteria in subsections (2)(a) through (2)(d) for a period defined in the certification, and in accordance with the following:

- (A) The Department finds that the source cannot practicably comply with criteria in subsections (2)(a) through (2)(d);
- (B) The Department finds for channel restoration or essential dredging that the activity will achieve long-term gains in the protection of beneficial uses that outweigh its potential adverse impacts to beneficial uses, or will offset or mitigate negative impacts to beneficial uses by achieving positive gains on the site or elsewhere in the basin;
- (C) The Department finds that there will be no permanent impairment to any beneficial use from the activity due to or as a result of turbidity, sediment, or sedimentation impacts; and
- (D) The Department coordinates with the Department of Fish and Wildlife regarding water quality and resource protection before authorizing exceedances under this section.

**Rationale:**

The findings required in the draft rule, above, along with conditions for monitoring and documentation (section 4.2.5) are intended to minimize turbidity, prevent permanent damage from turbidity and sedimentation, and promote the improvement of BMPs for necessary projects. For these activities that may have difficulty meeting the specific magnitude and duration criteria, other alternatives are limited, including: 1) prohibit these activities, which may not be environmentally or economically viable; 2) exempt these activities from criteria, which would not likely result in improved BMPs and minimized turbidity discharges; and 3) have activities apply for variances, which would probably have a similar water quality protection result to an exemption; and, may not be realistic considering the number of projects and the amount of time and effort required to get a variance or site specific criteria.

#### 4.2.5.3 More Stringent Criteria

The purpose of this criteria is to: 1) provide more stringent turbidity controls than those specified in draft rule language (2)(d) in order to protect specific areas from potential turbidity, sedimentation impacts, or ancillary impacts for which turbidity (NTUs) may double as a surrogate; and 2) to be used as a maximum criteria substituting for the 5 NTU maximum criteria.

**Recommendation:** The following draft rule language is proposed:

(2)(f) The Department may establish criteria for limited duration exceedances more stringent than the criteria in subsection (2)(d) to protect beneficial uses from activities that occur in areas or situations such as:

- (A) In scenic waterways;
- (B) In waters listed under §303(d) of Clean Water Act for turbidity or sedimentation;
- (C) Upstream of public drinking water intakes;
- (D) Upstream of redds or active spawning areas;
- (E) Activities occurring outside the in-water work period as defined by ODFW; or
- (F) At any location where special circumstances, cumulative impacts, or other conditions require additional protection.

**Rationale:**

Sediment and sedimentation impacts were not incorporated into calculating turbidity magnitude and duration allowances in draft rule language in (3)(d). While these NTU levels may be protective regarding turbidity light and sight effects, they may not be protective of some beneficial uses regarding site-specific impacts of sediment in the water column or sedimentation to aquatic habitat; or regarding other potential parameters for which turbidity can be a surrogate measurement, such as nutrients, bacteria, or toxics. There may also be circumstances warranting decreased turbidity levels, for example with respect to recreational areas for swimming, fishing, or viewing.

#### **4.2.6 Visual criteria**

The purpose of visual contrast criteria is to: 1) utilize a simple and inexpensive method to monitor turbidity during activities in order to provide feedback to improve BMP effectiveness and 2) provide a compliance tool under limited circumstances.

DEQ has incorporated visual observation in 401 certifications as a substitute for using a turbidity meter, presuming that an observable plume extending beyond the compliance point indicates an increase of turbidity that is greater than 10% above background levels (current criteria). NPDES storm water permits have also used visual monitoring. The Oregon Department of Forestry (ODF) incorporates a visual observation compliance tool in their rules regarding wet weather hauling.

Increasing the criteria from 10% to the proposed 5 NTU maximum increase in turbidity may result in less accuracy in determining compliance with respect to the visual criteria, especially under low turbidity background conditions. That is because information from scientific literature and also anecdotal field observations indicates that a plume representing less than a 5 NTU increase in turbidity may be perceptible against a clear water background.

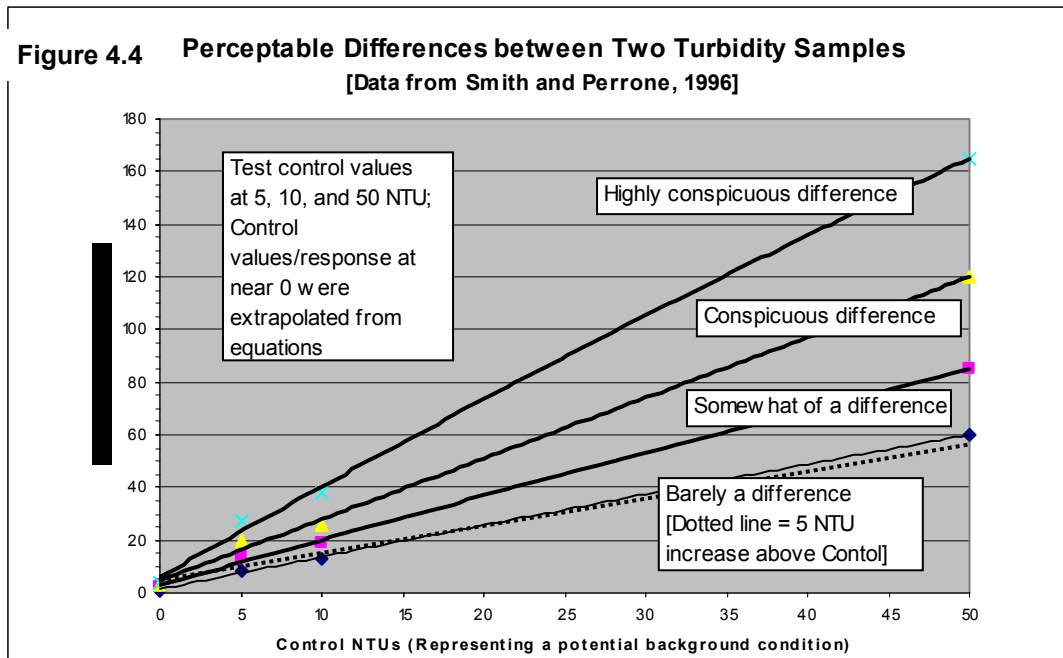
Smith and Perrone (1996) presented survey data regarding human subjects' perceptions of slight to conspicuous differences between turbidity samples in glass containers, with controls of 5, 10, and 50 NTUs (Table 4.5). Perceived contrasts occurred with smaller differences between control and test samples as controls levels approached clear water conditions. This relationship is depicted in Figure 4.4 with values for clear conditions (0 NTUs) extrapolated from regression equations that were

**Table 4.5** Visible differences between turbidity control and test samples (data from Smith and Perrone, 1996)

Compared to Control:	Test level NTU (and increase above control levels)			
	0 NTUs (predicted)	5 NTUs (surveyed)	10 NTUs (surveyed)	50 NTUs (surveyed)
Barely perceptible difference	1.4 (1.4)	8.4 (3.4)	13 (3)	60 (10)
Somewhat of a difference	2.8 (2.8)	14 (9)	19 (9)	85 (35)
Conspicuous difference	4.7 (4.7)	20 (15)	26 (16)	120 (70)
Highly conspicuous difference	5.9 (5.9)	28 (23)	38 (28)	165 (115)

developed from the Table 4.5 data ( $R^2 \geq 0.997$ ). Extrapolated values should be viewed with caution as to representing actual human response. In general, the ability to see and perceive a difference in turbidity follows along the same pattern displayed by other indices regarding light interaction and turbidity, with small increases causing a greater response and perceptible contrasts with respect to clear water conditions compared to contrasts at higher level turbidities.

The dotted line in Figure 4.4 represents a 5 NTU increase (maximum criteria) above control (or potential background) turbidity conditions and where a perceived plume magnitude might hit on that line. While most contrasts would occur at levels greater than 5 NTUs indicating a violation of the maximum criteria, some perceptible increases could also occur at less than 5 NTUs. Since the test samples were presented in jars, the results may have limited bearing on direct field observations where perceptions of a plume are influenced by color, contrast, light attenuation and depth, and other factors.



Field observations suggests the human eye may perceive less than a 5 NTU increase in a turbidity plume observed downstream of activities in very clear stream conditions, with some casual observations reporting a noticeable difference at ~1 NTU above clear water conditions, which is not out of line with the Smith and Perrone (1996) study data. However, there has not been a formal controlled field study to confirm these observations.

Overall the data suggests that a visual contrast method might provide more stringent control than the 5 NTU criteria under the clearest background conditions, and potentially less protection at higher

background levels. If a visible plume does not occur at the compliance distance and in the activity area of influence (and not because it is too deep to see) it would be presumed that the turbidity criteria are being met. Turbidity can be seen, and a visual observation criteria provides an inexpensive method to determine when an activity or discharge elevates turbidity above background. Many activities including channel work, as well as agricultural and forestry operations, may not have turbidity meters available or the expertise to calibrate, verify, and utilize them in monitoring. Turbidity monitoring of some type during activities is important to verify that BMPs are effective and turbidity is being minimized to protective increase levels.

Visual observation has been implemented in determining compliance, with requirements for monitoring typically incorporated into permits or certifications that require an action if the plume is observed. As a standard observation, the proposed criteria would result in two separate regulatory demands. A less precise and potentially more strict criteria under the clearest water conditions. The observable plume requirement would make it clear to everyone including the regulated community that extensive visible plumes from activities are not permissible.

**Recommendation:** Provide a visible criteria in the rule that is not coupled to the maximum criteria, since a perceptible plume may represent turbidities below the criteria. Also, give precedence to turbidity meter measurements if the visual observation is in doubt and a turbidity meter is available. Recommended rule language:

(2)(c) Visual Criteria. A conspicuous turbidity plume must not extend further than the compliance point distances in section (3) of this rule, except as consistent with the numeric or other applicable criteria stated in this rule.

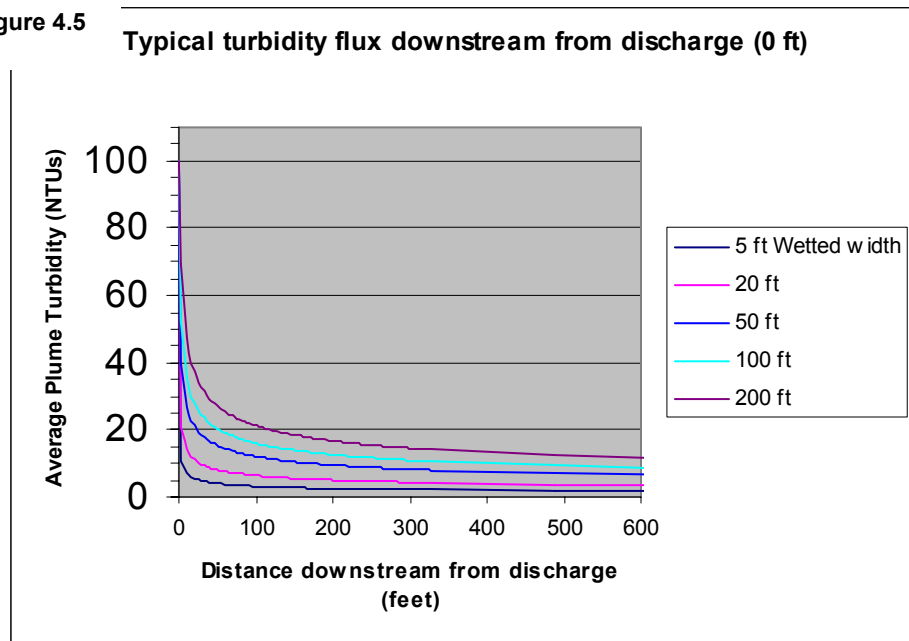
#### 4.2.7 Compliance Determination Distances

Monitoring by sources for turbidity during activities, either visually or using turbidity meters, will continue to be important in protecting water quality with respect to in-stream work (regulated through CWA 401 certifications), and for other activities. The distance downstream at which compliance is measured is an important part of the criteria since it may influence dilution and influence the amount of turbidity-causing material that may discharged.

Because the chief concerns regarding turbidity increases are fish behavioral effects and primary production in the water body, and not acute toxic effects, it makes sense to control turbidity level increases regarding the materials that remain suspended in the water column for some distance, but that do not have a broad negative affect on the receiving waterbody.

Oregon's current turbidity rule does not specify compliance distance

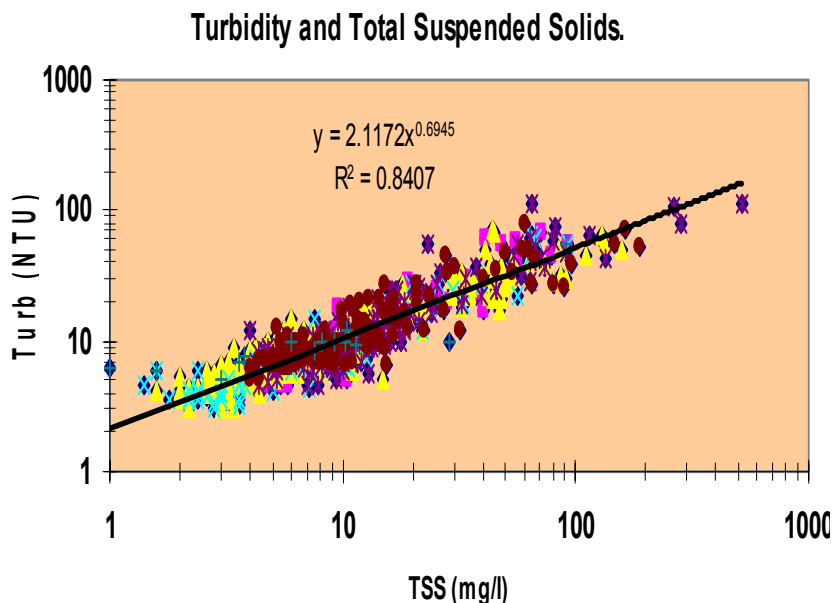
Figure 4.5



locations for monitoring and achieving compliance with the turbidity criteria.

However, in 401 certifications we have often prescribed a distance of 100 feet downstream from an activity for monitoring turbidity increases for compliance determination. Because mixing characteristics are dependent in part on stream width, it may be reasonable to base compliance distances on stream size.

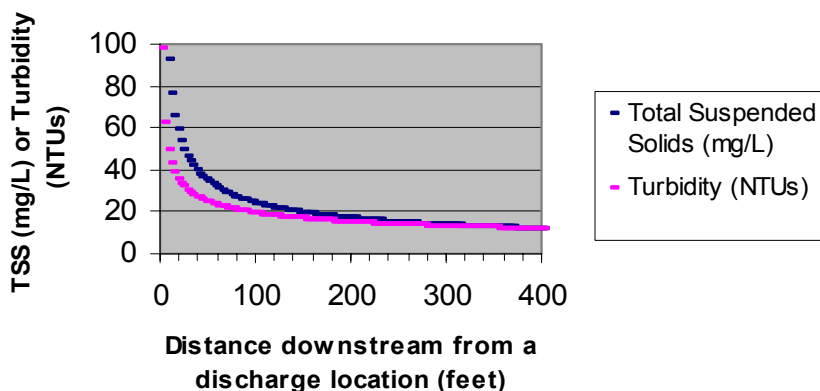
As stream size increases, the distance downstream from a discharge point to the distance where partial or full mix levels are achieved also increases proportionately; and according to suspended sediment dispersal models. Figure 4.5 illustrates this for stream widths of from 5 to 200 feet, with all discharges initiated at 100 NTUs. Where the curves flatten out with downstream distances, the discharged turbidity-causing materials are approaching full mix with the receiving stream.



**Figure 4.6** Turbidity and corresponding suspended sediment concentration [DEQ and Unified Sewerage Agency data]

In order to understand how turbid discharges would behave in mixing, a fairly simple dispersal model was developed and used to obtain a rough idea of the mixing extent at distances downstream from the discharge. The model used suspended sediment as surrogate for turbidity, based on linear regressions on Willamette Basin sediment and turbidity data (see Figures 4.6 and 4.7). For modeling simplicity, it was assumed that all of the discharge ( 1 : 100 dilution to the receiving stream 0 NTUs) would remain suspended in the water column. Stream gradient slopes of 0.0001 to 0.03 were tested, along with depths of 0.5 to 20 feet, widths of 5 to 200 feet, and roughness (Mannings N) of 0.02 to 0.06.

**Figure 4.7** Potential downstream turbidity levels resulting from suspended sediment concentrations in the Willamette Basin. [DEQ and Unified Sewerage Agency data]



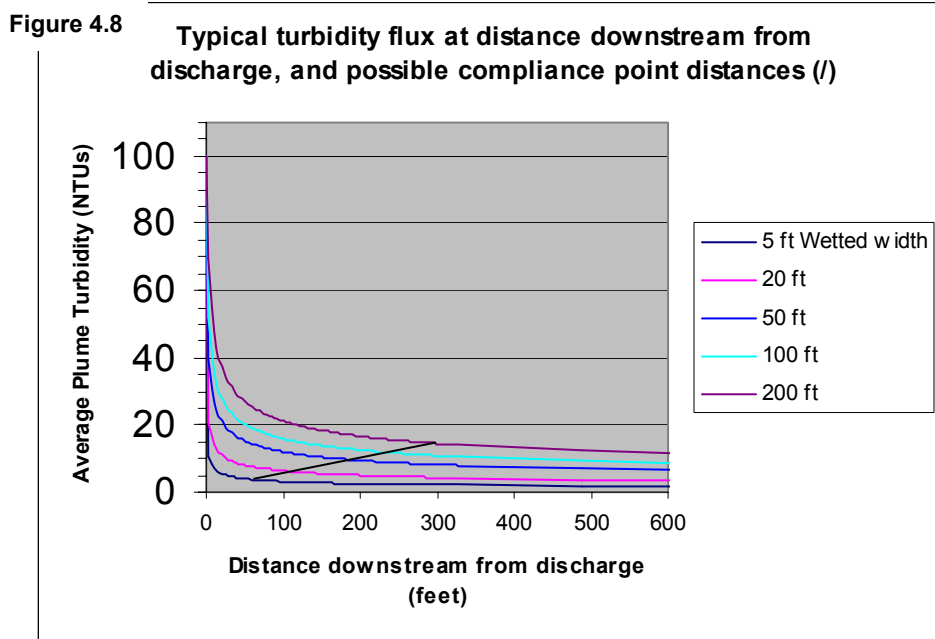
These figures illustrate that high levels of turbidity at or near the discharge point decrease substantially over a fairly short distance. This pattern is not dissimilar to what any dissolved or suspended constituent might exhibit in mixing. However, because the impacts of turbidity considered in developing criteria are mostly behavioral, some initial mixing is reasonable.

For making consistent assessments of turbidity inputs, measurements should be taken beyond the steeper part of the curve, at points where the slope flattens out and values measured at locations of a few feet nearer or farther from the discharge point would not greatly differ.

Achieving a universal monitoring goal on all streams, even under idealized circumstances, is probably not possible. Small streams mix rapidly within a few meters downstream of discharges. It makes sense to allow some distance for settling of material from the immediate discharge area but beyond 50 feet for the smallest streams results in little more mixing and more work in monitoring. The largest water bodies are often of slower velocity, have more upstream sources, and may take many thousands of feet to reach full or even partial mix, so limiting compliance distances here should also be considerate of the spatial extent of turbidity increases for resource protection, and for monitoring efficiency.

Since flow volumes and dilution rates are often difficult to determine, stream width can be used as a rough estimator for categorizing water bodies by sizes since it is an important driver in mixing. Figure 4.8 illustrates the use of stream width and related dispersal curves to estimate compliance distances in order to achieve the following goals in monitoring for turbidity criteria:

- Monitor activity-related turbidity at a distance downstream where ~25% of full mix occurs in order to allow some settling of turbidity-causing materials, and to provide reliable monitoring out of the steeper, unmixed area.
- To be at practical distance from activity in order to adjust BMPs
- Limit spatial extent of mixing on larger water bodies to protect shoreline and other habitats.



The practical result of this approach is tabulated in Table 4.4. While there appears to be a large difference in proportions mixed, ranging from 25 to 100 %, these differences occur in the flattest part of the dispersal curve, whereas the biggest changes in turbidity plume levels occur between 0 and 25 % mix in the steeper are of the curve, near the discharge point.

**Table 4.6**

Possible compliance distances and predicted mixing, based on width of stream.

Wetted width of stream (ft)	Monitoring distance (ft) down stream from discharge/activity	Proportion of full mix with receiving waters
5 – 30	50	100 – 25%, respectively
31 – 100	100	50 – 25%
101 – 200	200	30 – 25%
201 – >201	300	25 – <25%

*Why include compliance distances in the turbidity rule?*

- Distances specified in the turbidity rule are part of the criteria. Distances specified outside the rule, such as in guidance, would be more open to interpretation and judgment by the Department.
- Specifying distances in the rule provides for uniform implementation of the turbidity criteria. For in-stream work there is no discrete discharge point for which we could establish an end-of-pipe limit, but rather a channel disturbance zone where turbid discharges can occur, often sporadically.
- Having no compliance distance specified in the current turbidity rule would result in more evaluation for some individual projects or permits. However, the Department could be constrained by the distances specified in the rule. There may be site-specific conditions where more flexibility is justified.
- The State of Washington Department of Ecology (DOE) has recently incorporated compliance distances (or temporary areas of mixing) into their turbidity rule for in-stream construction projects subject to work orders, with a maximum distance of 300 ft as allowed in their mixing zone regulation.

**Recommendation:** The following draft rule language is proposed:

(3) Turbidity criteria points of compliance for activities not subject to an OAR-340-041-0053 mixing zone. Compliance with the numeric turbidity criteria established in section 2 of this rule is determined within the following distances directly downstream, and within any existing turbidity plume, from a source or activity discharge point:

(a) For wetted stream widths no greater than 30 feet at the discharge point: 50 feet.

(b) For wetted stream widths greater than 30 feet but not greater than 100 feet at the discharge point: 100 feet.

(c) For wetted stream widths greater than 100 feet but not greater than 200 feet at the discharge point: 200 feet.

(d) For wetted stream widths greater than 200 feet at the discharge point: 300 feet.

(e) For ponded systems such as lakes, reservoirs, ponds, wetlands, backwater systems, and similar waterbodies: 100 feet, or the maximum surface dimension of the water body, which ever is less.

The proposed distance for ponded systems was not chosen as the result of dispersion modeling, but because the turbidity variability in static systems is not expected to be as great as in flowing systems. It was also assumed that mixing would not move measurable levels of turbidity as far or as fast as seen in many flowing systems.

Other possible options for utilizing compliance distances for turbidity criteria:

- Include compliance distances in the rule for in-stream activities, only.
- Include compliance distances in guidance, only.
- Require individual certifiers and permit writers to assign compliance distances on a case by case basis. Selected distances may be open to challenges. Individual compliance distance evaluations have already become a time-consuming process which would be addressed by the rule recommendation.

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DRAFT	Duration	Test Type	Response Type	Response Level, Turbidity NTU	Range of potential effect: Highest NOEL (or control) to LOEL	Reference	Table A1. Fish: Summary of Adverse Turbidity Response Data
Species							Comment

<i>Salvelinus namaycush</i> (lake trout)	4 hrs	Lab	Reactive distance	3 (LOEL)	0.09 to 3.18	Vogel and Beauchamp 1999	Reactive distance was significantly less at 3.18 NTUs compared to the lowest test level (0.09 NTUs). As light intensity increased passed the SIT (saturation intensity threshold) the reactive distance trended in the negative direction at higher turbidity levels tested (0.09, 3.18, 7.40), possibly giving more advantage to prey.
<i>Oncorhynchus nerka nerka</i> (sockeye salmon)		Field	Euphotic volume, fish abundance.	5 (LOEL)	NA	Lloyd et al. 1987	Juvenile smolt production in lakes decreased significantly with decreasing euphotic volume (linear equation: $r^2=0.99$ ). A 5 NTU increase in turbidity reduced the productive euphotic volume of a naturally clear lakes by as much as 80%. Chlorophyll-a concentrations in glacially turbid lakes with decreased euphotic volume were significantly less than clear lakes. Zooplankton densities in turbid glacially fed lakes were as little as 5% of those in clear lakes. In streams, arctic grayling were absent from reaches below mines (with average turbidities ranging from 75 to 727 NTUs). Un-mined reaches (NTUs: averaging from 1.3 to 2.7) had 0.5 to 8.7 grayling per haul. Based on a series of equations and calculations assembled by the authors, a 5 NTU increase in turbidity decreases primary productivity in clear streams by 3-13%; a 25 NTU increase may decrease primary productivity by 13-50 %. Negative effects on primary production in streams would be even greater at depths >0.5 meters [NTUs tested: 0-15, 28, 52, and 79]

DRAFT							<b>Table A1. Fish: Summary of Adverse Turbidity Response Data</b>
Species	Duration	Test Type	Response Type	Response Level, Turbidity NTU	Range of potential effect: Highest NOEL (or control) to LOEL	Reference	Comment

<i>Galaxius fasciatus</i> (Banded Kokopu)	30 min	Lab	Mean feeding rate (prey/fish)	10 (LOEL)	0 - 10	Rowe and Dean 1998	The mean feeding rate decreased significantly at 10 NTUs (control = 0 NTUs; p<0.05), and at 20 NTUs (p<0.001). [Tested: 0, 10, 20, 40, 80, 160, 320, and 640 NTUs]
<i>Salvelinus fontinalis</i> (Brook trout)	~20 min	Lab: Experimental stream	Reactive distance	10 (LOEL)	0 - 10	Sweka and Hartman 2001a	The probability of a brook trout's reacting to a prey item decreased curvilinearly with increased turbidity (tested at 0, 10, 15, 20, 25, 30, 35, and 40 NTUs); i.e. the encounter rate decreased. Brook trout are an introduced cold-water species ( <i>Salvelinus fontinalis</i> ) related to native Bull trout ( <i>Salvelinus confluentus</i> ). Foraging success was influenced by the ability to detect and react to prey. Growth effects occurred due to a shift to an active feeding strategy caused by turbidity according to the authors (for more, see below in this table). An EL50 of ~10 NTUs for reactive distance was estimated for this report from the study data.
Fathead minnow, <i>Pimephales promelas</i>	20 min	Lab	Predator/prey behavior	13 (LOEL)		Abrahams and Kattenfeld (1997)	Potential predation (the presence of predators near feeding fathead minnows) increased significantly in turbid waters (13 NTUs). However, if the rate of encounter is decreased in the field due to high turbidity or low predator populations, then predation may be decreased. The author's generalized, "If the turbidity causes prey to detect predators at distances where they should have initiated escape, then most anti-predator behaviors become ineffective....This would contrast with clearer water situations where prey would have the opportunity to modify their behavior to limit their mortality rates." [NTUs tested: <1, and 13]

DRAFT  Species	Duration	Test Type	Response Type	Response Level, Turbidity NTU	Range of potential effect: Highest NOEL (or control) to LOEL	Reference	<b>Table A1. Fish: Summary of Adverse Turbidity Response Data</b>  Comment
<i>Galaxius fasciatus</i> (Banded Kokopu)	20 min	Lab	Avoidance	17 (EL50) 6.4 (EL25)	NA	Boubee et al. 1997	<p>The authors suggested that habitat preferences may influence banded kokopu sensitivity to turbidity. Banded kokopu typically inhabit small brush-covered headwater streams with clear water. The authors predicted a 6.5 NTUs level that would cause an avoidance response in 25% of cases. [tested: 0 - 1000 NTUs using two different types of clay particles; ~20 NTUs~EL50]</p>
<i>Galaxius brevipinnis</i> (Koaro)	20 min	Lab	Avoidance	69.2 (EL50) 6.5 (EL25)	NA	Boubee et al. 1997	<p>Study suggested that the protection of sensitive migratory species, such as banded kokopu or koaro, would also protect other visually-orientated migratory species such as salmonids with respect to mobility and ability to migrate and find suitable habitat, but not necessarily protect benthic invertebrates. The authors predicted a 6.5 NTUs level that would cause an avoidance response in 25% of cases. [tested: 0 - 1000 NTUs using two different types of clay particles; 25 NTUs~EL50]</p>

DRAFT  Species	Duration	Test Type	Response Type	Response Level, Turbidity NTU	Range of potential effect: Highest NOEL (or control) to LOEL	Reference	<b>Table A1. Fish: Summary of Adverse Turbidity Response Data</b>  Comment
<i>Oncorhynchus mykiss</i> (Rainbow Trout)	1-2 hr	Lab	Reactive distance	15 (LOEL)	<5 - 15	Barrett et al. 1992	Rainbow trout, at 15 NTUs (lowest test level) and 30 NTUs, saw 20% and 55% reductions (each statistically significant) in reactive distance, respectively, compared to the ambient turbidity (or control: 4-6 NTUs) [Tested: 4-6, 14-16, and 29-31 NTUs]
<i>Oncorhynchus tshawytscha</i> (Chinook Salmon)	5 min	Lab	Reactive distance	10 (EL50)	NA	Gregory and Northcote, 1993	Reactive distance juvenile Chinook feeding on Artemia prey was strongly correlated to turbidity (R <sup>2</sup> =0.98). An EL50 of 10 NTUs was estimated for this report from the log-linear relationship developed by the authors. [NTUs tested: 0.5 - 243]
<i>Oncorhynchus tshawytscha</i> (Chinook salmon)	10 min and 5 min	Lab	Surface and Benthic foraging rates on <i>Drosophila melanogaster</i> (surface prey) and <i>Tubifex</i> (benthic prey)	35-150: positive effect on foraging  <1 and 810: negative effect on foraging	NA	Gregory and Northcote, 1993	Surface and benthic feeding rates of juvenile chinook salmon (smallest size category) on prey ( <i>Drosophila</i> , 10-minute test; and <i>Tubifex</i> , 5-minute test) increased significantly at turbidity levels of 35-150 NTUs compared to rates at <1 NTU and 810 NTUs). Results were counter-intuitive with respect to reactive distance results (see above). Two important factors: visibility and perception of risk by both predators and prey. In both cases, a large proportion (>60%) of fish at the <1 and 810 NTUs did not feed at all. [ NTUs tested: <1, 18, 35, 70, 150, 370, and 810]

DRAFT  Species	Duration	Test Type	Response Type	Response Level, Turbidity NTU	Range of potential effect: Highest NOEL (or control) to LOEL	Reference	<b>Table A1. Fish: Summary of Adverse Turbidity Response Data</b>  Comment
<i>Salvelinus fontinalis</i> (Brook trout)	5 days	Lab: Artificial stream	Growth rate	25 NTUs (EL50) 14 NTUs (EL25)	NA	Sweka and Hartman, 2001b	<p>Growth rates decreased significantly with increasing turbidity. Brook trout exhibited a 62 % decrease in growth rates between the highest level tested and the clear water control. Growth did not appear to be affected by mean daily consumption. Authors assumed that a transition to active feeding which took place between 10 and 20 NTUs which caused growth rates to decrease with increasing turbidity. EL50 of 25 NTUs was estimated from the author's equation: specific growth rate = 0.051 – 0.001(NTUs) from a regression with an R<sup>2</sup> of 0.48 [Tested: 0.8, 6.1, 10.1, 14.8, 20.3, 25.6, 30, and 40 NTUs]</p>
<i>Oncorhynchus clarki henshawi</i> (Lahontan Cutthroat Trout)	2 hrs	Lab	Feeding rates	20 (LOEL)	10 - 20	Vinyard and Yuan 1996	<p>Lake: Feeding rate (percent eaten) decreased significantly from low levels (3.5, 6, and 10 ntus) compared to levels of 20 ntus and greater. Predation rates decreased by 80% between the 3.5 ntu and 25 ntu test levels (multiple regression:F=35.1, P&lt;0.001). While the difference between 3, 6, and 10 ntus was not tested for statistical significance, there exists a strong linear relationship between turbidity and predation rate in this study. At 3.5 ntus, 80 to 100 % of potential prey were consumed. At 6 ntus, 75 to 95% of prey were consumed, and at 10 ntus, 65 to 90 % of prey were consumed. [3.5, 6, 10, 20, 23, and 25 NTUs tested]</p>

DRAFT  Species	Duration	Test Type	Response Type	Response Level, Turbidity NTU	Range of potential effect: Highest NOEL (or control) to LOEL	Reference	<b>Table A1. Fish: Summary of Adverse Turbidity Response Data</b>  Comment
<i>Richardsonius egregius</i> (Lahontan redbreasted shiner)	2 hrs	Lab	Feeding rates	20 (LOEL)	10 - 20	Vinyard and Yuan 1996	Lake: Feeding rate (percent eaten) decreased significantly from low levels (3.5, 6, and 10 ntus) compared to levels of 20 ntus and greater. Predation rates decreased by 60 to 80% between the 3.5 ntu and 25 ntu test levels (F=27.15, P<0.001). While the difference between 3, 6, and 10 ntus was not tested for statistical significance, there exists a strong linear relationship between turbidity and predation rate in this study. At 3.5 ntus, 85 to 100 % of potential prey were consumed. At 6 ntus, 80 to 95%, and at 10 ntus, 65 to 90 % of potential prey were consumed. [3.5, 6, 10, 20, 23, and 25 NTUs tested]
<i>Salvelinus fontinalis</i> (Brook trout)	5 days	Lab: Artificial stream	Shift from drift consumption to 'energetically taxing' active food searching	20 (LOEL) 10 (NOEL)	10 - 20	Sweka and Hartman, 2001b	Authors stated, "the transition from a typical drift-feeding strategy to an active searching strategy took place between 10 and 20 ntus. [Tested: 0.8, 6.1, 10.1, 14.8, 20.3, 25.6, 30, and 40 NTUs]
<i>Oncorhynchus kisutch</i> (Coho Salmon)	48 hr	Lab: Experimental stream	Feeding behavior (prey capture success)	20 (LOEL)	0 - 20	Berg and Northcote 1985	A significant decrease in prey capture success occurred at the the lowest level tested (20 ntus) compared to the control (0 ntus). [tested 0, 20, and 30 NTUs]

DRAFT	Duration	Test Type	Response Type	Response Level, Turbidity NTU	Range of potential effect: Highest NOEL (or control) to LOEL	Reference	Table A1. Fish: Summary of Adverse Turbidity Response Data
Species							Comment

<i>Oncorhynchus kisutch</i> (Coho Salmon)	~11 days	Lab: Experimental stream	Reaction distance	20 (LOEL)	0 - 20	Berg and Northcote 1985	A significant increase in reaction distance occurred at the lowest level tested (20 NTUs) compared to the control (0 NTUs). [tested 0, 20, and 30 NTUs]
<i>Oncorhynchus kisutch</i> (Coho Salmon)	~11 days	Lab: Experimental stream	Feeding rates	20 (LOEL)	0 - 20	Berg and Northcote 1985	A significant decrease in feeding rate occurred at the the lowest level tested (20 ntus) compared to the control (0 ntus). [tested 0, 20, and 30 NTUs]
<i>Oncorhynchus kisutch</i> (Coho Salmon)	11 days	Lab	Growth rate	22 (LOEL)	0 - 22	Sigler et al. 1984	In two separate laboratory tests, one using straight 'raceway' channels and one using oval channels, weight and length were significantly decreased in turbid waters compared to clear waters. Oval channel [Tested: clear, and 22 NTUs] Raceway channel [Tested: clear and 11-32 NTUs]
<i>Oncorhynchus tshawytscha</i> (Chinook Salmon)	1 day	Lab	Avoidance	23 (LOEL)	0 -23	Gregory, 1993	Fish exposed to the turbid water condition (23 NTUs) distributed randomly in the experimental tank. Fish in clear water conditions (<1 NTU) associated with the bottom area of the tank. [tested: <1, 23 NTUs]

DRAFT  Species	Duration	Test Type	Response Type	Response Level, Turbidity NTU	Range of potential effect: Highest NOEL (or control) to LOEL	Reference	<b>Table A1. Fish: Summary of Adverse Turbidity Response Data</b>  Comment
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Salmonids, including: Cutthroat trout (Oncorhynchus clarki); Rainbow trout (Oncorhynchus mykiss); Chinook salmon (Oncorhynchus tshawytscha); Coho salmon ((Oncorhynchus kisutch); Northern squawfish (Ptychocheilus oregonensis); Prickly sculpin (Cottus asper); Brown bullhead (Ictalurus nebulosus)	2-8 hr.	Field	Reduction of Predation, Effects on Prey	27 (LOEL)	0 - 27	Gregory and Levings, 1998	Predation by fish species, including salmonids, in the most turbid study site, the Fraser River (SW British Columbia), was significantly less than predation in two other less turbid sites. Fraser River water turbidity ranged from 27 to 108 NTUs between Apr 16 and May 22 (1991). Predation at the Fraser River site remained consistently low (relative to the two other study sites) during the period when turbidity was ~27 NTUs; i.e. no temporal or spatial differences in salmonid predation rates. The percentage of prey-containing salmonids from the two clearest water sites was approximately 3-5 times greater than from the high-turbidity Fraser River site. Of the fish with at least one ingested prey item, the numbers of ingested prey in salmonids were approximately 1.5 to 3 times greater than from the Fraser River site. Of the more than 35,000 fish caught (75% salmonids) for the study survey, the greatest numbers of juvenile salmon came from the clearest water site, the Harrison River, with up to 300 fish per set (mean catch). The highest number of juvenile salmon caught at either the Fraser River or Nicomen Slough sites was approximately 20 fish per set during the same period, April and May, 1991. Northern Squawfish, a native Oregon species, were the most successful predator in turbid waters, probably due to the use of olfaction, as well as vision, to locate prey. [NTUs tested: 0.8-1.0 (Harrison R.), 1.3-6.1 (Nicomen Slough), 27-107.5 (Fraser R.)]
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DRAFT  Species	Duration	Test Type	Response Type	Response Level, Turbidity NTU	Range of potential effect: Highest NOEL (or control) to LOEL	Reference	<b>Table A1. Fish: Summary of Adverse Turbidity Response Data</b>  Comment
<i>Oncorhynchus kisutch</i> (Coho Salmon)	~11 days	Lab: Experimental stream	Social dominance hierarchy	30 (LOEL)	0 - 30	Berg and Northcote 1985	Coho salmon dominance hierarchies broke down when fish were subjected to 30 – 60 NTUs for at least one day, and re-established when turbidity was returned to 0 – 20 NTUs (Berg and Northcote, 1985). A sudden pulse of turbidity that quickly introduced 60 NTUs to an otherwise clear arena caused fish to initially swim upstream toward the pulse to investigate, and then drift downstream to remain in clear water as long as possible, then exhibiting alarmed behavior with some fish entering the gravel for several hours.
<i>Oncorhynchus mykiss</i> (Steelhead Trout)	19 days	Lab	Growth rate	38 (LOEL)	0 - 38	Sigler et al. 1984	In laboratory tests using straight 'raceway' channels, weight and length were significantly decreased in turbid waters compared to clear waters. [Tested: 0, and 38 NTUs]
<i>Salvelinus fontinalis</i> (Brook trout)	5 days	Lab: Artificial stream	Mean daily consumption	20 (NOEL)	NA	Sweka and Hartman, 2001b	Results inconclusive based on Fig. 3. [Tested: 0.8, 6.1, 10.1, 14.8, 20.3, 25.6, 30, and 40 NTUs]
<i>Oncorhynchus kisutch</i> (Coho Salmon)	30 min	Lab	Avoidance	70 (LOEL)	NA	Bisson and Bilby 1982	The authors stated, " juvenile coho salmon did not exhibit significant avoidance until the turbidity reached 70 NTUs" with test fish acclimated to clear water conditions. Some trials suggested avoidance behavior at less than 70, though not statistically significant. Similar test fish that were acclimated to more turbid water conditions (2 - 15 NTUs) exhibited significant avoidance response at ~ 100 NTUs [NTUs Tested: 10, 16, 19, 41, 42, 53, 70, 97, 158, and 184]

DRAFT	Duration	Test Type	Response Type	Response Level, Turbidity NTU	Range of potential effect: Highest NOEL (or control) to LOEL	Reference	<b>Table A1. Fish: Summary of Adverse Turbidity Response Data</b>
Species							Comment

<i>Oncorhynchus tshawytscha</i> (Chinook Salmon)	1 min	Lab	Planktonic foraging on <i>Artemia</i>	70 (NOEL)	35 - 70	Gregory and Northcote, 1993	Planktonic foraging was highest at all low treatment levels (<1 – 70 NTUs) but not significantly decreased (compared to low levels) until the turbidity reached 350 NTUs. Percent feeding was fairly even (~ 100%) for all turbidity level treatments [NTUs tested: 1, 18, 35, 70, 150, 370, and 810]
<i>Morone saxatilis</i> (Striped Bass)	25 min	Lab	Feeding Rate on Copepods	77 (NOEL)		Breitburg (1988)	
<i>Galaxius cotidianus</i> (Common Bullies)	30 min	Lab	Mean feeding rate (prey/fish)	80 (NOEL)		Rowe and Dean 1998	
<i>Oncorhynchus kisutch</i> (Coho Salmon)	30 min	Lab	Avoidance	92 (NOEL)		Bisson and Bilby 1982	
<i>Galaxius maculatus</i> (Inanga)	20 min	Lab	Avoidance	115.5 (NOEL)		Boubee et al. 1997	
<i>Galaxius maculatus</i> (Inanga)	30 min	Lab	Feeding rates	>160 (NOEL)		Rowe et al. 2002	

DRAFT	Duration	Test Type	Response Type	Response Level, Turbidity NTU	Range of potential effect: Highest NOEL (or control) to LOEL	Reference	Table A1. Fish: Summary of Adverse Turbidity Response Data
Species							Comment

<i>Retropinna retropinna</i> (Smelt)	30 min	Lab	Feeding rates	>160 (NOEL)		Rowe et al. 2002	
<i>Oncorhynchus tshawytscha</i> (Chinook Salmon)	1 min	Lab	Decreased foraging rates on <i>Artemia salina</i> (planktonic prey)	370 (LOEL)	150 - 370	Gregory, 1994	Planktonic foraging was highest at all low treatment levels (<1 – 70 NTUs) for all fish sizes, but not significantly decreased (compared to low levels) until the turbidity reached 350 NTUs. [NTUs tested: 1, 18, 35, 70, 150, 370, and 810]
<i>Oncorhynchus tshawytscha</i> (Chinook Salmon)	10 min	Lab	Decreased foraging rates on <i>Drosophila melanogaster</i> (surface prey)	18 (LOEL)	<1 - 18	Gregory, 1994	Fish in the two smallest size categories surface feeding on <i>Drosophila</i> behaved differently than as described in Gregory and Northcote (1993), with the greatest feeding rate observed at the lowest turbidity level (<1 NTU); with the feeding rate declining with increasing turbidity. The largest fish group (of 3 size categories) consumed more prey at the intermediate turbidity levels (18-150 NTUs). [NTUs tested: 1, 18, 35, 70, 150, 370, and 810]
<i>Oncorhynchus tshawytscha</i> (Chinook Salmon)	5 min	Lab	Decreased foraging rates on <i>Drosophila melanogaster</i> (surface prey)	<1 and 810 (LOEL)	NA	Gregory, 1994	Benthic foraging on <i>Tubifex</i> resulted in the highest feeding rates for all size categories occurring between 18 and 150 NTUs, but without the pronounced dome-shaped curve relationship for the two smaller fish groups that was seen for the largest fish group (the dome-shaped curve depicts low foraging at the extremes, the low and high turbidity levels, with the greatest foraging rates occurring in the intermediate turbidity levels, as discussed above). [NTUs tested: 1, 18, 35, 70, 150, 370, and 810]

DRAFT	Duration	Test Type	Response Type	Response Level, Turbidity NTU	Range of potential effect: Highest NOEL (or control) to LOEL	Reference	Table A1. Fish: Summary of Adverse Turbidity Response Data
Species							Comment

<i>Galaxius maculatus</i> (Inanga)	30 min	Lab	Mean feeding rate (prey/fish)	320 (NOEL)		Rowe and Dean 1998	
<i>Anguilla australis</i> (Shortfinned Elvers)	20 min	Lab	Avoidance	>500 (NOEL)		Boubee et al. 1997	
<i>Anguilla dieffenbachii</i> (Longfinned Elvers)	20 min	Lab	Avoidance	>500 (NOEL)		Boubee et al. 1997	
<i>Galaxius brevipinnis</i> (Koaro)	30 min	Lab	Mean feeding rate (prey/fish)	>640 (NOEL)		Rowe and Dean 1998	
<i>Gobiomorphus huttoni</i> (Redfinned Bully)	30 min	Lab	Mean feeding rate (prey/fish)	>640 (NOEL)		Rowe and Dean 1998	

DRAFT  Species	Duration	Test Type	Response Type	Response Level, Turbidity NTU	Range of potential effect: Highest NOEL (or control) to LOEL	Reference	<b>Table A1. Fish: Summary of Adverse Turbidity Response Data</b>  Comment
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<i>Gobiomorphus huttoni</i> (Redfinned Bully)	20 min	Lab	Avoidance	1000 (NOEL)		Boubee et al. 1997	
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DRAFT  Species	Duration	Test Type	Response Type	Response Level, Turbidity NTU	Range of potential effect: Highest NOEL (or control) to LOEL	Reference	<b>Table A2. Invertebrates: Summary of Adverse Turbidity Response Data</b>  Comment
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Benthic invertebrates	> 2 Months	Field	Density	3.7 EL50 1.8 EL25	NA	Quinn et al. 1992	<p>Turbidity effects clear: invertebrate densities lower at all downstream sites tested. Bodies and gills clean of sediments. 7.3 NTUs (median) was the lowest downstream site level with significant difference from the upstream site (1.1). Data was also pooled for an overall comparison of turbidity to invertebrate density. Using Density = 408.5 (NTUs<sup>-0.585</sup>), turbidity was well correlated with invertebrate densities (R<sup>2</sup>=0.715) with an estimated EL50 of 3.7 NTUs, and an EL25 of 1.8 NTUs. Effects on invertebrate populations were thought to be due to food supply (primary productivity) affected by shading. [(Upstream, downstream) turbidity NTUs tested: (4.0, 86), (2.0, 15), (1.1, 7.3), (2.8, 27), (1.5, 8.4), and (2.4, 15)] Factors other than shade caused by turbidity were ruled out as causing the effect, including nutrient levels, color, or other sources of shade. These results are for shallow streams (0.2 – 0.4 meters), so turbidity effects could be greater in deeper streams. The findings suggested that autochthonous production predominated, with only low levels of allochthonous materials being retained in the system. Therefore, systems with greater inputs of allochthonous materials may not be as susceptible to shading effects. Also, the authors suggested that shading effects may be greater in humic colored waters, such as those in the study site, than in non-humic colored waters.</p>
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DRAFT  Species	Duration	Test Type	Response Type	Response Level, Turbidity NTU	Range of potential effect: Highest NOEL (or control) to LOEL	Reference	<b>Table A2. Invertebrates: Summary of Adverse Turbidity Response Data</b>  Comment
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Benthic invertebrates	> 2 Months	Field	Richness	100 (EL50) 8 (EL25)	NA	Quinn et al. 1992	<p>Turbidity effects clear: invertebrate taxonomic richness down at all but two sites tested. Bodies and gills clean of sediments. 8.4 NTUs (median) was the lowest downstream site level with significant difference from the upstream site (1.5). Data was also pooled for an overall comparison of turbidity to invertebrate richness. Using Richness = <math>16.3 (\text{NTUs}^{-0.15})</math>, Turbidity was not as well correlated with invertebrate richness (<math>R^2=0.415</math>) as with densities (<math>R^2=0.71</math>). Therefore EC values are less reliable with an EL50 estimate of 100 NTUs, and an EL25 of 8 NTUs. Effects on invertebrate populations were thought to be due to food supply (primary productivity) affected by shading. [(Upstream, downstream) turbidity NTUs tested: (4.0, 86), (2.0, 15), (1.1, 7.3), (2.8, 27), (1.5, 8.4), and (2.4, 15)] Factors other than shade caused by turbidity were ruled out as causing the effect, including nutrient levels, color, or other sources of shade. These results are for shallow streams (0.2 – 0.4 meters), so turbidity effects could be greater in deeper streams. The findings suggested that autochthonous production pre-dominated, with only low levels of allochthonous materials being retained in the system. Therefore, systems with greater inputs of allochthonous materials may not be as susceptible to shading effects. Also, the authors suggested that shading effects may be greater in humic colored waters, such as those in the study sites, than in non-humic colored waters; but results may be similar in deeper non-humic colored streams.</p>
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DRAFT Appendix A  Species	Duration	Test Type	Response Type	Response Level, Turbidity NTU	Range of potential effect: Highest NOEL (or control) to LOEL	Reference	Table A3. Plants: Summary of Adverse Turbidity Response Data  Comment
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Plants, Aquatic (Periphyton Productivity)	12 weeks	Field	Periphyton Productivity, g O <sub>2</sub> /m/day	2.6 (EL50) 1.6 (EL25)	NA	Davies-Colley et al. (1992)	<p>All study sites had significant downstream decreases in periphyton productivity (g O<sub>2</sub>/m/day) as well as increases in turbidity which the authors observed were responsible for periphyton productivity decreases due to light shading. 7.3 NTUs (median) was the lowest downstream site level with significant difference from the upstream site (1.1). Data was also pooled for an overall comparison of turbidity to periphyton productivity. Using productivity = 3.82 (NTUs<sup>-0.82</sup>), turbidity was well correlated with periphyton productivity (R<sup>2</sup>=0.815) with an estimated EL50 of 2.6 NTUs, and an EL25 of 1,6 NTUs.</p> <p>[(Upstream, downstream) turbidity NTUs tested: (4.0, 86), (2.0,15), (1.1, 7.3), (2.8, 27), (1.5, 8.4), and (2.4, 15)] Factors other than shade caused by turbidity were ruled out as causing the effect, including nutrient levels, color, or other sources of shade. These results are for shallow streams (0.2 – 0.4 meters), so turbidity effects could be greater in deeper streams. The findings suggested that autochthonous production predominated, with only low levels of allochthonous materials being retained in the system. Therefore, systems with greater inputs of allochthonous materials may not be as susceptible to shading effects. Also, the authors suggested that shading effects may be greater in humic colored waters, such as those in the study site, than in non-humic colored waters.</p>
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DRAFT Appendix A  Species	Duration	Test Type	Response Type	Response Level, Turbidity NTU	Range of potential effect: Highest NOEL (or control) to LOEL	Reference	Table A3. Plants: Summary of Adverse Turbidity Response Data  Comment
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Plants, Aquatic (Periphyton Biomass)	12 weeks	Field	Algal (Periphyton) Biomass, g/m <sup>2</sup>	3.5 (EL50) 1.8 (EL25)	NA	Davies-Colley et al. (1992)	<p>All study sites had significant downstream decreases in periphyton biomass productivity (mg/m<sup>2</sup>). Increases in turbidity were assumed by the authors to be responsible for periphyton biomass productivity decreases due to light shading. 7.3 NTUs (median) was the lowest downstream site level with significant difference from the upstream site (1.1). Data was also pooled for an overall comparison of turbidity to periphyton biomass. Using Biomass = 27.5 (NTUs<sup>-0.61</sup>), turbidity was well correlated with periphyton biomass (R<sup>2</sup>=0.703) with an estimated EL50 of 2.6 NTUs, and an EL25 of 1.8 NTUs [(Upstream, downstream) turbidity NTUs tested: (4.0, 86), (2.0, 15), (1.1, 7.3), (2.8, 27), (1.5, 8.4), and (2.4, 15)] Factors other than shade caused by turbidity were ruled out as causing the effect, including nutrient levels, color, or other sources of shade. These results are for shallow streams (0.2 – 0.4 meters), so turbidity effects could be greater in deeper streams. The findings suggested that autochthonous production predominated, with only low levels of allochthonous materials being retained in the system. Therefore, systems with greater inputs of allochthonous materials may not be as susceptible to shading effects. Also, the authors suggested that shading effects may be greater in humic colored waters, such as those in the study site, than in non-humic colored waters.</p>
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DRAFT Appendix A  Species	Duration	Test Type	Response Type	Response Level, Turbidity NTU	Range of potential effect: Highest NOEL (or control) to LOEL	Reference	Table A3. Plants: Summary of Adverse Turbidity Response Data  Comment
Cold, freshwater algae (Primary production)		Field	Euphotic volume, Algal abundance.	5 (LOEL)	NA	Lloyd et al. 1987	<p>Turbidity was strongly correlated to the 1% compensation depth (log log linear <math>r^2=0.85</math>). Lakes: A 5 NTU increase in turbidity reduced the productive euphotic volume of a naturally clear lakes by as much as 80%. Chlorophyll-a concentrations in glacially turbid lakes with decreased euphotic volume were significantly less than clear lakes. (other studies have indicated that primary productivity can be decreased by turbidity as low as 4 - 15 NTUs in lakes.) Shallow streams (&lt;0.5 meters): Based on a series of equations and calculations assembled by the authors, a 5 NTU increase in turbidity decreases primary productivity in clear streams by 3-13%; a 25 NTU increase may decrease primary productivity by 13-50 %. Negative effects on primary production in streams would be even greater at depths &gt;0.5 meters. [NTUs tested: 0-15, 28, 52, and 79]</p>
Plants, Aquatic (Whole Stream Respiration, includes all plants and animals)	~2.5-3 mo	Experimental stream	Night-time measurements of whole-stream respiration	25-30 (LOEL) 15-20 (NOEL)	15 - 25	Parkhill and Gulliver 2002	<p>Whole stream plant respiration decreased significantly in stream simulation treatments exhibiting 25 to 35 ntus. The treatment with 15 to 20 ntus saw no significant decrease in whole stream respiration.[ Tested: 5-10, 15-20, 25-30, and 30-35 NTUs]</p>

<b>DRAFT Appendix A</b>	<b>Duration</b>	<b>Test Type</b>	<b>Response Type</b>	<b>Response Level, Turbidity NTU</b>	<b>Range of potential effect: Highest NOEL (or control) to LOEL</b>	<b>Reference</b>	<b>Table A3. Plants: Summary of Adverse Turbidity Response Data</b>
<b>Species</b>							<b>Comment</b>

Plants, Aquatic ( <i>Elodea</i> )	~2.5-3 mo	Lab: Experimental stream	Percent cover	30-35 (LOEL)	0 - 30	Parkhill and Gulliver 2002	The study referenced a personal communication which indicated that visual observations showed significant decreases in percent cover with increasing turbidity. The 30-35 NTU level is given in this table as a default LOEL since data was not included in the study. [ Tested: 5-10, 15-20, 25-30, and 30-35 NTUs]
Plants, Aquatic ( <i>Elodea</i> )	~2.5-3 mo	Lab: Experimental stream	Elodea Growth and Whole Stream Photosynthetic Activity	30-35 (NOEL)	NA	Parkhill and Gulliver 2002	30-35 ntus was the highest level tested. [Tested: 5-10, 15-20, 25-30, and 30-35 NTUs]
Plants, Aquatic (Macrophytes, Algae)	~2.5-3 mo	Lab: Experimental stream	Whole stream productivity	30-35 (NOEL)	NA	Parkhill and Gulliver 2002	30-35 ntus was the highest level tested. [ Tested: 5-10, 15-20, 25-30, and 30-35 NTUs]

**Appendix B. Draft Summary statistics for turbidity monitoring data (1992 – 2002): data compiled from DEQ Lazar database**

Annual cycles (8/01/92 – 7/31/02)

STA.ID	Monitoring Station	Average	Median	Minimum	Maximum	Std.Dev.	N
10339	Willamette River At Canby Ferry	14.3	5.0	2.0	231.0	33.6	48
10386	Middle Fork Willamette At Jasper Bridge	5.0	4.0	2.0	34.0	5.1	49
10391	Siletz River 5 Mi D/S Of Siletz (Rm 30.9)	5.2	2.0	0.5	80.0	12.1	44
10411	Deschutes River At Deschutes River Park	19.7	4.0	0.5	802.0	106.0	57
10411	Deschutes River At Deschutes River Park (w/o 802 max)	5.7	4.0	0.5	79.0	10.3	56
10418	Rogue River At Robertson Bridge (Merlin)	5.5	3.0	1.0	50.0	7.5	56
10437	Umpqua River At Elkton Bridge	24.8	2.5	0.5	699.0	95.6	64
10456	Tualatin River @ Boones Ferry Road	16.8	10.0	2.0	239.0	26.4	88
10611	Willamette River At Hawthorne Bridge	14.0	6.0	3.0	178.0	22.1	111
10637	Molalla R. @ Canby	3.7	2.6	0.5	15.0	3.0	48
10690	Metolius River North Of Camp Sherman (Bridge 99)	1.1	0.5	0.3	5.4	1.2	47
10729	Owyhee River At Hwy 201 Bridge (Owyhee)	54.7	27.0	6.0	330.0	68.9	36
10765	Klamath River At Hwy 66 (Keno)	13.3	9.5	2.0	76.0	13.0	58
10770	Williamson River At Williamson River Store	4.9	3.0	1.0	20.0	4.8	56
11140	Long Tom River At Stow Pit Road (Monroe)	21.8	18.0	7.0	104.0	18.1	42
11233	Clackamas River @ Old Highway 213 Bridge (High Rocks)	5.8	2.0	0.5	79.0	10.8	69
11386	John Day River At Hwy 206	9.0	4.0	0.5	78.0	13.8	51
11483	Chetco River At Usgs Gage (10 Mi U/S Brookings)	9.9	1.0	0.5	167.0	29.3	47
11489	Umatilla River At Westland Road (Hermiston)	15.3	5.6	0.5	175.0	29.0	70
11856	Nehalem River At Foley Rd (Roy Creek Campground)	8.4	3.0	0.5	121.0	20.2	55
13421	Wilson R. @ 101 Bridge	7.5	2.0	0.5	218.0	17.0	50
	All data points	12.7	4.0	0.3	802.0	40.0	1146
	All station stats (average)	13.0	5.7	1.6	185.1	26.9	20
	All data points (w/o 802)	12.1	4.0	0.3	699.0	32.5	1145
	All station stats (w/o 802) average	12.3	5.7	1.6	185.1	22.1	20
	All station stats (w/o 802) std dev	11.8	6.4	1.9	212.5	29.4	(20)
	All data points (w/o 802 & Owyhee)	10.7	4.0	0.3	699.0	29.7	1109
	All station stats (w/o 802 & Owyhee) average	10.1	4.6	1.3	139.4	19.6	19
	All station stats (w/o 802 & Owyhee) std dev	6.4	4.1	1.6	154.2	20.7	(19)

**Appendix B. Draft Summary statistics for turbidity monitoring data (1992 – 2002): data compiled from DEQ Lazar database**

**High Flow Period (10/6 – 5/25)**

STA.ID	Monitoring Station	Average	Median	Minimum	Maximum	Std.Dev.	N
10339	Willamette River At Canby Ferry	19.9	7.0	3.0	231.0	40.8	31
10386	Middle Fork Willamette At Jasper Bridge	6.2	5.0	2.0	34.0	5.8	33
10391	Siletz River 5 Mi D/S Of Siletz (Rm 30.9)	8.0	3.0	1.0	80.0	15.3	26
10411	Deschutes River At Deschutes River Park	4.8	4.0	0.5	12.0	3.0	36
10418	Rogue River At Robertson Bridge (Merlin)	7.4	5.0	1.0	50.0	9.2	34
10437	Umpqua River At Elkton Bridge	38.1	8.0	0.5	699.0	117.9	41
10456	Tualatin River @ Boones Ferry Road	22.2	15.0	3.0	239.0	31.8	56
10611	Willamette River At Hawthorne Bridge	18.8	9.5	3.0	172.0	26.2	71
10637	Molalla R. @ Canby	4.7	4.0	1.0	15.0	3.3	29
10690	Metolius River North Of Camp Sherman (Bridge 99)	0.7	0.5	0.4	2.0	0.3	30
10729	Owyhee River At Hwy 201 Bridge (Owyhee)	25.7	20.0	6.0	83.0	21.9	23
10765	Klamath River At Hwy 66 (Keno)	17.3	12.5	3.0	76.0	14.5	38
10770	Williamson River At Williamson River Store	6.3	4.0	1.0	20.0	5.0	37
11140	Long Tom River At Stow Pit Road (Monroe)	26.4	20.0	7.0	104.0	21.0	27
11233	Clackamas River @ Old Highway 213 Bridge (High Rocks)	7.6	4.0	0.5	79.0	12.7	46
11386	John Day River At Hwy 206	10.1	8.0	0.5	56.0	10.9	34
11483	Chetco River At Usgs Gage (10 Mi U/S Brookings)	16.6	2.0	0.5	167.0	37.6	27
11489	Umatilla River At Westland Road (Hermiston)	20.6	11.0	0.5	175.0	34.6	46
11856	Nehalem River At Foley Rd (Roy Creek Campground)	12.8	4.0	1.0	121.0	25.2	33
13421	Wilson R. @ 101 Bridge	12.9	6.0	1.0	91.3	21.9	27
	All data points	14.9	7.0	0.4	699.0	36.1	725
	All station stats (average)	14.3	7.6	1.8	125.3	23.0	20
	All station stats (std dev)	9.3	5.6	1.9	152.1	25.4	(20)

**Appendix B. Draft Summary statistics for turbidity monitoring data (1992 – 2002): data compiled from DEQ Lazar database**

**Low Flow Period (5/26 – 10/5)**

STA.ID	Monitoring Station	Average	Median	Minimum	Maximum	Std.Dev.	N
10339	Willamette River At Canby Ferry	4.0	3.0	2.0	16.0	3.4	17
10386	Middle Fork Willamette At Jasper Bridge	2.6	2.0	2.0	5.0	1.0	16
10391	Siletz River 5 Mi D/S Of Siletz (Rm 30.9)	1.1	1.0	0.5	2.0	0.4	18
10411	Deschutes River At Deschutes River Park	45.2	3.9	2.0	802.0	174.2	21
10411	Deschutes River At Deschutes River Park (w/o 802 max)	7.4	3.5	2.0	79.0	16.9	20
10418	Rogue River At Robertson Bridge (Merlin)	2.7	2.8	1.0	6.0	1.0	22
10437	Umpqua River At Elkton Bridge	1.0	1.0	0.5	2.0	0.4	23
10456	Tualatin River @ Boones Ferry Road	7.4	6.5	2.0	20.0	3.5	32
10611	Willamette River At Hawthorne Bridge	5.5	4.0	3.0	27.0	4.5	40
10637	Molalla R. @ Canby	2.0	2.0	0.5	5.0	1.3	19
10690	Metolius River North Of Camp Sherman (Bridge 99)	1.7	1.0	0.3	5.4	1.8	17
10729	Owyhee River At Hwy 201 Bridge (Owyhee)	106.0	76.0	8.0	330.0	92.2	13
10765	Klamath River At Hwy 66 (Keno)	5.7	5.0	2.0	15.8	3.2	20
10770	Williamson River At Williamson River Store	2.3	1.3	1.0	15.0	3.2	19
11140	Long Tom River At Stow Pit Road (Monroe)	13.5	12.0	7.0	21.0	4.9	15
11233	Clackamas River @ Old Highway 213 Bridge (High Rocks)	2.2	1.0	1.0	16.0	3.1	23
11386	John Day River At Hwy 206	7.0	1.4	0.5	78.0	18.5	17
11483	Chetco River At Usgs Gage (10 Mi U/S Brookings)	0.9	0.5	0.5	4.0	0.8	20
11489	Umatilla River At Westland Road (Hermiston)	5.1	4.0	1.0	22.0	4.6	24
11856	Nehalem River At Foley Rd (Roy Creek Campground)	1.8	1.2	0.5	5.0	1.2	22
13421	Wilson R. @ 101 Bridge	1.3	1.0	0.5	3.0	0.7	23
	All data points	9.0	2.7	0.3	802.0	45.8	421
	All station stats (average)	11.0	6.5	1.8	70.0	16.2	20
	All data points (w/o 802)	7.1	2.7	0.3	330.0	24.4	420
	All station stats (w/o 802) average	9.1	6.5	1.8	33.9	8.3	20
	All station stats (w/o 802) std dev	23.0	16.6	2.1	73.1	20.3	(20)
	All data points (w/o 802 & Owyhee)	4.0	2.0	0.3	79.0	6.5	407
	All station stats (w/o 802 & Owyhee) average	4.0	2.9	1.5	18.3	3.9	19
	All station stats (w/o 802 & Owyhee) std dev	3.2	2.7	1.5	22.6	5.1	(19)

**Appendix C. Draft** Frequency statistics for turbidity monitoring data (1992 – 2002): data compiled from DEQ Lazar database

	NTU range and % frequency of measurements in that range: 1992 - 2002						
<b>All flows (8/01/92 - 7/31/02)</b>	0-5	>5-10	>10-20	>20-50	>50-100	>100-150	>150
Willamette River at Canby Ferry	56.3	12.5	14.6	14.6	0.0	0.0	2.1
Middle Fork Willamette At Jasper Bridge	75.5	18.4	4.1	2.0	0.0	0.0	0.0
Siletz River 5 Mi D/S Of Siletz (Rm 30.9)	76.7	16.3	4.7	0.0	2.3	0.0	0.0
Deschutes River At Deschutes River Park	70.7	24.1	1.7	0.0	1.7	0.0	1.7
Rogue River At Robertson Bridge (Merlin)	77.2	12.3	7.0	3.5	0.0	0.0	0.0
Umpqua River At Elkton Bridge	51.4	17.6	16.2	5.4	4.1	1.4	4.1
Tualatin River @ Boones Ferry Road	13.6	37.5	23.9	22.7	1.1	0.0	1.1
Willamette River At Hawthorne Bridge	43.3	27.5	9.2	15.8	2.5	0.0	1.7
Molalla River At Knights Bridge Road (Canby)	77.1	18.8	4.2	0.0	0.0	0.0	0.0
Metolius River North Of Camp Sherman (Bridge 99)	100.0	0.0	0.0	0.0	0.0	0.0	0.0
Owyhee River At Hwy 201 Bridge (Owyhee)	0.0	24.3	13.5	27.0	21.6	5.4	8.1
Klamath River At Hwy 66 (Keno)	23.8	30.2	30.2	14.3	1.6	0.0	0.0
Williamson River At Williamson River Store	71.9	12.3	15.8	0.0	0.0	0.0	0.0
Long Tom River At Stow Pit Road (Monroe)	0.0	28.6	38.1	26.2	4.8	2.4	0.0
Clackamas River @ Old Highway 213 Bridge (High Rocks)	75.4	10.1	8.7	4.3	1.4	0.0	0.0
John Day River At Hwy 206	53.8	19.2	19.2	3.8	3.8	0.0	0.0
Chetco River At Usgs Gage (10 Mi U/S Brookings)	83.0	4.3	2.1	4.3	2.1	2.1	2.1
Umatilla River At Westland Road (Hermiston)	41.1	17.8	22.2	13.3	2.2	1.1	2.2
Nehalem River At Foley Rd (Roy Creek Campground)	80.0	9.3	5.3	2.7	1.3	1.3	0.0
Wilson River At Hwy 101	67.9	12.5	12.5	1.8	3.6	0.0	1.8
Total	56.4	18.6	12.6	8.6	2.3	0.5	1.1

	NTU range and % frequency of measurements in that range: 1992 - 2002						
<b>High flow (Oct 6 - May 25)</b>	0-5	>5-10	>10-20	>20-50	>50-100	>100-150	>150
Willamette River at Canby Ferry	38.7	16.1	19.4	22.6	0.0	0.0	3.2
Middle Fork Willamette At Jasper Bridge	63.6	27.3	6.1	3.0	0.0	0.0	0.0
Siletz River 5 Mi D/S Of Siletz (Rm 30.9)	58.3	29.2	8.3	0.0	4.2	0.0	0.0
Deschutes River At Deschutes River Park	67.6	29.7	2.7	0.0	0.0	0.0	0.0
Rogue River At Robertson Bridge (Merlin)	64.7	17.6	11.8	5.9	0.0	0.0	0.0
Umpqua River At Elkton Bridge	29.4	25.5	23.5	7.8	5.9	2.0	5.9
Tualatin River @ Boones Ferry Road	7.1	25.0	28.6	35.7	1.8	0.0	1.8
Willamette River At Hawthorne Bridge	23.4	32.5	13.0	24.7	3.9	0.0	2.6
Molalla River At Knights Bridge Road (Canby)	62.1	31.0	6.9	0.0	0.0	0.0	0.0
Metolius River North Of Camp Sherman (Bridge 99)	100.0	0.0	0.0	0.0	0.0	0.0	0.0
Owyhee River At Hwy 201 Bridge (Owyhee)	0.0	33.3	20.8	33.3	12.5	0.0	0.0
Klamath River At Hwy 66 (Keno)	2.6	28.2	43.6	23.1	2.6	0.0	0.0
Williamson River At Williamson River Store	58.3	16.7	25.0	0.0	0.0	0.0	0.0
Long Tom River At Stow Pit Road (Monroe)	0.0	3.7	48.1	37.0	7.4	3.7	0.0
Clackamas River @ Old Highway 213 Bridge (High Rocks)	65.2	15.2	10.9	6.5	2.2	0.0	0.0
John Day River At Hwy 206	40.0	22.9	28.6	5.7	2.9	0.0	0.0
Chetco River At Usgs Gage (10 Mi U/S Brookings)	70.4	7.4	3.7	7.4	3.7	3.7	3.7
Umatilla River At Westland Road (Hermiston)	25.0	20.3	28.1	18.8	3.1	1.6	3.1
Nehalem River At Foley Rd (Roy Creek Campground)	70.6	13.7	7.8	3.9	2.0	2.0	0.0
Wilson River At Hwy 101	41.9	22.6	22.6	3.2	6.5	0.0	3.2
Total	43.2	22.3	17.2	12.8	2.6	0.6	1.2

**Appendix C. Draft** Frequency statistics for turbidity monitoring data (1992 – 2002): data compiled from DEQ Lazar database

	NTU range and % frequency of measurements in that range: 1992 - 2002						
	0-5	>5-10	>10-20	>20-50	>50-100	>100-150	>150
Low flows (May 26 - Oct 5)	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Willamette River at Canby Ferry	88.2	5.9	5.9	0.0	0.0	0.0	0.0
Middle Fork Willamette At Jasper Bridge	100.0	0.0	0.0	0.0	0.0	0.0	0.0
Siletz River 5 Mi D/S Of Siletz (Rm 30.9)	100.0	0.0	0.0	0.0	0.0	0.0	0.0
Deschutes River At Deschutes River Park	76.2	14.3	0.0	0.0	4.8	0.0	4.8
Rogue River At Robertson Bridge (Merlin)	95.7	4.3	0.0	0.0	0.0	0.0	0.0
Umpqua River At Elkton Bridge	100.0	0.0	0.0	0.0	0.0	0.0	0.0
Tualatin River @ Boones Ferry Road	25.0	59.4	15.6	0.0	0.0	0.0	0.0
Willamette River At Hawthorne Bridge	79.1	18.6	2.3	0.0	0.0	0.0	0.0
Molalla River At Knights Bridge Road (Canby)	100.0	0.0	0.0	0.0	0.0	0.0	0.0
Metolius River North Of Camp Sherman (Bridge 99)	100.0	0.0	0.0	0.0	0.0	0.0	0.0
Owyhee River At Hwy 201 Bridge (Owyhee)	0.0	7.7	0.0	15.4	38.5	15.4	23.1
Klamath River At Hwy 66 (Keno)	58.3	33.3	8.3	0.0	0.0	0.0	0.0
Williamson River At Williamson River Store	95.2	4.8	0.0	0.0	0.0	0.0	0.0
Long Tom River At Stow Pit Road (Monroe)	0.0	46.7	46.7	6.7	0.0	0.0	0.0
Clackamas River @ Old Highway 213 Bridge (High Rocks)	95.7	0.0	4.3	0.0	0.0	0.0	0.0
John Day River At Hwy 206	82.4	11.8	0.0	0.0	5.9	0.0	0.0
Chetco River At Usgs Gage (10 Mi U/S Brookings)	100.0	0.0	0.0	0.0	0.0	0.0	0.0
Umatilla River At Westland Road (Hermiston)	80.8	11.5	7.7	0.0	0.0	0.0	0.0
Nehalem River At Foley Rd (Roy Creek Campground)	100.0	0.0	0.0	0.0	0.0	0.0	0.0
Wilson River At Hwy 101	100.0	0.0	0.0	0.0	0.0	0.0	0.0
Total	79.1	12.1	4.5	1.2	1.7	0.5	1.0

**Appendix D. Draft** Umatilla Basin Comparison of 10-year turbidity monitoring data to 2-year daily measurements.

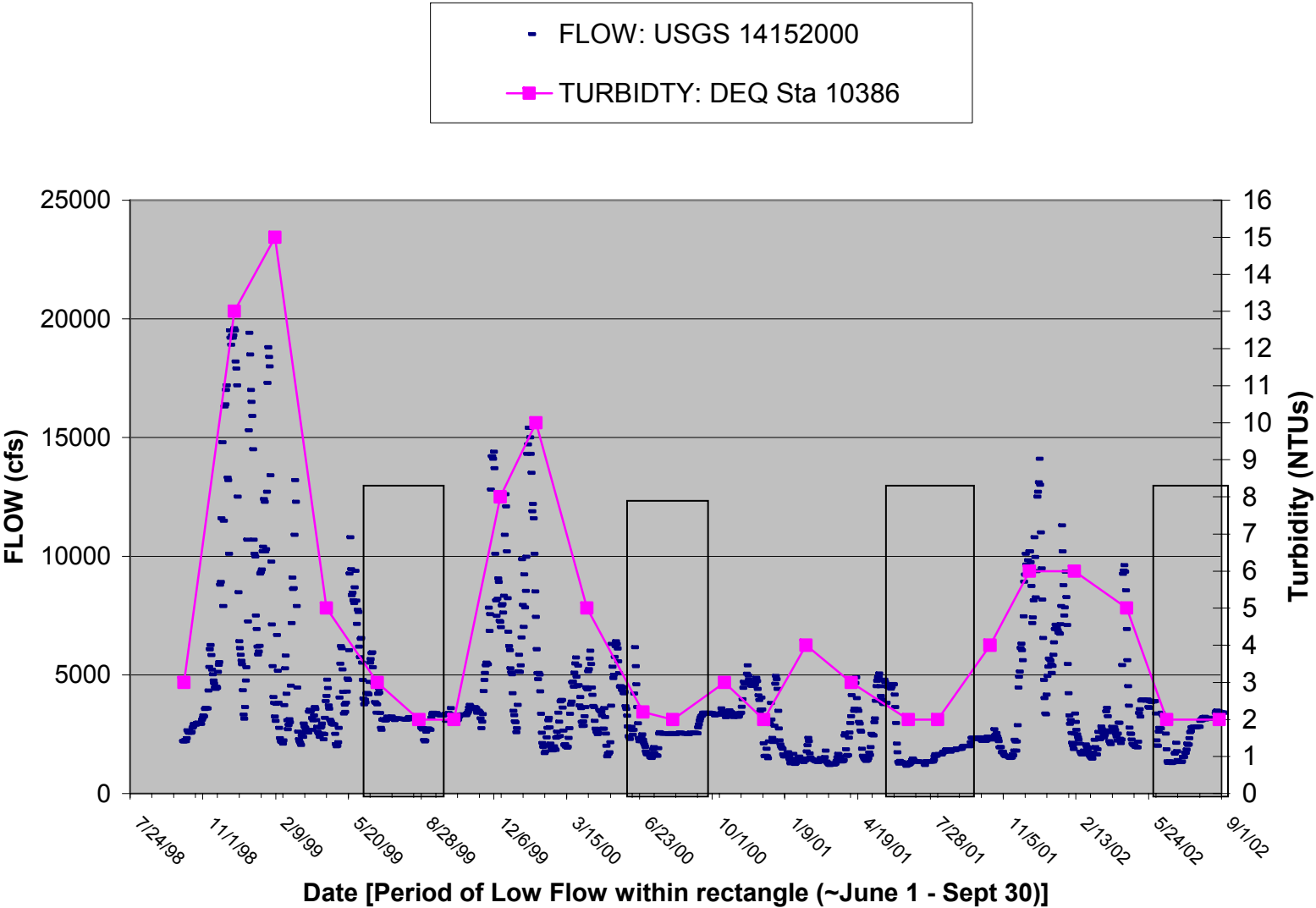
Turbidity Statistic	Umatilla River @ Westland Rd. Crossing. One measurement every two months (1992-2002)  10 years of data: High flow period	Umatilla River @ Westland Rd. Crossing (1998-1999). *	Aggregate of six Umatilla River stations (1998-1999). *  Two wet weather seasons
average	20.6	20.1	15.4 ntus
median	11.0	10.1	7.4
minimum	0.5	1.3	0.5
maximum	175	317.0	962.0
standard deviation	34.6	37.4	43.5
N (values)	46	162	885
freq 0-10 NTU	45.3%	49.4%	65.2%
freq >10-50	46.9%	43.8%	31.1%
freq >50-100	3.1%	3.7%	1.9%
freq >100-150	1.6%	1.2%	0.8%
freq > 150	3.1%	1.9%	1.0%
Values > 150 ntus	167, 175	215, 225, 317	190, 193, 215, 225, 241, 252, 317, 467, 962

\*Daily composite turbidity data were collected at 6 sites on the Umatilla River:

- Umatilla River near Gibbon, east boundary of Reservation
- Umatilla River near Mission, west boundary of Reservation
- Umatilla River @ Reith Bridge
- Umatilla River @ Echo
- Umatilla @ Westland Road
- Umatilla River@3 mile dam

Appendix E. Turbidity and flow (1998 – 2002) DEQ turbidity data and USGS flow data.

Figure E1. Middle Fork Willamette River at Jasper Bridge



Appendix E. Turbidity and flow (1998 – 2002) DEQ turbidity data and USGS flow data.

Figure E2. Siletz River 5 miles D/S of Siletz (R.M. 30.9)

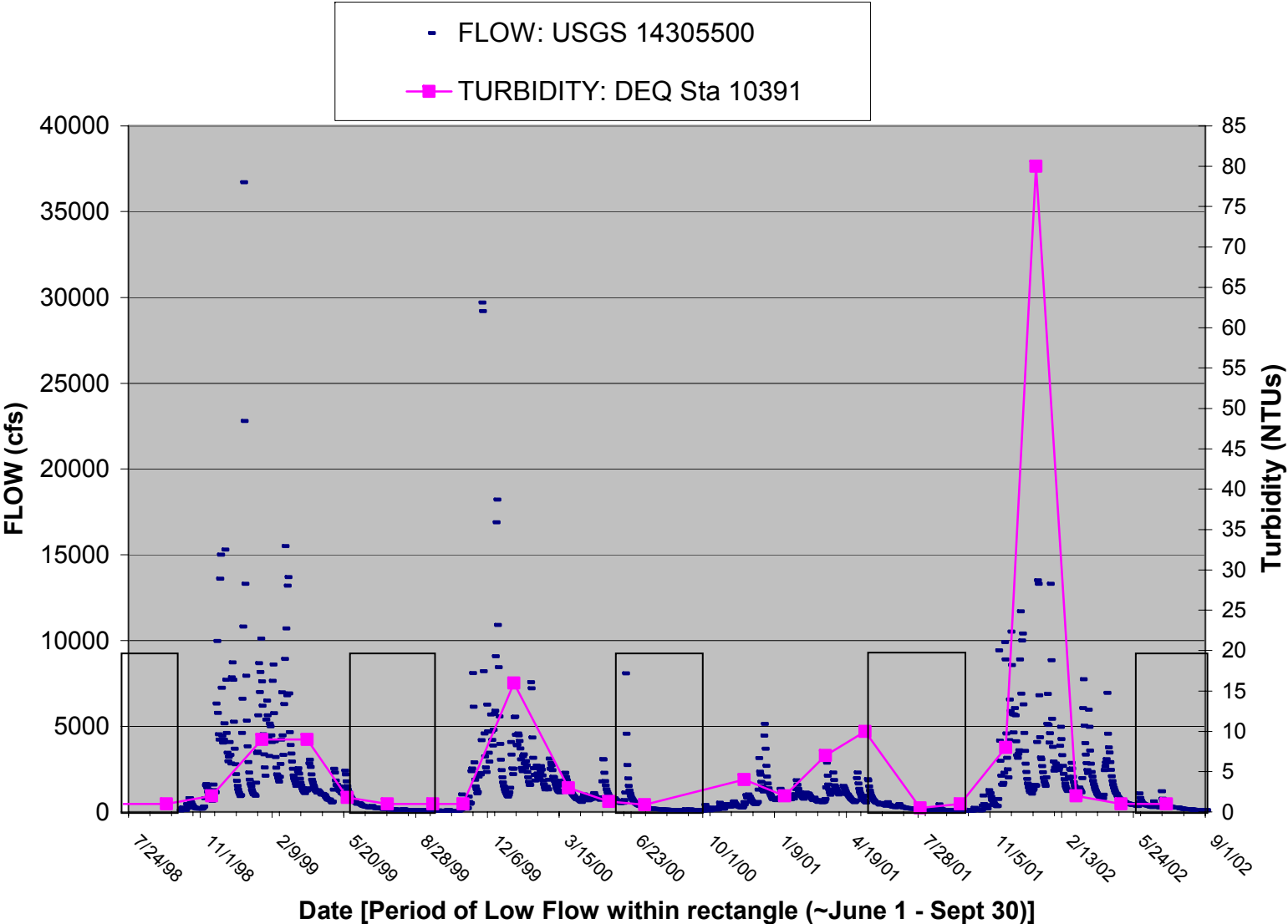


Figure E3. Deschutes River at Deschutes River Park

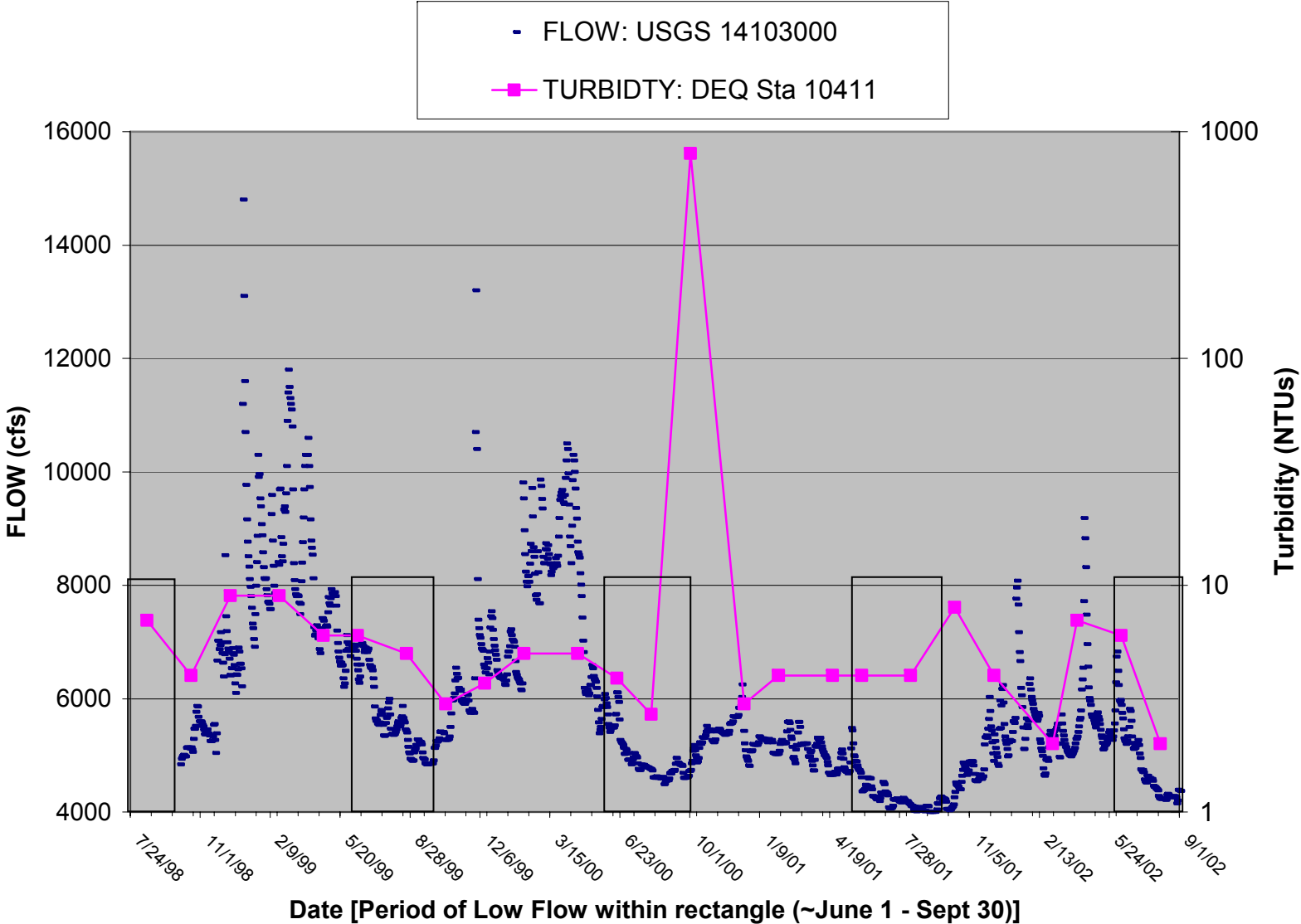


Figure E4. Rogue River at Robertson Bridge (Merlin)

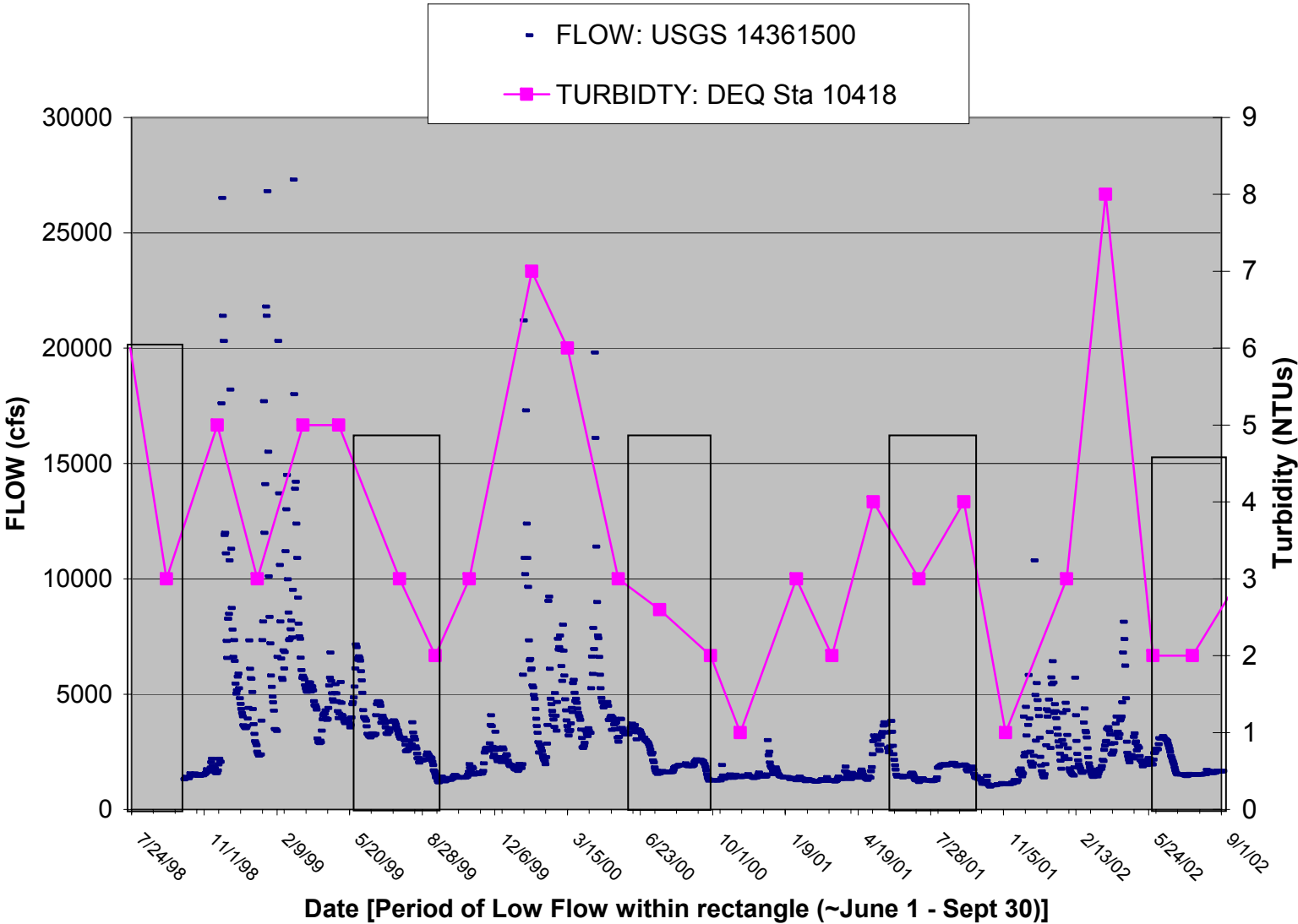


Figure E5. Umpqua River at Elkton Bridge

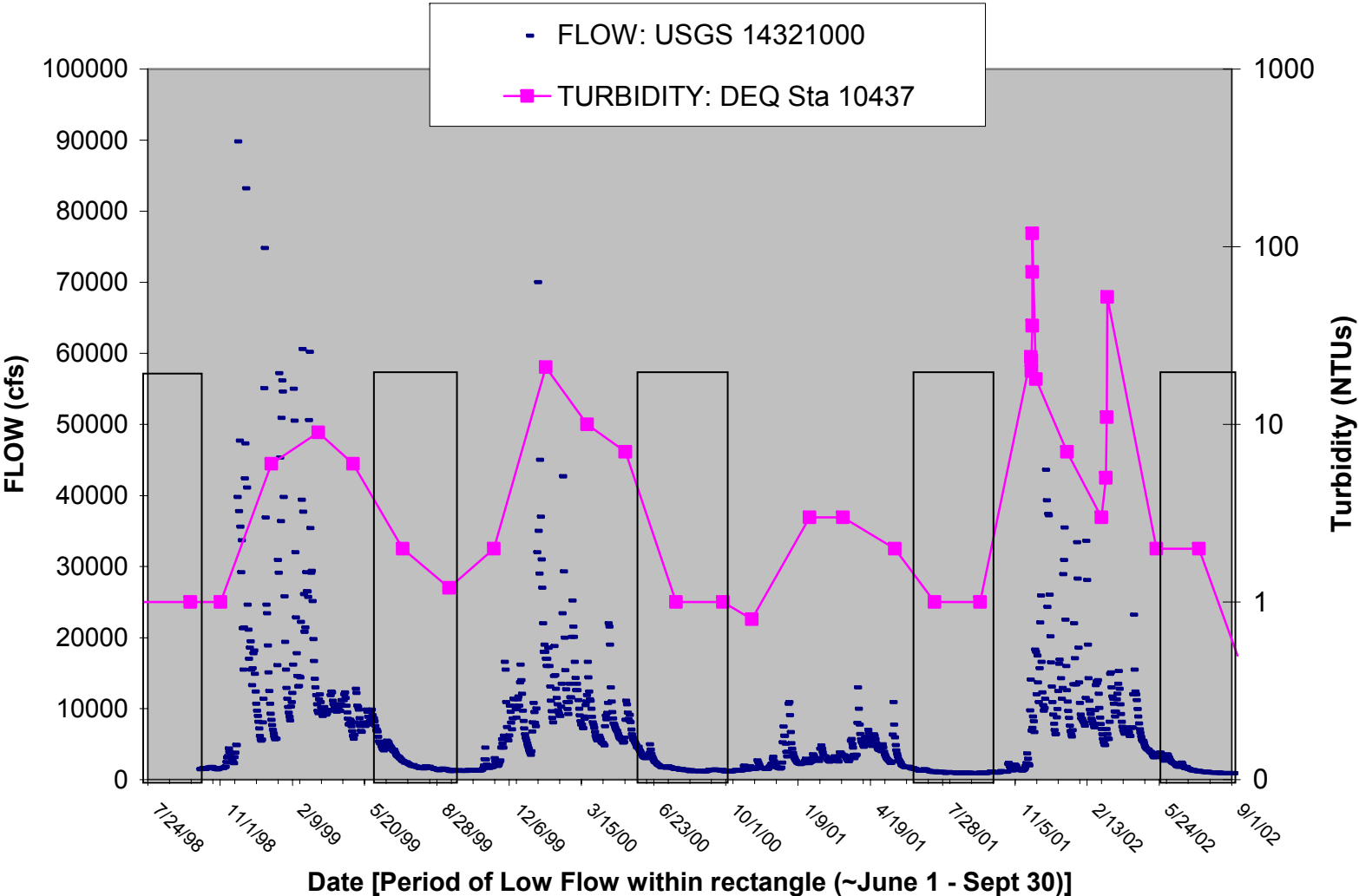


Figure E6. Tualatin River at Boones Ferry Road

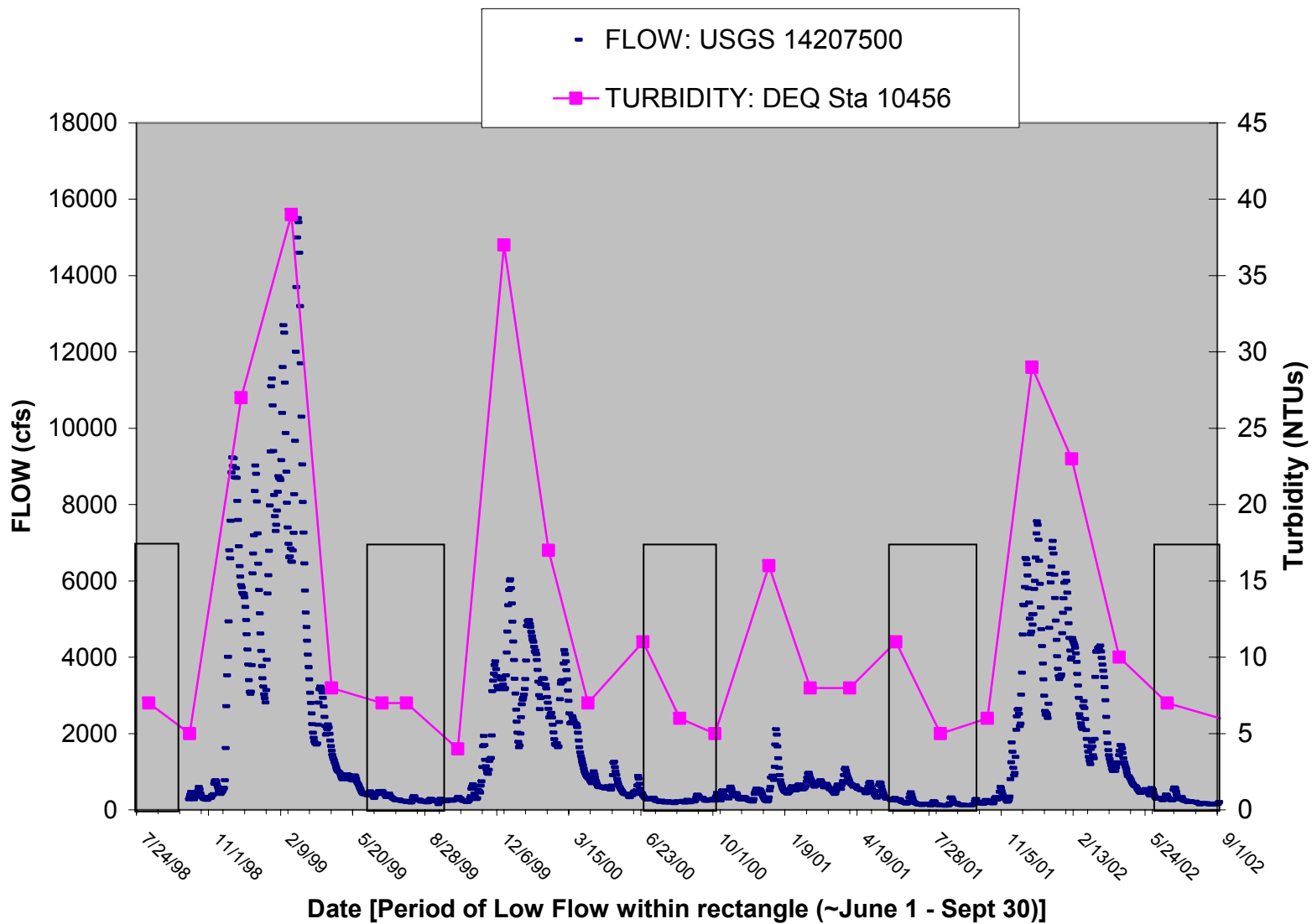


Figure E7. Willamette River at Hawthorne Bridge at Portland

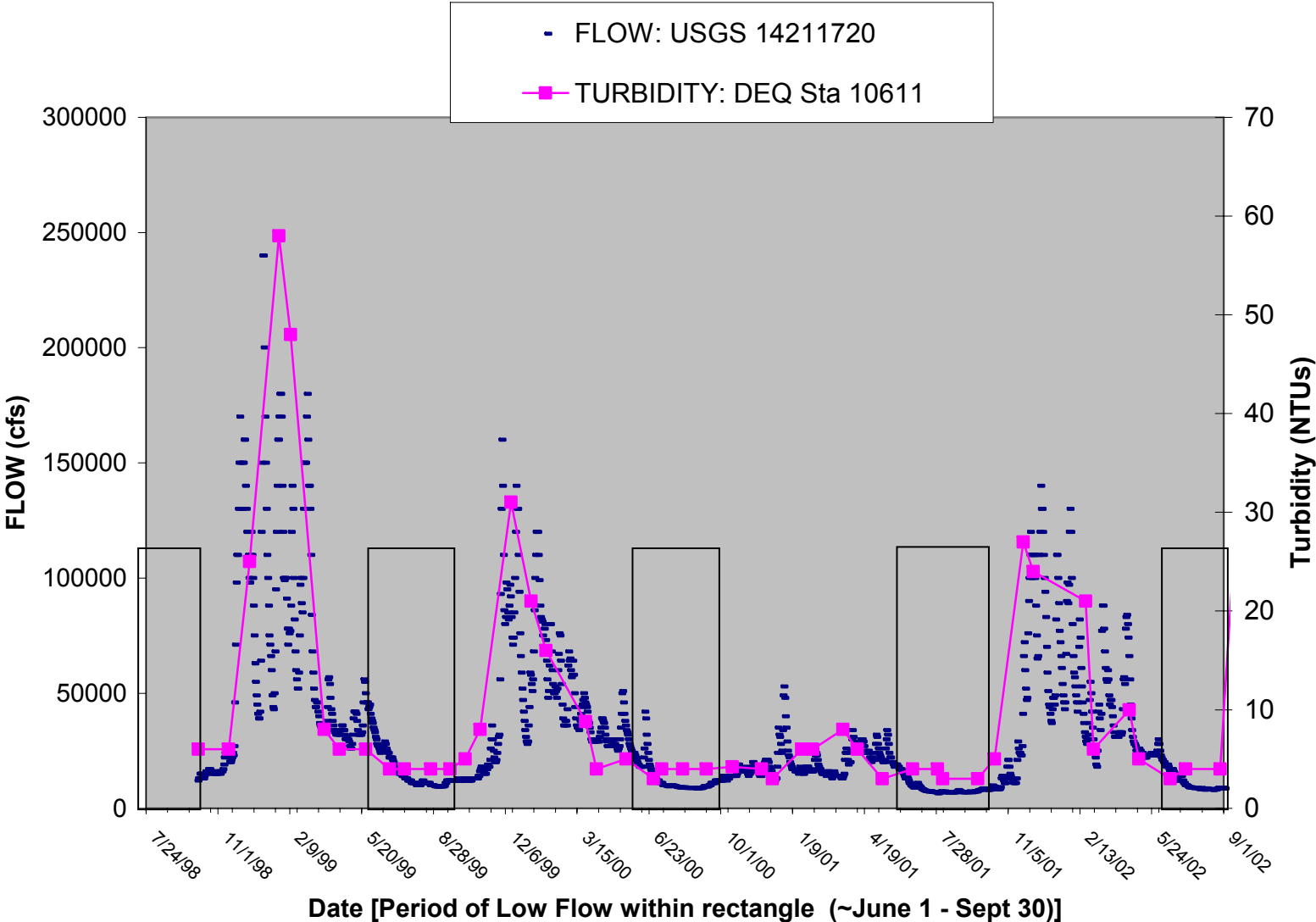
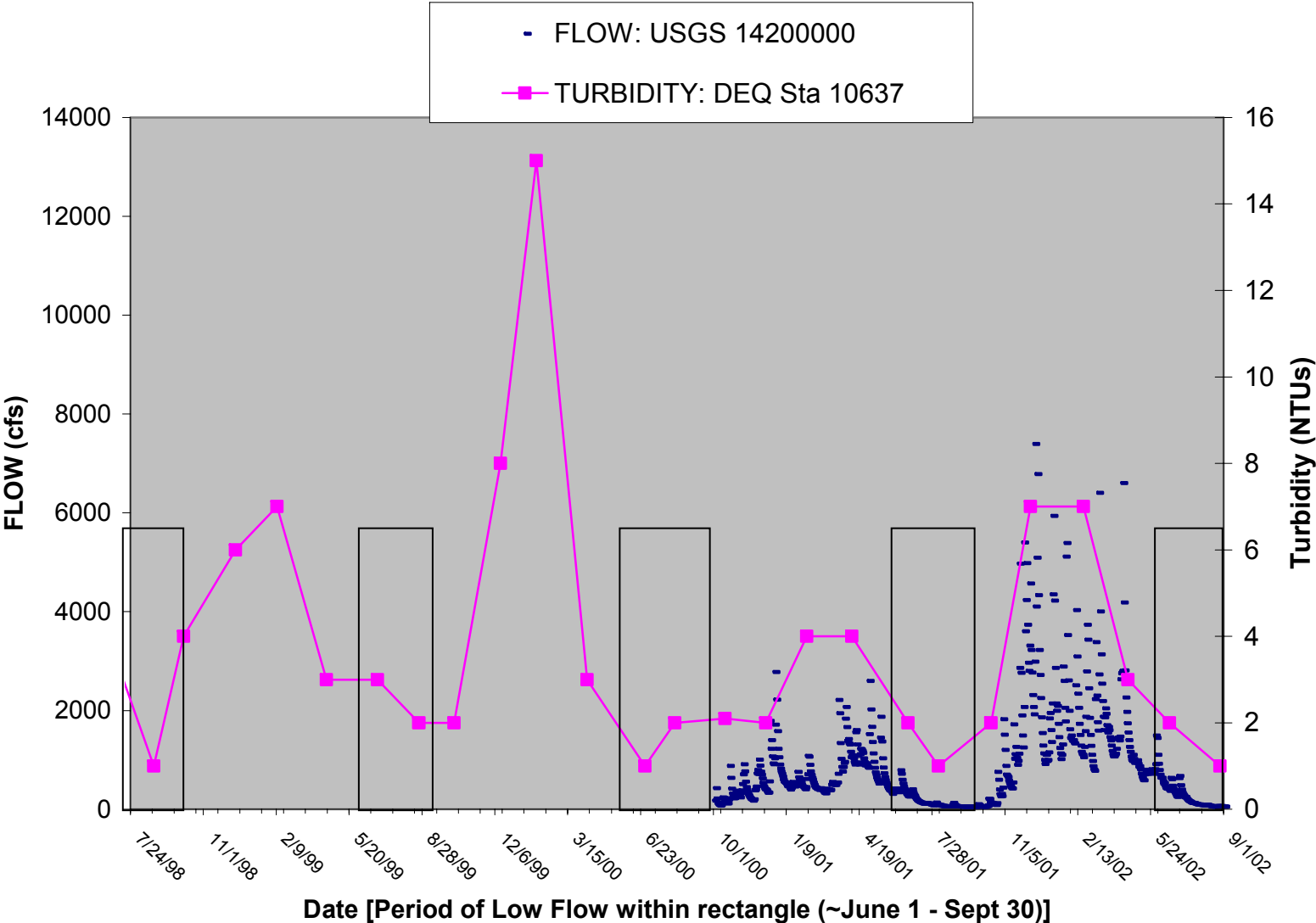


Figure E8. Molalla River at Knights Bridge Rd (Canby)



Appendix E. Turbidity and flow (1998 – 2002) DEQ turbidity data and USGS flow data.

Figure E9. Metolius River north of Camp Sherman (Bridge 99)

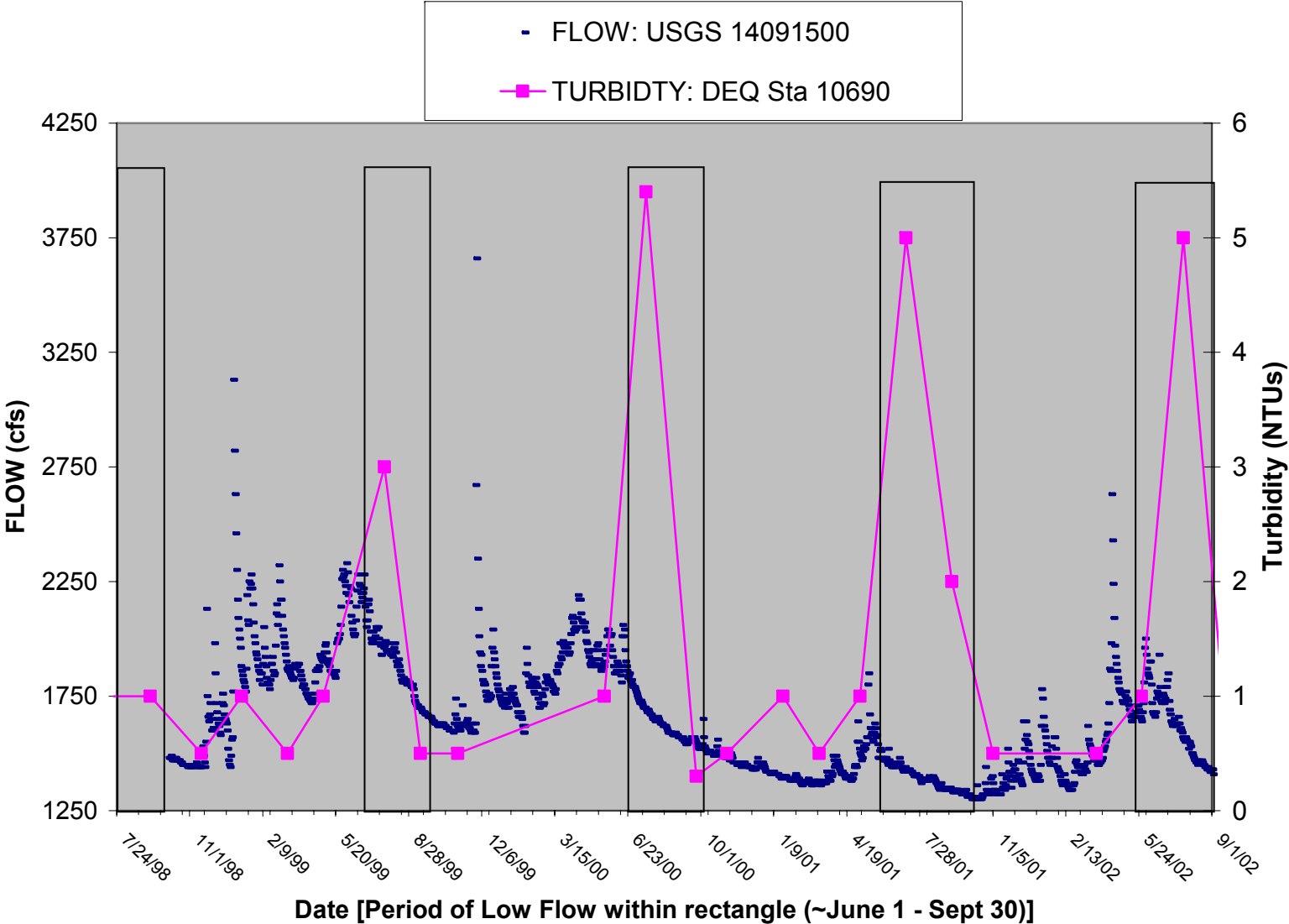


Figure E10. Owyhee River at Hwy 201 Bridge

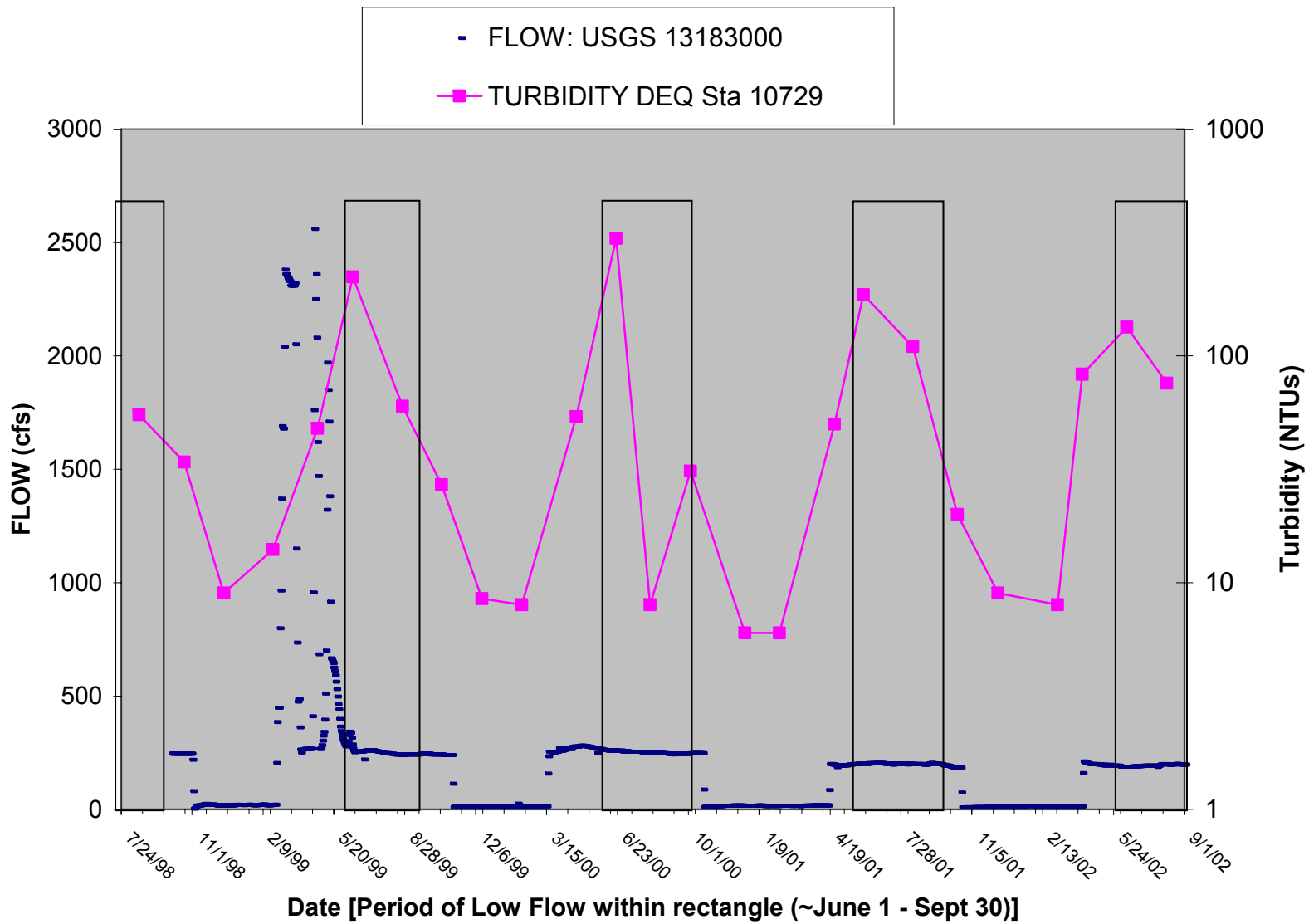


Figure E11. Klamath River at Hwy 66 (Keno)

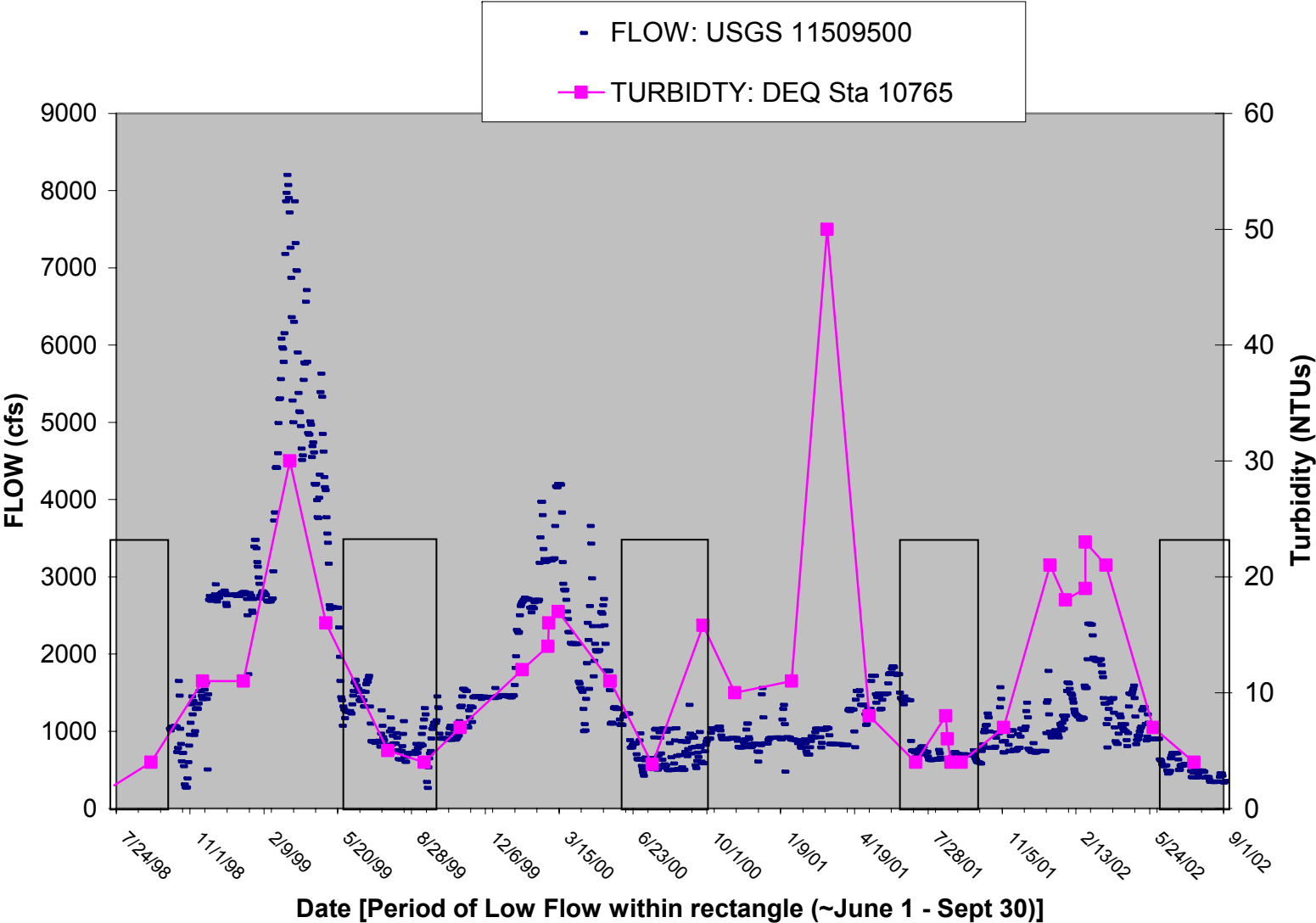


Figure E12. Williamson River at Williamson River Store

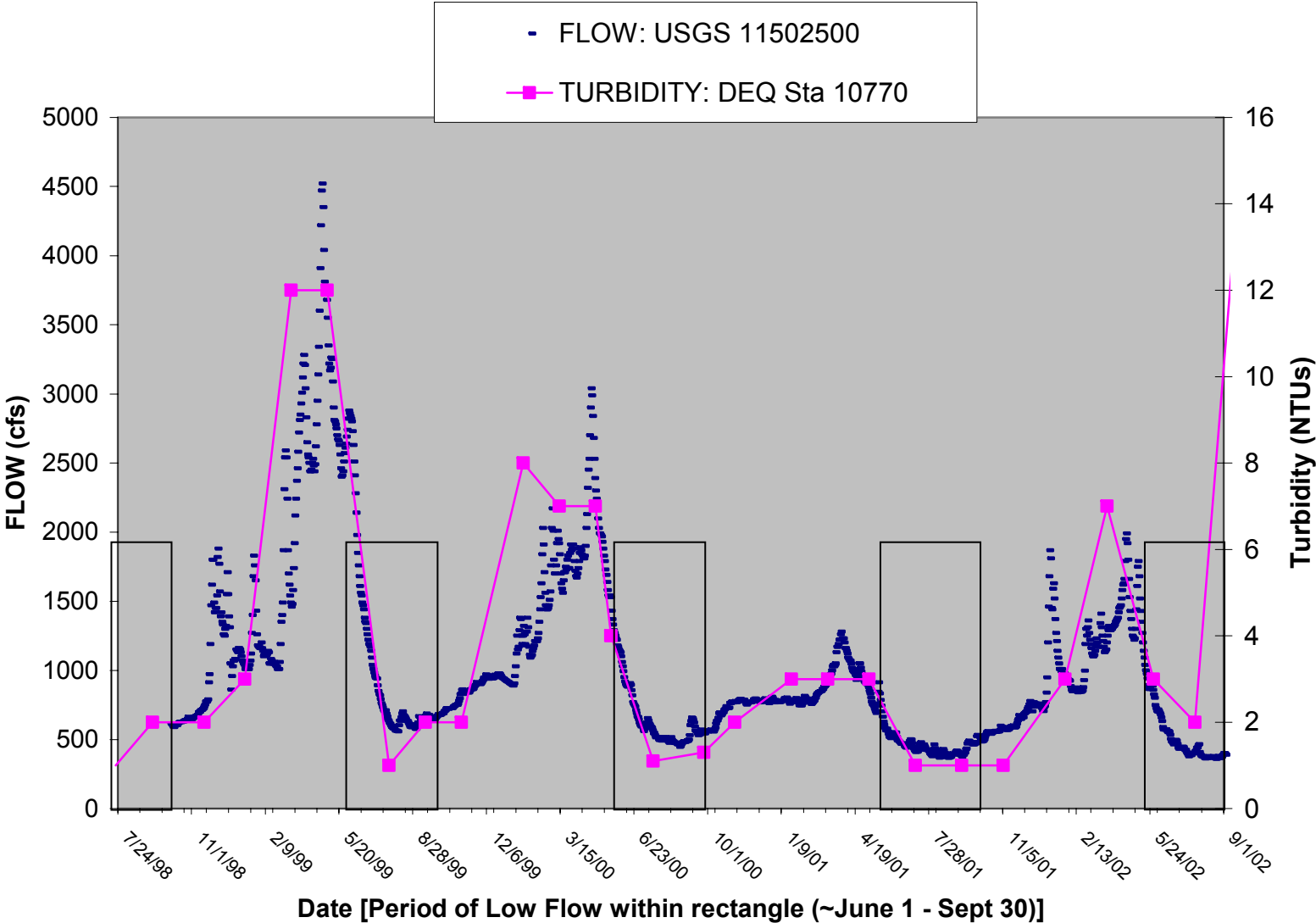
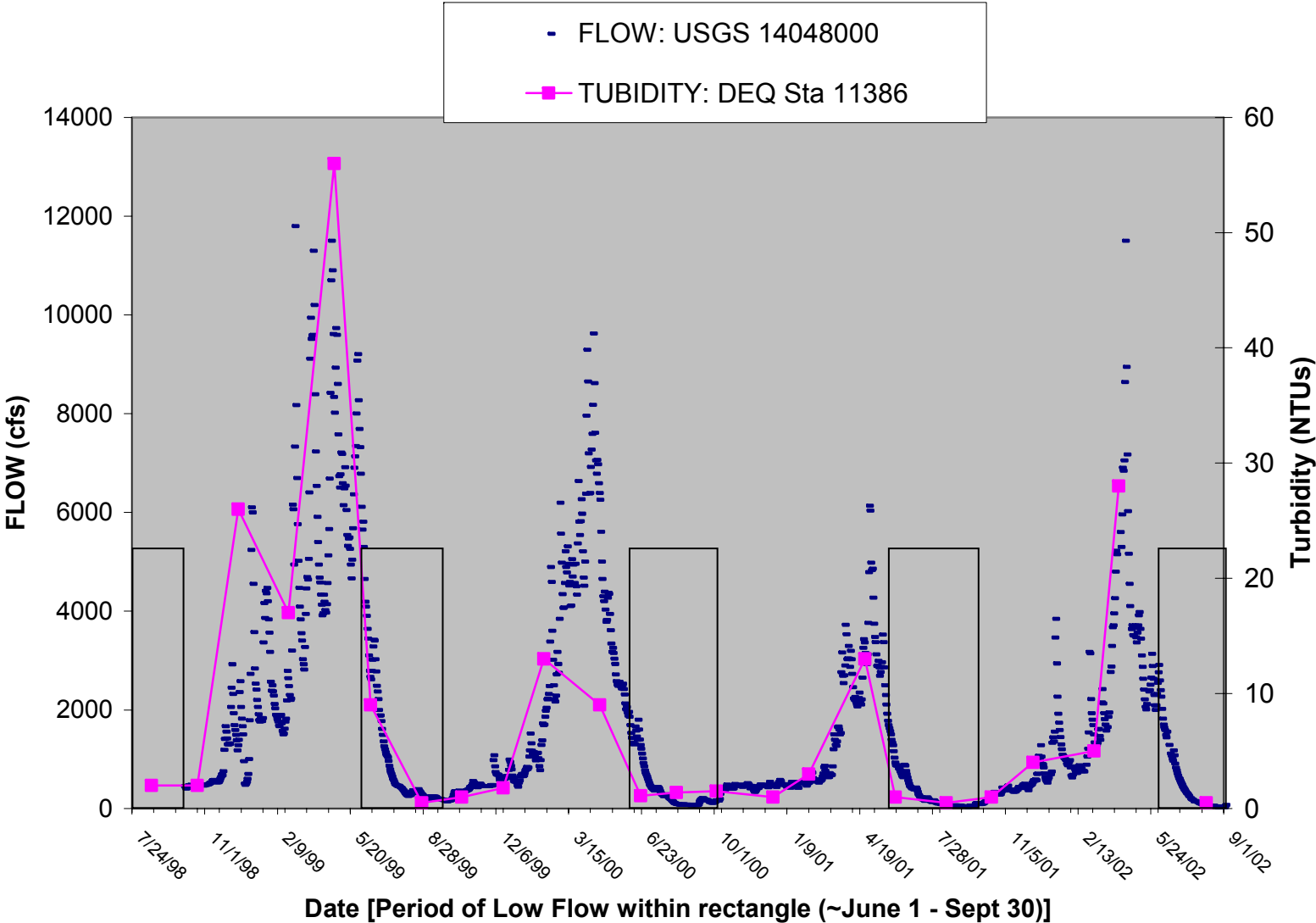


Figure E13. John Day River at Hwy 206



Appendix E. Turbidity and flow (1998 – 2002) DEQ turbidity data and USGS flow data.

Figure E14. Chetco River at USGS Gage (10 Mi U/S of Brookings)

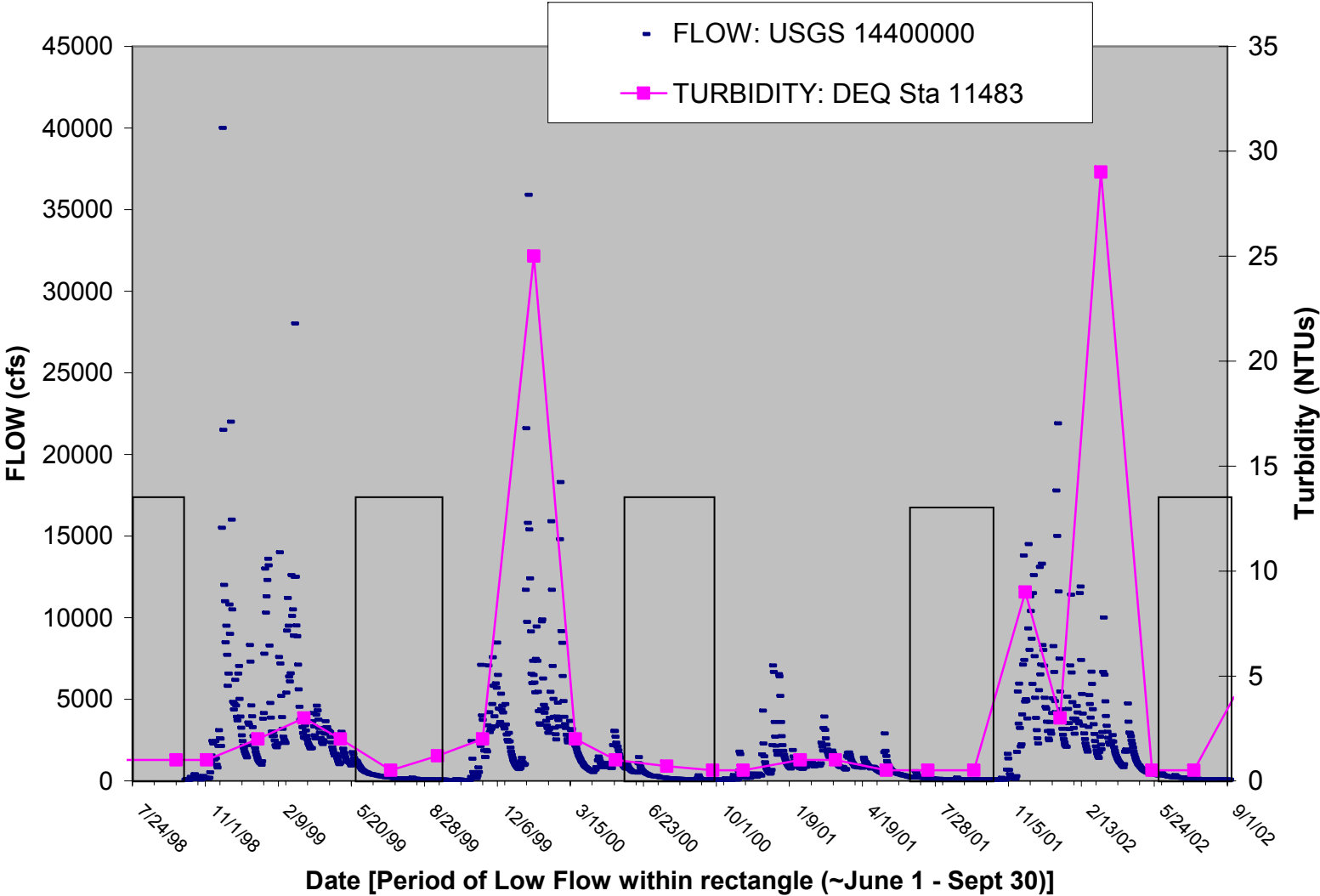


Figure E15. Umatilla River at Westland Road (Hermiston)

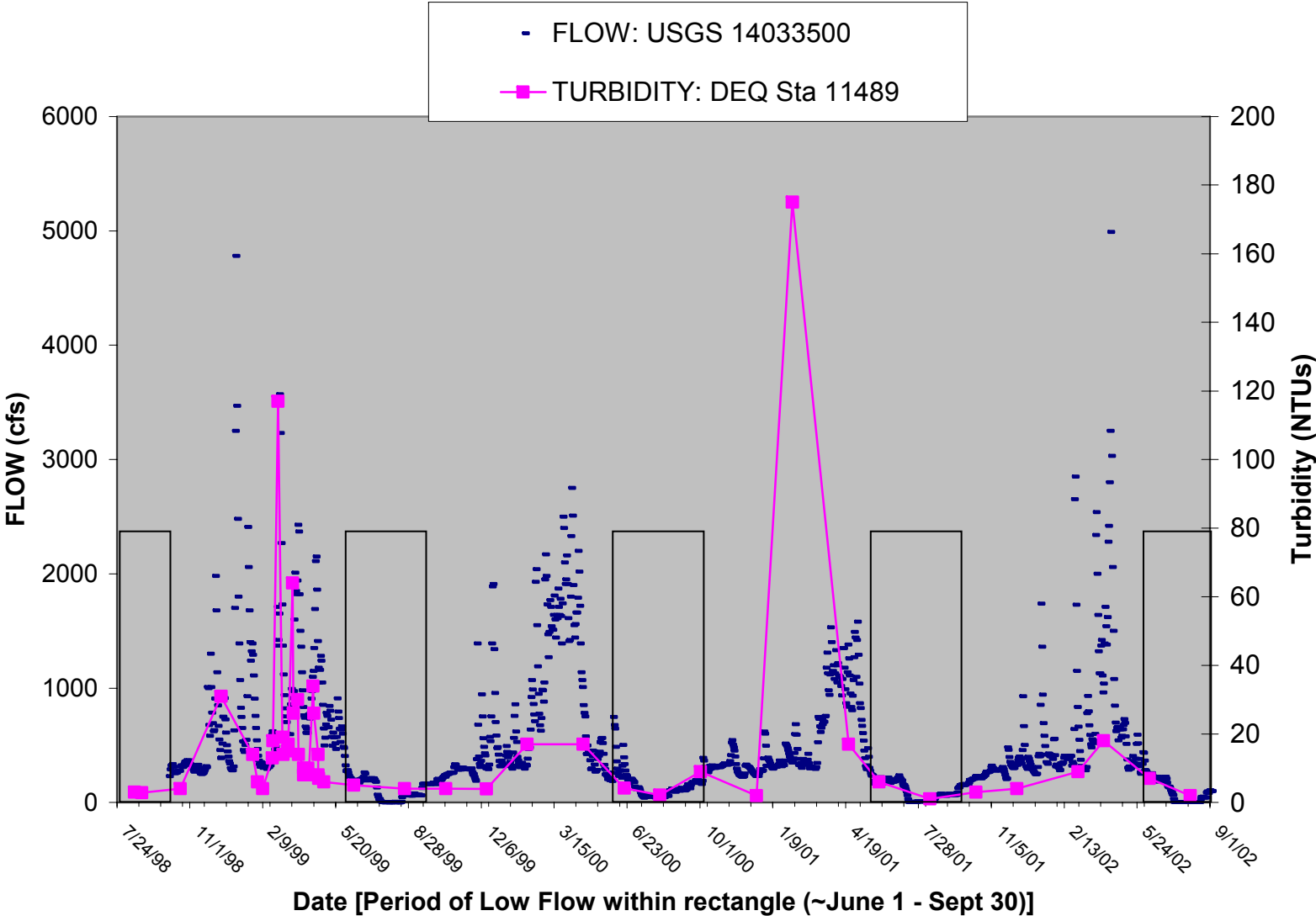


Figure E16. Nehalem River at Foley Rd (Roy Cr Campground)

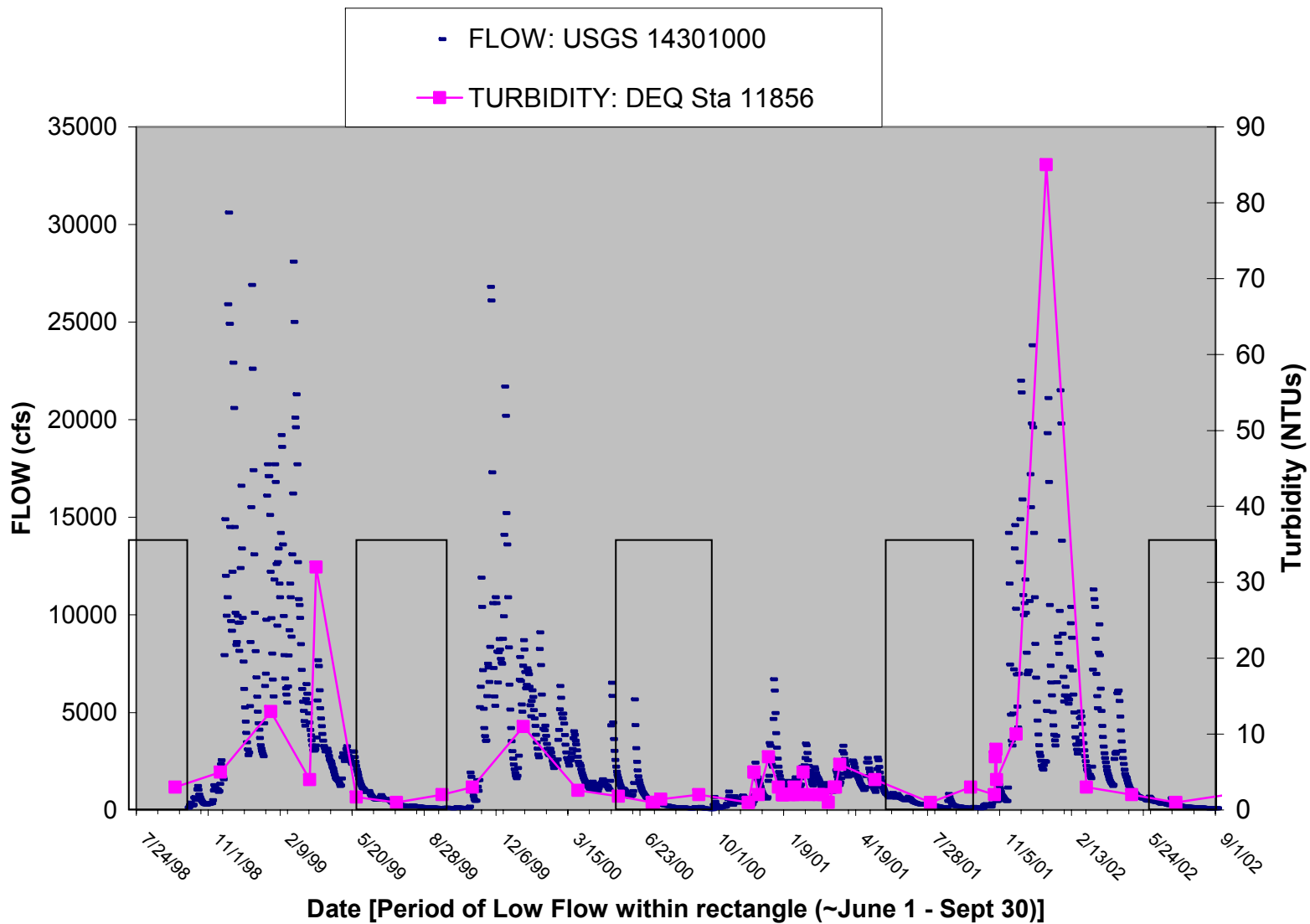


Figure E17. Wilson River at Hwy 101 Bridge

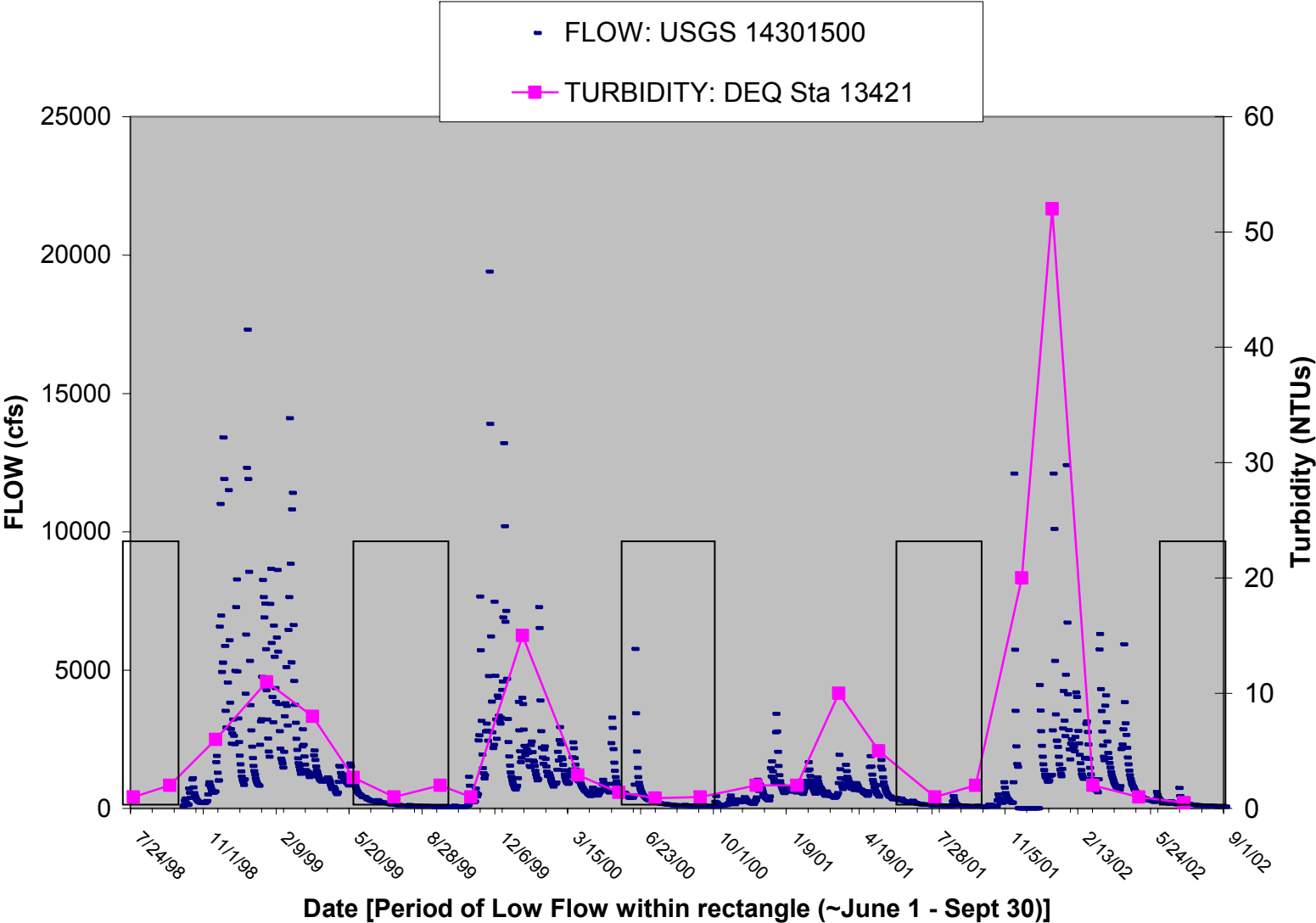
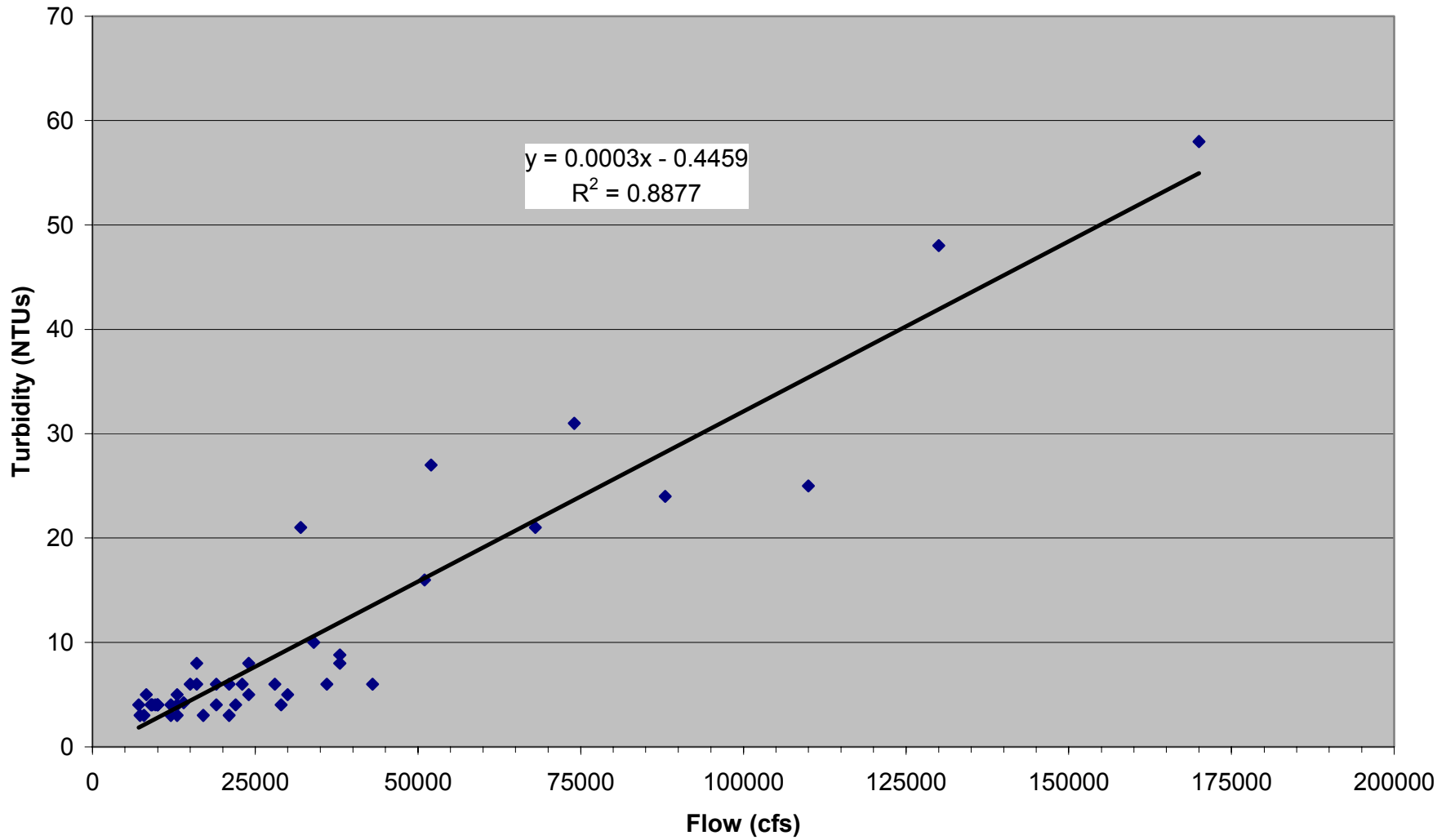
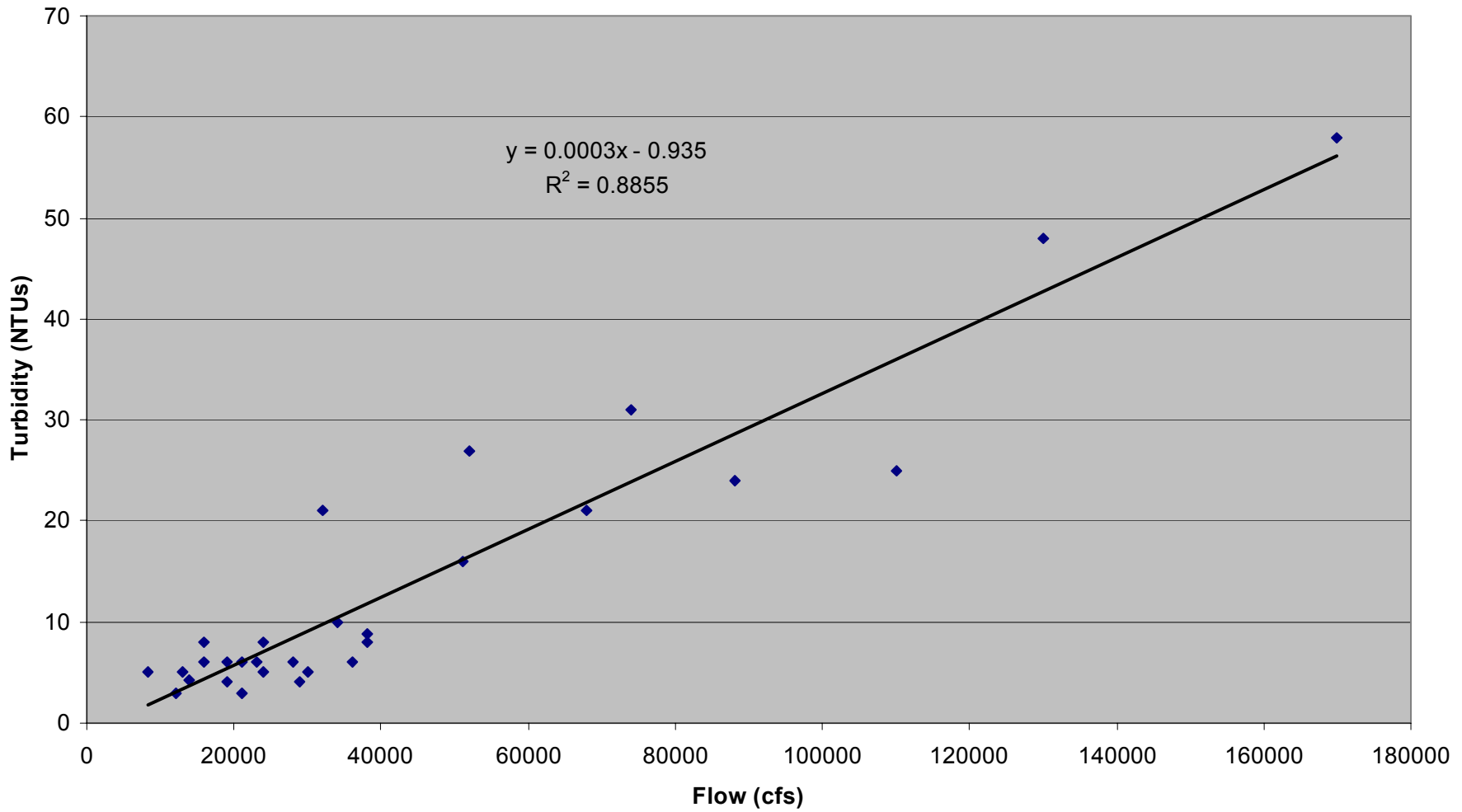


Figure F1. Willamette River at Hawthorne Bridge at Portland: Flow and Turbidity [1998 - 2002; DEQ turbidity data, Sta 10611; and USGS flow data, 14211720]

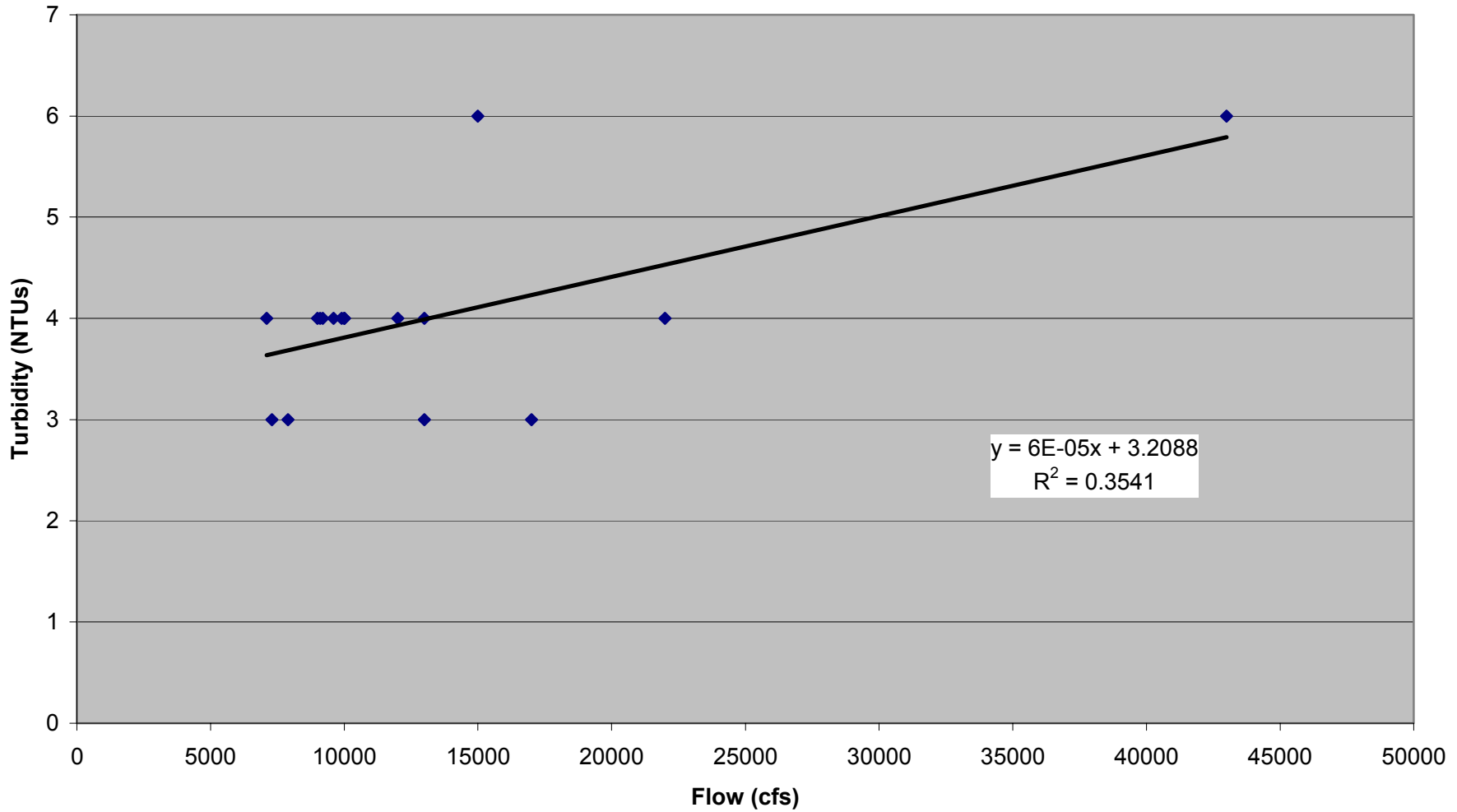


**Figure F2. Willamette River at Hawthorne Bridge at Portland:  
Flow and Turbidity during high flow period: ~Oct 1 - May 31 [1998 - 2002; DEQ turbidity data,  
Sta 10611; and USGS flow data, 14211720]**



Appendix F. Turbidity and flow regressions for selected data [DEQ turbidity data and USGS flow data]

Figure F3. Willamette River at Hawthorne Bridge at Portland:  
Flow and Turbidity during low flow period: ~June 1 - Sept 30 [1998 - 2002; DEQ turbidity data,  
Sta 10611; and USGS flow data, 14211720]



## Appendix G. Uncertainties Regarding Turbidity NTU Measurement

### **Uncertainties regarding Nephelometric measurement:**

Turbidity is a 'relative index of side scattering of light', and not an absolute measure of water clarity. As such, instruments of different types may produce a range of NTU readings for the same water sample due to optical design differences (Davies-Colley and Smith, 2001). For example, Figure 1 (from Davies-Colley and Smith, 2001) shows the differences in NTU readings between two different types of Hach turbidimeters measuring identical river water samples from 77 sites in New Zealand.

While the correlation is very close between the two instruments, the responses differ by 30% overall. The authors stated that, "Appreciably greater discrepancy between different makes and models of nephelometer, including field instruments, may sometimes be encountered". No data was found to quantify differences between makes or models in Oregon waters. Instrument variability may also be influenced by interactions with different size, shape, and concentration of particles, preventing universal relationships to be developed.

This type of uncertainty is most important when assessing various effects levels cited in the literature, making it unreliable to differentiate between relatively small differences in turbidity levels (especially at >10 NTUs) and their effects resulting from different studies. Therefore, criteria levels must be considered 'rough', accounting for as much information as possible, and weigh in on the conservative side in order to guarantee water quality protection. It should be noted that Telesnicki and Goldberg (1995) observed that measurement of turbidity levels of 10 NTUs or less could be accurately determined (based on comparisons to percent transmittance measurements), with variability increasing at higher levels. In a personal communication, Charles Newcombe stated that "at cloudiness levels of <10 NTUs either device—side scatter NTU meter or beam attenuation meter—should be equally reliable and straightforward to use". Percent transmittance or beam attenuation are considered absolute measures of turbidity.

The use of turbidimeters in the field should not pose as much of a problem for making accurate 'relative' comparisons between upstream background samples and downstream activity-related samples, for the very reason that turbidity is a 'relative' comparison. If the same properly calibrated nephelometer is used to measure both samples, the relative difference should be comparable between most instrument types, as could be surmised from Figure 1. However, the range of variability between samples is known to increase at higher turbidity levels. This is part of the rationale for going to a percent based criteria at a specified background NTU level. With respect to the 5 NTU criteria, going to 10% above a background of 50 NTUs or more would result in an allowable criteria of 10 NTUs at a background of 100 NTUs.

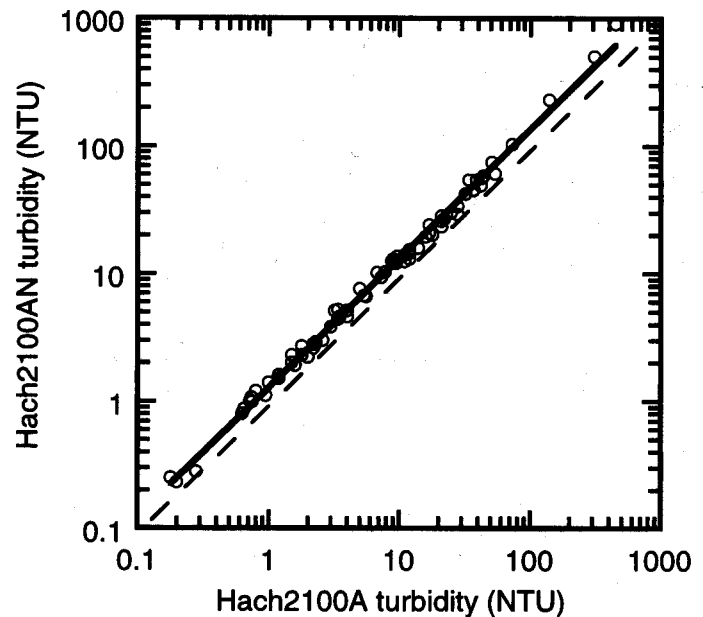


Figure 1

Figure 3. Comparison of Turbidity Measured Simultaneously Using Two Different Nephelometers. A Hach 2100A nephelometer (vertical incident light beam) and its modern replacement, a Hach 2100AN ratio nephelometer (horizontal incident light beam) were used side-by-side on the same batch of 77 New Zealand river water samples. (Average ratio = 1.3, coefficient of variation of the ratio = 12 percent.)

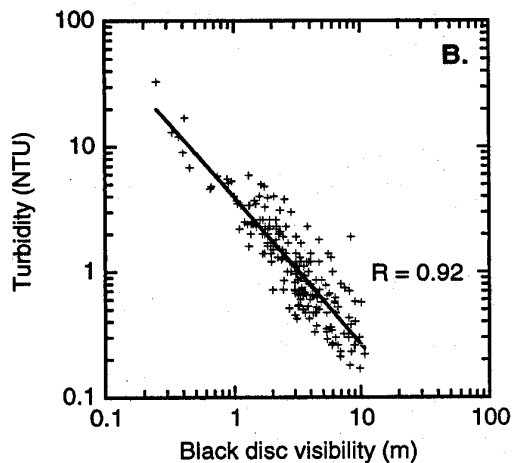
## Appendix G. Uncertainties Regarding Turbidity NTU Measurement

### **Uncertainties regarding translation between black disk transmissometry measurements and nephelometry:**

Turbidity NTU translations from black disk visibility are used in this report regarding the Impact Assessment Model for Clear Water Fishes Exposed to Excessively Cloudy Water (Newcombe, 2003), and with respect to some of the data regarding water contact recreation and aesthetics. The correlation between turbidity (a relative measure of water clarity) and back disk visibility (an absolute measure of water clarity) is not a universal relationship providing a direct translation from one method of measurement to the other. However, understanding correlations between the two methods can make it a useful tool for estimating NTUs based on black disk visibility measurements.

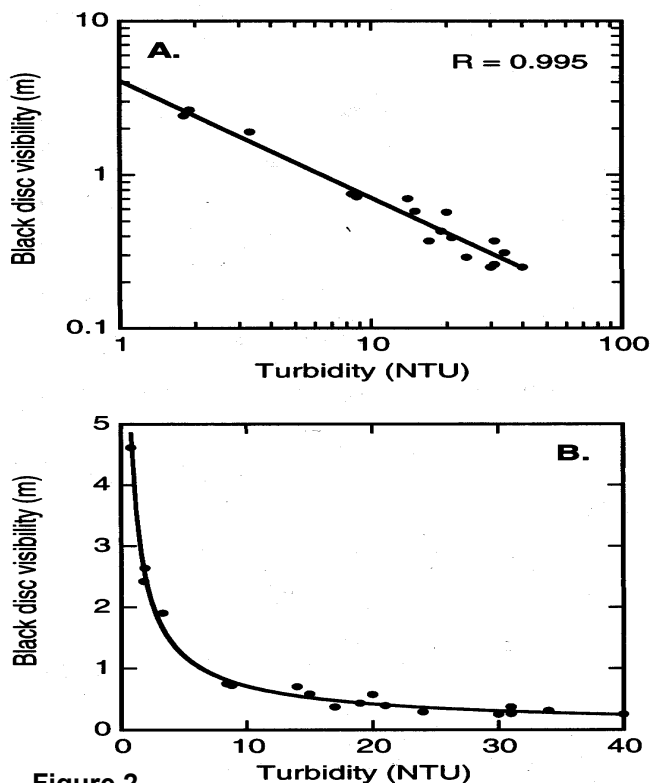
The correlations are strongest in waters where similar particle characteristics produce similar optical effects, for example, as shown in Figure 2 (from Davies-Colley and Smith, 2001) comparing turbidity and black disk visibility measurements from 16 sites in New York state.

The correlation is less strong where a variety of suspended particle characteristics from many locations causes dissimilar optical effects as seen in Figure 3 (from Davies-Colley and Smith, 2001), which compares black disk visibility and turbidity measurements from 97 New Zealand Rivers.



**Figure 3**

Figure 6. Mutual Relationships of Visual Clarity, Turbidity (Hach 2100A) and Suspended Sediment Concentration in 97 New Zealand Rivers (each river site sampled up to three times- $n = 274$  in total). Panel A. Turbidity Versus Suspended Sediment, B. Turbidity Versus Black Disc Visibility, and C. Black Disc Visibility Versus SSC. (Davies-Colley and Close, 1990).



**Figure 2**

Figure 8. Black Disc Visibility Versus Turbidity (Hach 2100AN nephelometer) for 16 Sites in the Esopus and Schoharie Catchments, in the Catskill Region of New York (New York City Department of Environmental Protection, unpublished data). A. Logarithmic Scales, B. Same Data on Linear Scales. The data is well fitted ( $r = 0.995$ ) by a power law:  $y_{BD} = 4.09T^{-0.76}$ .

A slightly better correlation was obtained by using median values from turbidity and black disc visibility measurements at 64 river sites in New Zealand as shown in Figure 4. It should be noted that each comparison was done using the same type of turbidimeter. Based on the first discussion regarding the variability of turbidity readings from various types of turbidimeters, it could be assumed that the correlations

## Appendix G. Uncertainties Regarding Turbidity NTU Measurement

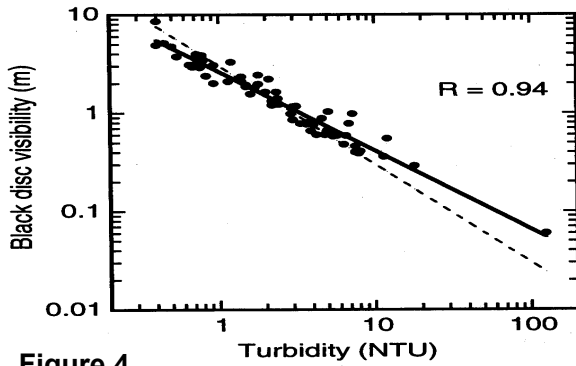


Figure 4

Figure 7. Black Disc Visibility and Nephelometric Turbidity (Hach 2100A) at 64 River Sites in New Zealand. Data are medians for sites in New Zealand's National Rivers Water Quality Network (Smith *et al.*, 1997). Each site is sampled monthly, and six years of data were used for the analysis, that is, each point represents the median of 72 samples. Both the power law fit to the data (solid line) and a simple inverse ( $v_{BD} = 3.02/T$ ) (dashed line) are shown.

shown here would probably be better than if many different types of turbidimeters were used in the comparison.

The trend lines indicate that making a direct translation from a single black disc reading to a single turbidity value may be problematic. However, it may be a valid comparison if used in a more general way as was done by Newcombe (2003) for modelling, or with respect to developing a 'protection level' from black disc visibility measurements to 'estimate' the turbidity.

## Appendix H. Suspended sediments and turbidity.

Suspended sediments and turbidity: Suspended sediments (or solids) can be an important constituent of turbidity and thus many of the reported effects on fish and aquatic systems associated with suspended sediments are also the same 'light and sight' effects attributed to turbidity already discussed in this report. The following information regards 'other' sedimentation effects which should be considered if site-specific criteria are proposed in order to assure that any proposed turbidity criteria for the area in question would not inadvertently allow negative impacts from sedimentation that range beyond the 'turbidity' effects. This exercise does not propose a 'sedimentation' standard. Rather, it provides information parameters that might be useful in checking site-specific turbidity criteria. It is a useful opportunity since monitoring is required for turbidity-causing activities, and turbidity monitoring can also be an indirect measure of suspended sediment concentrations on a basin-specific or reach-specific level.

Important effects of suspended sediments, outside the realm of turbidity, include gill trauma (physical abrasion) leading to fish stress and respiratory interference symptoms including gill flaring and coughing. Reproductive impacts occur from egg smothering and fry emergence trapping caused by settling particles that can also reduce fish food sources by inhibiting or preventing macro invertebrate production in the benthos (Bash et al., 2001).

The ability of juvenile salmonids to survive high sediment concentrations may be subject to season and life stage. During the Summer (smolt transformation), LC50's (the sediment concentration causing 50% mortality) were less than 1500 mg/L, compared to Fall bioassay tests producing LC50's of greater than 30,000 mg/L suspended sediments (Noggle, 1978). Physical *stress* caused by suspended sediments (or turbidity) has been associated with elevated blood sugars (Servizi and Martens, 1992).

Adverse habitat effects result from the loss of habitat complexity and availability, including the loss of refugia caused by anthropogenic inputs of sediments, and from sediment sealing of areas of upwelling, reducing temperature buffering hyporheic inputs to surface waters (Bash et al., 2001). Effects of suspended sediments (and turbidity) can be divided into three categories and appear in Table 1 from Bash et al. (2001).

Table 1 Effects of suspended sediments (and turbidity) on salmonids (Bash et al., 2001)

<b>Physiological</b>	<b>Behavioral</b>	<b>Habitat</b>
Gill trauma	Avoidance	Reduction in spawning habitat
Osmoregulation	Territoriality	Effect on hyporheic upwelling
Blood chemistry	Foraging and predation	Reduced benthic invertebrates
Reproduction and growth	Homing and migration	Damage to redds

The importance of particle size should also be noted, and was reviewed by Bash et al. (2001). Fine particles (silts, clays, and very fine sands: < 75um) are most important to adverse effects on juvenile salmonids, freshwater and estuarine non-salmonids, and freshwater and estuarine eggs and larvae for salmonids and non-salmonids. Fine particles, as well as course particles (fine sand:75 – 250 um), are important to adverse effects on adult and juvenile salmonids. All particle sizes, when suspended in the water column, can be important to turbidity. Smaller, highly suspendable clays (< 4 um) have a greater potential to affect water 'cloudiness' far downstream, while heavier particles such as sands (> 75 um) may settle quickly but have more severe abrasion effects on fish (dependent on particle angularity).

## Appendix H. Suspended sediments and turbidity.

In general, negative effects from suspended sediments increase as the particle size increases, with angularity of particles also considered to be important (Newcombe and Jensen, 1996). Besides particle size and angularity, Bash et al. (2001) have listed the following as environmental factors that affect the effect of sediments on salmonids: type of particles, severity/magnitude of pulse, duration and frequency of exposure, natural background turbidity, time of occurrence, life stage of fish, availability of and access to refugia, other stressors and general condition of biota, temperature, and toxicity. An indirect effect of suspended sediments occurs in the transport of toxicants adsorbed to particles in the water column, increasing the exposure and availability of contaminants to aquatic biota. Examples include urban stormwater or irrigation return flows from erodable areas applied with pesticides.

Extensive tabulations of suspended sediment effects have been presented in the following citations: Bash et al. (2001), and Newcombe and Jensen (1996); and will not be re-iterated for this report. Newcombe and Jensen (1996) further delineated data regarding suspended sediment effects on fish and their habitat by quantifying the magnitude of effects as a function of the suspended sediment concentration and the duration of exposure, a similar method to the one cited in this report regarding turbidity and clear water fish from Newcombe (2003). This approach essentially takes the physiological, behavioral, and habitat effects discussed above and re-organizes them into four hierarchies: Nil effect, behavioral effects, sublethal effects, and lethal effects and para-lethal effects (reduced growth, reduced fish density, habitat damage, delayed hatching, and reduction in population size); all organized along a vertical scale, 0-14, 14 being the most negative effect, and with subcategories further delineating the magnitude of effect, within each hierarchy. It should be noted that duration of effects plays a key role in determining the overall severity of the effect. For example, a reduction in the feeding rate, categorized as a sublethal impact, may be elevated to a para-lethal impact if the behavior reduces fish growth rates over time.

Table 2 was assembled for this report from regression equations developed by Newcombe and Jensen (1996) in order to evaluate, in a simplified format, the suspended sediment concentrations and potential effects with respect to turbidity levels of interest. Table 3 presents tabulated suspended sediment concentrations and a range of turbidity values (NTUs) that have been shown through selected comparative evaluations to roughly correspond to those concentrations.

It is notable that a wide range of turbidity values may be associated with a single suspended sediment concentration value (and vice versa), as exemplified in the 95% confidence intervals from examples D and E, and reflected in  $R^2$  values as well. Many researches have suggested that suspended sediment and turbidity relationships are most relevant to the specific waters from which the data was assembled, and caution against broader application of their use. For example, the proposed state water quality criteria level of 3 NTUs has been associated with wide range of suspended sediment concentrations, for example, averages from ~1.8 to 20 mg/L (or ~1 to 80 mg/L from 95% C.I.), based on the limited data sets presented in Table 3. The low end of the range (~1-2 mg/L) would most likely be associated with finer sediments and more turbidity or water cloudiness effects, whereas the high end of the range (~20 - 80 mg/L) would likely be associated with coarser (larger-sized particle) sediment effects and higher velocity streams; considering light scattering surface area to mass ratios, decreasing with larger particle sizes.

**Appendix H.** Suspended sediments and turbidity.

While there is limited application in comparing proposed state water quality turbidity criteria to suspended sediment concentrations, there may be utility in making comparisons for specific areas where strong correlations between turbidity and suspended sediment concentrations can be determined, and for the purpose of minimizing both turbidity and suspended sediment effects where site-specific criteria are proposed.

**Appendix H.** Suspended sediments and turbidity.

Table 2 Predicted magnitude of adverse effect from suspended sediment concentrations (Mg/L) and duration of exposure to various groups of fish, eggs, and larvae based on regression equations derived from empirical data and a 15-point scale of severity of ill effects (Z) developed by Newcombe and Jensen (1996). **Shaded values** were extrapolated outside the range of empirical data.

Duration	Juvenile & Adult Salmonids			Adult Salmonids			Juvenile Salmonids			Eggs & Larvae of Salmonids and Nonsalmonids			Adult Estuarine Nonsalmonids			Adult Freshwater Nonsalmonids		
	Z* ~ 3.5	6.0	8.5	3.5	6.0	8.5	3.5	6.0	8.5	3.5	6.0	8.5	3.5	6.0	8.5	3.5	6.0	8.5
1 hrs	27.1	810	23600	11.2	305	8250	49	1650	53500	<1	1420		1	12100		<1	900	
2 hrs	15.4	460	13400	7.2	195	5350	24.5	820	27000		122		<1	73	845000		155	
3 hrs	11.0	325	9580	5.5	153	4150	16.5	550	18100		30	89000		3.7	43000		57	
4 hrs	8.7	260	7560	4.6	127	3450	12.5	415	13600		10.6	32500		0.5	5150		27	
8 hrs	4.9	145	4300	3.0	82	2225	6.3	210	6900		1	2840		<1	32		4.7	32400
12 hrs	3.5	105	3070	2.3	63	1725	4.2	145	4600		<1	685			1.6		1.7	11700
1 d	2.0	60	1735	1.5	41	1115	2.1	71	2330			60			1.0		0.3	2050
5 d		16	463		15	405		14.5	480			0.21						36
2 wk		6.8	199		7.8	210		5.3	174									2.7
3 wk		4.9	142		6.0	163		3.6	117									
1 m		3.6	106		4.8	130		2.5	82									
4 m		1.2	34		2.0	55		0.64	21									
11 m		0.5	15		1.1	29		0.24	7.8									

\* Z  
 ~ 3.5 above which, sublethal effects such as short-term reductions in feeding rates or success are predicted to occur.  
 ~ 6 at which, moderate physiological stress is predicted to occur.  
 ~ 8.5 above which, lethal and para-lethal effects such as reduced growth rate, delayed hatching, and reduced fish density are predicted to occur.

**Appendix H.** Suspended sediments and turbidity.

Table 3 Turbidity (NTUs) predicted from suspended sediment concentrations from several comparative evaluations.

Suspended sediment concentration (mg/L)	A	B	C	D		E	
	NTUs	NTUs	NTUs	NTUs	95% C.I.	NTUs	95% C.I.
1	2.1	0.2	0.2	1.1	0.31-3.9	0.5	0.08-2.4
1.8	3						
3	4.5	0.6					
5	6.5	0.9					
10	11	1.7	1.8	10	2.9-36	3.2	0.58-17
15	14	2.4					
20	17	3.1	3.7	20	5.7-71	5.8	1.0-31
25	20	3.9	4.6	25	7.1-88	7.0	1.3-38
35	25	5.2					
50	32	7.3	9.2	49	14-172	13	2.3-70
65	38	9.2					
80	44	11	15	77	21-271	19	3.4-104
100	52	14	18	95	27-337	23	4.2-126
150	69	20					
200	84	26					
300	110	38					
400	140	49	73	360	103-1,291	75	13-417
500	160	60	91				
1,000	260	110	180				
5,000		490					
10,000		930					

- A Lower Willamette R. & Tribs (Portland, OR ); using, NTUs = 2.1172 ((mg/L)<sup>0.6945</sup>); R<sup>2</sup> = 0.8407; DEQ data compilation
- B Fraser R. (SW British Columbia); using NTUs = 113 ((g/L)<sup>0.916</sup>); r = 0.952; Servizi and Martens (1992)
- C Susitna River (Alaska; glacially turbid); using, NTUs = 0.185 ((mg/L)<sup>0.998</sup>); R<sup>2</sup> = 0.92; equation from Peratrovich et al. (1982)
- D Interior Alaska streams; NTUs = 1.103 ((mg/L)<sup>0.968</sup>); R<sup>2</sup> = 0.92; Lloyd et al.(1987)
- E Statewide Alaska streams; NTUs = 0.44 ((mg/L)<sup>0.858</sup>); R<sup>2</sup> = 0.83; Lloyd et al.(1987)

**Appendix I. Turbidity criteria from other western states and British Columbia.**

Jurisdiction & State Law Reference	Turbidity Criteria or Guidelines (by Beneficial Use)	Justification
Alaska 18 ACC 70, 2003	<p><b>Water Supply (Aquaculture) and Growth and Propagation of Fish, Shellfish, other Aquatic Life and Wildlife:</b> 25 NTU above natural condition level</p> <p><b>Water Supply (Drinking, Culinary, and Food Processing):</b> 5 NTU above natural background conditions when the natural turbidity is 50 NTU or less, and may not have more than 10% increase in turbidity when the natural turbidity is more than 50 NTU, not to exceed a maximum increase of 25 NTU.</p> <p><b>Water Supply (Agriculture, Including Irrigation and Stock Watering):</b> May not cause detrimental effects on intended use.</p> <p><b>Livestock Watering:</b> Shall not cause detrimental effects on intended use.</p> <p><b>Contact Recreation:</b> 5 NTU above natural conditions when the natural turbidity is 50 NTU or less, and may not have more than 10% increase in turbidity when the natural turbidity is more than 50 NTU, not to exceed a maximum increase of 15 NTU.</p> <p><b>Secondary Contact Recreation:</b> 10 NTU above natural background conditions when the natural turbidity is 50 NTU or less, and may not have more than 20% increase in turbidity when the natural turbidity is more than 50 NTU, not to exceed a maximum increase of 15 NTU.</p> <p><b>Industrial Water Supply:</b> Shall not cause detrimental effects on established water supply treatment levels.</p>	Based on the criteria established by USEPA, 1976.
California NCRWQCB 2001	<p><b>North Coast Region, All Uses:</b> shall not be increased more than 20 percent above naturally occurring background levels. Allowable zones of dilution within which higher percentages can be tolerated may be defined for specific discharges upon the issuance of discharge permits or waiver thereof.</p>	Adopted in 1975, but no reference source.
CVRWQCB 1994	<p><b>Central Valley Region, All Uses:</b> Where natural turbidity is between 0-5 NTU, increases shall not exceed 1 NTU. Where natural turbidity is between 5-50 NTU, increases shall not exceed 20 percent. Where natural turbidity is between 50-100 NTU, increases shall not exceed 10 NTU. Where natural turbidity is greater than 100 NTU, increases shall not exceed 10 percent.</p>	Adopted in 1975, but no reference source available, and modified in 1994 for waters with turbidity between 0-5 NTU due to inaccuracy of turbidimeters below 1 NTU. Same range (0-5 NTU) currently being amended.
CCRWQCB 2002	<p><b>Central Coast Region, All Uses:</b> Waters shall be free of changes in turbidity that cause nuisance or adversely affect beneficial uses. Where natural turbidity is between 0 and 50 Jackson Turbidity Units (JTU), increases shall not exceed 20 percent. Where natural turbidity is between 50 and 100 JTU, increases shall not exceed 10 JTU. Where natural turbidity is greater than 100 JTU, increases shall not exceed 10 percent.</p>	Adopted in 1975, but no reference source.
SFBRWQCB 1995	<p><b>San Francisco Bay Region, All Uses:</b> Waters shall be free of changes in turbidity that cause nuisance or adversely affect beneficial uses. Increases from normal background light penetration or turbidity relatable to waste discharge shall not be greater than 10 percent in areas where natural turbidity is greater than 50 NTU.</p>	Adopted in 1975, but no reference source.
LARWQCB 1994	<p><b>Los Angeles Region, Drinking Water:</b> shall not exceed 5 NTU, All Other Uses: Where natural turbidity is between 0 and 50 NTU, increases shall not exceed 20%. Where natural turbidity is greater than 50 NTU, shall not exceed 10%.</p>	Adopted in 1975, but no reference source
SDRWQCB	<p><b>San Diego Region, All Uses:</b></p>	

**Appendix I. Turbidity criteria from other western states and British Columbia.**

<p>1994</p> <p>SARWQCB 1995</p> <p>LRWQCB 2002</p> <p>CRBRWQCB 2002</p>	<table border="0"> <tr> <td>Natural Turbidity</td> <td>Maximum Increase</td> </tr> <tr> <td>0-50 NTU</td> <td>20%</td> </tr> <tr> <td>50-100 NTU</td> <td>10 NTU</td> </tr> <tr> <td>Greater than 100 NTU</td> <td>10%</td> </tr> </table> <p><b>Santa Ana Region, Drinking Water:</b> The secondary drinking water standard for turbidity is 5 NTU.</p> <p>All Other Uses:</p> <table border="0"> <tr> <td>Natural Turbidity</td> <td>Maximum Increase</td> </tr> <tr> <td>0-50 NTU</td> <td>20%</td> </tr> <tr> <td>50-100 NTU</td> <td>10 NTU</td> </tr> <tr> <td>Greater than 100 NTU</td> <td>10%</td> </tr> </table> <p><b>Lahontan Region, All Uses:</b> Waters shall be free of changes in turbidity that cause nuisance or adversely affect the water for beneficial uses. Increases in turbidity shall not exceed natural levels by more than 10 percent.</p> <p><b>Colorado River Basin Region, All Uses:</b> Waters shall be free of changes in turbidity that cause nuisance or adversely affect beneficial uses.</p>	Natural Turbidity	Maximum Increase	0-50 NTU	20%	50-100 NTU	10 NTU	Greater than 100 NTU	10%	Natural Turbidity	Maximum Increase	0-50 NTU	20%	50-100 NTU	10 NTU	Greater than 100 NTU	10%	<p>Adopted in 1975, but no reference source.</p> <p>Adopted in 1975, but no reference source.</p> <p>Adopted in 1975, but no reference source.</p> <p>Adopted in 1975, but no reference source.</p>
Natural Turbidity	Maximum Increase																	
0-50 NTU	20%																	
50-100 NTU	10 NTU																	
Greater than 100 NTU	10%																	
Natural Turbidity	Maximum Increase																	
0-50 NTU	20%																	
50-100 NTU	10 NTU																	
Greater than 100 NTU	10%																	
<p>Idaho</p> <p>IDAPA 58.01.02.250</p> <p>IDAPA 58.01.02.252</p>	<p><b>Cold Water Aquatic Life:</b> shall not exceed background turbidity by more than fifty (50) NTU instantaneously or more than twenty-five (25) NTU for more than ten (10) consecutive days. (8-24-94)</p> <p><b>Small Public Water Supplies:</b> shall not exceed background turbidity by more than 5 NTU above natural background, when background turbidity is 50 NTU or less, or increase by more than 10% above natural background, not to exceed 25 NTU, when background turbidity is greater than 50 NTU.</p>	<p>Justification for criteria is not available. Similarity to USEPA Guidelines prior to 1986 allows for the presumption of this reference.</p>																
<p>Washington</p> <p>WAC 173-201A</p>	<p><b>Char; Salmon and Trout spawning, core rearing, and migration; Salmon and Trout spawning, noncore rearing, and migration; and Non-anadromous Interior and Redband Trout :</b> 5 NTU over background turbidity when the background turbidity is 50 NTU or less, or have more than a 10% increase in turbidity when the background turbidity is greater than 50 NTU.</p> <p><b>Salmon and Trout Rearing and Migration Only; and Indigenous Warm Water Species:</b> 10 NTU over background turbidity when the background turbidity is 50 NTU or less, or have more than a 20% increase in turbidity when the background turbidity is greater than 50 NTU.</p>	<p>Justification for criteria is not known. Criteria first established in 1967 in JTUs and changed between 1973-1977 following USEPA Guidelines 1976.</p>																
<p>British Columbia</p> <p>MWLAP 1997 &amp; 2001</p>	<p><b>Raw Drinking Water: untreated:</b> 1 NTU when background is ≤ 50 NTU, treated: 5 NTU when background is less than or equal to 50, 10% when background is &gt; than 50.</p> <p><b>Aquatic Life:</b> 8 NTU in 24 hours when background is ≤ 8, mean of 2 NTU in 30 days hours when background is ≤ 8 or 8 NTU when background is between 8 - 80 NTU, 10% when background is ≥ 80.</p> <p><b>Wildlife, Livestock, Irrigation, Industrial Water Supplies:</b> should not exceed 10 NTU when background is ≤ 50 NTU, nor should be greater than 20% of background when background is &gt; 50 NTU.</p> <p><b>Recreation &amp; Aesthetics:</b> Maximum 50 NTU, secchi disc visible at 1.2 m.</p>	<p>Health Canada 1991, USEPA 1978, Alaska DEC 1982, Manitoba DE 1983.</p> <p>WA and MT criteria 1997.</p> <p>Enviro Saskatchewan 1975, Alberta DE 1977, Alaska DEC 1979, Montana Health &amp; Enviro Sci 1980, Idaho DHW 1980, State of WA 1982.</p> <p>BC Health 1969, Enviro Canada 1972, Enviro Saskatchewan 1975, Alberta DE 1977, Ontario Min of Enviro 1979, Manitoba DE 1979 &amp; 1983, Alaska DEC 1979 &amp; 1982, Montana Health &amp; Enviro Sci 1980, Idaho DHW 1980, State of WA 1982.</p>																

**Appendix J.** Flow chart for application of turbidity criteria rule.

