Report

Turbidity Analysis for Oregon Public Water Systems

Water Quality in Coast Range Drinking Water Source Areas

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State of Oregon
Department of
Environmental
Quality

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Executive Summary

After catastrophic storms and landslides hit the Oregon Coast in 2006 and 2007, the Oregon Department of Environmental Quality and Oregon Department of Human Services had concerns about the resiliency of public water systems that rely on surface waters in watersheds prone to heavy rains and landslides. Landslides in such areas can deposit large amounts of sediment that can increase turbidity and significantly lower the quality of drinking water obtained and treated by these water systems. Increasing levels of turbidity may interfere with public water system operations, can increase operational costs and can also cause shutdowns. In addition, DEQ and DHS were interested in the potential effects from climate change in these watersheds.

DEQ sent e-mail inquiries and interviewed staff at numerous public water systems in the Coast Range and Southwest Oregon. It also obtained and analyzed available daily turbidity data from seven water systems (Hillsboro-Cherry Grove and the cities of Astoria, Carlton, Falls City, Forest Grove, Siletz and Yamhill) and collected data on water treatment facility shutdowns from Arch Cape Water District.

DEQ evaluated as case studies a total of eight public water systems in the North and Middle Oregon Coast Range area and used available turbidity data to analyze long-term trends. DEQ's analysis concludes that there are long-term concerns about system viability or increased treatment costs at five systems (Arch Cape Water District and the cities of Astoria, Carlton, Siletz, and Yamhill), based on large numbers of high-turbidity days and/or increasing numbers of high-turbidity days recorded in daily water samples for these systems. Also, DEQ found that turbidity is increasing in the long term in Drinking Water Source Areas for five systems, remains stable at one system, and is decreasing at two others.

Drinking Water Source Areas for these Coast Range systems are predominantly forested. Only the City of Siletz has a significant amount of rural residential and/or agricultural land in the lower part of its source area.

Precipitation has the greatest impact on turbidity patterns for these systems, with the largest spikes in turbidity occurring during the autumn months. In addition to this seasonal variation, for the five systems with increasing turbidity trends, there are an increasing number of days reported with turbidity levels above 5 nephelometric turbidity units (a system of measuring water's clarity in terms of visible light), turbidity spikes of increasing magnitude and/or increasing baseline turbidity. In addition to the problems high turbidity can cause on drinking water treatment and system operation, changes in turbidity may also adversely affect aquatic life or other beneficial uses of the water, such as fishing and swimming.

High turbidity levels at some of these eight public water systems may be the result of inherent watershed characteristics, natural events (such as storms, slides and bank erosion), and land-use activities (forestry, agriculture, rural residential, road building and maintenance). Regardless of the source of turbidity, watershed protection and restoration activities can reduce unacceptable levels of sediment deposited into public water system sources and can reduce the cost of drinking water treatment.

This analysis was not designed or intended to answer cause-and-effect questions related to turbidity. Further statistical and Geographic Information System analysis is necessary to evaluate the effects of human-caused changes, natural disturbances and inherent watershed features on public water systems. But collection of new data, further analysis of existing data, enhanced source water monitoring and evaluation and analysis of sediment sources and movement will help DEQ and DHS further understand and manage risks to public water systems. In addition, changes in weather patterns and precipitation due to climate change should be considered as this topic is studied further.

Introduction

The storms of December 2007 resulted in catastrophic flooding in the northern Coast Range of Oregon, destroying or harming homes, water supplies, fisheries, roads, farms, and businesses. Many of Oregon's Public Water Systems (PWSs) were directly impacted by the flooding, wind damage, and landslides in their municipal watersheds. The Department of Human Services (DHS) and the Department of Environmental Quality (DEQ) had previously mapped all of these watersheds and prepared Source Water Assessment (SWA) reports for the community officials (http://www.deq.state.or.us/wq/dwp/dwp.htm). The SWAs included maps of the source area boundaries, natural characteristics of the watersheds, and identified potential risks for the systems.

The damage from the storms raised questions about the sensitivity of these PWSs as the number of severe storms could increase due to climate change. The landslide near Clatskanie in northwest Oregon completely destroyed Westport's water system. DHS was concerned about the potential for complete loss of, or severe damage to, the systems due to storms. As part of the existing drinking water protection planning and implementation, DEQ embarked on this analysis of potential turbidity problems for PWSs. The purpose of this first phase of analysis is to use existing data to identify the PWSs that have ongoing turbidity problems and to conduct a trend analysis if data is available.

Work was initiated in January 2008 with an email/phone questionnaire to 148 surface water systems in Oregon. DEQ asked them if there were any recent landslides in their watershed that impacted the intake(s). We indicated our purpose was to evaluate whether we need to put more resources into this problem at the state level. Out of this initial query, we received information from 17 different systems that had turbidity impacts, but not necessarily from landslides. Several system operators asked for assistance to determine what was causing the turbidity and to assist them in reducing the loading to the source stream. At that point, both DHS and DEQ determined that we should proceed with an analysis of the turbidity issues and follow this with recommendations for reducing the risks for those systems.

Applicable Turbidity Standards for Water Quality

The turbidity water quality standard (OAR 340-41-0036) is:

Turbidity (Nephelometric Turbidity Units, NTU): No more than a ten percent cumulative increase in natural stream turbidities may 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:

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

(2) 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 OAR 14l-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.

In Oregon, there are many waters with low NTU levels and a 10 % increase is very difficult to measure in a clear stream. In addition, the original 10% Turbidity water quality standard was based on Jackson turbidity units (JTUs) which are measureable to 25 JTU with an accuracy of ± of 1 JTU. The standard switched to NTUs which are measureable to 1 NTU with an accuracy of ± 0.1 NTU. This has led to claims that DEQ's turbidity standards cannot by implemented. In reality, the 10% exceedence criteria was designed to take into account the fact that natural conditions in streams do not produce consistent low turbidity at all times. DEQ recognizes that there is some natural variation and this creates difficulty in determining whether turbidity levels exceed the criteria of a 10% increase. There are several characteristics of turbidity by which a 10% increase could be documented: the baseline turbidity of a stream, the number of spikes in a stream's turbidity, the median or 75th percentile of turbidity, and/or the statistical trend that the stream's turbidity is following. However, the standard relates to a control point immediately upstream and is not applicable at the watershed scale but at the reach scale. The turbidity WQS may be revisited in 2009 or 2010.

Turbidity is one of the primary pollutants regulated in finished drinking water under the Safe Drinking Water Act (SDWA). To protect human health, the EPA has set the level of allowable turbidity in finished drinking water at: 0.3 Nephelometric Turbidity Units (NTU) in 95% of samples (1 NTU absolute maximum) for conventional (sedimentation and rapid sand filtration) and direct (rapid sand only) filtration; and 1 NTU in 95% of samples (5 NTU absolute maximum) for membrane, cartridge, slow sand, and diatomaceous earth filtration (US EPA 1998, US EPA 2001, US EPA 2002b). Turbidity limits prevent drinking water from having excessive levels of suspended fine sediment (US EPA 1999). Suspended sediment is of concern for drinking water safety as it can reduce the effectiveness of disinfection treatments (LeChevallier *et al* 1981), harbor pathogens (e.g. Chang *et al* 1960, Tracy *et al* 1966, Sen & Jacobs 1969, Meschke & Sobsey 1998), contribute to formation of disinfection by-products (Nikolaou *et al* 1999, US EPA 2002a), and carry nutrients, heavy metals, pesticides, and other toxic chemicals (Lick 2008). Unpleasant tastes and odors frequently co-occur with excessive turbidity (US EPA 1998). Prevention or removal of fine sediment pollution from water reduces these risks to acceptable levels (US EPA 2001).

Most drinking water treatment facilities run by Public Water Systems (PWSs) have the capacity to remove turbidity-causing sediments during treatment of raw water; however, the amount of turbidity that can be effectively removed depends on the treatment technology in use (US EPA 1999, *personal communication* with PWS managers). For example, water can be treated using a flocculent/coagulant agent to collect fine sediments into larger particles which are then removed by rapid pressurized filtration through a bed of sand. Another common drinking water treatment system, slow sand filtration, allows water to slowly percolate through a large bed of sand to be collected through an underdrain. When source water turbidity exceeds 5 NTU, a treatment plant using these treatment systems will usually need to shut down (National Drinking Water Clearinghouse (NDWC) 1996, *pers comm* with PWS managers). PWSs with additional pre-filtration or pre-sedimentation basins can treat source water with turbidity higher than 5 or 10 NTU (US EPA 2004, *pers comm* with PWS managers). Some systems in Oregon with frequent high turbidity install advanced filtration systems that can treat water with turbidity higher than 50 or 100 NTU (e.g. City of Coquille). These advanced filtration systems are expensive to install and maintain and may not be affordable for all small PWSs. Some studies have shown that prevention of turbidity and fine sediment pollution is a cost effective way to ensure that current PWS treatment can meet the SDWA Maximum Contaminant Level (MCL) for turbidity (Brown 2000).

Public Water System Evaluations

Some Public Water Systems have historic and/or current problems with turbidity in their source water. There are 161 PWSs with all or part of their Drinking Water Source Areas (DWSAs) in the Coast Range and mountains of Southwestern Oregon (Appendix A). This report focuses on 8 PWS Case Studies in the North Coast and Mid Coast regions that included interviews with PWS directors/supervisors and analysis of available raw water turbidity data. We also conducted field visits in the DWSAs for the Arch Cape, Siletz, and Yamhill PWSs. The PWS examined in this report are:

- Arch Cape Water District,
- City of Astoria,
- City of Carlton,
- City of Falls City,

- City of Forest Grove,
- Hillsboro-Cherry Grove,
- City of Siletz,
- City of Yamhill.

In addition, the following PWS were also interviewed and status reports were written based on the interview. The status reports give some history of each PWS, the operators' opinions of the current situation, and their concerns about potential threats to the PWS. Those status reports are not included in this report because we could not get turbidity data or conduct a site visit:

- City of Clatskanie,
- City of Coquille,
- Langlois Water District,
- City of Myrtle Point,
- City of Port Orford,
- City of Powers,
- Rainier Water Department,
- Seaside Water Department,
- City of Waldport,
- Westport Water Association.

Some water systems did not have daily turbidity data available in an accessible format, and not all PWSs collect precipitation data. Several were affected by a large landslide in December 2007 above Highway 30 near the Columbia River. One (Westport Water Association) had their intake and associated infrastructure completely destroyed by the slide. Out of the 18 water systems that were interviewed, 14 had problems or expressed concerns about high and/or increasing turbidity in their source water.

Map 1

Methods

We received beginning-of-the-day turbidity data from 7 PWSs, giving a snapshot of turbidity conditions at about 8am each day. One PWS (Arch Cape) gave us data with the dates of treatment shutdowns due to turbidity. Data were organized and counts of high turbidity days per water year were done using Microsoft Excel 2007. Minitab v15.1 was used for graphing and data analysis, including time series trend analysis for high turbidity days using the method of Box and Jenkins (1994) and seasonally-adjusted trend analysis of turbidity data over time (Makridakis *et al* 1998). The trend analysis of high turbidity days showed whether the number of days with turbidity ≥5 NTU ("high turbidity days") is changing directionally over time. We fitted linear, quadratic, and exponential models and chose the model with the best accuracy, as shown by lower Mean Absolute Percent Error

(MAPE), Mean Absolute Deviation (MAD), and Mean Squared Deviation (MSD) scores. In no cases did the exponential model have the best fit. The seasonally-adjusted trend analysis of turbidity separated the data into seasonal and linear trend components. The decomposition of seasonal and linear trends allowed examination of long-term change while accounting for the tendency of stream systems to have elevated turbidity at the beginning of the autumn rainy season. Trend equations take the form:

$$\text{Linear: } Y_t=\alpha+\beta t$$
$$\text{Quadratic: } Y_t=\alpha+\beta t+\gamma t^2$$

where Y_t is the turbidity at time t, α is the y-axis intercept, and β and γ are the coefficients of change for t and t^2, respectively.

We used ArcGIS v9.3, operator interviews, and field visits to evaluate patterns in land ownership and conditions on the ground.

Definitions of terms

Low Turbidity Status—Turbidity baseline lower than 5 NTU greater than or equal to 50% of the time
High Turbidity Status—Turbidity baseline lower than 5 NTU less than 50% of the time
Occasional Spikes—Sudden increases in turbidity that exceed 5 NTU occurring less than 30 times/year
Frequent Spikes—Sudden increases in turbidity that exceed 5 NTU occurring more than 30 times/year
Increasing Trend—$\beta > 0.000150$ for seasonally-adjusted turbidity trend
Decreasing Trend—$\beta < -0.000150$ for seasonally-adjusted turbidity trend
Stable Trend—$0.000150 \geq \beta \geq -0.000150$ for seasonally-adjusted turbidity trend

Summary of Results

Conditions ranged from low turbidity with occasional spikes to frequent large spikes that require intervention by operators to consistently high turbidity throughout the late autumn, winter, and early spring. Turbidity trends range from historic problems that are improving to steady turbidity patterns (whether high or low) to increasing turbidity leading to more frequent problems. There is significant variation among Public Water Systems, with some having noticeably more high turbidity days than others (Figure 1.) Currently, the Cities of Astoria and Falls City have the most consistently low turbidity while the Cities of Carlton, Siletz, and Yamhill have frequent high turbidity days. Arch Cape was analyzed differently because daily turbidity data were unavailable.

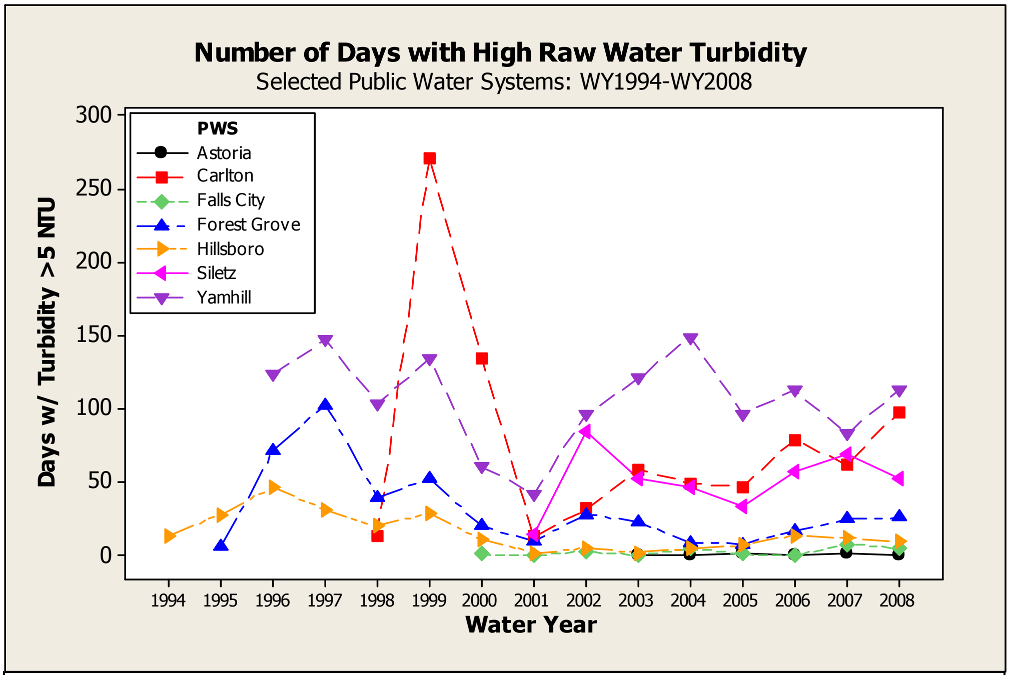


Figure 1: Count of days when influent water turbidity equal or exceeds 5 NTU by water year for 1994 through 2008. The water year is October 1st through September 30th.

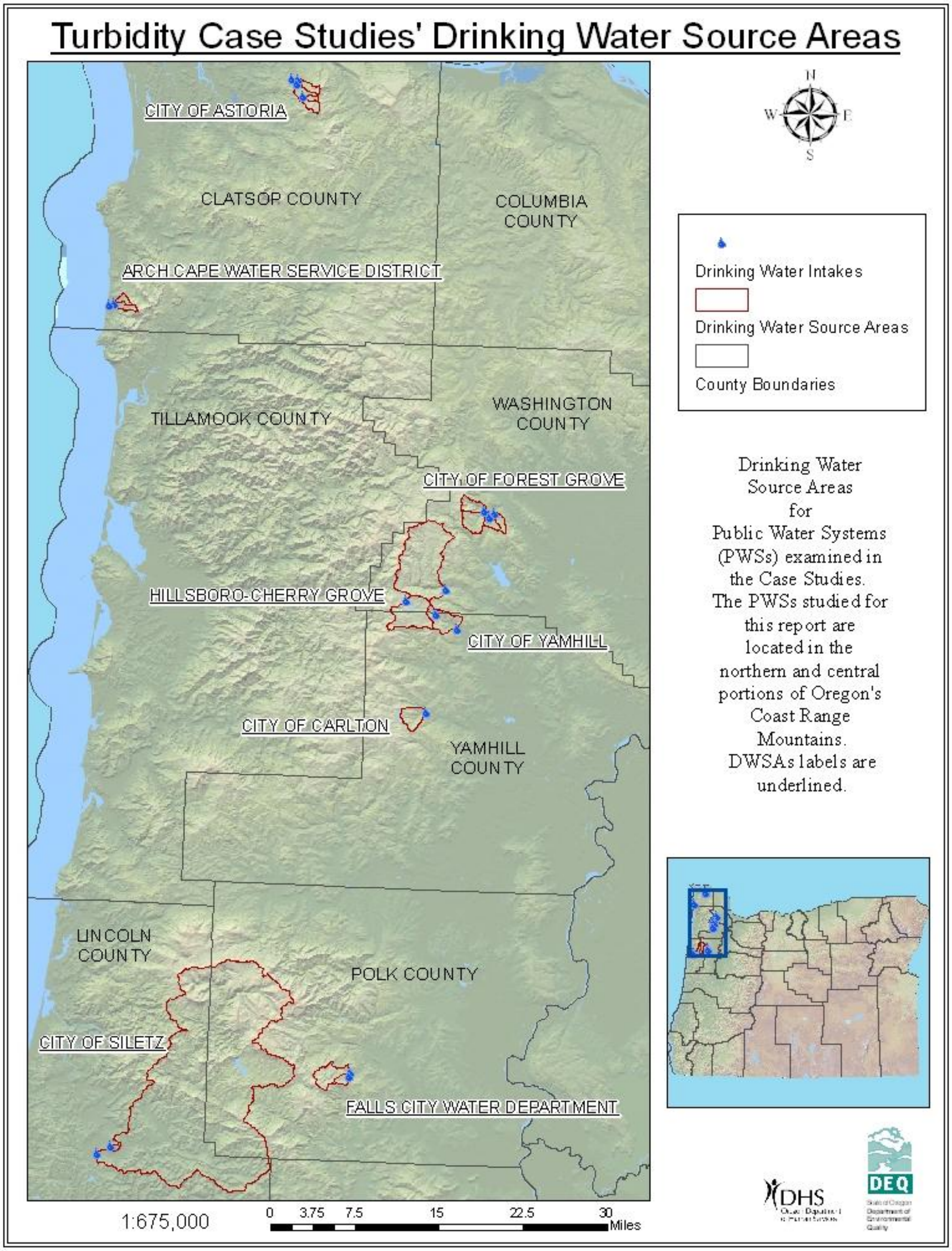
Below are suggested approaches for PWSs or agencies to address a situation, generally speaking. Specifics will vary from system to system based on their particular watershed(s) and the level of resource protection within it. It is also important to note that many PWSs do not have resources beyond those needed for day-to-day operations and maintenance; additional protection measures require additional funding (Drinking Water Needs Survey 2009).

Table 1: Recommendations for Future Work Based on Turbidity Status and Trend

	Low Turbidity (Occasional Spikes)	Low Turbidity (Frequent Spikes)	Consistent High Turbidity
Trend of Decreasing Turbidity	N/A	Evaluate situation/ Consider DWSA protection measures	Find causes/Consider additional DWSA protection measures
Trend of Stable Turbidity	Evaluate situation/ Consider DWSA protection measures	Find causes/Consider additional DWSA protection measures	Find causes/Change DWSA mgmt. & implement restoration
Trend of Increasing Turbidity	Find causes/ Consider additional DWSA protection measures	Find causes/Change DWSA mgmt. & implement restoration	Find causes/Change DWSA mgmt. & implement restoration

Case Studies

Map 2



Turbidity Case Studies' Drinking Water Source Areas

Drinking Water Source Areas for Public Water Systems (PWSs) examined in the Case Studies. The PWSs studied for this report are located in the northern and central portions of Oregon's Coast Range Mountains. DWSAs labels are underlined.

Analysis of Public Water System Turbidity Data

Arch Cape Water District (PWS# 4100802)

Thomas Merrell, Director
503-436-2790

Increasing Trend [Reported by PWS]: Low Turbidity (Occasional Spikes) transitioned to Low Turbidity (Frequent Spikes)

Arch Cape is small coastal community in southern Clatsop County with a mixture of year-round and part-time residents. The treatment plant uses chemical coagulation and pressurized (rapid) sand filtration to remove particulates from the source water. The district has two drinking water intakes in its 1,250 acre Drinking Water Source Area (DWSA): on Asbury Creek, a medium-sized coastal stream, and on Shark Creek, a medium-sized tributary of Asbury Creek. The primary intake on Shark Creek is behind a small dam that forms an intake pool, and the secondary intake is on Asbury Creek below its confluence with Shark Creek. The land of the forested DWSA has been owned by a succession of private industrial timber companies. Arch Cape Water District does not have a backup source of water.

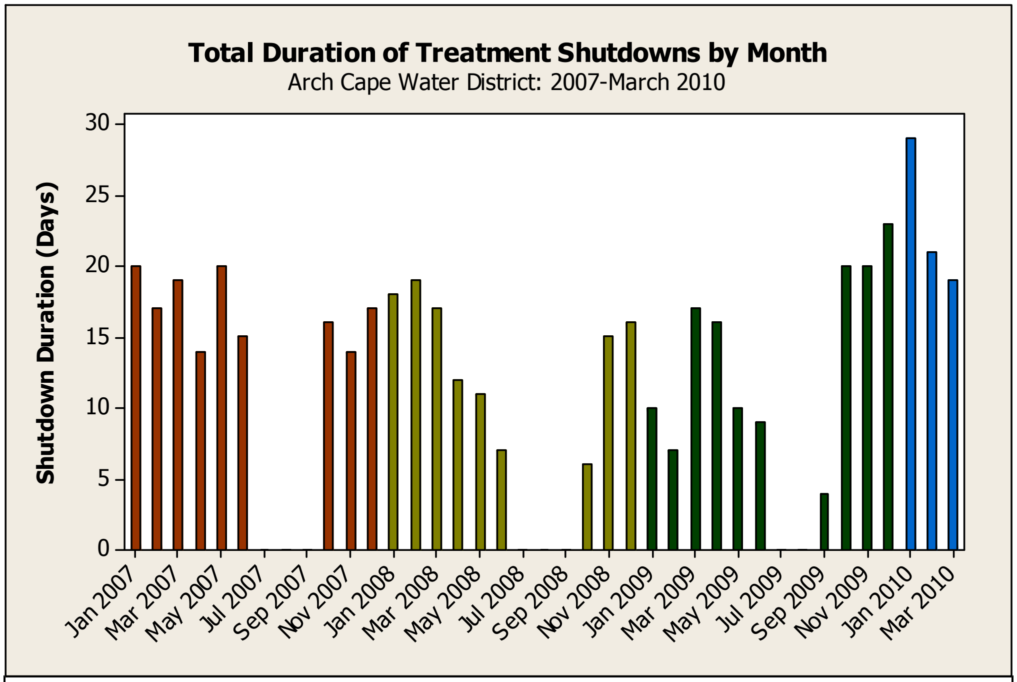


Figure 2: Number of days per month that Arch Cape Water District's treatment plant spent shutdown due to high turbidity from January 2007 through March 2010. Bar colors highlight the calendar year.

Arch Cape Water District has difficulty with operations due to high turbidity and spends a significant proportion of each month shutdown due to turbidity with the exception of the summer months (Figure 2). Arch Cape Water District does not have a backup source of water. If the PWS cannot use the Shark Creek intake, then they must use the Asbury Creek intake (downstream of the confluence of Shark and Asbury Creeks). If neither intake is usable, then the PWS must shut down water purification and use stored water (3 to 7 day supply).

Further increases in suspended sediment in Arch Cape's DWSA could be very problematic. As little as 0.5 inches of rain raises stream turbidity to the point that Arch Cape's rapid sand filtration can not remove enough fine sediment to meet finished water standards (T. Merrell, *pers comm*). For the last 3 years, the intake pool has needed to be dredged yearly by necessity where during the previous decade the PWS only dredged it once every 3 or 4 years as routine maintenance. To cope with the increased turbidity, Arch Cape recently applied for and received over $1 million in American Recovery and Reinvestment Act ("stimulus") funds to replace their rapid sand filtration and chlorination treatment with membrane filtration and UV disinfection. Leaking distribution pipes will also be replaced with these funds.

City of Astoria (PWS #4100055)

Jim Hatcher, Public Works Operations
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Increasing Trend: Low Turbidity (Occasional Spikes)

The City of Astoria is located on the Columbia River estuary. Astoria has water supply intakes on two lakes (Middle and Main Lakes) and two creeks (Cedar and Bear Creeks). They can switch among intakes as needed, depending on weather and source conditions. Astoria typically draws more water from the creeks during the summer and more from the lakes in winter due to turbidity fluctuations. This ability to change sources is an important asset. Astoria uses a slow-sand filter to remove particulates, and these filters can be easily clogged by turbidity higher than 5 NTU. Since 1956, the City of Astoria has owned nearly all of the 2,736 acre forested Drinking Water Source Area (DWSA), in addition to a small part of neighboring Wikiup's DWSA. The City does harvest timber from the DWSA. The Forest Stewardship Council (FSC) certified Astoria's management and harvest operations as "Well Managed" forestland (the highest classification) in 2003. A private industrial timber (PI) company owns less than 5% of Astoria's DWSA, of the southern and northern edges. Private industrial companies own the land surrounding Astoria's DWSA.

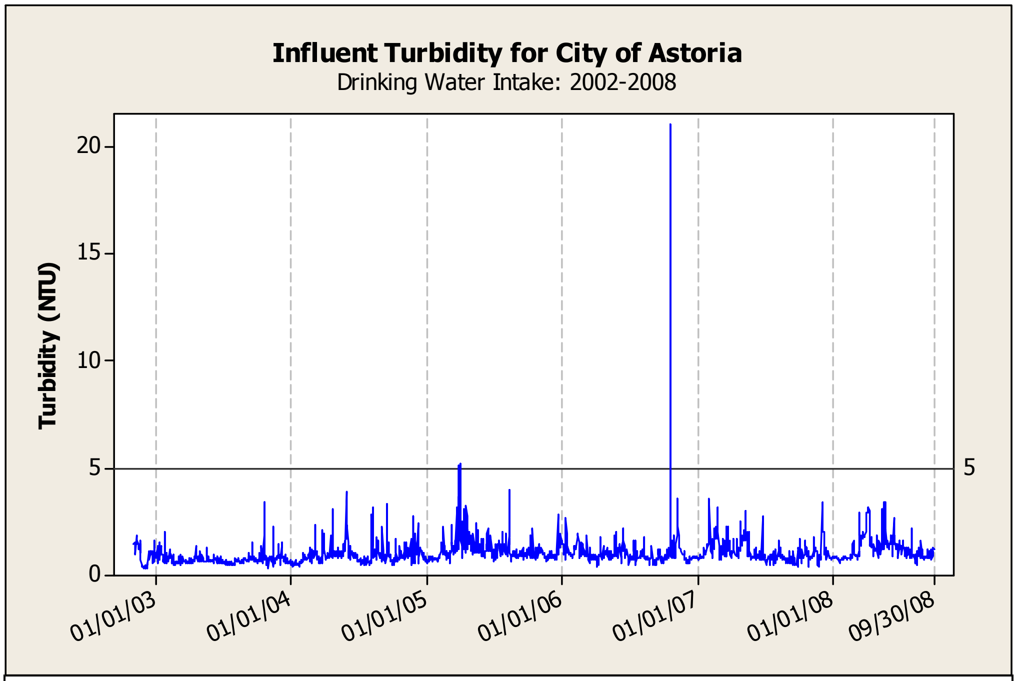

Figure 3a: Turbidity for City of Astoria's drinking water system. Since the City can switch between sources as needed, this represents a composite of whichever source has the lowest turbidity at any given time. Other sources within the DWSA probably had higher turbidity at the time.

Turbidity for water entering Astoria's water treatment plant is shown below (Figure 3a). When the source supplying the treatment plant begins to be too turbid, then operators survey all sources to determine which has the lowest turbidity and is most suitable for use (Figures 3b&c). Therefore, the source in use is typically the one with the lowest turbidity. Rises in turbidity are frequently triggered by precipitation (Figure 3d). The turbidity patterns in Astoria's water sources are fairly stable and easily managed with the multitude of potential intakes. However, influent turbidity is slightly increasing overall (Figure 3e), albeit at low rate and well below levels that would drive serious concerns. All of the individual sources except Cedar Creek show at least some recent increase in turbidity (Table 2). Spur 14 Creek has very low turbidity, so its fluctuations in turbidity may appear meaningful when in fact they are very small.

As the influent turbidity approaches 5 NTU, Astoria's drinking water system switches to another source with lower turbidity. High turbidity days in the influent water are therefore rare, even when several of the sources have elevated turbidity (Figure 3f). The flexibility among sources created a flat, and extremely low, trend in high turbidity days (for influent) over the last 6 years (Figure 3g). Bear Creek's trend in high turbidity days remained level after a jump in 2005, and Middle and Main Lakes had noticeable increasing trends in the last two years (Table 2). The turbidity increases in Bear Creek and the two lakes may be cause for concern and are likely contributed to by ground disturbed as trees toppled in large numbers during the December 2007 windstorm that struck Oregon's North Coast. Much of this blowdown was adjacent to clearcuts on neighboring private land.

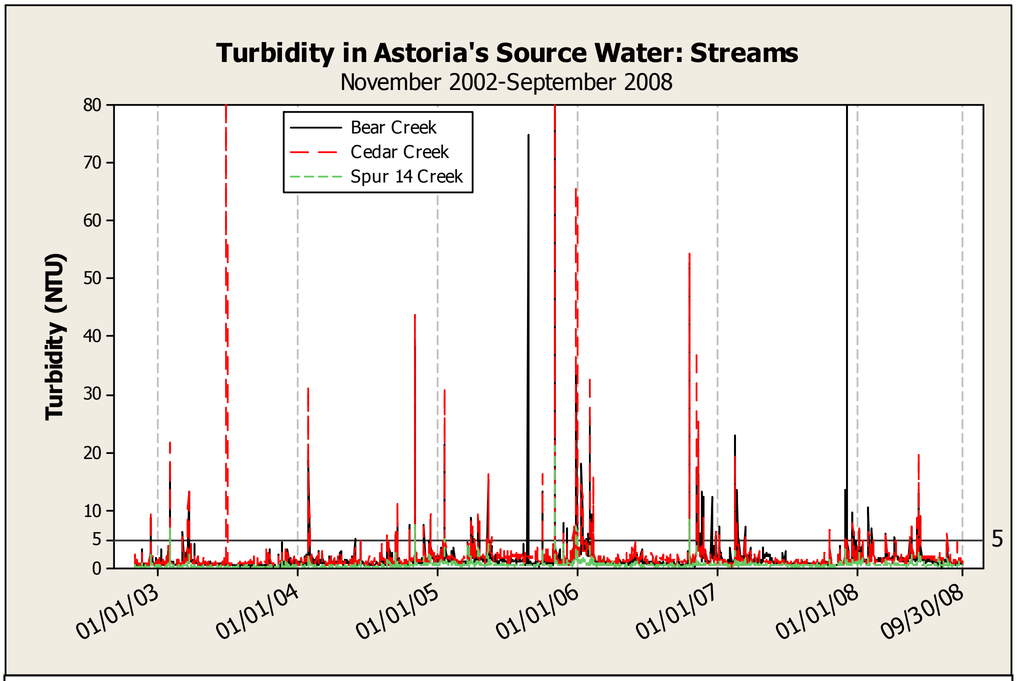

Figure 3b: Turbidity for the stream sources of Astoria's drinking water (Bear Creek, Cedar Creek, and Spur 14 Creek).

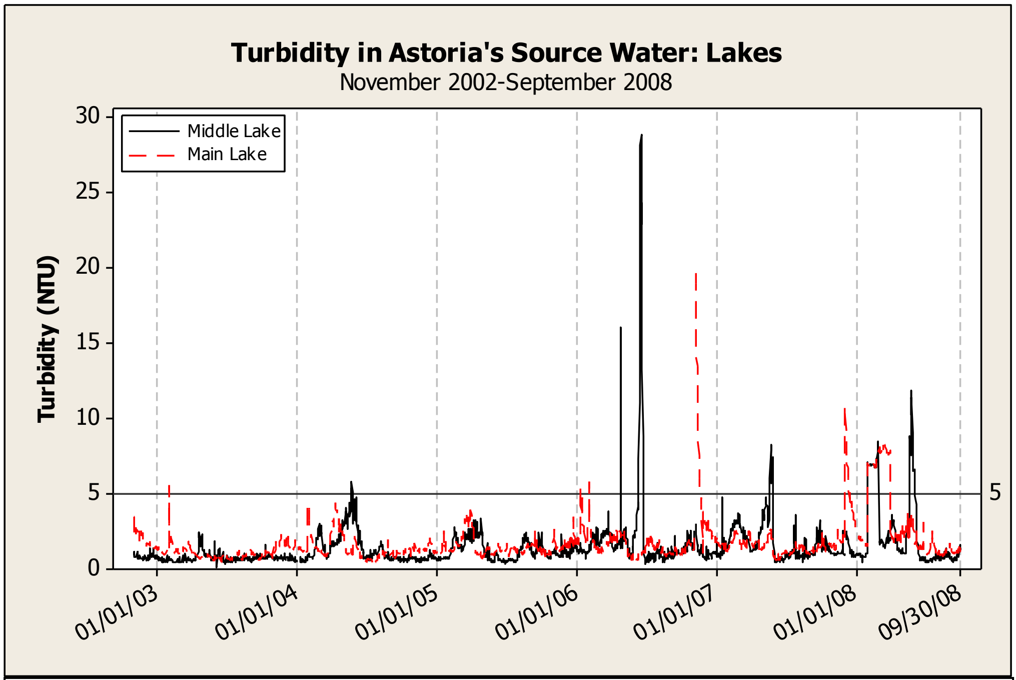

Figure 3c: Turbidity for the lake sources of Astoria's drinking water (Middle Lake and Main Lake).

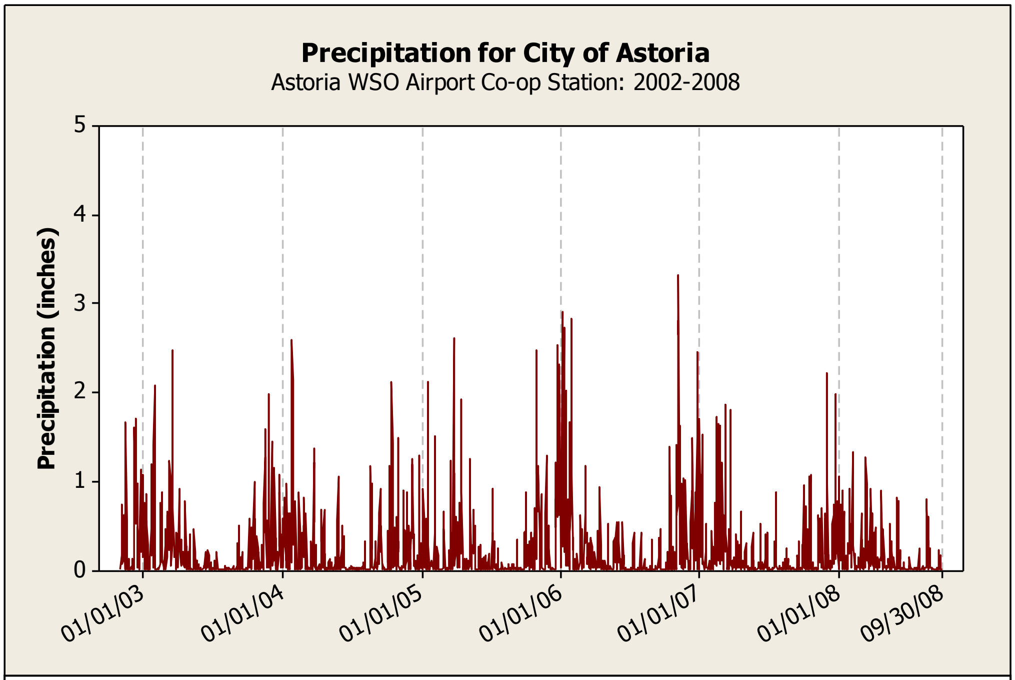

Figure 3d: Precipitation at the Astoria WSO Airport co-op weather station, the nearest weather data to Astoria's DWSAs. The seasonal pattern of precipitation drives the seasonal pattern in turbidity.

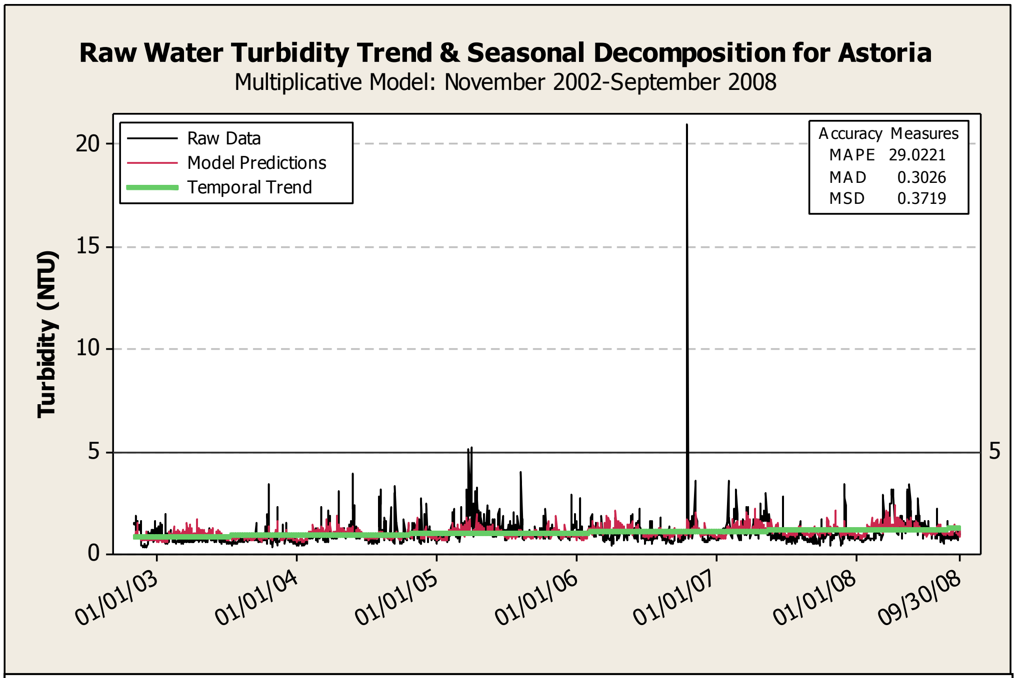

Figure 3e: The turbidity trend for the influent (raw) water is gradually increasing (Y_t=0.85+0.000183*t), but the trend is not strong. Generally, the turbidity remains low.

Seasonally-Adjusted Turbidity & High Turbidity Day Trends for Astoria's Water Sources

Source Water	Turbidity Trend Equation	Direction of Change	Days >5 NTU Trend Equation
Bear Creek	$Y_t = 1.27+0.000455*t$	Increasing	$Y_t = -4.27+8.44*t-0.82*t^2$
Cedar Creek	$Y_t = 1.93+0.000065*t$	Stable	$Y_t = 6.27+1.69*t$
Spur 14 Creek	$Y_t = 0.455+0.000169*t$	Increasing	$Y_t = 1.20-0.057*t$
Main Lake	$Y_t = 0.975+0.000728*t$	Increasing	$Y_t = 31.9-31.2*t+6.05*t^2$
Middle Lake	$Y_t = 0.890+0.000572*t$	Increasing	$Y_t = 11.3-11.4*t+2.66*t^2$

Table 2: Trend for seasonally-adjusted turbidity and trend in the number of days with high turbidity for each of Astoria's water source. Trends are calculated for time period between November 2002 and September 2008.

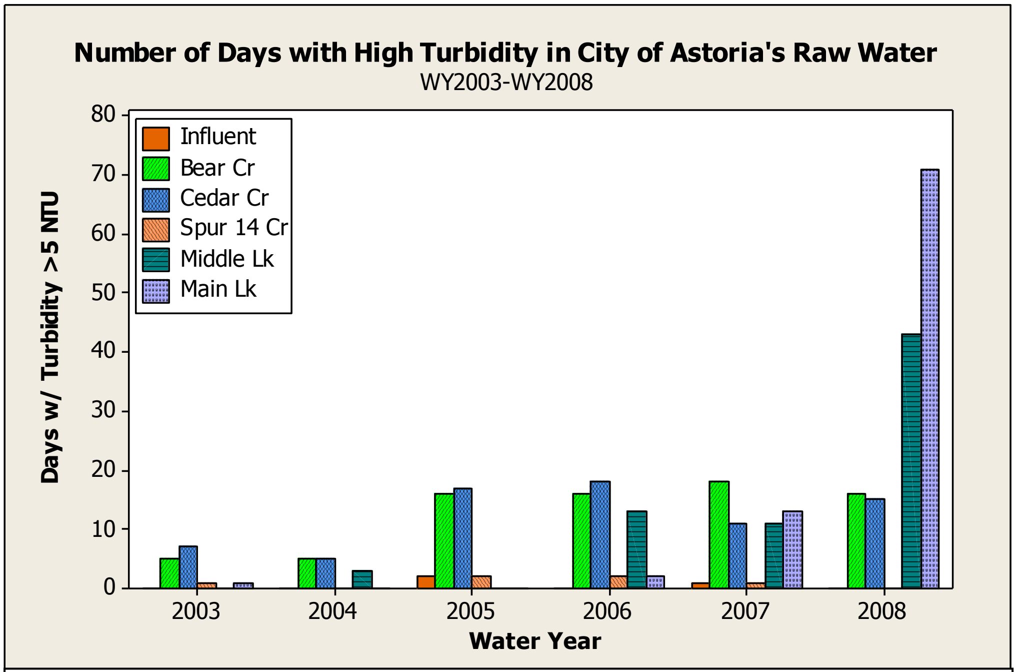

Figure 3f: Number of high turbidity days (>5NTU) per water year in Astoria's DWSA as measured at the drinking water treatment plant from the intake(s) in use (Influent) and as measured at each source. The water year runs from October 1st through September 30th.

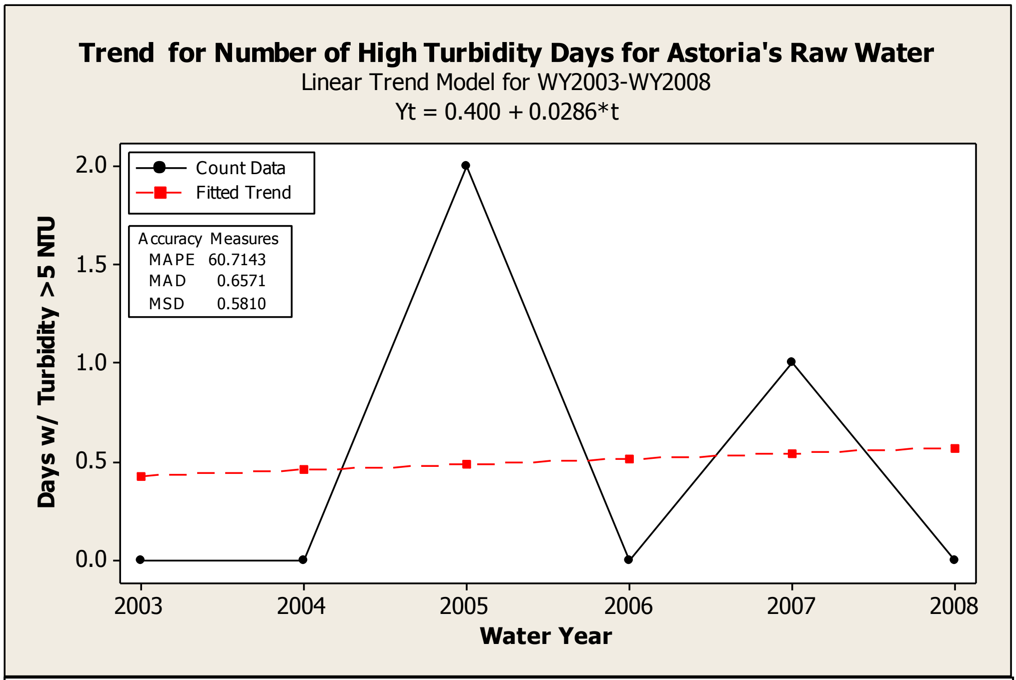

Figure 3g: Trend in number of high turbidity days in Astoria's DWSA for 2003 through 2008.

City of Carlton (PWS# 4100171)

Bryan Burnham, Public Works Supervisor
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Increasing Trend: Low Turbidity (Occasional Spikes) transitioned to Low Turbidity (Frequent Spikes)
The City of Carlton is in Yamhill County near the eastern foothills of the Coast Range. Carlton has a reservoir on Panther Creek with their intake on the downstream end. Panther Creek is a tributary of the North Yamhill River on the east side of the Coast Range. The City has a dam and intake structure; a reservoir behind the dam stores water for use during low flows. Carlton installed a floating intake structure in 2001 to draw water from the top of the reservoir rather than the bottom, as a means of reducing sediment entering the intake. The treatment plant filters out particulates by coagulation and flocculation with chemicals, followed by pressurized (rapid) sand filtration. Carlton owns 17 acres of their nearly 2100 acre DWSA; the City's triangular parcel includes the reservoir and intake and a small section of forestland directly south of the reservoir. The remainder is a checkerboard of Bureau of Land Management (BLM) land and private industrial forestland (approximately 50% each). The BLM land is currently managed under NWFP. The private industrial landowners have clearcut most of their forestland in the watershed since 2000; some small harvests occurred in the1970's, 80's, and early 90's. The Panther Creek intake is the sole year-round water source; Carlton does not have an emergency or backup source.

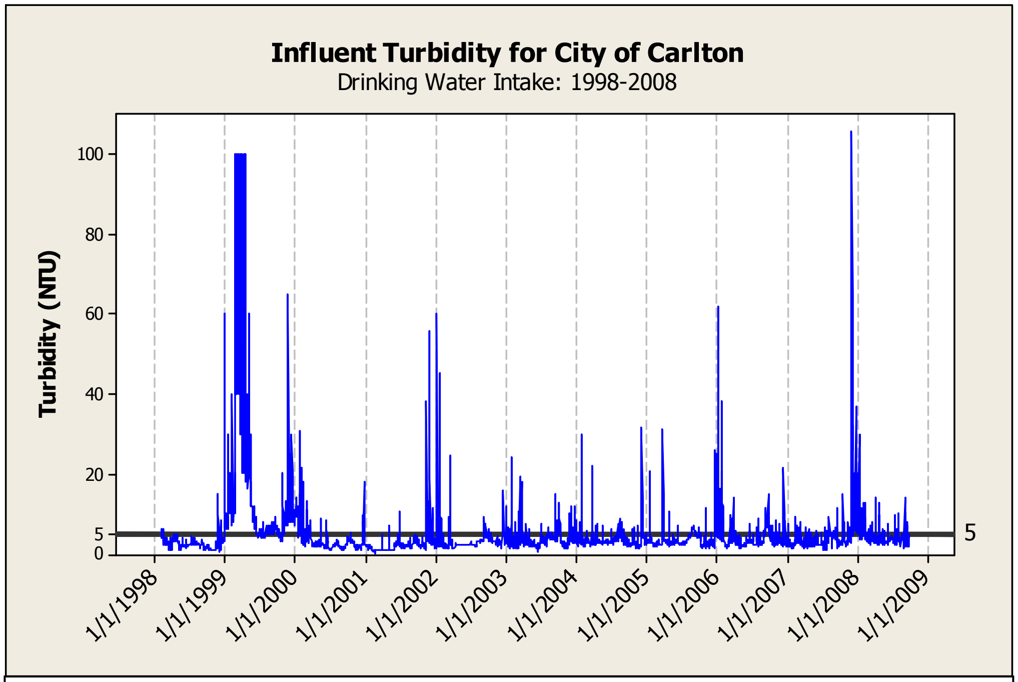


Figure 4a: Carlton DWSA intake turbidity levels from February 1998 through September 2008. In 1999, a debris flow occurred in a tributary 600ft upstream of the reservoir. Turbidity returned to 1998 levels by 2001. More recently, spikes in turbidity increased.

Turbidity data collected by the Carlton PWS at their intake from February 1998 through September 2008 was used (Figure 4a). In February 1999, a debris flow occurred on BLM land several hundred meters upstream of Carlton's reservoir. Turbidity levels in 1999 and 2000 were higher than in 1998 and returned to 1998 levels by 2001, although this decrease may be due to the change to a floating intake. In the last five years, baseline turbidity is rising and the frequency and magnitude of spikes is increasing. The seasonal weather patterns appear to have been consistent (Figure 4b) and indicate that other factors may be contributing to the turbidity trends. The debris flow created a short-term impact to the water system that was resolved within two years. The event was of a great enough magnitude that the PWS's turbidity trend appears to be declining when the debris flow is included in the trend analysis (Figure 4c). However, trend analysis of the post-recovery data (2001-2008) demonstrates that either turbidity in the DWSA is becoming steadily worse since 2001 or the sediment deposited by the debris flow is moving deeper into the reservoir and being pulled into the intake (Figure 4d).

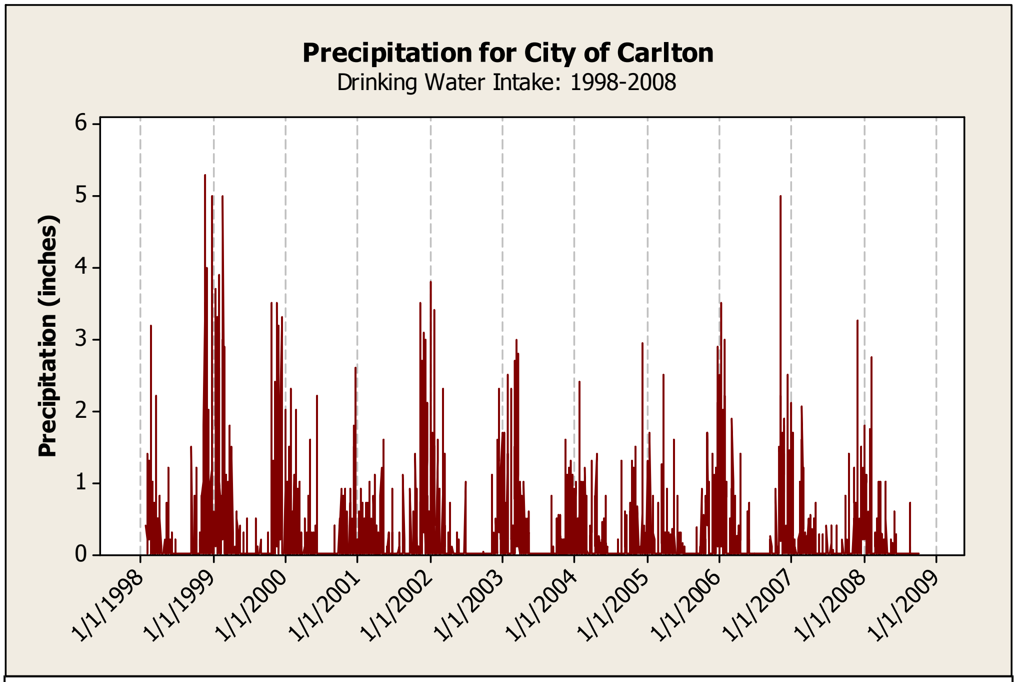
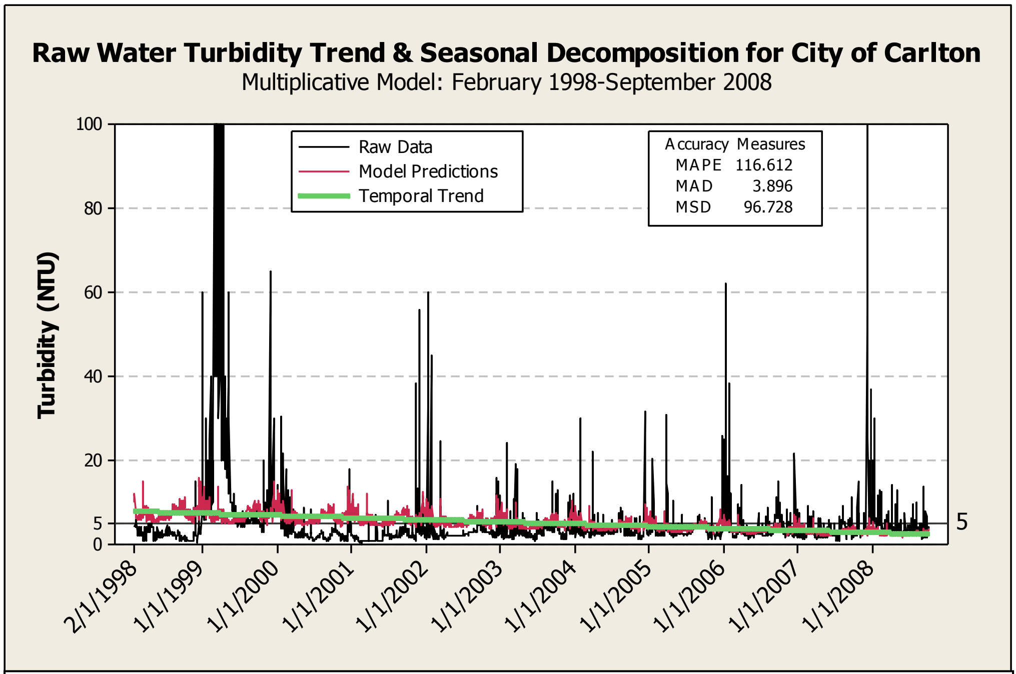


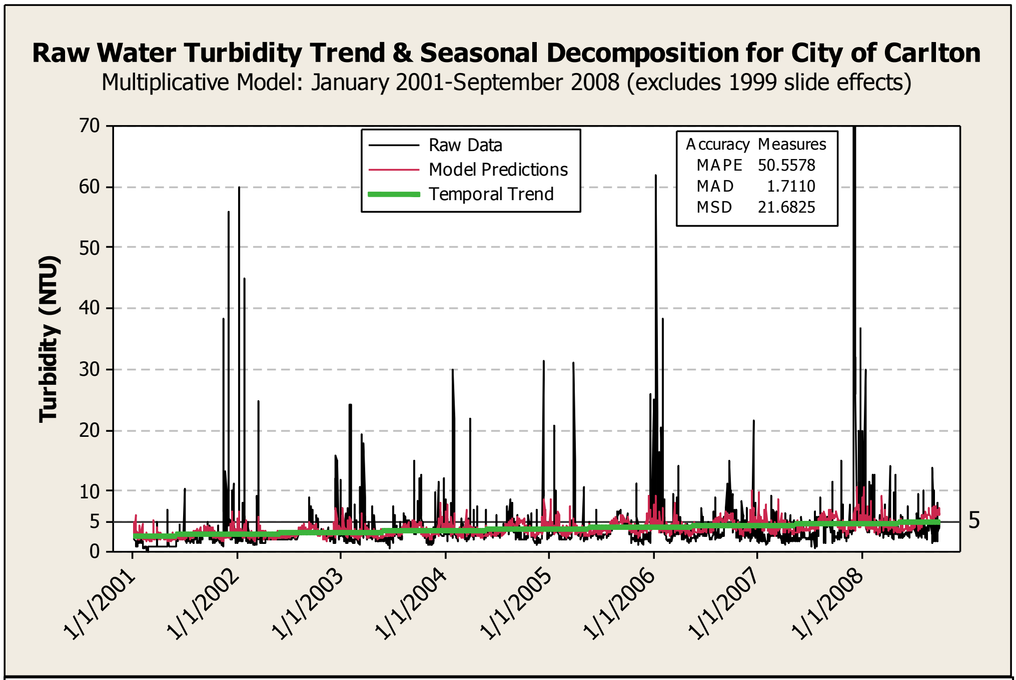
Figure 4b: Precipitation at Carlton's water treatment facility. The seasonal pattern of precipitation drives the seasonal pattern in turbidity. Many of the changes in turbidity appear seasonal and weather-driven, but other factors are also suspected.

As stated above, days with turbidity ≥5 NTU were characterized as "high turbidity days" because at this level the PWS risks clogging its sand filter unless it has a means to pre-treat the raw water. Carlton's DWSA reached its maximum of 271 high turbidity days in 1999 before returning to a low of 13 days in 2001. Since then, the maximum number of high turbidity days has increased gradually to 98 days in Water Year 2008, the maximum since stabilization of the tributary landslide (Figure 4e). Analysis of the trend in high turbidity days shows a linear increase in high turbidity episodes over the last eight years (Figure 4f). Carlton has advanced filtration systems and is usually able to purify water adequately. The PWS supervisor reported that during the winter of 2007-08 a silt bar formed where Panther Creek flows into the reservoir. In addition, reservoir storage is being lost due to sediment settling out in the reservoir (Figure 4g). Carlton plans to dredge the reservoir to restore lost capacity and prevent future problems.


Raw Water Turbidity Trend & Seasonal Decomposition for City of Carlton

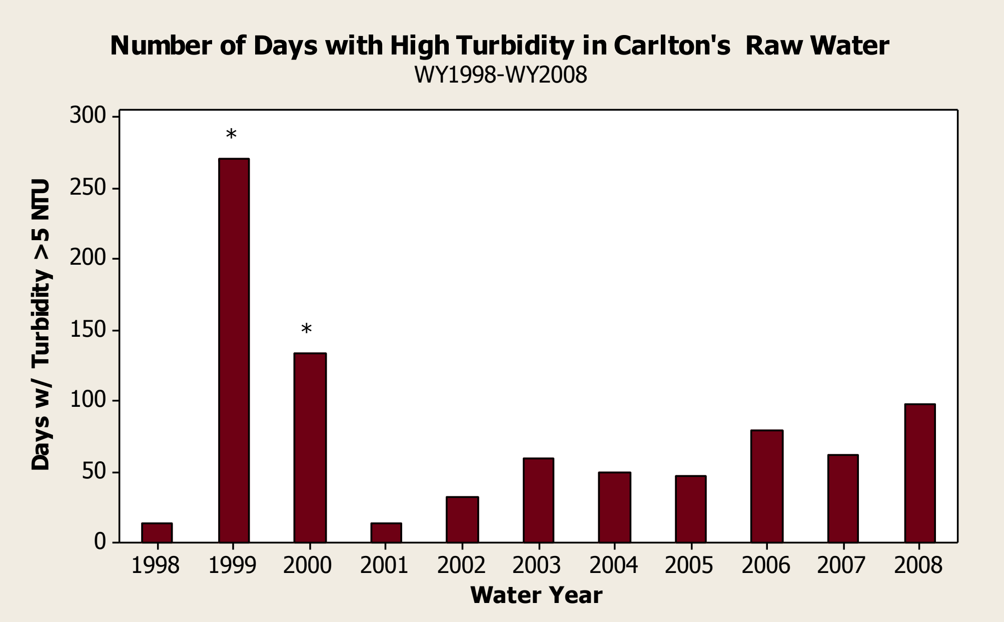
Multiplicative Model: February 1998-September 2008

Figure 4c: The trend decreases over time (Y_t=7.88-0.00139*t). The linear shape of the trend fails to capture the true trend of the data, which has a curved (quadratic) shape. The accuracy measures are relatively high (MAD of 3.896 NTU), showing that the fit of the trend is somewhat poor.


Raw Water Turbidity Trend & Seasonal Decomposition for City of Carlton

Multiplicative Model: January 2001-September 2008 (excludes 1999 slide effects)

Figure 4d: Turbidity levels in 2001 are similar to those in 1998 and subsequently show an increasing trend of turbidity levels (Y_t=2.62+0.000796*t). The lower values of the accuracy measures (MAD of 1.711 NTU) reflect a better fitting trend than in Figure 2c.



** 1999 & 2000 show effects of landslide near intake*

Figure 4e: Number of high turbidity days (≥5NTU) per water year at Carlton's drinking water intake. The water year runs from October 1st through September 30th.

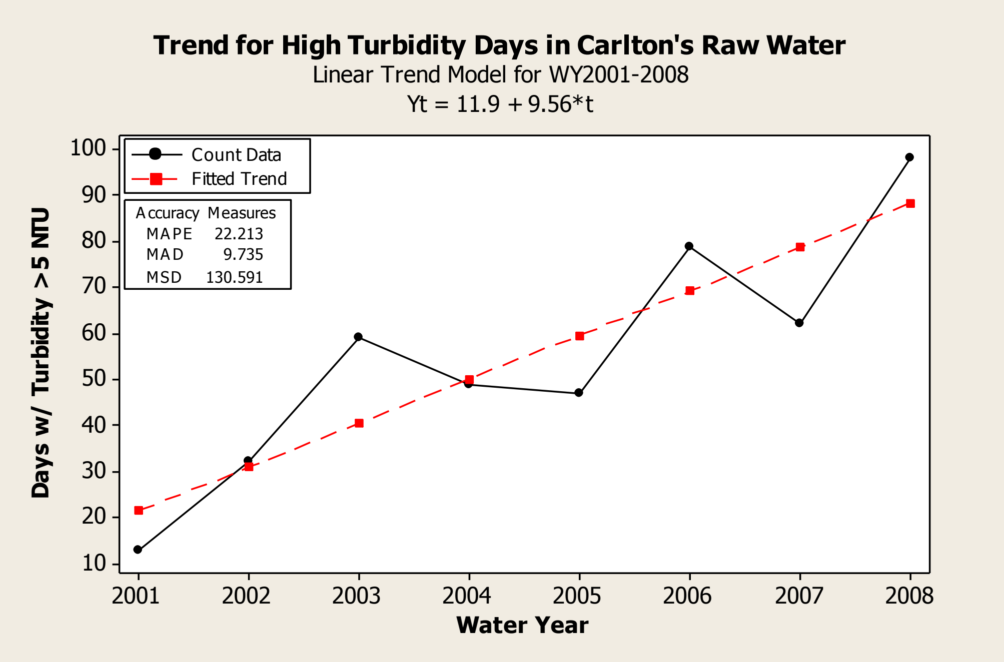


Figure 4f: Trend in number of high turbidity days in Carlton's DWSA for 2001 through 2008.

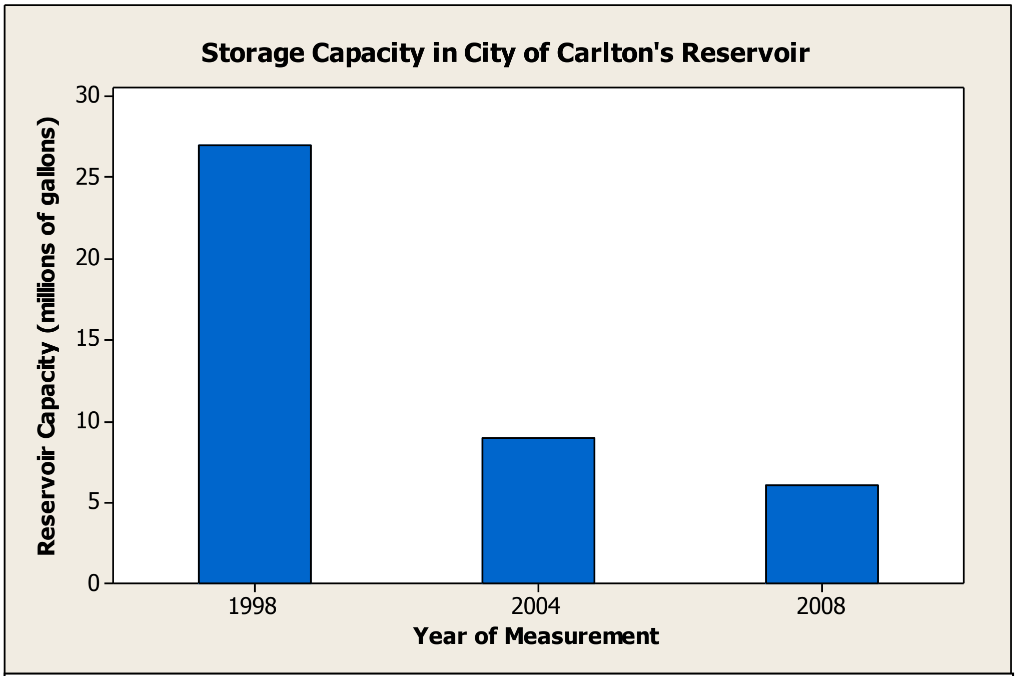


Figure 4g: Storage capacity of Carlton's reservoir from soundings done in 1998, 2004, and 2008. The decrease in capacity is thought to be due to a landslide that occurred in 1999.

City of Falls City (PWS# 4100297)

PWS # 4100297
Don Poe
Public Works Supervisor
503-787-1305

Stable Trend: Low Turbidity (Occasional Spikes)

The City of Falls City is in Polk County near the Coast Range; Falls City's treatment facility uses slow sand filtration for removal of particulates. They cease water purification when turbidity goes above 5 NTU, as higher turbidity clogs the filters. Their 3,219 acre combined Drinking Water Source Areas are located on the eastern slopes of the Coast Range. Falls City has two drinking water intakes: one on Glaze Creek and the other on Teal Creek. The intake on Glaze Creek is only ½ mile from the springs, resulting in very low turbidity the majority of the time. The Glaze Creek intake is usually the sole intake in use during late autumn and winter, water from Glaze and Teal Creeks are mixed during spring and early summer, and only Teal Creek is used in the late summer and early autumn when flows are too low on Glaze Creek. The use pattern of the intakes probably keeps influent turbidity low by relying on Glaze Creek during the early rainy season when high turbidity events are most common (*personal communication* w/ PWS staff). Ownership of the Glaze Creek DWSA (648 acres) is split between a private industrial (PI) company and the Bureau of Land Management with each owning about half of the drainage. The Teal Creek DWSA (2571 acres) is ~90% owned by the PI company. The BLM owns ~ 10% of the drainage with an unidentified private non-industrial landowner owning ~50 acres near the intake. Falls City does not own any of the land in their DWSAs. Private landowners logged half of the Teal Creek DWSA and about 15% of the Glaze Creek DWSA in the last ten years. Water quality in the watershed is historically very good.

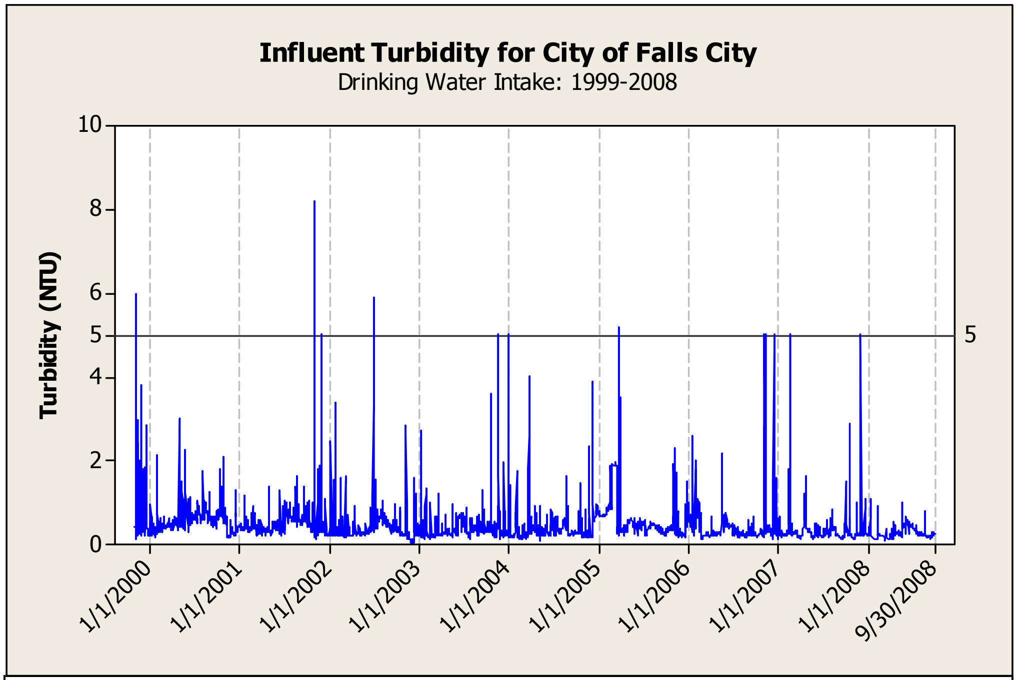


Figure 5a: Falls City's influent turbidity levels from November 1999 through September 2008. Water from Falls City's DWSAs generally has low baseline turbidity with infrequent spikes.

Turbidity data collected daily at approximately 8am by the Falls City PWS from November 1999 through September 2008 was used (Figure 5a). [Falls City must shutdown their intake for 1 to 3 days during storm-triggered turbidity spikes greater than 5 NTU. Data were censored (>5 NTU but of indeterminate value) on days of treatment plant shutdowns due to high turbidity. These data are counted as 5 NTU in the analyses, but the values are likely to be higher.] The collected data represent the source water being used at the time, so they cannot characterize Teal Creek during the winter or Glaze Creek during the late summer, for example. Teal Creek could have high or low turbidity during the winter, but it cannot be evaluated with this data. The composite influent for Falls City has very low baseline turbidity with few spikes, relative to other PWSs in this report. The seasonal weather pattern had few large storms earlier in the decade (2001-2004; Figure 5b). This appears to have been a calm period relative to 2000 and 2005 onward. Seasonally-adjusted trend analysis of the data (1999-2008) demonstrates that influent turbidity is remaining steady in the time period analyzed (Figure 5c).

As stated above, days with turbidity ≥5 NTU were characterized as "high turbidity days" because at this level the PWS risks clogging its sand filter without the means to pre-treat the raw water. Falls City's influent water reached its maximum of 8 high turbidity days in 2007 (Figure 5d). Three years did not have any high turbidity days at all. Analysis of the trend in high turbidity days shows a slight quadratic increase in high turbidity episodes over the last eight years (Figure 5e). Falls City reports that they currently get spikes in turbidity during moderate-to-heavy rain that requires shutdowns. Nevertheless, Falls City experiences high turbidity days very rarely compared to other Coast Range PWSs examined in this report, so the physical significance of this trend may be minimal. If this trend continues, it would be cause for concern.

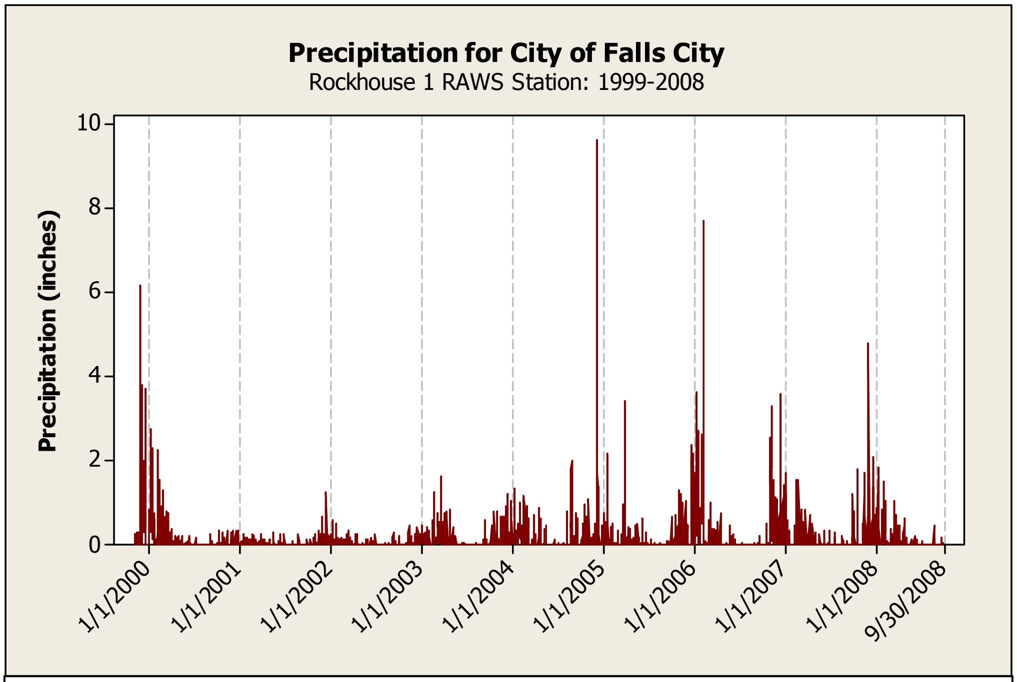


Figure 5b: Precipitation at the Rockhouse1 RAWS weather station, the nearest weather data to Falls City's DWSAs. The seasonal pattern of precipitation drives the seasonal pattern in turbidity.

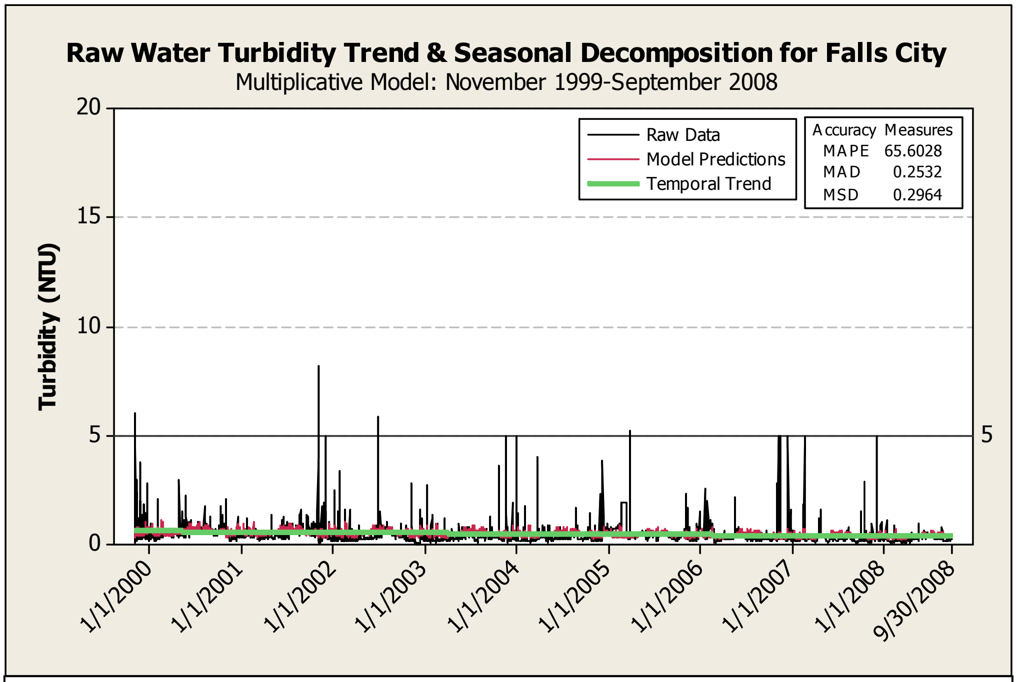


Figure 5c: The trend remains relatively steady over time (Y_t=0.62-0.000076*t). Censored data from treatment plant shutdowns due to high turbidity (in 2003, 2006, and 2007) are entered as 5 NTU when the values were possibly higher. However, the trend does not change much and remains "stable" even if censored data are assigned higher values (15 NTU, Y_t=0.61-0.000037*t; 50 NTU, Y_t=0.62+0.000093*t).

In November of 2006, Falls City had several days of high turbidity triggered by logging and hauling operations near the springs of Glaze Creek in the midst of heavy rains. Oregon Department of Forestry later determined that there were violations of forest practice rules including wet weather hauling limitations. Shortly after the incident, DEQ acquired minimum, maximum, and mean daily turbidity data for 11/01/2006 through 11/10/2006. We graphed this data with the 8am data used in this analysis of Falls City (Figure 5f). The 8am data is fairly close to the mean, but does not accurately show the extremes, especially the maximum. More systematic data collection that shows the range of daily turbidity is probably needed to characterize DWSAs accurately.

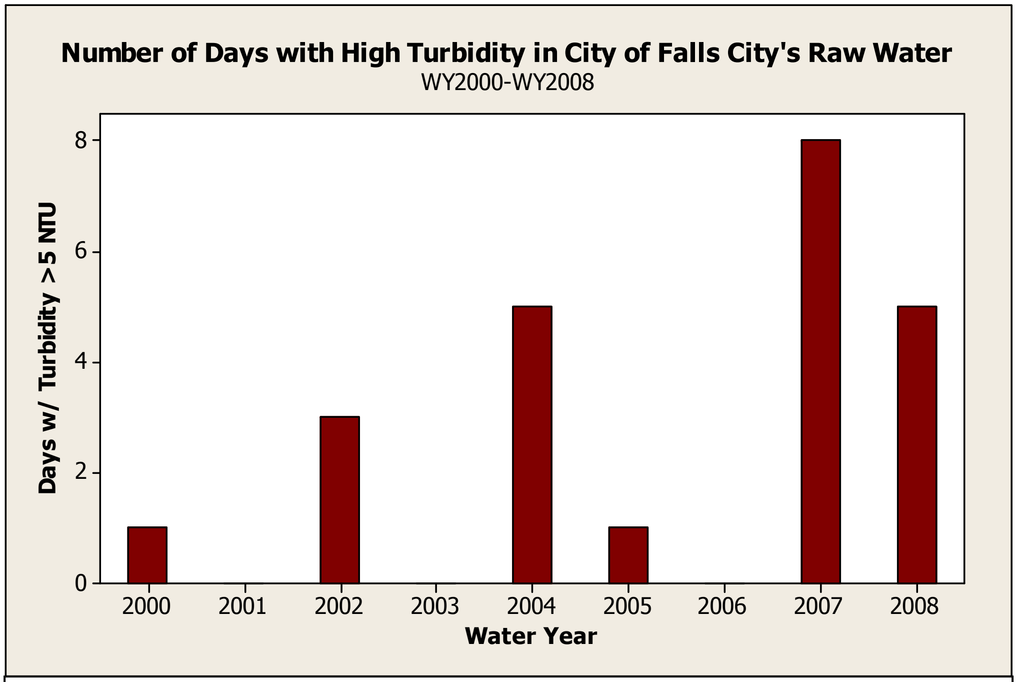


Figure 5d: Number of high turbidity days (≥5NTU) per water year in Falls City's influent drinking water. The water year runs from October 1st through September 30th.

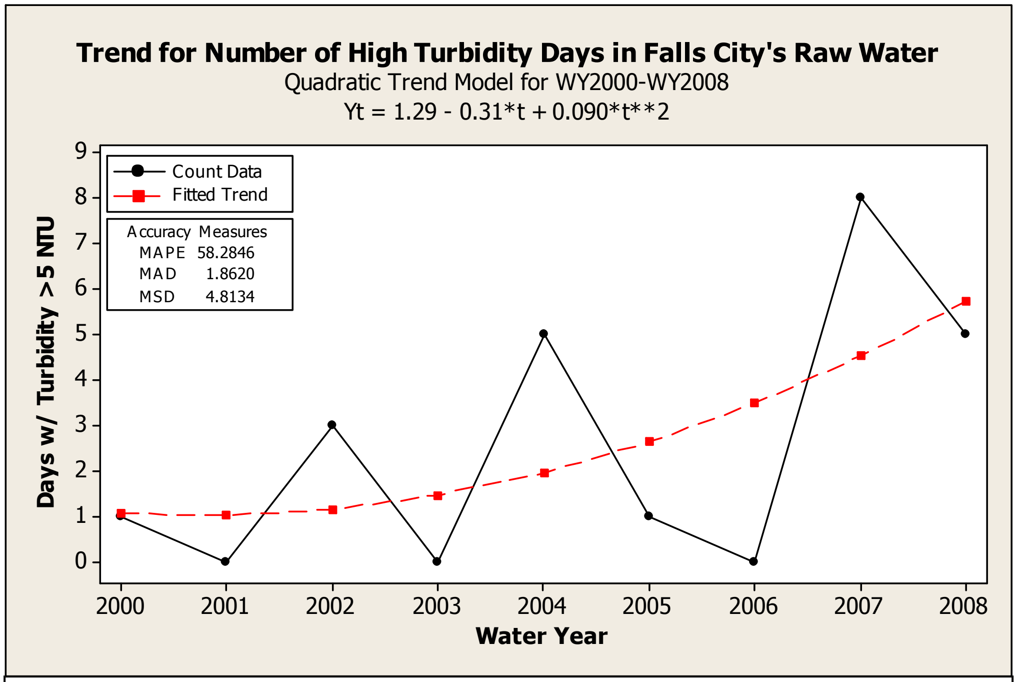


Figure 5e: Trend in number of high turbidity days in Falls City's influent water for 2000 through 2008.

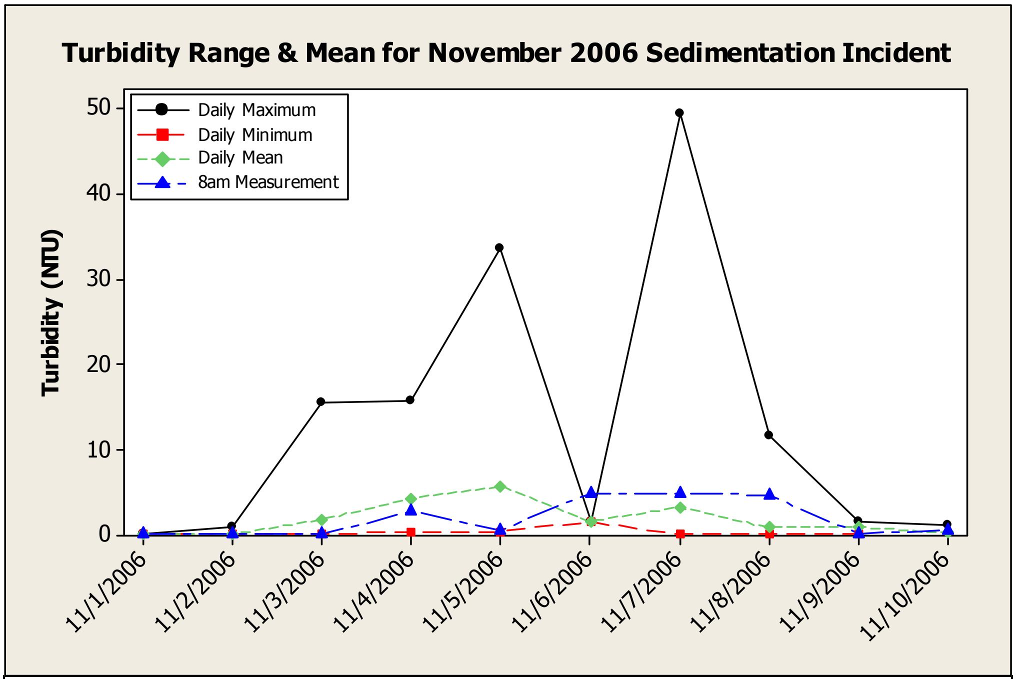


Figure 5f: Comparison of daily means, minima, and maxima with 8am 'snapshot' data during sedimentation incident in November, 2006. 8am data are close to the mean, but inexact. 8am data do not reflect maximum turbidity well.

City of Forest Grove (PWS #4100305)

Randy Smith, Water System Supervisor
503-992-3259

Decreasing Trend: Low Turbidity (Frequent Spikes) trending towards Low Turbidity (Occasional Spikes)
The City of Forest Grove is located to the west of Portland in Washington County. The PWS removes particulates with a sedimentation basin, followed by chemical coagulation and flocculation with rapid sand filtration. They own 4300 acres, most of which is in their small DWSA on the east side of Oregon's north Coast Range. Forest Grove's ownership is ~75% of the DWSA; the balance is ~7% state forest, ~7% private industrial (various owners), and ~10% private non-industrial. The streams in the DWSA are Clear Creek, Deep Creek, Roaring Creek, Smith Creek, and Thomas Creek, all upper tributaries of the Tualatin River. These watersheds are used most of the year; however, Forest Grove gets water from the Joint Water Commission (JWC, Hillsboro, Beaverton, and other municipalities) in summer if stream levels get too low to keep the intake at an adequate depth or in November and December if flushing of sediment from the stream system forces a shutdown of drinking water treatment. In 2000, the City Council approved a Forest Stewardship Council (FSC)-certified management plan. Trout Mountain Forestry manages the watershed sustainably on the City's behalf.

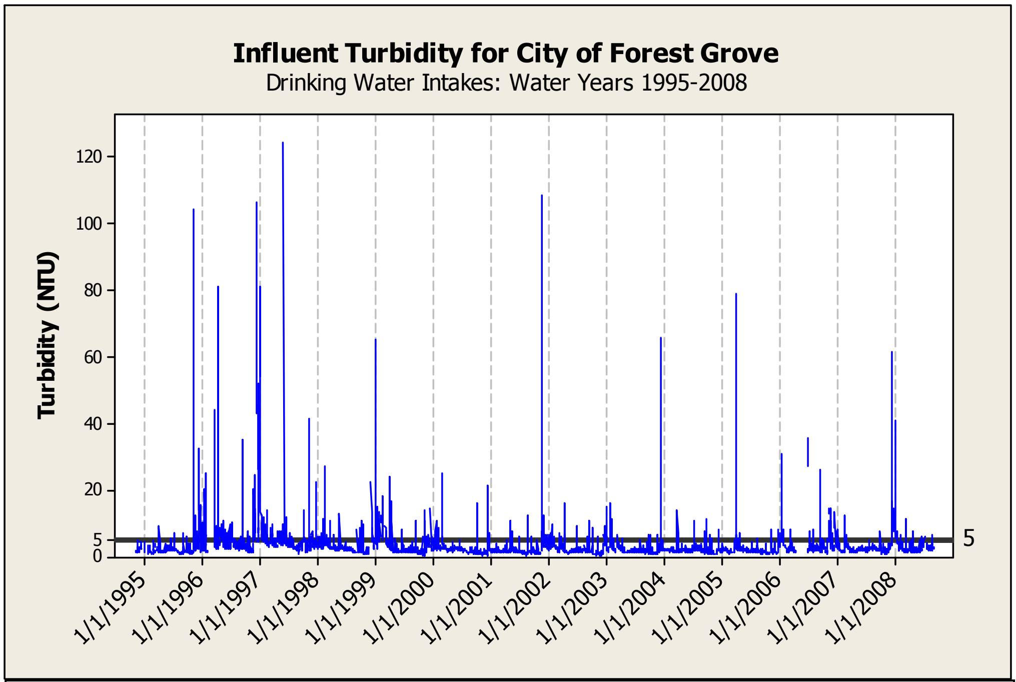


Figure 6a: Turbidity for the Forest Grove DWSA intake from November 1994 through September 2008. Note that while the seasonal patterns remained, the baseline turbidity declined, and the frequency and intensity of spikes decreased.

Turbidity data collected by the Forest Grove PWS at their intake from November 1994 through September 2008 was evaluated. There is a decreasing trend in turbidity (Figure 6a). The turbidity patterns are unlikely to be explained by weather, as the seasonal weather patterns appear to be consistent (Figure 6b). Trend analysis of the turbidity data shows the declining turbidity in the system since the mid-1990's (Figure 6c). In particular, 1996 and 1997 showed a great many large spikes in turbidity before and after the February 1996 storms. With time, the Creeks flushed out the additional fine sediment.

Days with turbidity ≥5 NTU can adversely affect the treatment of water for the Forest Grove PWSs. The number of high turbidity days for Forest Grove's DWSA reached a maximum of 103 days in 1997. The number of high turbidity days has stayed low during the last eight years (Figure 6d). Trend analysis shows the initial rapid decrease in high turbidity days is leveling off (Figure 6e). Their FSC-certified plan has allowed Forest Grove to generate revenue and solve the legacy problems from previous activity, including removal of risky/unnecessary roads and culverts, revegetation, and geoengineering. Highly erosive or steep areas are not harvested. Riparian protection zones are 75 to 200 feet wide with the following requirements:

- Timber removal is prohibited within riparian protection zones, except for restoration activities (no commercial harvest is allowed). Practices promote older forest structure and diversity.
- Skid trails or roads in riparian areas are retired or relocated wherever possible.
- Equipment operation in riparian areas is prohibited, except for restoration activities.
- Restoration activities within riparian areas use methods with the lightest possible impacts.

(Forest Grove Watershed Plan, Chapter 4).

The current turbidity and fine sediment situation is easily managed by PWS staff because of the generally low turbidity, the identification of problem sources by their forester, and their ability to switch to JWC water when necessary. In 2001, Forest Grove received a League of Oregon Cities award for their efforts.

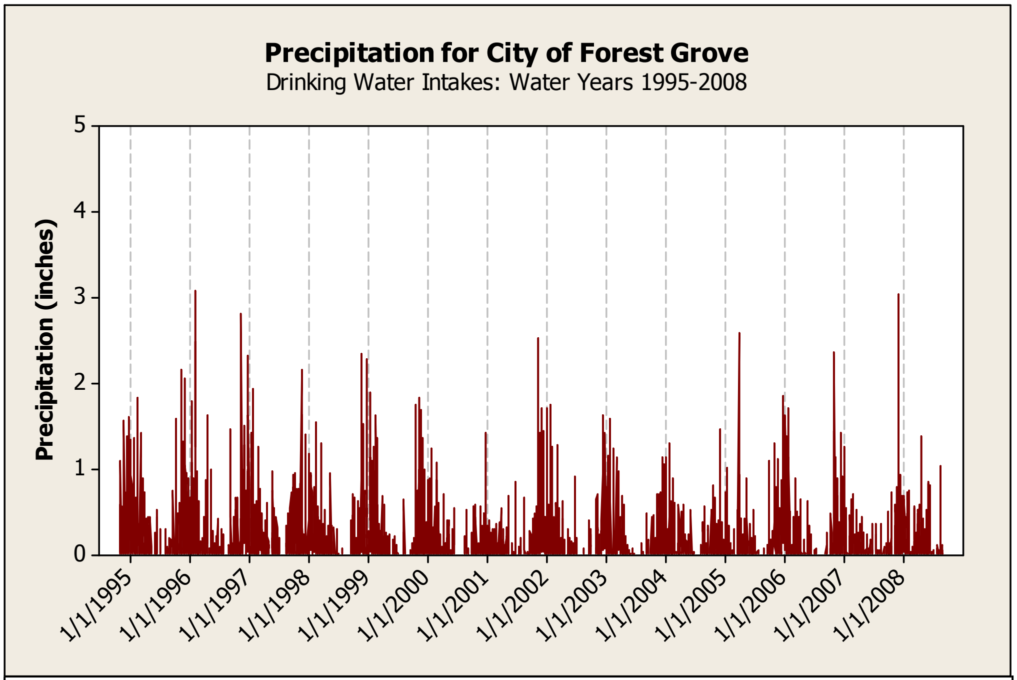


Figure 6b: Precipitation in Forest Grove's DWSA. The seasonal pattern of precipitation drives the seasonal pattern in turbidity.

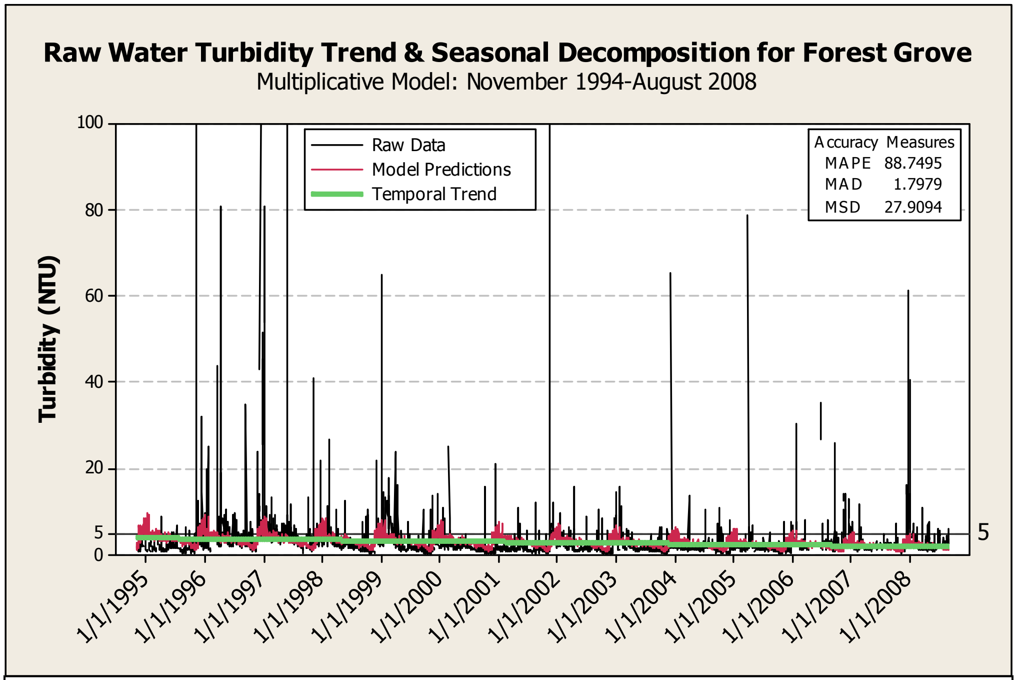


Figure 6c: Turbidity trend for Forest Grove (Y_t=3.97-0.000401*t). The decreases in both baseline turbidity and the frequency of spikes results in a downward linear trend. The trend without the effects of the 1996 flood is similar (Y_t=3.90-0.000482*t; graph of 1997-2008 not shown).

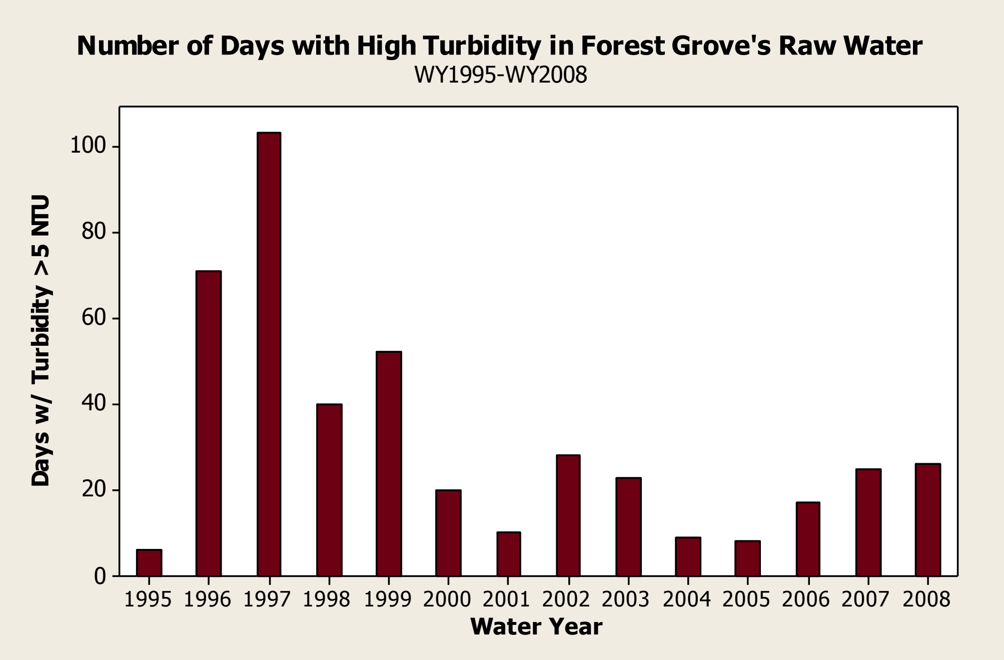


Figure 6d: Number of high turbidity days (>5NTU) per water year in Forest Grove's DWSA as measured at the drinking water intake. The water year runs from October 1st through September 30th.

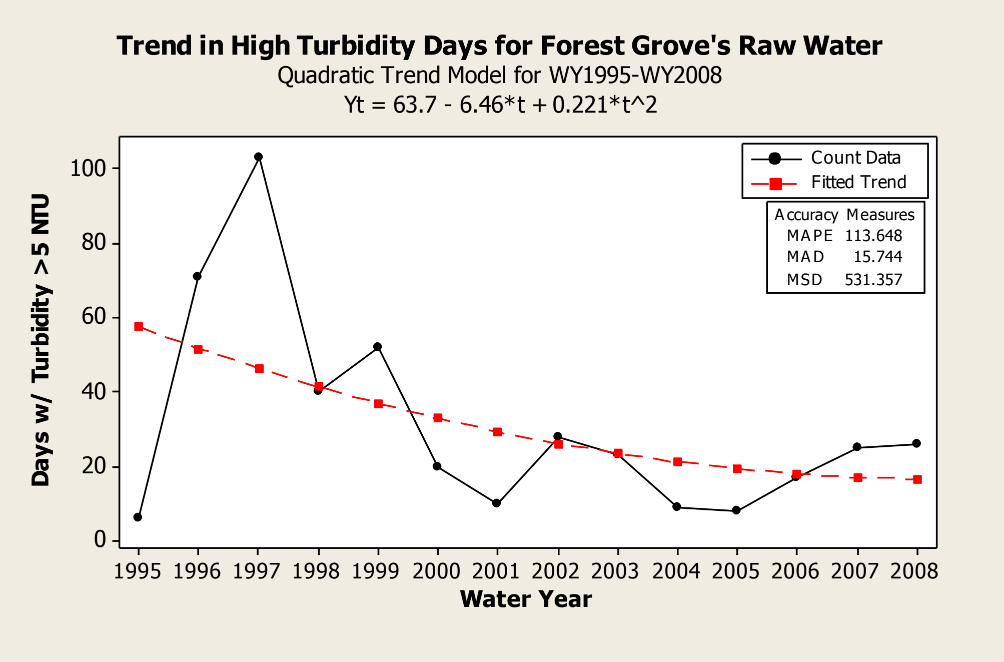


Figure 6e: Trend in number of high turbidity days in Forest Grove's DWSA.

Hillsboro-Cherry Grove (PWS# 4100985)

Niki Iverson
Water Resources Manager
503-615-6770
nikii@ci.hillsboro.or.us

Stable Trend: Low Turbidity (Occasional Spikes)
[Formerly a Decreasing Trend: Transitioned from Low Turbidity (Frequent Spikes) to Low Turbidity (Occasional Spikes)]

The Hillsboro-Cherry Grove Public Water System (PWS) is the sole provider of drinking water to the community of Cherry Grove and the primary provider for the City of Gaston, the community of Dilley, and the LA Water Co-op. (The other provider is the Joint Water Commission, PWS# 4100379.) These communities are west of Portland near the Coast Range. The PWS has two water sources: the upper Tualatin River and Barney Reservoir, on the upper Trask River. Water from Barney Reservoir is piped into the upper reaches of the Tualatin River during drier months (June through October) to supplement the Tualatin's flow. The PWSs Slow Sand Filtration Plant (SSFP), which removes particulates by means of a settling pond (sedimentation) and slow sand filtration, is currently benefitting from low turbidity in the upper Tualatin River, but, as a precaution, the water district shuts the slow-sand plant when turbidity is 5 NTU or greater. The forested Drinking Water Source Area (DWSA) in the upper Tualatin River is over 15,500 acres of mixed public and private ownership. The terrain is landslide prone in the area near the slow-sand water filtration plant. The southeastern corner of the DWSA (near the intake) is a checkerboard of land owned by the PWS (~3% of DWSA) and the Bureau of Land Management (~5%). A small parcel (~1% of DWSA) of private non-industrial timberland straddles the southern edge. A private industrial (PI) company owns the Lee Creek drainage and the headwaters of Sunday Creek, amounting to the eastern edge and the northeastern third of the DWSA (~45% of the DWSA). The remaining (~45%) area of the DWSA is in the Tillamook State Forest, including most of Sunday Creek and nearly all of Maple Creek, in addition to the headwaters of the Tualatin River. Some partial cuts (thinning) occurred on state and federal lands. Since 2000, the major private industrial (PI) landowner has harvested approximately half of their land by clearcutting. The forested DWSA for the intake on Barney Reservoir is 5275 acres of mixed ownership. The PWS owns land surrounding the Reservoir (~8% of the DWSA). The lower (northern) part of the DWSA contains most of the Reservoir; it is in the Tillamook State Forest (~40%). The upper (southern) part is PI forestland (~45%). BLM owns scattered parcels (~7%) around the edges of the Barney DWSA. The Barney Reservoir (North Fork Trask) DWSA experienced

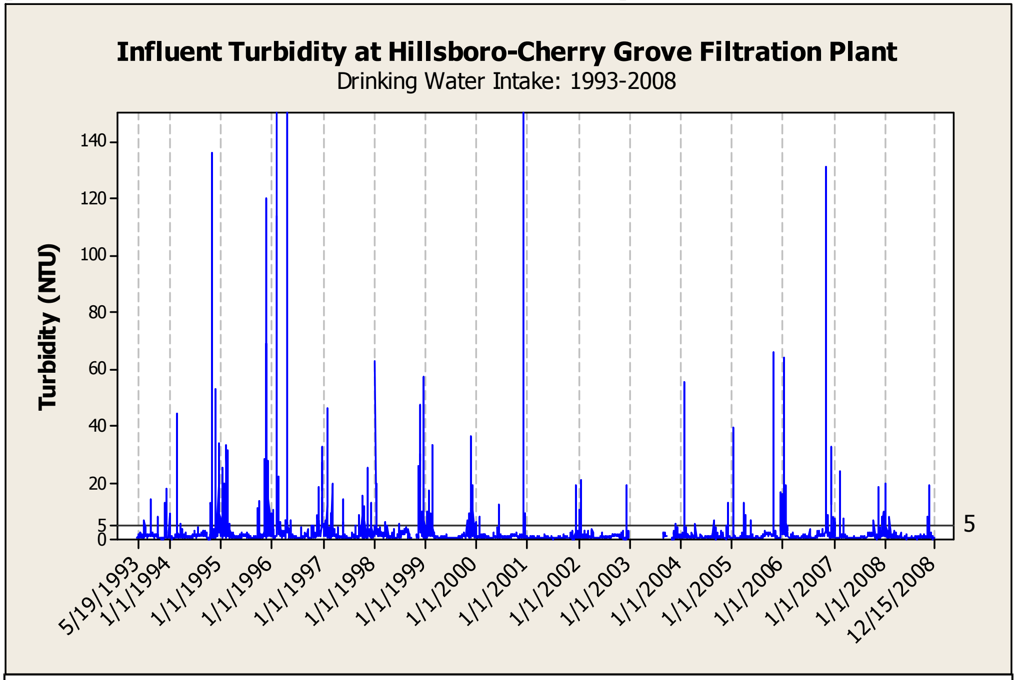


Figure 7a: Turbidity for the Hillsboro-Cherry Grove DWSA intake from May 1993 through December 2008. The frequency and intensity of turbidity spikes decreased during the early part of this decade. Recently, the number and intensity of spikes has increased. Most of the 2003 data is missing.

some scattered clearcuts in the last 10 years on PI land and some partial cuts on State Forest land. Conditions in the upper Tualatin River DWSA probably have the greatest impact on source water turbidity.

Figure 7a shows the improvement in turbidity in the upper Tualatin River watershed. While spikes in turbidity above 5 NTU were common 12 years ago, the watershed recovered from disturbances in the mid-1990's and now has consistently low turbidity. Baseline turbidity has decreased also. Large spikes do occur from time to time, as do periods of high turbidity. These spikes do appear to be triggered by extreme precipitation events at times (Figure 7b), but other factors may contribute to surges in stream turbidity. Seasonally-adjusted trend analysis shows a downward trend in the watershed's turbidity (Figure 7c), although some recent winters had multiple large turbidity spikes that reduce the fit of the trend and may indicate potential problems.

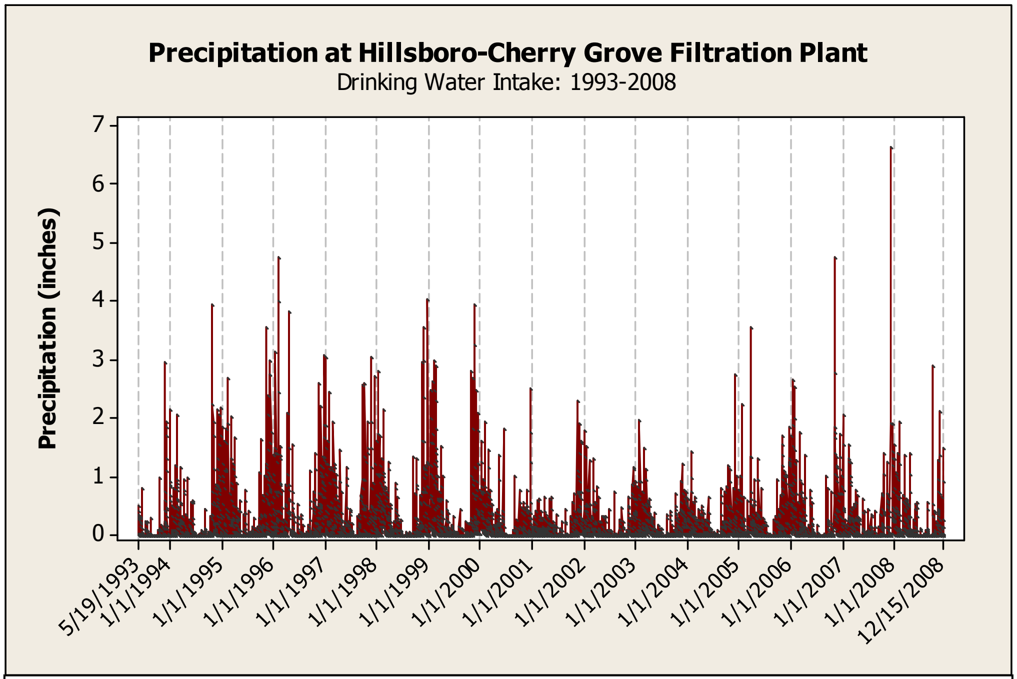


Figure 7b: Precipitation at Hillsboro-Cherry Grove's slow-sand filtration plant. The seasonal pattern of precipitation drives the seasonal pattern in turbidity.

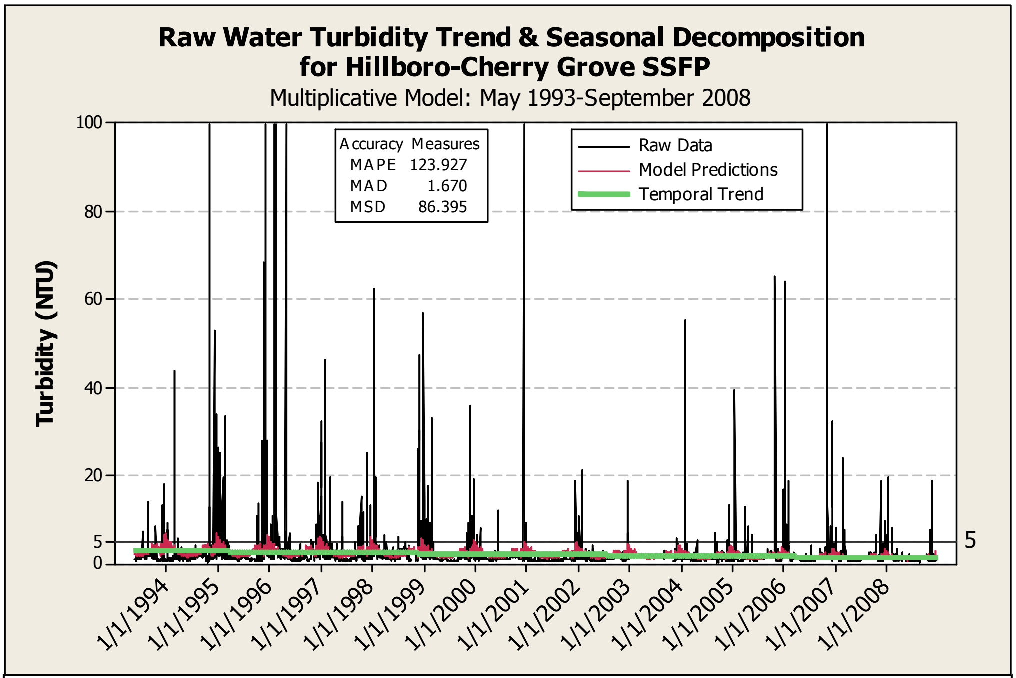


Figure 7c: Turbidity trend for the Hillsboro-Cherry Grove Slow Sand Filtration Plant (Y_t=2.79-0.000297*t). After frequent large spikes in the 1990's, the frequency and intensity of high turbidity events declined. The trend without the effects of the 1996 flood is similar (Y_t=2.33-0.000269*t; graph of 1997-2008 not shown).

The number of high turbidity days (≥ 5NTU) decreased from a high of 47 days during the 1996 water year to a low of 2 days in the 2001 water year (Figure 7d). This shows a healthy recovery from the effects of disturbances before and during the February 1996 floods. Analysis of the trend in high turbidity days shows that the number of days greater than 5 NTU decreased until 2001 when there were only

2 high turbidity days (Figure 7e). Turbidity stayed low before climbing somewhat recently (14, 12, and 10 days in 2006, 2007, and 2008, respectively). It is unknown if the 2006-2008 level represents the typical equilibrium for this watershed, or if the lower turbidity of 2001-2004 is the norm. The result is a curved trend with sharp declines in high turbidity events followed by leveling off. If the trend continues, then the slight upward inflection at the end could become a steady upward climb in stream turbidity. Lee Creek drains into the Tualatin River approximately 1500 meters upstream of the SSFP, so any individual or cumulative timber harvest effects could be felt quickly. The next several years will demonstrate whether land use activities are likely to increase turbidity and negatively impact water quality in the upper Tualatin River watershed.

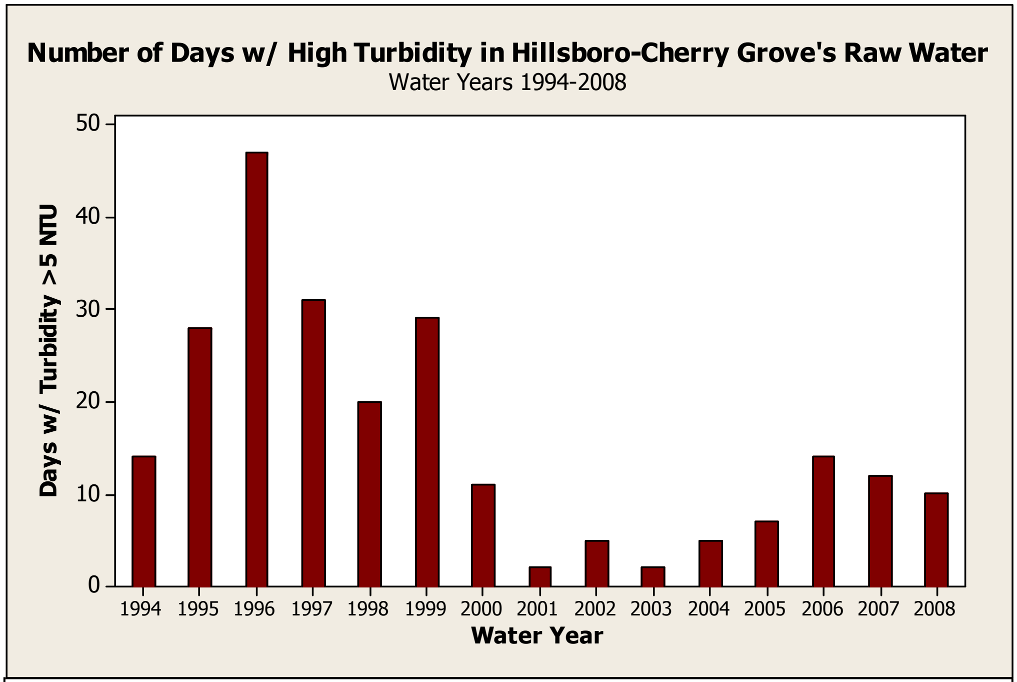


Figure 7d: Number of high turbidity days (≥5NTU) per water year in Hillsboro-Cherry Grove's DWSA as measured at the drinking water intake. The water year runs from October 1st through September 30th.

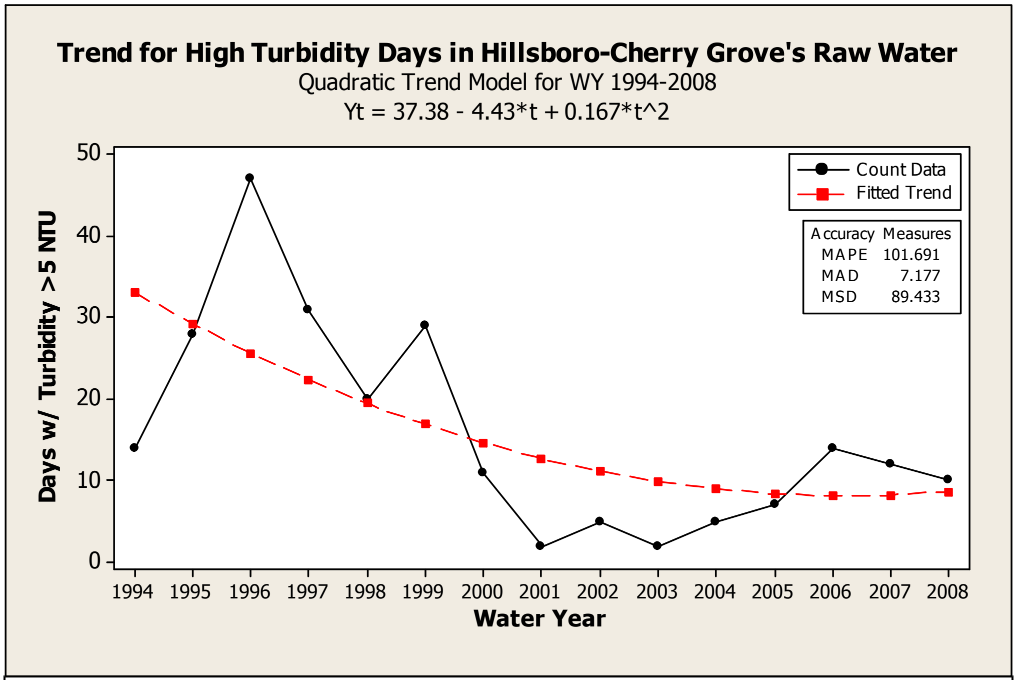


Figure 7e: Trend in number of high turbidity days in Hillsboro-Cherry Grove's DWSA by water year.

City of Siletz (PWS# 4100821)

Allen Middaugh, Superintendent of Public Works
541-444-2521

<u>Increasing Trend: Low Turbidity (Occasional Spikes) transitioned to Low Turbidity (Frequent Spikes)</u>
<u>Baseline Turbidity Increasing</u>

In the western foothills of the middle Coast Range, the City of Siletz is located on the banks of the Siletz River in Lincoln County. The City uses the Siletz River as their year round water source. The PWS accomplishes particulate removal with chemical coagulation and flocculation and rapid sand filtration. The City has a small storage tank for raw water. It does not hold more than a roughly two day supply, so Siletz is planning construction of a water storage pond to provide a backup supply of water when the River's turbidity is too high. Approximately 1/3 of the PWS's finished water is purchased by the Confederated Tribes of Siletz Indians. At 131,540 acres, the Drinking Water Source Area is larger than any other PWS cited in this study. Most of the DWSA is made up of steep terrain with large amounts of rainfall. The majority (~75%) of the DWSA is privately owned by industrial timber companies. Landowners logged some of the Boulder Creek drainage in the 1980's, and, in 1988, Boise Cascade removed the Valsetz Lake dam. Mr. Middaugh (PWS supervisor) reports that the River is flashier now-more prone to sudden rises and falls in turbidity and flow. In the 1990's and 2000's, landowners logged extensively in the Gravel Creek and South Fork Siletz River drainages and along the mainstem Siletz River ("the Gorge"). The Siletz tribe owns scattered portions of the watershed (~2.5% of the DWSA). The low gradient properties along the river (just upstream of the City) are occupied by agricultural and rural residential lands, making up a very small (~7%) but important portion of the DWSA's area. Small landowners along the river in lower part of the DWSA occasionally conduct land disturbing activities, such as the illegal clearing of vegetation and fill operations by a riverfront landowner in September 2008, just a couple of miles upstream of Siletz' intake. Public ownership includes some state land in the south-east corner (~5% of the DWSA) and BLM land in the northern headwaters portion (~10% of the DWSA). BLM did some small scale clearcut logging on their land around the North Fork Siletz River and Boulder Creek in the 1980's. The City of Siletz does not own or manage any of the DWSA.

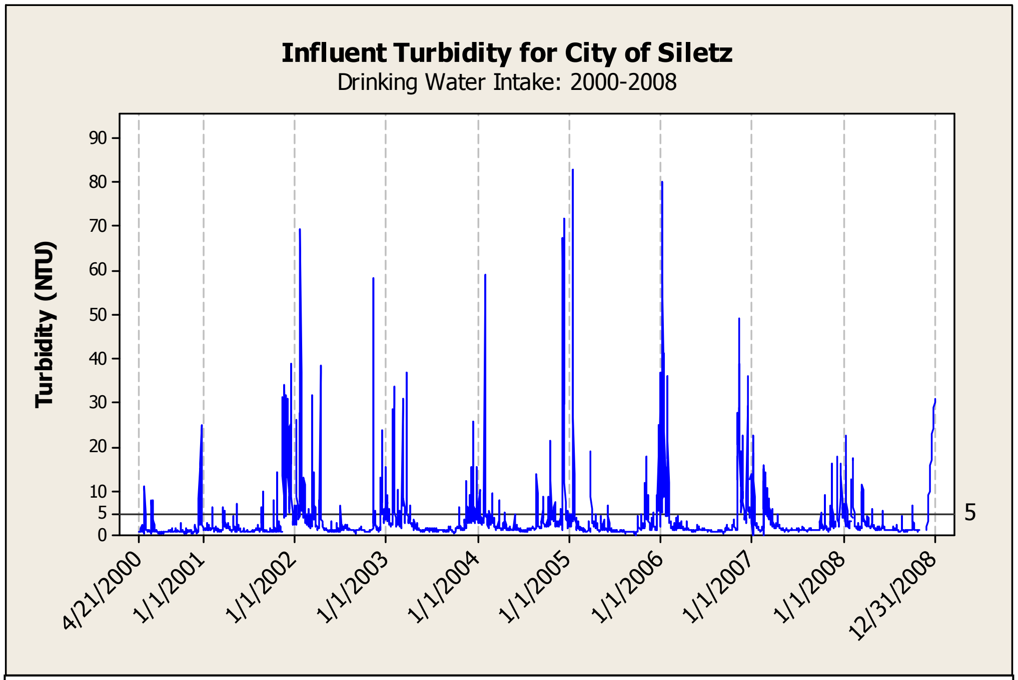


Figure 8a: Influent turbidity for the City of Siletz' drinking water intake on the Siletz from April 2000 through December 2008.

The City of Siletz PWS started monitoring Siletz River turbidity year round in April of 2000, after they built a new water treatment plant and begin using the Siletz River as a water source all year long. From 1967 to 2000, they used Tangerman Creek except in the summer/early autumn. (Prior to that, Logan Creek was the water source. Source changes have been driven by water quality problems.) The years 2000 and 2001 had low turbidity with few large spikes, but in subsequent years, large spikes in turbidity occur frequently before

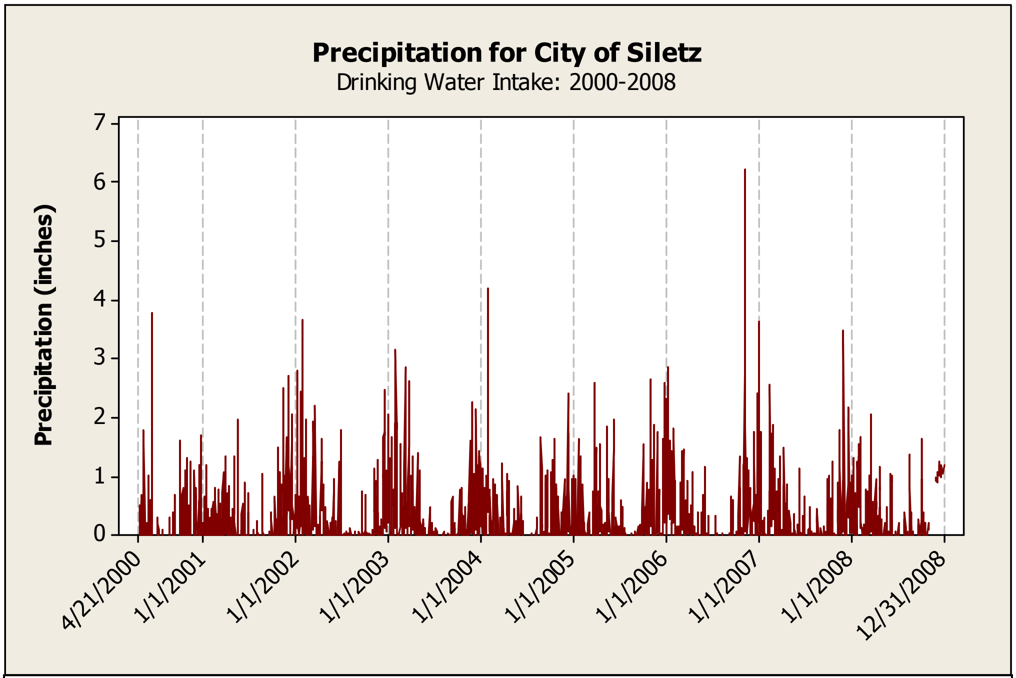


Figure 8b: Precipitation at Siletz' water treatment facility. The seasonal pattern of precipitation drives the seasonal pattern in turbidity.

dropping back to the baseline (Figure 8a). The baseline turbidity itself is higher, especially during the winter rains. Turbidity follows the seasonal precipitation pattern (Figure 8b), but the biggest storms frequently do not coincide with the high turbidity events. The seasonally-adjusted trend analysis demonstrates a gradually increasing trend (Figure 8c); the relatively less turbid 2007/2008 rainy season slightly reduces the slope of the trend.

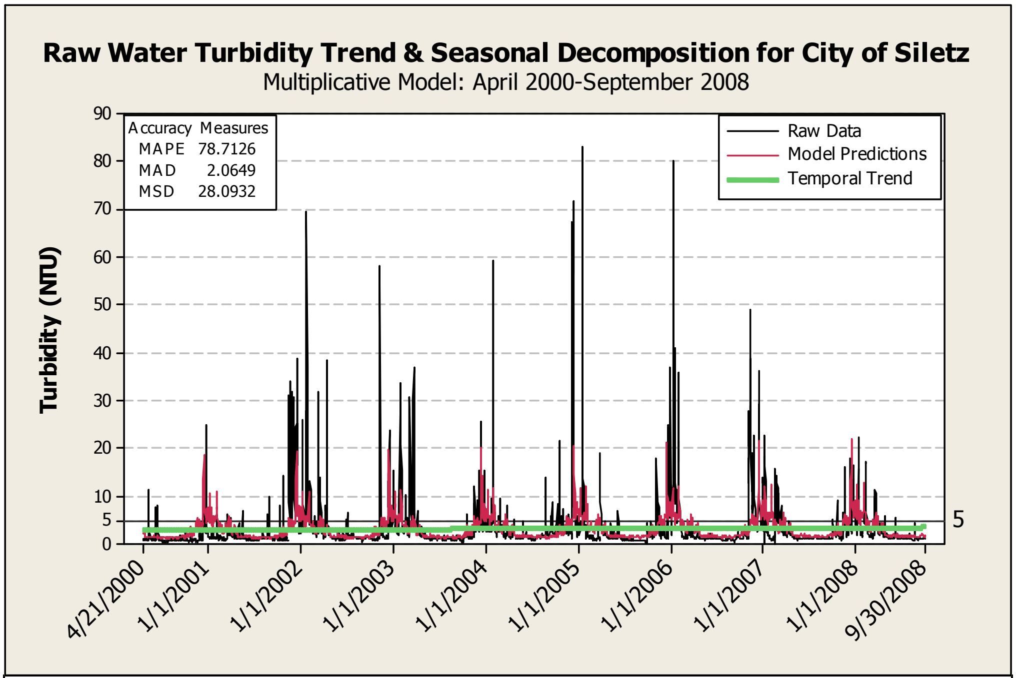


Figure 8c: Turbidity trend for the City of Siletz ($Y_t=2.87+0.000197*t$). The frequency and intensity of high turbidity events increased starting in the autumn of 2001.

The Siletz River experienced few high turbidity (≥5NTU) days in the latter half of the 2000 water year (4 days, April-September) and in the whole 2001 water year (15 days; Figure 8d). In contrast, the following water year (WY2002) had 85 high turbidity days, the highest number since year-round use of the Siletz River began. The number of high turbidity days has not returned to the levels seen in 2001, being 52 days in the 2008 water year. After excluding the incomplete data for WY2000, analysis of the count data show a generally increasing trend in turbidity (Figure 8e). The turbidity varies around a central tendency since 2002. It is possible that WY2000 and WY2001 were anomalously low. Alternately, events since WY2001 may also have created sediment sources, accounting for the elevated turbidity since 2002. Analysis of turbidity and Total Suspended Solids (TSS) data collected by the Siletz Tribe indicates that turbidity is spatially and temporally complex and generally higher farther down in the watershed (Appendix B). Source identification information and turbidity data prior to April 2000 would be useful to better evaluate the trend in the DWSA.

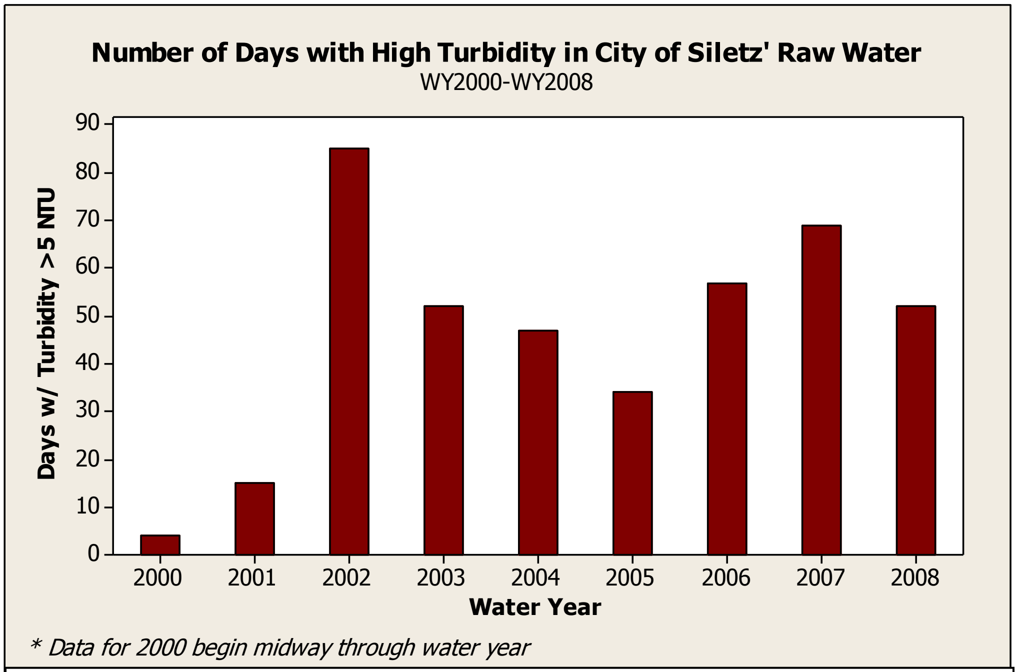


Figure 8d: Number of high turbidity days (≥5NTU) per water year in the Siletz River as measured at the drinking water intake. The water year runs from October 1st through September 30th.

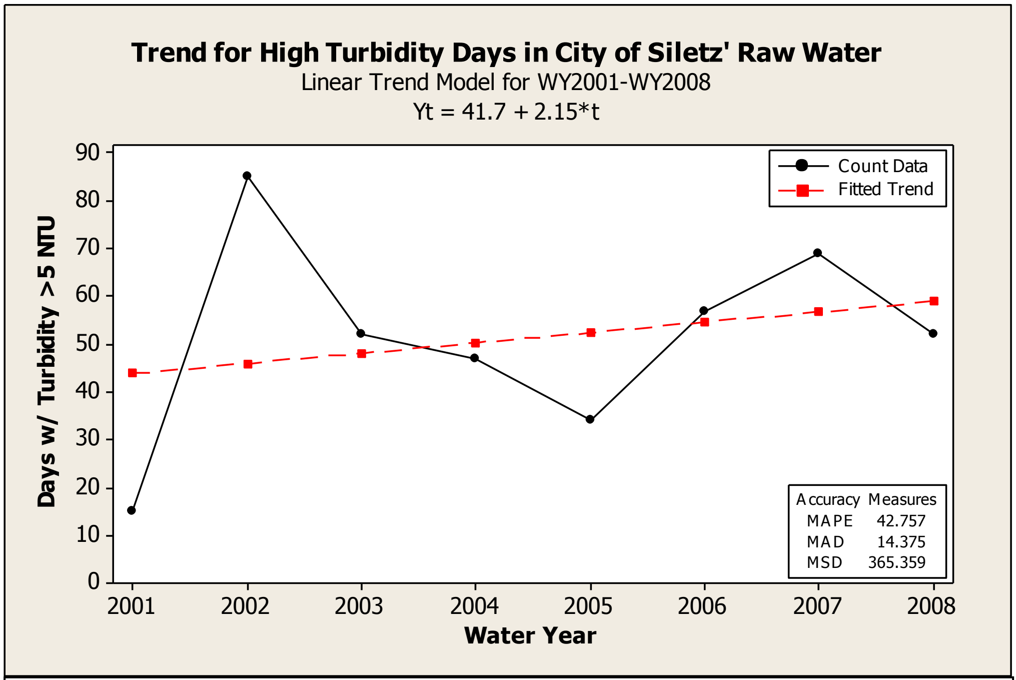


Figure 8e: Trend in number of high turbidity days at Siletz' intake. The linear trend model shows the increase in high turbidity days since 2001.

City of Yamhill (PWS# 4100968)

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Stable/Increasing Trend: Low Turbidity (Frequent Spikes)

The City of Yamhill is in Yamhill County near the foothills of the Coast Range, north of Carlton. Yamhill's PWS removes particulates by settling in their upper reservoir, chemical coagulation and flocculation, and rapid sand filtration. Yamhill's Drinking Water Source Area is 2900 acres of the Turner Creek watershed, a tributary of the North Yamhill River on the eastern slopes of the Coast Range. A small dam forming a pool keeps the intake submerged during lower flow periods. Another structure upstream forms an impoundment to store water to supplement low flows in the late summer and early autumn. The DWSA is mostly rolling hills with steeper slopes in the valleys and occasional steep slopes in the uplands. The watershed ownership is a patchwork pattern of public and private ownership with nearly all the private land harvested within the last ten or fifteen years. Yamhill owns 60 acres of mature forest just upstream of the intake (given to the City by President Calvin Coolidge) and another 10 acres on the south side of their water storage impoundment in the upper reaches of the watershed. BLM owns approximately 27% of the watershed. The remainder is private industrial forestland (70% of the DWSA total). There is a 75 acre parcel near the intake owned by a small woodland owner; the portion of it in the DWSA is roughly 20 acres (<1% of the DWSA).

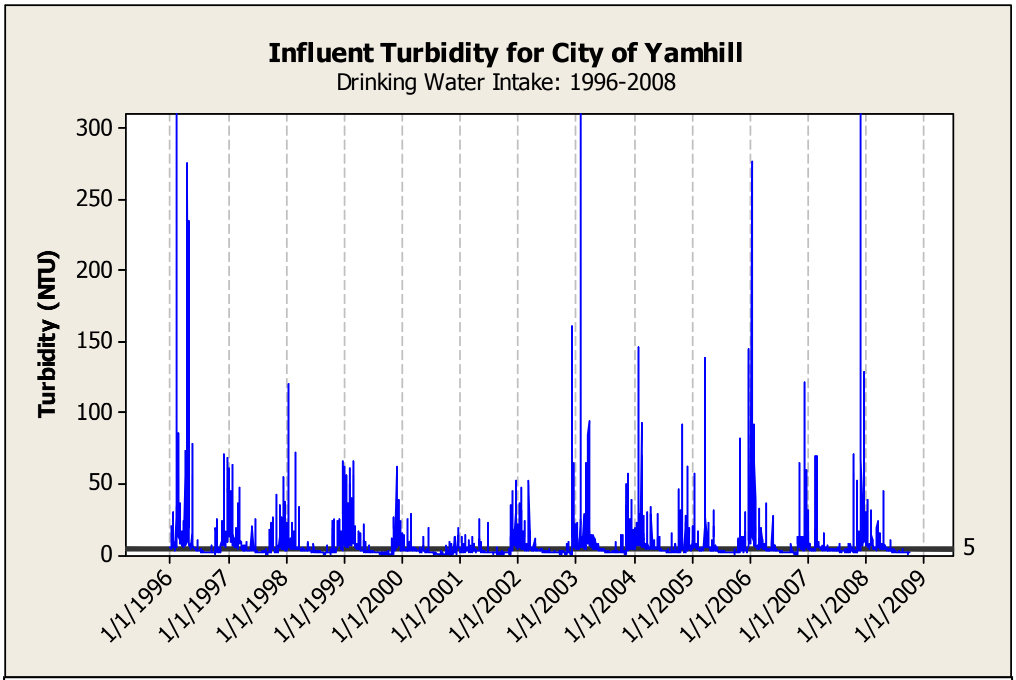

Figure 9a: Turbidity for the Yamhill DWSA intake from January 1996 through September 2008. Note the effect of the 1996 storm followed by relatively low turbidity until 2003. More recently, large turbidity spikes occur with greater frequently.

We graphed and analyzed the turbidity data collected by the Yamhill PWS at their intake from January 1996 through September 2008 (Figure 9a). Following the impacts of the 1996 storm, the turbidity decreased with fewer large spikes and falling baseline turbidity. Turbidity then increases starting in 2003 with frequent large spikes and a baseline that varies around 5 NTU. The large storm that hit the northern Coast Range in December of 2007 washed sediment into Turner Creek and initiated a landslide above the intake, filling the pool behind the dam with fine sediment and gravel. Poor road placement and a blocked culvert contributed to the slide. The intake turbidity data represents stream turbidity after fine sediment settles out in the impoundment and, to a lesser degree, the intake pool. The seasonal weather patterns appear to have been consistent, so storms alone cannot explain the changes in turbidity (Figure 9b). Seasonally-adjusted trend analysis shows a flat, stable trend when 1996 data is included (Figure 9c). Analysis without 1996 data (to account for the extreme and historically rare nature of the 1996 storm and high-flow events) shows an upward linear trend in turbidity (Figure 9d).

High turbidity days (≥5 NTU) are most problematic for PWSs. Yamhill's DWSA reached a maximum of 149 high turbidity days in 2004; the low of 42 days was in 2001. The count of high turbidity days has stayed near 100 days since 2004 and was 113 days in the 2008 water year (Figure 9e). This is much greater than the 2008 count of high turbidity days for Forest Grove and comparable to the current situation in Carlton. Statistical analysis of the trend shows a decline in high turbidity episodes until six years ago, followed by increased episodes in recent years (Figure 9f). Data prior to 1996 would help to evaluate whether the high turbidity events in the late 1990's are due to 1996 flood effects or some other processes in the DWSA. The intake will eventually need to be moved to a more stable location and designed in a way that allows adequate fish passage. Yamhill needs to dredge the intake pool and the impoundment in the upper watershed to restore lost storage capacity.

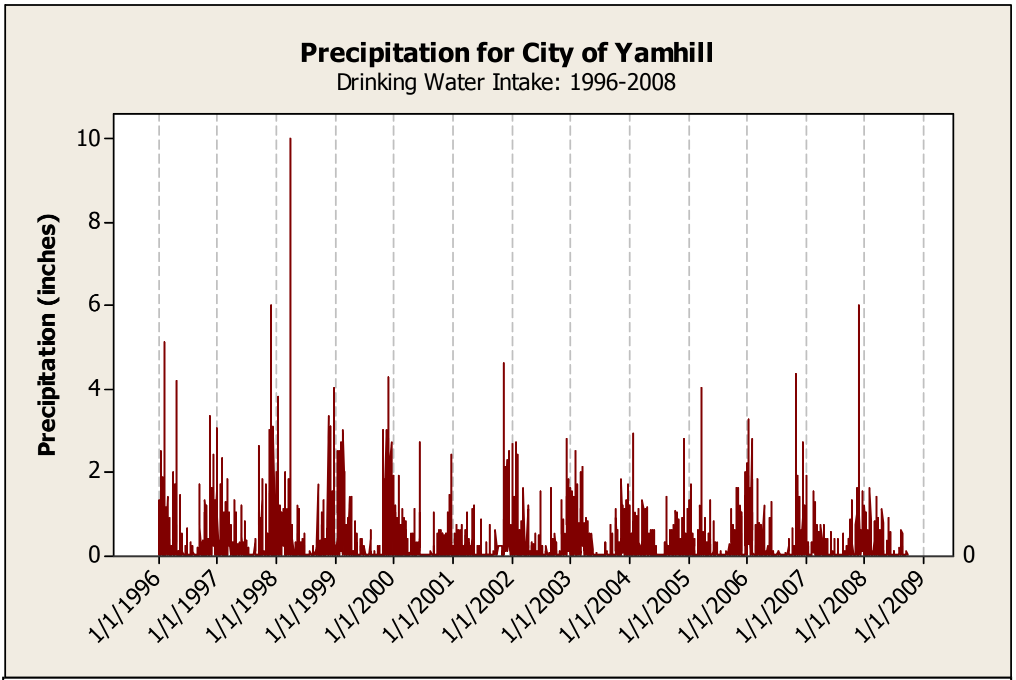

Figure 9b: Precipitation at Yamhill's water treatment facility. The seasonal pattern of precipitation drives the seasonal pattern in turbidity. Analysis shows that many of the changes in turbidity are seasonal and weather-driven, but other factors are also at work.

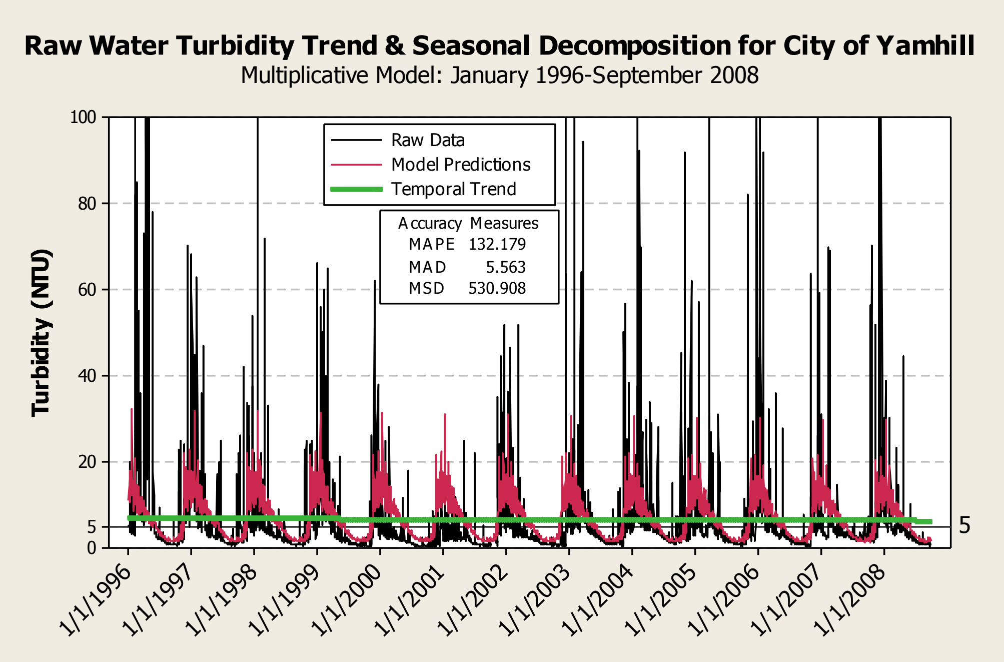

Figure 9c: Turbidity trend for the City of Yamhill for 1996-2008 (Y_t=6.88-0.000122*t). The frequency and intensity of high turbidity events decreased through 2001 and increased thereafter.

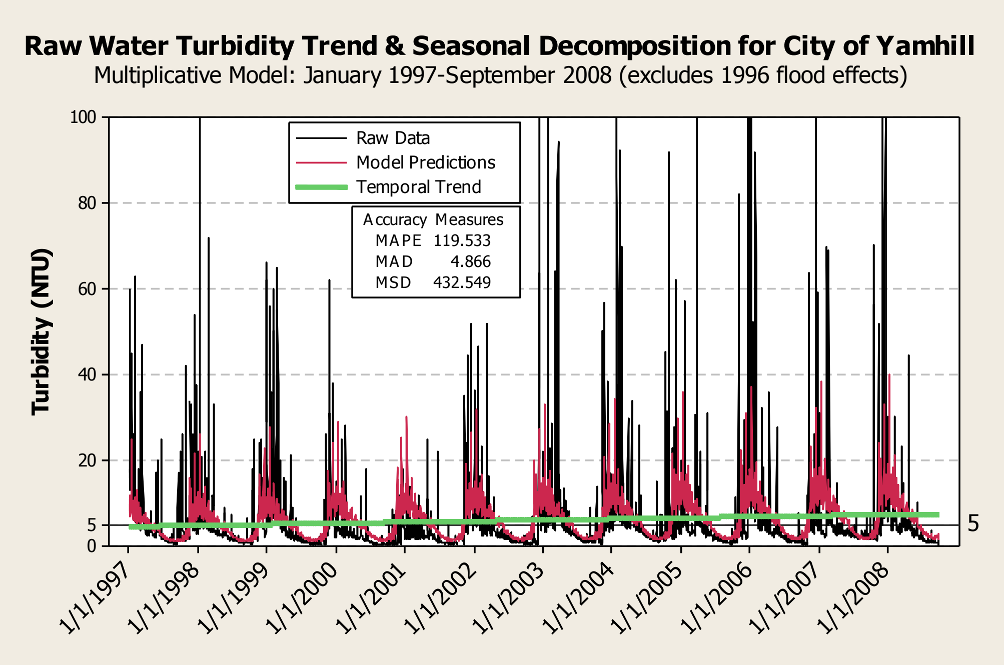

Figure 9d: Turbidity trend for the City of Yamhill for 1997-2008 (Y_t=4.58+0.000688*t). Removal of 1996 alters the trend noticeably.

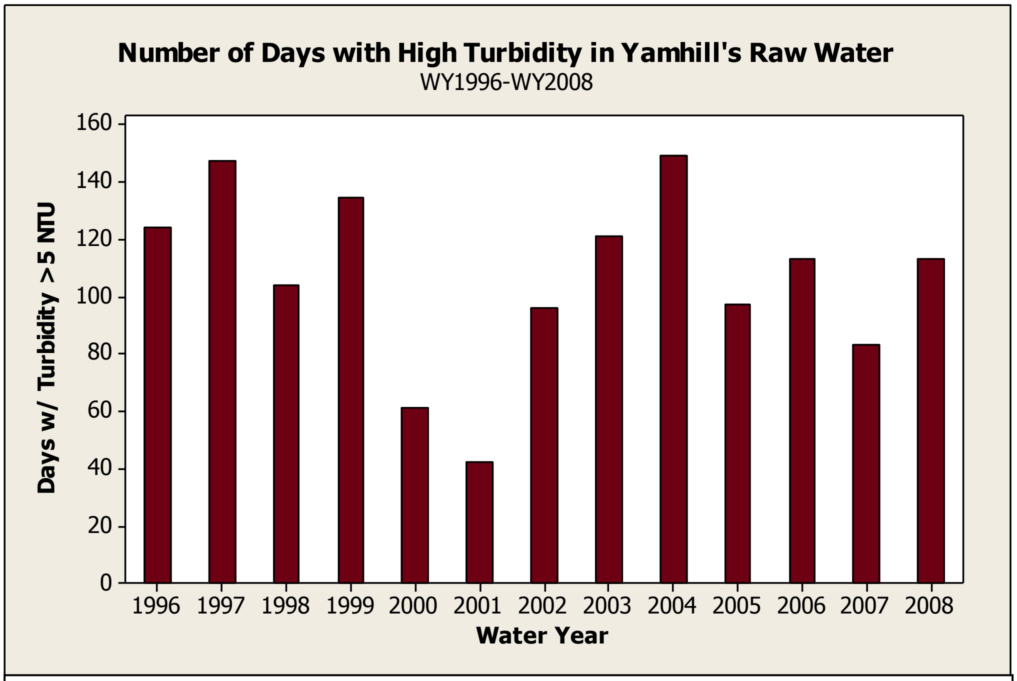

Figure 9e: Count of high turbidity days (≥5NTU) per water year in Yamhill's DWSA as measured at the drinking water intake. The water year runs from October 1st through September 30th.

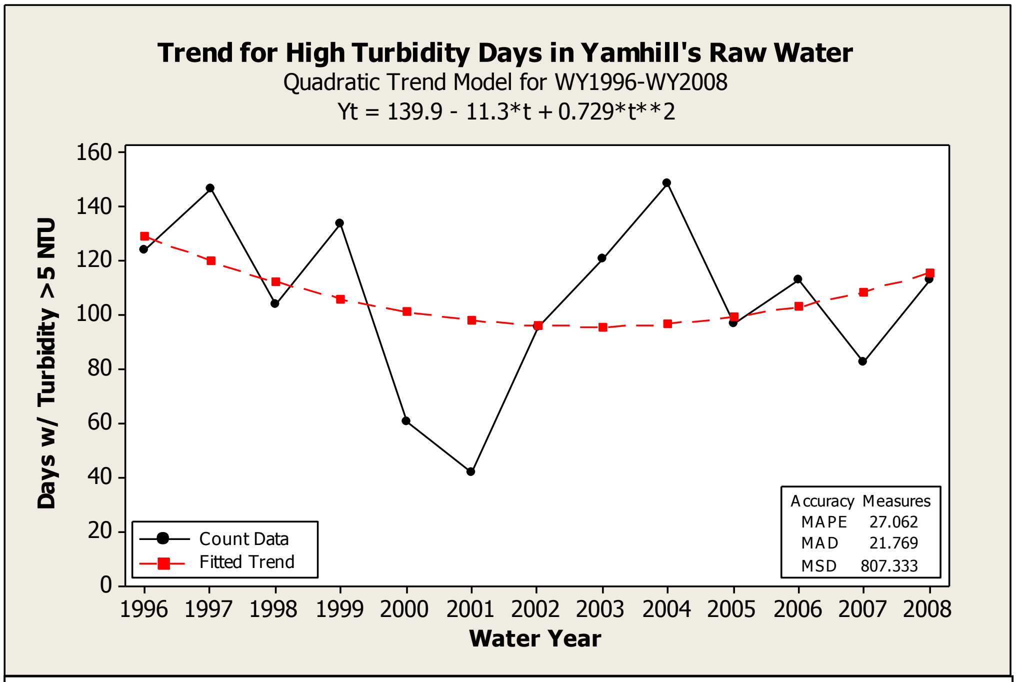

Figure 9f: Trend in count of high turbidity days in Yamhill's DWSA. The quadratic trend model reflects the dip in high turbidity days in 2000 and 2001. The trend is largely flat with substantial variation around the mean.

Ecological and Economic Implications

In 2002, Oregon Departments of Forestry (ODF) and Environmental Quality (DEQ) released a review of the then-current rules under the Forest Practices Act (FPA): "Sufficiency Analysis: A Statewide Evaluation of FPA Effectiveness in Protecting Water Quality" (ODF/ODEQ 2002). The report examined the ability of forest practice rules to meet some of DEQ's water quality standards, including turbidity and sedimentation (accumulation of bedded sediment). The Sufficiency Analysis (SA) discussion of turbidity and sedimentation focused primarily on the effects of roads and landslides, the largest sources of sediment. The SA states that roads built to post-1984 road construction standards are less likely to fail, cause landslides, or otherwise contribute sediment. However, roads can generate substantial amounts of fine sediment the first few years after road construction and during wet-weather log hauling. The SA also discussed the effects of yarding (moving logs across the ground) on erosion, the increased incidence of landslides on clearcut forestland, and the effects of landslides on stream channels. Changes to wet weather hauling, management of ground-based yarding on steep or erosive slopes, and management of landslide-prone locations were recommended. The SA does not discuss the effects of windthrow on sediment regimes or the adequacy of riparian buffers to prevent production of fine sediment or intercept sediment before it reaches water bodies. The SA identifies that the effects of practices along small non-fish-bearing streams on downstream sediment regimes is an issue that needs research and that data are lacking on turbidity and fine sediment effects of forest practices. The data and scientific literature in this report may be able to meet some of these identified data gaps and research needs.

Natural Disturbances and Land Use Have Potential Effects on Sediment/Turbidity

Turbidity fluctuations are a normal part of stream systems and an inherent risk in the use of surface water for drinking water supplies. Disturbances affect even unmanaged watersheds in the form of bank erosion, landslides, fires, floods, and windthrow. The 1999 debris flow in Carlton's Drinking Water Source Area is an example of a natural disturbance resulting in impacts to a Public Water System. Generally, natural disturbances are infrequent and stream systems can flush the additional fine sediment from the stream (Reeves *et al* 1995, Gomi *et al* 2004, Gomi *et al* 2005). Episodic landslides move a much greater volume of fine sediment into stream networks than small, frequent disturbances; however, landslides are discrete events to which biological systems are adapted while chronic sedimentation creates chronic stress that has detrimental effects (Kirchner *et al* 2001). The woody debris and coarse sediment in landslides can enhance fish habitat, even though there are short term impacts to aquatic life and drinking water uses (Reeves *et al* 1995, Reeves *et al* 2006). The data for the Hillsboro-Cherry Grove and the Cities of Forest Grove and Yamhill show impacts from the February 1996 storms, but within two or three years, turbidity is equal to or lower than pre-storm levels. This may confirm the short-term impacts of natural disturbances discussed by Reeves and Kirchner. The Institute for Natural Resources completed ODF's Dynamic Ecosystem Policy Project in 2009, and the synthesis documents and seminar white papers give more information about the dynamic nature of forest ecosystems and the importance of planning for natural events (http://egov.oregon.gov/ODF/STATE_FORESTS/FRP/RP_Home.shtml#Dynamic_Forest_Ecosystems).

Forests are the major land use in the Drinking Water Source Areas described in this report, but DWSAs throughout the state contain a variety of land uses. There are three major categories of forest ownership in Oregon: privately owned (industrial and non-industrial), state owned, and federally owned. There are also smaller amounts of forestlands owned by Native American nations, counties, cities, and public water systems. Impacts from land management (such as agriculture, silviculture, roads, and (sub)urban development) can create chronic sediment sources that take time and resources to resolve, such as production of fine sediment by forest roads (see Sufficiency Analysis and Reid & Dunne 1984). A temporary 2-4 hour increase in turbidity due to legitimate land use activities is allowable under DEQ's water quality standards, but chronic introduction of fine sediment is not allowed. It is also possible for management to increase the rate of other disturbances, as in the case of clearcut timber harvests increasing rates of landslides and windthrown trees (Sidle *et al* 1985, Grizzel & Wolff 1998, Robison *et al* 1999). Klein and others (2008) found a significant association of large scale clearcutting and increased turbidity in Northern California redwood forests. Agriculture and suburban development introduces sediment and toxics into source water, resulting in increased turbidity, toxic chemicals, and disinfection by-products in finished drinking water (Ritter *et al* 2002, Carpenter *et al* 2008). PWSs may not have resources to mitigate disasters or to upgrade equipment. Future studies should examine how land management practices affect operations and costs of PWSs.

Land Use May Alter Flow Regimes

Fluctuations in stream flow and modifications due to land use are another potential risk for PWSs with human use in Drinking Water Source Areas. Urban or suburban development modifies stormwater flows, creating flashier systems with larger high flows, smaller low flows, and more concentrated pollutants, including fine sediment and toxics (Schueler 2000). Agricultural uses can consume large amounts of water during summer low flows, contribute to flashier stream systems, and pollute waterways (Hunter 1992, Perkins *et al* 2009). Silviculture, particularly clearcutting and road building, increases soil moisture during the rainy season and the likelihood of damaging flood events and landslides (Keppeler & Brown 1998). Peak flows can increase during the first fall storms because of clearcutting (Grant *et al* 2008); flows can increase due to roads (Jones & Grant 1996), potentially moving more sediment through channels and carrying sediment from roads. Several years following harvest and replanting, rapidly growing young trees consume large amounts of water and may result in lower base flows (Jones & Post 2004). Summer flow deficits are especially great in 35-50 year-old plantations (Perry 2007). Fast-growing trees in previously harvested riparian areas consume large amounts of water and reduce low flows (Hicks *et al* 1991), while older riparian forests consume significantly less water (Moore *et al* 2004). It should be noted that any flow alterations due to timber harvest are small in comparison to effects of agriculture or urbanization. Regardless of the cause, changes in flow regimes can make planning for adequate water supplies difficult for PWSs and potentially contribute to water shortages during summer when water use is highest.

Climate Change Risks for Public Water Supplies

Global climate change compounds the risks of detrimental effects on streamflow and sediment regimes. Generally, wetter winters and higher storm intensity could create more risk of flooding and erosion, and drier, hotter summers could contribute to smaller low flows and greater risk of water shortages (Bates *et al* 2008). In the Coast Range and Western Cascades geologies, low flows are likely to stay similar but begin earlier in the year (Tague *et al* 2008, G. Grant *personal communication*). Scientists do not know whether the streamflow effects of changes in vegetation (such as re-growing trees) and climate will compound each other and create greater problems or whether those effects will negate each other to some extent. More storms of high intensity are likely to interact with land use effects to amplify sediment generation (Grizzel & Beschta 1993). For example, soil exposed by agriculture or log skidding is more vulnerable to erosion in intense storms, especially exposed soil near streams (Gomi *et al* 2005, Gomi *et al* 2006). The compounding effects of land use and climate change could severely impact public water supplies, especially for small PWSs. It is not yet known what the biggest effects of climate change are likely to be, what the risks are, or how these risks interact with vegetation changes such as harvest and succession. Scientists are studying this topic intensively.

Potential Costs Related to Higher Turbidity

Financial resources are a crucial concern for the operation of small communities' Public Water Systems. A typical small PWS has sufficient income to maintain facilities, pay staff, and fund other operating costs, but water rates are not usually high enough to absorb substantial cost increases or the need for upgraded equipment. Several examples of additional costs attributable to higher turbidity are:

- Increased use of coagulation/flocculation chemicals to remove sediment from raw water;
- Dredging of sediment-filled reservoirs, impoundments, and intake pools;

- Increased staff time to monitor turbidity, flush filters, inspect waterways and facilities, and apply for funding and permits to do additional maintenance work such as dredging;
- Equipment upgrades such as new filter systems and pre-filters to remove high levels of fine sediment if high turbidity conditions are or become chronic;
- Installation of new intake structures and/or switching to another water source, such as groundwater or a neighboring PWS;
- In the case of extended shutdowns during high turbidity events, there is a risk of catastrophic loss of structures if a fire occurs when there is insufficient water in the PWS's reservoirs with which to fight the fire. (Falls City and Arch Cape officials expressed this concern to the *Salem Statesman-Journal* newspaper and to DEQ staff, respectively);
- Costs to procure water from a vendor or neighboring PWS if extended shutdowns are too prevalent;
- Short-term public health risks due to loss of a water supply, the inability to sufficiently purify water, and/or toxics; and
- Long-term health risks and costs as a result of toxic chemicals (such as pesticides, solvents, and heavy metals) adsorbed onto the surface of fine sediment (Ambachtsheer *et al* 2007).

Monitoring effectiveness of land use BMPs is necessary to ensure that land management is not increasing public health risks and PWS operating costs.

Land Management Effectiveness for Source Water Protection

It is cheaper and more effective to protect source water quality than it is to clean up degraded water prior to use (Freeman *et al* 2008). The recent award of $1 million in ARRA funds to Arch Cape for membrane filtration is driven in large part by rising turbidity. In addition, modern treatment methods are not able to remove all contaminants (Stackelburg *et al* 2004). Of particular concern are wastewater contaminants like pharmaceuticals and personal care products (Benotti *et al* 2009) and the synergistic effects of multiple contaminants (Hayes *et al* 2006). These contaminants can sorb to or move with turbidity-causing particles. Postel and Thompson (2005) summarize the hydrological services provided by healthy watersheds and the economic costs of losing or reducing those services. Some municipalities embarked on source water protection and restoration approaches to both reduce present and future costs and to ensure that their delivered water is free of contaminants that treatment cannot effectively remove. Seattle, Washington, and New York City, New York, are two notable examples, but there are others such as Boston, Massachusetts. Their examples showcase potential management directions that may be of use to Public Water Systems in Oregon.

New York City needed to correct water quality problems. Faced with US Environmental Protection Agency (EPA) requirements to upgrade treatment facilities, New York applied for a waiver (Limited Alternative to Filtration) and took the more cost-effective approach of engaging land owners in their municipal watershed, changing land management practices, and monitoring watershed conditions and water quality. In 1995, negotiations took place around watershed protection and included representatives of EPA, New York City, New York State, environmental groups, local governments, and residents of the watershed. New York City protected their resource and created benefits for the watershed communities through a comprehensive program that includes land acquisition, conservation easements, regulatory revisions, stream restoration, and incentives for farm- and forest-owners to keep land safe from development and encourage Best Management Practices that protect water quality (Watershed Agricultural Program and Watershed Forestry Program, respectively). The watershed communities benefit from economic development money, infrastructure improvements, and a healthier environment. New York City benefits by saving money and protecting its source water for the long-term. Through forward-thinking efforts and working closely with partners, New York City's approach saves millions of dollars, improves the quality of life for watershed residents, and protects and restores the environment in their municipal watershed (http://www.nyc.gov/watershed, NRC 2000).

Seattle, in Washington State, gets 2/3 of its water supply from the Cedar River. After buying up the Cedar River watershed over the last 100+ years, Seattle owns nearly the entire 90,000 acre watershed. (The remaining 1/3 of the water supply comes from the Tolt River's 11,000 acre watershed of which Seattle owns 70%.) Active logging in the Cedar River watershed until the middle of the 1990's left numerous roads and legacy effects from clearcutting. Seattle built an $80 million disinfection system early in this decade, but they also needed to build a new $100 million filtration plant because of turbidity from roads and landslides. (The cost to build the plant would now be $150 million with an additional $3-5 million per year in operating costs.) Instead, Seattle Public Utilities (SPU) received permission to use a Limited Alternative to Filtration under SDWA, requiring watershed protection with an annual survey of conditions. Their comprehensive protection strategy includes roads, culverts, bridges, bank stabilization, security, dealing with problematic downed trees, road removal and maintenance, and cultural resources protection. SPU crafted the Cedar Transportation Plan to manage their 650 miles of roads and reduce sediment pollution. They have a road inventory for their watersheds and use WARSEM (Washington Road Surface Erosion Model) to find the worst road segments and estimate the cumulative effects on the watershed. They have decommissioned 105 miles of roads as of September, 2008, and will decommission almost 300 miles of roads over a 10 year period. Reductions in fine sediment pollution are already apparent (Figure 10, graph provided by Seattle Public Utilities). Combined with the other measures, such as prohibiting public access to the watershed to prevent microbial contamination and vandalism, the restoration and protection measures taken by Seattle create significant savings in money, materials, and energy (Source: Todd Bohle, Seattle Public Utilities).

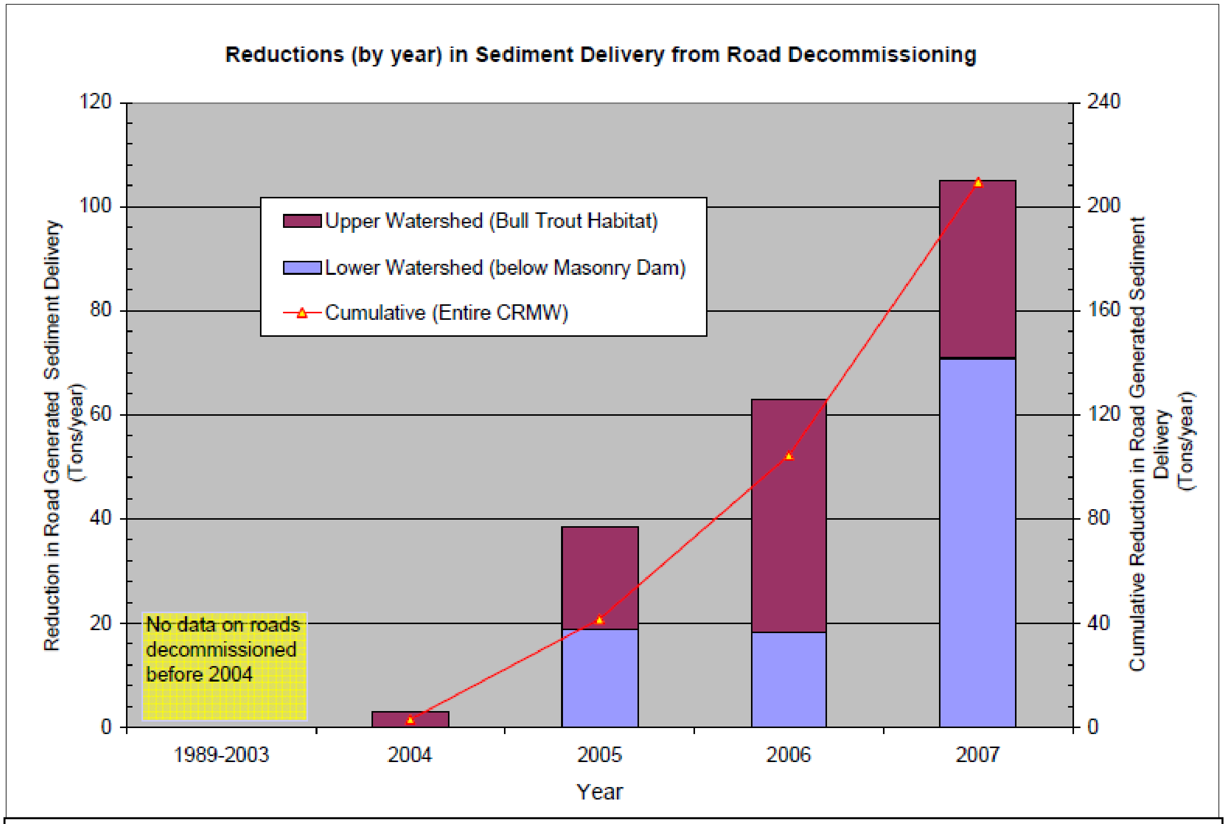

Figure 10: Reductions in the amount of fine sediment generated from roads and delivered to streams in Seattle's Cedar River watershed. These reductions are due to the decommissioning of the worst actors for sediment delivery.

The City of Portland has special management and legislative protections on the US Forest Service land (the Bull Run watershed) that provides drinking water to the largest city in Oregon. These protections give Portland clean, easy-to-treat source water that is free of contamination. The Cities of Astoria and Forest Grove own their watershed forestlands; both are Forest Stewardship Council (FSC) certified and use FSC guidelines to manage the forests in their watersheds (Forest Stewardship Council 2005). According an analysis by EPA (US EPA 2005), FSC guidelines are at least as effective in protecting source water quality and salmonid fisheries as EPA and NOAA-Fisheries guidelines. FSC certification also allows the harvested wood to be sold with a price premium that adds an economic benefit to FSC management (Bensel *et al*, *in press*). Other private land management methods (such as SFI, the Sustainable Forestry Initiative) can potentially protect source water quality, but they need to be monitored and evaluated to insure that they are in fact adequate. Currently, Oregon State Forest Management Plans, the federal Northwest Forest Plan, FSC-certified private operations, and other forest management schemes meeting or exceeding EPA and NOAA-Fisheries guidelines are the demonstrated means most likely to protect and restore source water quality and limit turbidity impacts while producing timber.

The examples of New York City and Seattle suggest that restoration and protection of source water is an effective means of reducing treatment costs and ensuring safe, high quality water. Source water protection is a critical part of the Multi-Barrier Approach to providing safe drinking water (NRC 2000, Barnes *et al* 2009). Roads are the greatest source of fine sediment and landslide initiation sites (Montgomery 1994) and can be significant sources of toxic pollutants (Christensen *et al* 1997). Therefore, road removal can be an extremely effective means of protecting source water quality (Switalski *et al* 2004). When roads are needed, proper road placement and maintenance contribute to water quality protection (Jones *et al* 2000). A 30-year turbidity study of managed forestland in Western Washington by Reiter et al (2009) found that turbidity decreased over the life of the study with the implication that road improvement and sediment controls were responsible. Thinning and multi-age management in plantations avoids large changes in peak flows (Grant *et al* 2008) and increases resiliency (Bisson *et al* 2003, Brown *et al* 2004), leaving forests and streams less vulnerable to climate change and disturbances such as fires. For example, the management strategies for the Tillamook and Clatsop State Forests incorporate thinning and multi-age management in addition to a robust riparian protection strategy (ODF 2001). As a result, water quality in state forests are on a generally improving trend (Rockwell *et al* 2006). The Northwest Forest Plan Aquatic Conservation Strategy, coupled with restoration in key watersheds, is also effective in improving water quality (Gallo *et al* 2005). Boston, Massachusetts, uses active management of its Quabbin watershed to increase resiliency and protect water quality and reduce treatment costs (Barten *et al* 1998). Watershed protection can be a very important part of providing safe drinking water in a manner that is cost effective overall (Brown 2000), although costs associated with protection can be a significant economic challenge for timber producers (Ice *et al* 2006). Incentives or ecosystem services payments could help producers meet economic challenges associated with source water protection and prevent conversion to non-forest use. The economic benefits of riparian protection are potentially massive (Palone & Todd 1997). New York City's example particularly suggests that voluntary measures by the owners and managers of working forests and farms can protect source water quality.

Potential Followup

There are several additional tasks that should be done to better understand turbidity dynamics and potential cause-and-effect relationships between stream conditions and natural conditions, land use activities, and climate change. The first is to continue acquiring information about the issues that Public Water Systems face, especially in small communities. This should include turbidity, precipitation, roads, and land use data for DWSAs. Continuous turbidity monitoring will show patterns more fully than once-per-day measurements, as shown by the comparison of Falls City's daily data with the more detailed data from November 1st-10th, 2007. Light Ranging and Detection (LiDAR) data would be an extremely effective tool for evaluating landscape conditions and characteristics. The results of the Drinking Water State Revolving Fund Needs Survey can be used to help assess the financial challenges faced by PWSs. Understanding the risks posed by climate change is essential. Further collection, examination, and analysis of data and expanding the geographic area of analysis will enable an improved understanding of source water protection.

Improved turbidity monitoring and assessment of source waters is needed when consistent turbidity problems or identified risks are present. As needed, waterbodies with newly identified problems can be put on the 303(d) list, and TMDLs or other protection and restoration plans can be developed to meet the requirements of the Clean Water Act. DEQ plans to revisit the turbidity water quality standard in 2010. A revised turbidity standard would provide more effective implementation through its existing programs in NPDES permits, CWA 303(d) water quality assessment and impaired waters listings, 401 certifications, TMDL development, drinking water protection, and nonpoint source programs. Another critical part of addressing turbidity issues where risks have been identified is ensuring that nonpoint source programs at other agencies (e.g. Oregon Departments of Agriculture and Forestry) are adequately funded and staffed to ensure best management practices are being applied and water quality standards are being met.

In order to accurately assess sources of fine sediment that lead to elevated turbidity in Coast Range DWSAs, an analysis of land use patterns and disturbances and how they relate to source water turbidity is needed. A thorough analysis would also include landslides and significant windthrow events (if known), precipitation effects, and sediment contributions from roads, new and old. Washington's WARSEM model is one potential tool for modeling the effects of roads on DWSA sediment movement. Eugene Water and Electric Board have a source water monitoring and assessment program that provides methods which could be applied to small PWSs. Ice *et al* (2006) explore methods for evaluating the areal extent of riparian protection. Other evaluation methods and examples exist as well.

DEQ should provide technical assistance to PWSs whenever such assistance is wanted. In the short term, DEQ can assist PWSs in applying for SDWA grants for testing and data collection to enhance our knowledge of what is actually happening on the landscape. Since small communities typically do not have the expertise or resources to thoroughly examine the collected data, the Drinking Water Protection program (DWP) can assist with analysis and inform them of Best Management Practices that may be of use. In the long term, the DWP program can help communities to develop land use plans for their DWSAs that are consistent with protecting their drinking water for generations to come. Such plans may include land acquisition through fee title and/or conservation easements or incentives/ecosystem services payments to land owners if more protective management practices are found to be necessary. The DWP program can assist PWSs in identification of funding needs and sources, such as loans and grants to implement plans for source water protection or collection of fees from water system users for ecosystem services payments.

DEQ works closely with the Oregon Department of Human Services on drinking water issues. In addition, close coordination with other state agencies such as Department of Forestry, Department of Land Conservation and Development, Department of Agriculture, and Department of Geology and Mineral Industries (DOGAMI) could enable the DWP to better target assistance to PWSs. DOGAMI, for example, has done excellent work recently to identify active landslides and landslide risk areas. EPA, NRCS, and NOAA-Fisheries are federal agencies with whom DEQ can increase cooperation to resolve concerns common to source water protection and implementation of the CWA and ESA.

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Appendices

Appendix A: Public Water Systems with All or Part of DWSA in the Coast Range

ID #	PWS Name	Water Source	County	Area (acres)
4100003	ADAIR VILLAGE WATER SYSTEM	WILLAMETTE R.	BENTON	234501.88
4100012	ALBANY, CITY OF	S. SANTIAM CANAL	LINN	7665.94
4100041	AMITY, CITY OF	S. YAMHILL R.	YAMHILL	17504.87
4100047	ASHLAND WATER DEPARTMENT	ASHLAND CR.	JACKSON	12736.58
4100055	ASTORIA, CITY OF	BEAR & CEDAR CR., MIDDLE LAKE	CLATSOP	2735.95
4100062	YOUNG'S RIVER-LEWIS & CLARK WD	N. & S. FORKS BARNEY CR.	CLATSOP	1899.51
4100063	WICKIUP WATER DISTRICT	LITTLE CR. & BIG/LITTLE FAT BUCK CR.	CLATSOP	1359.47
4100074	BANDON, CITY OF	GEIGER & FERRY CR.	COOS	2555.48
4100124	FISHHAWK LAKE RECREATION CLUB	FISHAWK CR.	COLUMBIA	10004.88
4100164	CANNON BEACH, CITY OF	W. FORK ELK CR.	CLATSOP	5277.47
4100169	CANYONVILLE, CITY OF	CANYON CR.	DOUGLAS	22656.81
4100171	CARLTON, CITY OF	PANTHER CR.	YAMHILL	2075.02
4100194	CLATSKANIE, CITY OF	ROARING & WEST CR.	COLUMBIA	1799.90
4100199	BEAVER WATER DISTRICT	BEAVER CR.	TILLAMOOK	18647.16
4100205	COOS BAY-NORTH BEND WATER BD.	PONY CR.	COOS	2557.01
4100213	COQUILLE, CITY OF	RINK CR.	COOS	429.18
4100214	GARDEN VALLEY WTR ASSOCIATION	CHINA CR.	COOS	419.24
4100225	CORVALLIS, CITY OF	WILLAMETTE R, S.&N. FORKS ROCK CR, GRIFFITH CR.	BENTON	47005.87
4100239	LONDON WATER CO-OP	BEAVER CR.	LANE	867.67
4100246	CRESWELL, CITY OF	COAST FORK WILLAMETTE R.	LANE	123064.39
4100248	DALLAS, CITY OF	RICKREAL CR.	POLK	17953.92
4100250	MILO ACADEMY	S. UMPQUA R, LICKEY CR.	DOUGLAS	21934.54
4100254	DEPOE BAY, CITY OF	ROCKY &DEPOE BAY CR.	LINCOLN	6695.81
4100260	DRAIN, CITY OF	BEAR & ALAN CR.	DOUGLAS	4017.17
4100276	ELKTON, CITY OF	UMPQUA RIVER	DOUGLAS	316072.91
4100297	FALLS CITY, CITY OF	TEAL &GLAZE CR.	POLK	3218.60
4100301	HECETA WATER DISTRICT	CLEAR LAKE	LANE	614.69
4100302	SILTCOOS HEIGHTS	SILTCOOS LAKE	LANE	39670.56
4100304	ALDERWOOD WATER DEVELOPMENT CO	WOAHINK LAKE	LANE	4334.51
4100305	FOREST GROVE, CITY OF	ROARING, CLEAR, THOMAS, DEEP, & SMITH CR.	WASHINGTON	4856.58
4100323	GLENDALE, CITY OF	COW, SECTION, & MILL CR.	DOUGLAS	119381.66
4100324	KERNVILLE-GLENEDEN-LINCOLN BCH W D	DRIFT CREEK	LINCOLN	22229.85
4100326	GLIDE WATER ASSOCIATION	NORTH UMPQUA RIVER	DOUGLAS	428437.01
4100333	GOLD HILL, CITY OF	ROGUE RIVER	JACKSON	284024.61
4100337	ROCK CREEK HIDEOUT WATER CO	UNNAMED CREEK	POLK	26.74
4100342	GRANTS PASS, CITY OF	ROGUE RIVER	JOSEPHINE	170961.64
4100379	HILLSBORO-FOREST GROVE-BEAVERTON	TUALATIN R. & N. FORK TRASK R. (BARNEY RES.)	WASHINGTON	120691.98
4100463	LAKESIDE WATER DISTRICT	EEL LAKE	COOS	3872.15
4100466	LANGLOIS WATER DISTRICT	FLORAS CREEK	CURRY	39049.91
4100483	LINCOLN CITY WATER DISTRICT	SCHOONER CREEK	LINCOLN	9591.86
4100497	MCMINNVILLE WATER AND LIGHT	HASKINS & MCGUIRE RES.	YAMHILL	6213.11
4100505	MANZANITA WATER DEPARTMENT	N.&W. FORKS ANDERSON CR.	TILLAMOOK	569.36

4100507	MAPLETON WATER DISTRICT	BERKSHIRE CREEK	LANE	501.69
4100513	MEDFORD WATER COMMISSION	ROGUE RIVER	JACKSON	290653.71
4100548	CLARKS BRANCH WTR. ASSOCIATION	SOUTH UMPQUA RIVER	DOUGLAS	84099.45
4100549	TRI-CITY WATER DISTRICT	SOUTH UMPQUA RIVER	DOUGLAS	106502.61
4100550	MYRTLE CREEK, CITY OF	S. UMPQUA R. & SPRINGBROOK SPRINGS	DOUGLAS	4809.62
4100551	MYRTLE POINT, CITY OF	NORTH FORK COQUILLE RIVER	COOS	180885.59
4100554	NEHALEM, CITY OF	BOB'S CREEK	TILLAMOOK	425.21
4100556	NETARTS WATER DISTRICT	EAST FALL CREEK	TILLAMOOK	367.50
4100564	BAY HILLS WATER ASSOCIATION	UNNAMED CREEK	LINCOLN	26.21
4100566	NEWPORT, CITY OF	BIG CR.&SILETZ R.	LINCOLN	2150.12
4100568	BEVERLY BEACH WATER DISTRICT	WADE CREEK	LINCOLN	1460.17
4100581	OAKLAND, CITY OF	CALAPOOYA CREEK	DOUGLAS	64894.66
4100585	OCEANSIDE WATER DISTRICT	SHORT CREEK	TILLAMOOK	1304.36
4100603	PANTHER CREEK WATER DISTRICT	PANTHER CREEK	LINCOLN	1106.43
4100610	TIERRA DEL MAR WATER COMPANY	BELTZ CREEK	TILLAMOOK	160.06
4100624	PHILOMATH PUBLIC WORKS	MARY'S RIVER	BENTON	85972.99
4100670	PORT ORFORD, CITY OF	HUBBARD CR. & GARRISON LAKE	CURRY	2845.60
4100672	POWERS, CITY OF	S. FORK COQUILLE R. & BINGHAM CR.	COOS	94207.20
4100689	RAINIER WATER DEPARTMENT	COLUMBIA R. & FOX CR.	COLUMBIA	44917.84
4100699	REEDSPORT, CITY OF	CLEAR LAKE	DOUGLAS	1382.96
4100706	RIDDLE, CITY OF	COW CREEK	DOUGLAS	192495.04
4100707	LAWSON ACRES WATER ASSOCIATION	COW CREEK	DOUGLAS	7025.14
4100708	ROCKAWAY BEACH WATER DEPT	JETTY CREEK	TILLAMOOK	1310.52
4100712	ROGUE RIVER, CITY OF	ROGUE RIVER	JACKSON	69007.97
4100717	ROBERTS CREEK WATER DISTRICT	S. UMPQUA RIVER	DOUGLAS	3094.75
4100719	UMPQUA BASIN WATER ASSOCIATION	N. UMPQUA RIVER	DOUGLAS	33475.75
4100720	ROSEBURG, CITY OF - WINCHESTER	N. UMPQUA RIVER	DOUGLAS	131134.54
4100731	SALEM PUBLIC WORKS	N. SANTIAM RIVER & IG	MARION	17149.09
4100792	SCAPPOOSE, CITY OF	GOURLEY, LAZY, & S.FK SCAPPOOSE CR	COLUMBIA	6059.81
4100799	SEASIDE WATER DEPARTMENT	NECANICUM R.	CLATSOP	30069.02
4100802	ARCH CAPE WATER SERVICE DISTRICT	ASBURY & SHARK CR.	CLATSOP	1249.34
4100808	COUNTRY VIEW MH ESTATES	ROGUE RIVER	JACKSON	734031.45
4100811	SHERIDAN, CITY OF	SOUTH YAMHILL RIVER	YAMHILL	135375.06
4100821	SILETZ, CITY OF	SILETZ R. & TANGERMAN CR.	LINCOLN	131836.17
4100843	STAYTON WATER SUPPLY	NORTH SANTIAM RIVER	MARION	4535.87
4100847	SUTHERLIN, CITY OF	CALAPOOYA & COOPER CR.	DOUGLAS	57605.19
4100893	TILLAMOOK WATER COMMISSION	KILLAM & FAWCETT CR.	TILLAMOOK	6176.20
4100898	TIMBER WATER ASSOCIATION	NEHALEM RIVER	WASHINGTON	7787.26
4100899	TOLEDO WATER UTILITIES	MILL CR. & SILETZ R.	LINCOLN	2680.81
4100922	VERNONIA, CITY OF	ROCK CREEK	COLUMBIA	3561.18
4100925	S.W. LINCOLN COUNTY WTR. DIST.	BIG, VINGIE, STARR, DICK’S FORK CR.	LINCOLN	3451.89
4100926	WALDPORT, CITY OF	ECKMAN & WEIST CR.	LINCOLN	3186.26
4100932	WARRENTON WATER SYSTEM	LEWIS&CLARK R. CAMP C CR.	CLATSOP	18375.81
4100950	WESTPORT WATER ASSOCIATION	WEST CREEK	CLATSOP	1326.04
4100952	WHEELER WATER DISTRICT	VOSBURG & JARVIS CR.	TILLAMOOK	365.23
4100953	CITY OF WILLAMINA WATER DEPARTMENT	WILLAMINA CREEK	YAMHILL	52478.62
4100954	WILSONVILLE, CITY OF	WILLAMETTE RIVER	CLACKAMAS	1050979.75
4100957	WINSTON-DILLARD WATER DISTRICT	SOUTH UMPQUA RIVER	DOUGLAS	111553.38
4100958	YONCALLA, CITY OF	ADAMS & WILSON CR.	DOUGLAS	1676.22
4100966	YACHATS, CITY OF	SALMON & REEDY CR.	LINCOLN	773.12
4100968	YAMHILL, CITY OF	TURNER CREEK	YAMHILL	2916.76
4100970	NESKOWIN REGIONAL WD	HAWK CREEK	TILLAMOOK	1542.70
4100971	CITY OF CAVE JUNCTION	EAST FORK ILLINOIS RIVER	JOSEPHINE	148775.61

4100985	HILLSBORO-CHERRY GROVE	TUALATIN RIVER	WASHINGTON	15565.00
4101012	PP&L-TOKETEE VILLAGE	TOKETEE LAKE (N. UMPQUA)	DOUGLAS	224207.72
4101062	RAINBOW ROCK VILLAGE MHP	TAYLOR CREEK WELLS	CURRY	1039.25
4101072	JOHNSON CREEK WATER SERVICE CO	JOHNSON CREEK	LINCOLN	660.07
4101092	USFS TILLER RANGER STATION	SOUTH UMPQUA RIVER	DOUGLAS	288525.43
4101095	USFS WOLF CREEK JOB CORPS	LITTLE RIVER	DOUGLAS	57801.95
4101139	MIDLAND WATER ASSOCIATION	GRAHAM CREEK	COLUMBIA	988.93
4101174	BUELL-RED PRAIRIE WATER ASSN	GOOSENECK CREEK	POLK	1057.58
4101361	RAINBOW ROCK CONDOMINIUMS	UNNAMED CREEK	CURRY	155.21
4101483	ANGLERS COVE/SCHWC	ROGUE RIVER	JACKSON	10705.24
4105246	PGE BEAVER GENERATING STATION	COLUMBIA RIVER	COLUMBIA	57081.64
4105581	WEISS ESTATES WATER SYSTEM	FAHY'S LAKE	COOS	1028.96
4105737	BERNDT CREEK WATER CORP	ROCK CREEK	COLUMBIA	35304.09
4190416	FORT JAMES OPERATING COMPANY	COLUMBIA RIVER	COLUMBIA	87190.52
4192139	TILLER ELEMENTARY, SD #15	SOUTH UMPQUA RIVER	DOUGLAS	54986.13
4192152	POPE & TALBOT, INC.,	WILLAMETTE RIVER	LANE	528459.96
4192674	USFS STAR RANGER STATION	APPLEGATE RIVER	JACKSON	178577.82
4194300	ROSEBURG FOREST PROD-DILLARD	SOUTH UMPQUA RIVER	DOUGLAS	28863.00

Appendix B: Relationship of Stream Turbidity and Suspended Solids in the Siletz River Basin:

Analysis of Data Collected by the Confederated Tribes of Siletz Indians

Joshua Seeds, Nonpoint Source Analyst, Oregon DEQ

The Confederated Tribes of Siletz Indians collected winter turbidity data from numerous sites on the Siletz River and its tributaries in 2002 through 2006. For some of the sampling events, tribal staff also collected samples for measuring total suspended solids (TSS), a measure of sediment in the water column. The sites with TSS data include 11 tributaries and 8 sites along the mainstem of the Siletz River. As Public Water Systems collect turbidity data, and since DEQ wrote a report detailing turbidity in Coast Range PWSs in 2009, it is important to understand what is contributing to elevated turbidity levels when they are present. High turbidity is typically caused by fine sediment, but algae and other factors may also be responsible. We needed to establish to what degree fine sediment pollution is driving turbidity in Coast Range streams, so we used the available data for the Siletz River to test this relationship.

Analysis of Relationships between Turbidity and Total Suspended Solids

We graphed the relationships with turbidity as the independent variable (X axis) and TSS as the dependent variable (Y axis) for the tributaries (Figure 1) and the mainstem of the Siletz River (Figure 2).

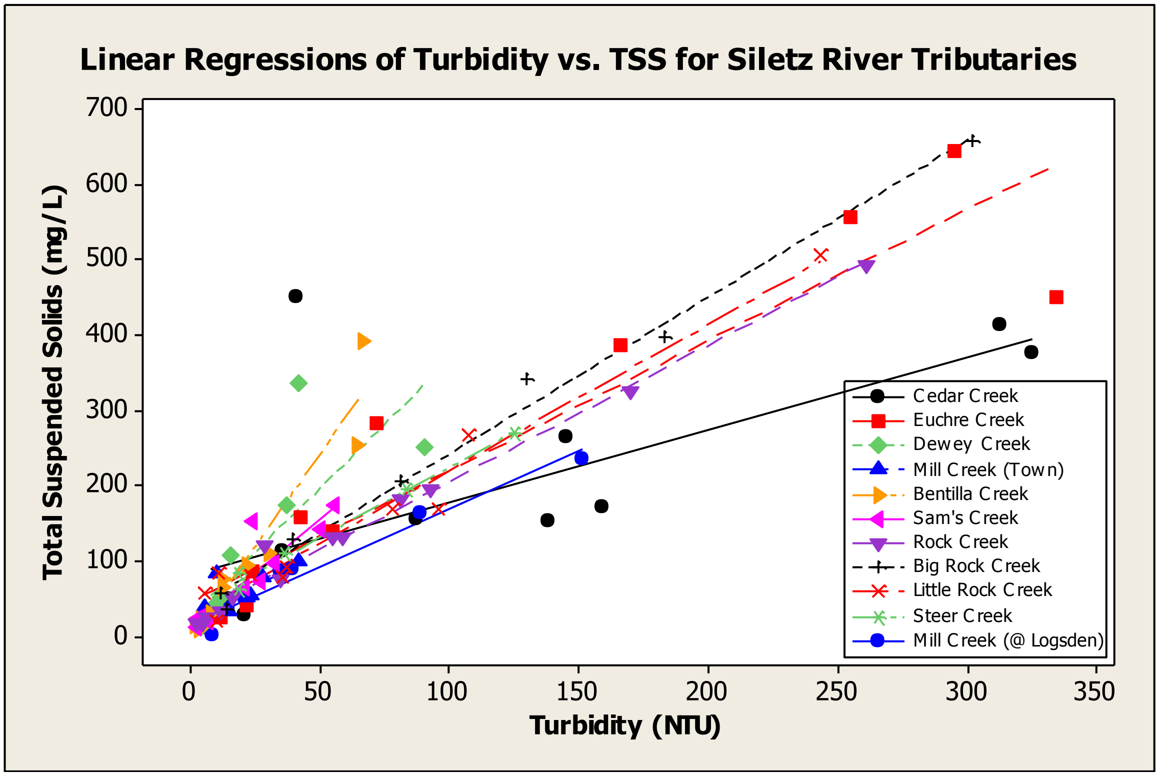


Figure 1

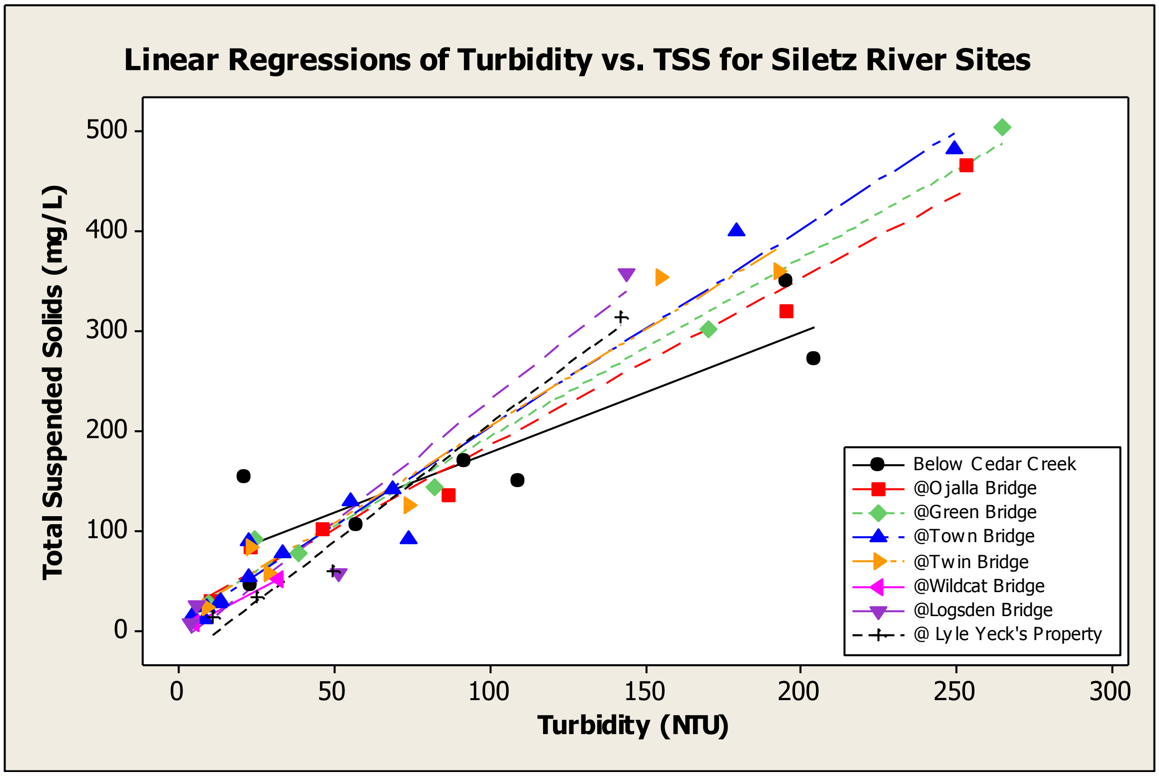


Figure 2

DEQ then graphed and analyzed the data using least-squares regressions to evaluate the relationship between turbidity and TSS in the Siletz River basin. We evaluated the combined data in three different groups: the pooled tributaries, the pooled mainstem sites, and both tributaries and mainstem sites (the whole system).

To insure the validity of the least-squares regression analysis, we needed to make sure that the assumption that data are normally distributed was met. Least-squares regressions can be especially sensitive to outliers that skew the line and give a false impression of its accuracy. Histograms of turbidity and TSS for the three groups all show lognormal distributions for the data sets (Figures 3-8). Analysis using a Ryan-Joiner test for normality confirms that transforming the data with a base10 logarithm results in normal distributions for all the variables except TSS for the tributaries (Figure 4). Because the data appear lognormally distributed, the likelihood that failure of the normality test is due to a couple outliers, and other data transformations did not result in a normal distribution, we proceeded with the regression on the tributary data in addition to the other two groups.

Figure 3

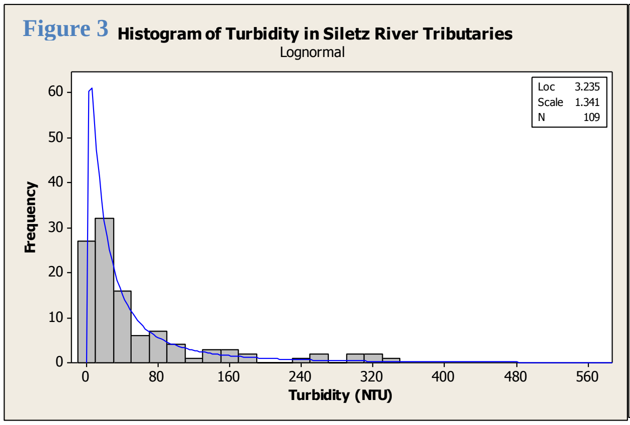


Figure 4

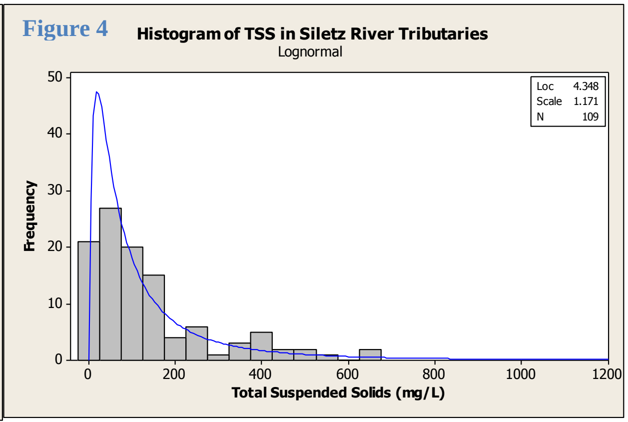


Figure 5 **Histogram of Turbidity in Siletz River Sites**

Lognormal

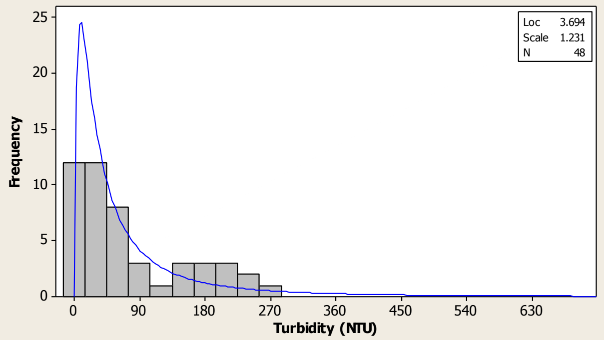


Figure 6 **Histogram of TSS in Siletz River Sites**

Lognormal

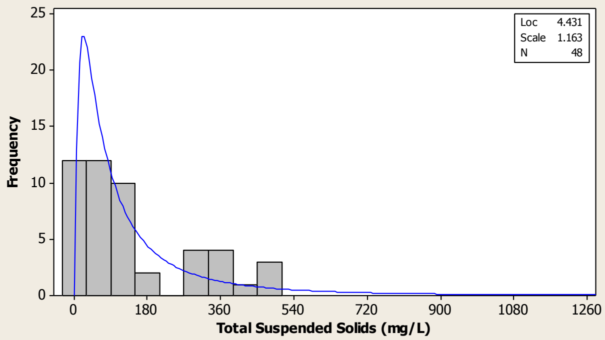


Figure 7 **Histogram of Turbidity in Siletz River System**

Lognormal

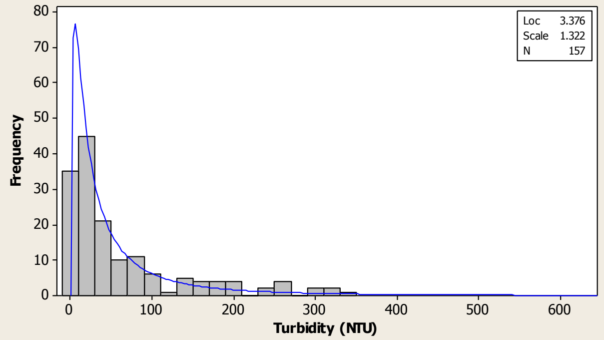
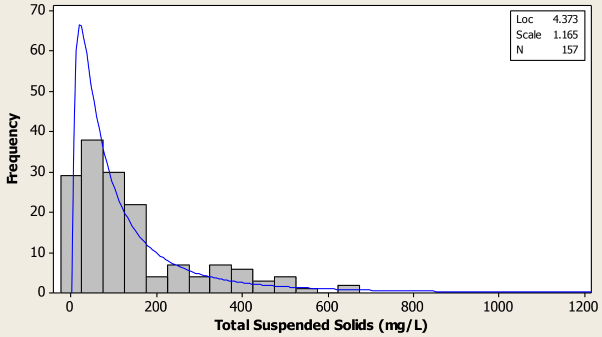


Figure 8 **Histogram of TSS in Siletz River System**

Lognormal



The least-squares regressions on the log transformed data for the tributaries, the mainstem, and the whole stream system show high correlations between turbidity and TSS (R^2=81.4%, 89.9%, 82.5%, respectively; Figures 9-11). The accuracy of the regression is excellent for the lower and middle reaches of the river (Figure 10). Confidence and prediction intervals are narrow at the lower end of the turbidity and TSS ranges, but widen greatly near the upper end of the range, showing less certainty about values at the upper end of the ranges. Therefore, turbidity is a good predictor of the combined organic and mineral suspended solids in the Siletz River system, but caution must be used in translating turbidity values into TSS at turbidities greater than 100 or 150 NTU.

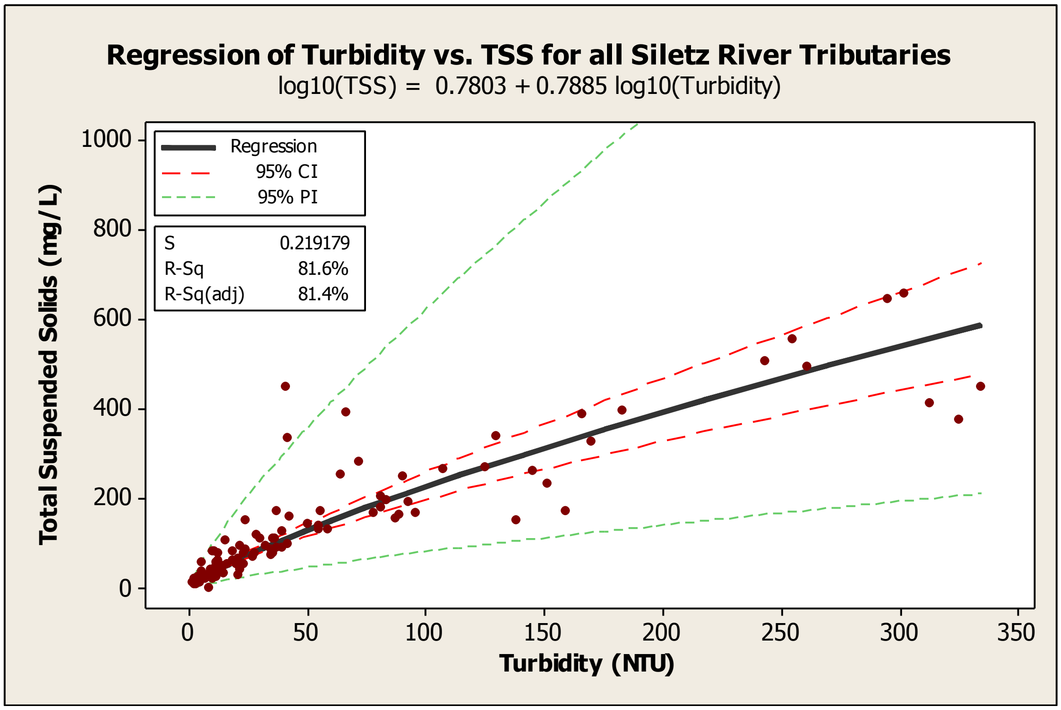


Figure 9

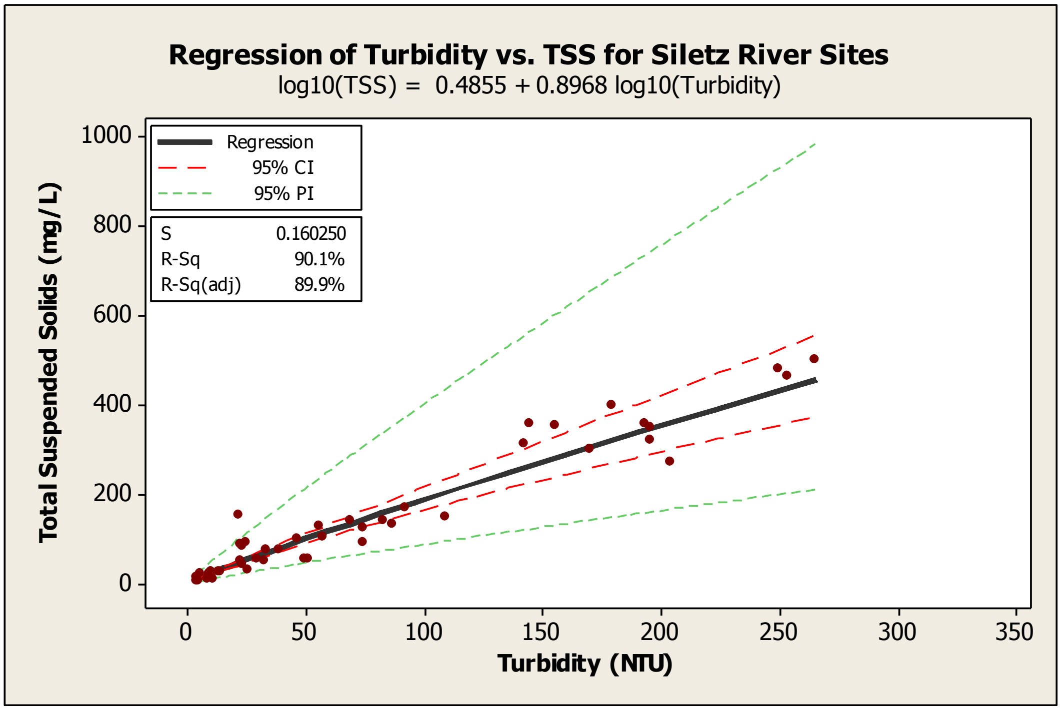


Figure 10

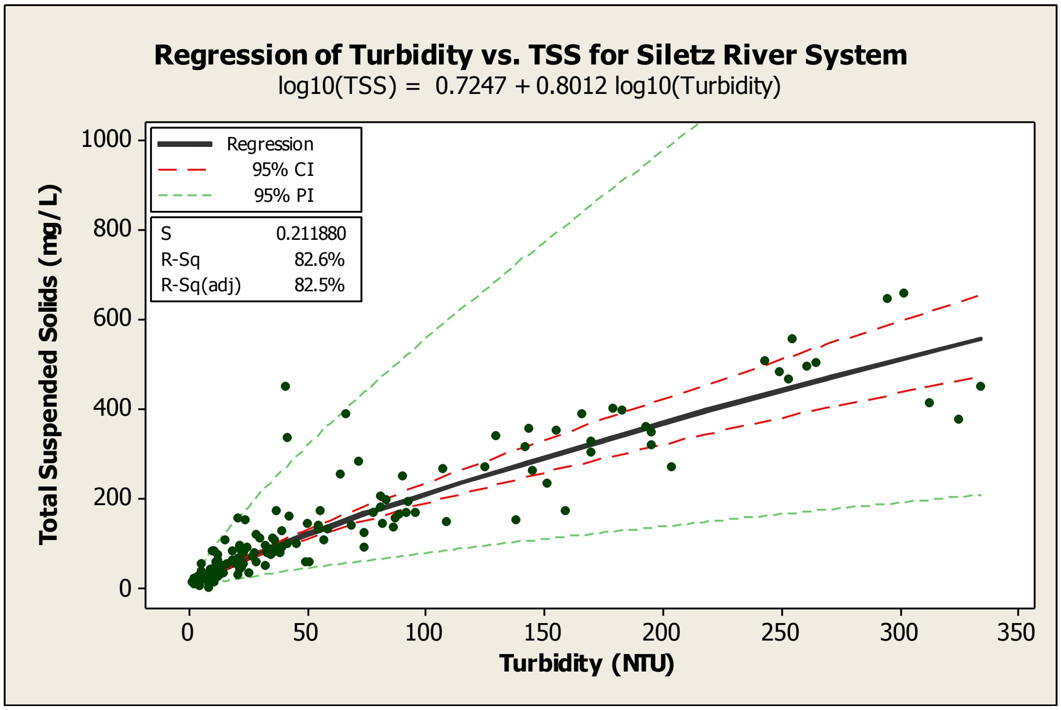


Figure 11

ANOVA: TSS:Turbidity by Site

Source	DF	SS	MS	F	P
Sites	18	13.80	0.767	3.13	0.000
Error	138	33.85	0.245		
Total	156	47.66			

S = 0.4953   R-Sq = 29.0%   R-Sq(adj) = 19.7%

Two tributaries of the Siletz River (Dewey and Bentilla Creeks) have much steeper slopes to their TSS vs. Turbidity lines, seen in Figure 1. Cedar Creek also has an outlier near the Dewey and Bentilla data. An analysis of variance on the logarithm-transformed ratio of TSS-to-Turbidity showed a statistically significant difference among sites (F=3.13, p<0.001). Bentilla and Dewey Creeks do indeed have the highest mean ratios, but Little Rock Creek, Mill Creek (near the City of Siletz), and Sam's Creek also have higher than average TSS:Turbidity ratios.

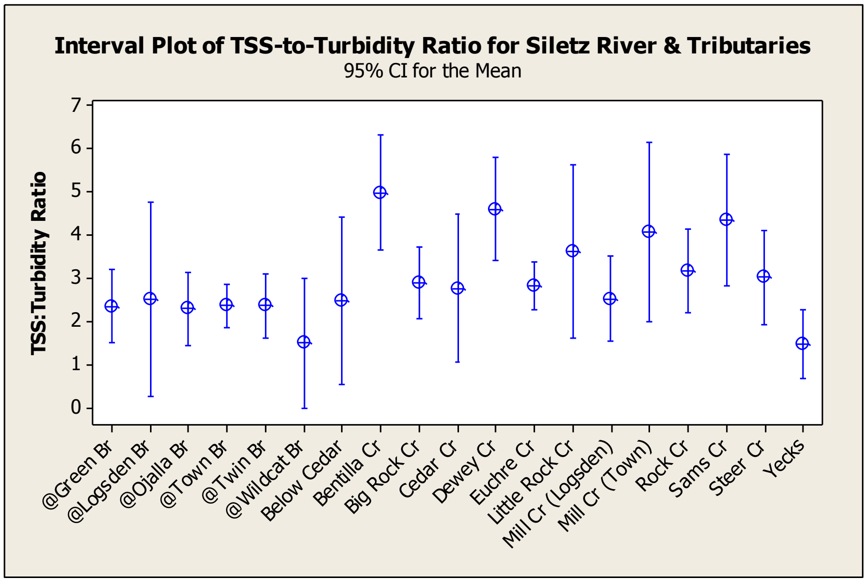


Figure 12

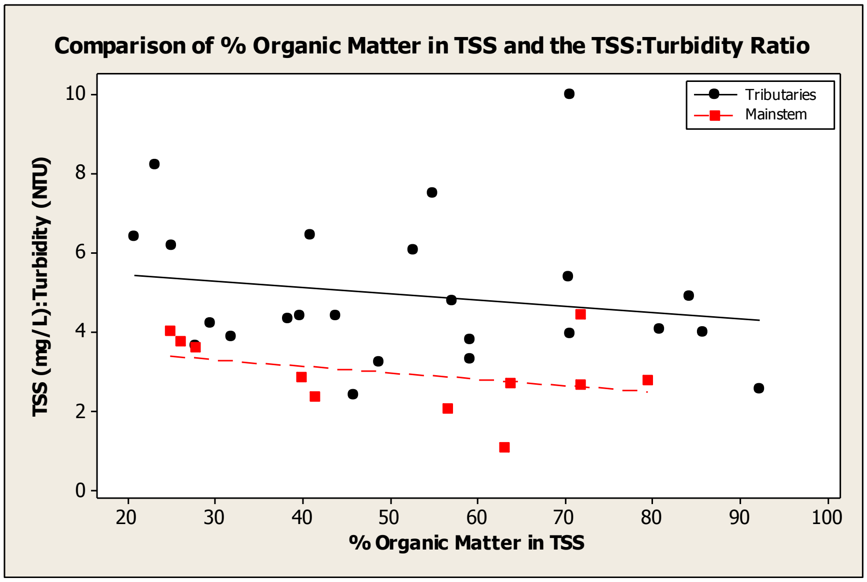


Figure 13

Possible explanations for these differences in sediment characteristics among sites include soil type, differences in road surfacing or density, land use differences, or a lower proportion of organic sediments in the total sediment in the stream. A USGS report (Madej *et al* 2002) indicates that organic sediments stay suspended in the water column and thereby contribute more to turbidity than mineral sediments of the same size. Some of the TSS samples collected by the tribe were analyzed for mineral and organic content. We plotted the percent of organic matter in TSS samples with that samples TSS:Turbidity ratio to see if there was a clear pattern, but no relationship exists (Figure 13). Soil type or other factors are therefore more likely to drive patterns in relationship between TSS and turbidity in the Siletz River watershed.

Conclusions

Turbidity is a useful predictor of sediment mass loads in the Siletz River and tributaries. I recommend using the regression equation for the whole system when estimating sediment loads(Figure 11), as the results are based on greater amounts of data and are thereby more robust. The equation from mainstem sites could be used on the middle and lower reaches of the mainstem where most of the mainstem sample sites were located (Figure 10). Caution should be used when applying the regression equations in the uppermost portions of the basin (above Gravel Creek or in the North and South Forks) because there are no TSS data for this part of the basin. Caution should also be used when turbidities exceed 100 NTU. Some tributaries (such as Bentilla and Dewey Creeks) have anomalous TSS-to-Turbidity relationships, so it may be necessary to derive individual regression equations for those streams.

References:

Madej, MA, M Wilzbach, K Cummins, C Ellis, and S Hadden. 2002. The contribution of suspended organic sediments to turbidity and sediment flux. *Turbidity and Other Sediment Surrogates Workshop*, Reno, NV.