

THE OREGON WATER QUALITY INDEX (OWQI) – A COMMUNICATOR OF WATER QUALITY INFORMATION

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ABSTRACT: The Oregon Water Quality Index (OWQI) provides a simple and concise method for communicating complex water quality information to the public and decision-makers. The OWQI expresses water quality by integrating measurements of eight water quality variables. OWQI results can be used to show water quality variation both spatially and temporally, providing a context for interpretation of water quality conditions and trends. Geographical Information Systems facilitate comparison of OWQI results by variables such as land use. The OWQI is used to develop environmental indicators, such as percentage of river monitoring sites with significantly improving water quality, or percentage of sites with excellent water quality. Application of the OWQI helps to evaluate the effectiveness of water quality management activities. Construction of the OWQI will be briefly described, and various applications of the OWQI as a communicator of water quality information will be discussed.

KEY TERMS: water quality index; environmental indicator; environmental communication; trend analysis.

INTRODUCTION

Water resource professionals generally communicate water quality status and trends in terms of the evaluation of individual water quality variables. While this technical language is understood within the water resources community, it does not readily translate into meaningful information to those communities having profound influence on water resources policy: the lay public and policy makers. Increasingly, these communities expect a comprehensible response to their right to know about the status of their environment. An example of this response is the annual Consumer Confidence Report provided by drinking water suppliers as required by the 1996 amendments to the Safe Drinking Water Act (US EPA, 1998). The purpose of the Oregon Water Quality Index (OWQI) is to improve understanding of water quality issues by integrating complex data and generating a score that describes water quality status and evaluates water quality trends. Although some information is lost when integrating multiple water quality variables, this loss is outweighed by the gained understanding of water quality issues by the lay public and policy makers. Improved understanding is very important to water resource managers in terms of increased support for water resource improvement efforts.

The science of water quality has improved markedly since the introduction of the OWQI in the 1970s (Dunnette, 1979). The OWQI was improved in 1995 to reflect advances in the knowledge of water quality and in the design of water quality indices. The historical basis and design of the OWQI are described in detail by Cude (in press). The OWQI is widely used and maintained by Oregon Department of Environmental Quality (DEQ). The OWQI has been used to report water quality status and trends in Oregon to state legislators and other water resource policy makers. OWQI reports are accessible to the public via the internet (<http://www.deq.state.or.us/lab/WQM/WQI/wqimain.htm>). The OWQI has been used as a supplement to more traditional reporting formats, such as the Water Quality Status Assessment (305(b)) Report (Oregon DEQ, 2000). The OWQI has been incorporated into larger sets of environmental indicators for the Oregon Benchmarks Report (Oregon Progress Board, 1999) and the Oregon State of the Environment Report (Oregon Progress Board, 2000). The OWQI has also been adopted or borrowed from for construction of other water quality indices (e.g., Richardson, A. M., 1997). The OWQI has been recognized as an important contribution to the lexicon of environmental communications. The purpose of this report is to provide a brief description of the OWQI and to explore methods by which the OWQI can be used to communicate water quality information.

OWQI DESCRIPTION

The OWQI analyzes a defined set of water quality variables and produces a score describing general water quality for Oregon's rivers and streams. The water quality variables included in the OWQI are temperature, dissolved oxygen (percent saturation and concentration), biochemical oxygen demand, pH, total solids, ammonia and nitrate nitrogens, total phosphorus, and fecal coliforms. Raw data for each variable are transformed into unitless subindex values, with values of 10 being worst case and 100 being ideal. These transformations are based upon the desire to protect general recreational uses, i.e., swimming and fishing for native species. The OWQI was designed to permit comparison of water quality among different stretches of the same

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river or between different watersheds. The pH and total solids subindices account for geological variability. The OWQI calculation formula, an unweighted harmonic square mean function, accounts for the variability of factors limiting water quality in different watersheds (Dojlido, et al., 1994). This formula allows the most impaired variable to impart the greatest influence on the OWQI. It acknowledges that different water quality variables will pose differing significance to overall water quality at different times and locations. The formula is given by:

$$WQI = \sqrt{\frac{n}{\sum_{i=1}^n \frac{1}{SI_i^2}}}$$

where WQI is Water Quality Index result, n is the number of subindices, and SI_i is Subindex i .

In order to help the public interpret the numeric OWQI scores, a classification scheme was derived from a normalized distribution of OWQI data to describe general water quality conditions (Cude, in press). OWQI scores that are less than 60 are considered very poor; 60-79 poor; 80-84 fair; 85-89 good; and 90-100 excellent. To account for differences in water quality between low flow summer months (June - September) and higher flow fall, winter, and spring (FWS, October - May), Oregon DEQ evaluates data by calculating average values for summer and FWS. Monitoring sites are ranked based on the minimum of the seasonal averages.

The OWQI aids in the assessment of water quality for general recreational uses (i.e., fishing and swimming). The OWQI cannot determine the quality of water for specific uses, nor can it be used to provide definitive information about water quality without considering all appropriate chemical, biological, and physical data. The OWQI cannot evaluate all health hazards. The OWQI was designed for Oregon's streams, and its application to other geographic regions or waterbody types should be approached with caution.

STATEWIDE WATER QUALITY INFORMATION

The OWQI was developed to provide a simple and concise method for expressing the significance of data regularly generated from Oregon DEQ's Ambient River Water Quality Monitoring Network. The Department of Environmental Quality Laboratory maintains a network of ambient water quality monitoring sites. These sites were selected to provide representative statewide geographical coverage, and to include major rivers and streams throughout the state. There are currently 159 monitoring sites in the network. The size of the network periodically changes due to logistical and budgetary constraints.

Annually, water quality status and trends are summarized by application of the OWQI to network sites. Where available, ten water years of data are used to generate OWQI scores. For each site, seasonal average OWQI scores are calculated. The minimum seasonal average is used to rank the site relative to all others. Water quality status for the site is labeled "Excellent", "Good", "Fair", "Poor", or "Very Poor" based on the classification scheme described above. Each site, with sufficient data, is analyzed for the presence of significantly increasing or decreasing trends. The nonparametric Seasonal-Kendall test (Hirsch, et al., 1982) is used for trend analysis to ensure that the significant trends that exist are not due to normal seasonal variation. Significant trends are reported at the 80% or greater confidence level.

Figure 1 displays OWQI status and trending information, with respect to geographical location. This affords a large-scale view of water quality status and trends in Oregon. Immediately noticeable is a lack of monitoring sites in the southeast portion of the state. This portion of the state is remote and arid, with few streams. Oregon DEQ is able to monitor a SE Oregon network of sixteen sites only twice per year, and is unable to meet holding times for all OWQI parameters due to the remoteness. While OWQI values may still be calculated under these circumstances, they would only be useful when compared between SE Oregon network sites. The SE Oregon sites are not compared with others in the program. Habitat data and macroinvertebrate samples are collected in tandem with water chemistry samples at SE Oregon network sites. One interesting finding is that OWQI scores are positively and significantly correlated ($r_s = 0.66$, p -value = 0.03) with macroinvertebrate assemblage integrity (Mochan and Mrazik, 2000).

Figure 1 shows some clustering of water quality conditions, which is correlated to land use. "Excellent" water quality tends to be found in high gradient, mountain streams where forestry is the dominant land use. Water quality conditions decline as the streams leave the mountains and enter areas with more intense human influence. Clusters of "Poor" and "Very Poor" water quality tends to be found in flat gradient streams where urban and/or intense agriculture is the dominant land use. Figure 2 displays the distribution of OWQI values based on land use type. For this analysis, land use categories are based on the dominant (>50%) land use within a five-mile radius of the monitoring site, calculated from USGS Land Use and Land Cover Digital Data (USGS, n.d.). If no land use type is dominant, than the land use for the site was designated "Mixed Use". Streams in forested areas are most likely to have "Excellent" water quality and least likely to have "Very Poor" water quality. Streams in urban or range areas are more likely to have "Poor" or "Very Poor" water quality. Streams in agricultural lands exhibit a range of water quality conditions between these extremes.

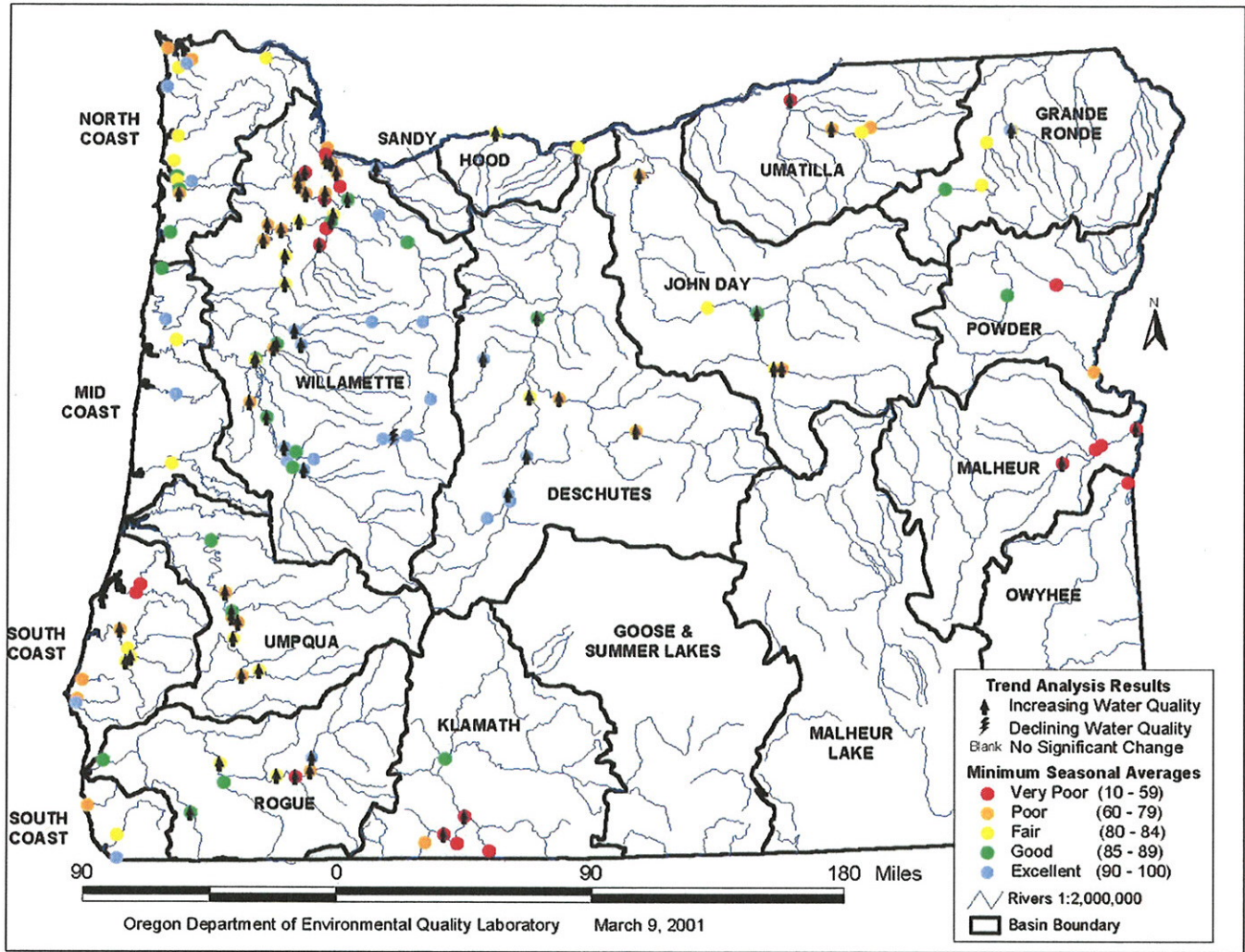


Figure 1 - Oregon Water Quality Status and Trends by OWQI, Ambient Monitoring Network, Water Years 1990-1999

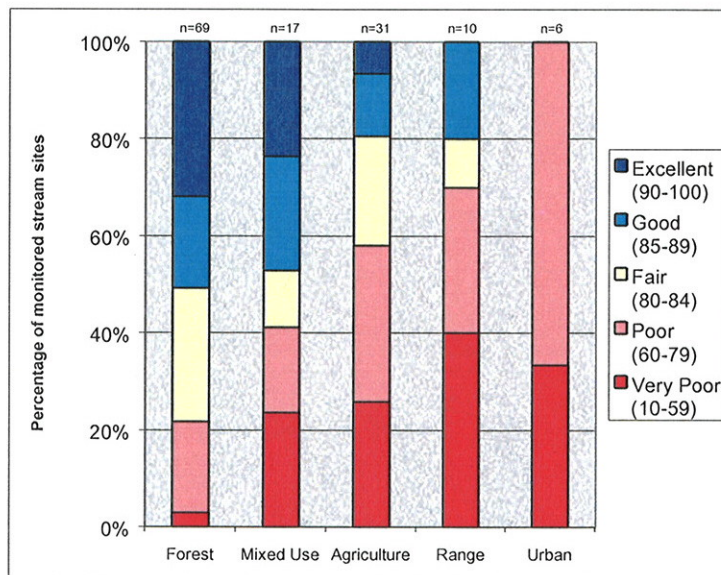


Figure 2 - Oregon Water Quality Status based on OWQI, by Land Use Type, Water Years 1990-1999

OWQI AS ENVIRONMENTAL INDICATOR

The OWQI is used as an environmental indicator in, among other publications, the Oregon Benchmarks Report (Oregon Progress Board, 1999). Environmental indicators summarize scientifically-based information on the significance of environmental conditions and trends. They can assist in communicating, consensus building, priority setting, and budgeting in natural resource areas. The Oregon Benchmarks Report monitors progress towards Oregon's strategic goals in areas ranging from the arts to public safety to the economy. The reports are published biennially to coincide with the start of the state legislative session and are used as an aid to legislators for priority setting. In the Oregon Benchmarks Report, "Percentage of stream monitoring sites with improving water quality" is contrasted with "Percentage of stream monitoring sites with decreasing water quality". These trend indicators represent the percentage of monitored stream sites with significantly increasing or decreasing trends in water quality, with respect to the total number of monitored stream sites having sufficient data for trend analysis. The next Oregon Benchmark Report will include "Percentage of monitored stream sites with water quality in good to excellent condition". This status indicator is calculated as the ratio of the number of stream monitoring sites ranked with either good or excellent water quality to the total number of ranked stream monitoring sites.

Table 1 presents Oregon water quality status and trends measured over time as an environmental indicator. The stated years represent the last water year in a ten water year period. For instance, calculated benchmark results for 1990 represent trend analyses on data gathered from water year (WY) 1981 to WY 1990. Also included, in italics, are challenging yet attainable goals for 2005 and 2010. Benchmark results are calculated annually to measure progress towards the targeted goals.

Table 1. Comparison of Calculated and Target Surface Water Quality Benchmarks

Benchmark	1990	1995	1996	1997	1998	1999	<i>2005</i>	<i>2010</i>
Percentage of monitored stream sites with significantly increasing trends in water quality	8%	21%	32%	52%	70%	64%	<i>75%</i>	<i>75%</i>
Percentage of monitored stream sites with significantly decreasing trends in water quality	20%	8%	2%	0%	1%	1%	<i>0%</i>	<i>0%</i>
Percentage of monitored stream sites with good to excellent water quality condition	27%	28%	35%	32%	37%	38%	<i>40%</i>	<i>45%</i>

Figure 1 and Table 1 show dramatic improvement in water quality throughout the state over the past several years. These improvements are at sites spanning the entire range of OWQI classifications and land use categories. The most significant gains are at monitoring sites downstream of significant point sources, primarily wastewater treatment plants (WWTPs), and in areas where water quality management plans have been implemented. There have been major efforts to reduce the quantity and improve the quality of discharge from point sources. Other sites showing significant improvement are not affected by point source discharges. Improvements at these sites may be attributed to reduced levels of non-point source activity, increased education about water quality impacts, and watershed restoration efforts. Underlying all of these factors is flow. As Oregon returns, in stages, from drought to the wet phase of the long-term cycle, flows and water quality improves.

EVALUATING WATER QUALITY MANAGEMENT EFFECTIVENESS

The Tualatin Subbasin in northwest Oregon, home to Silicon Forest, has one of the fastest growing populations in the state. The increase of high tech industries, their employees and families, and the attendant service sector have placed great pressures on water resources. Due in large part to the implementation of water quality management plans and WWTP upgrades, water quality has significantly improved during the past fifteen years, despite pressures from growth. Figure 2 presents the spatial distribution of minimum seasonal average OWQI scores (water years 1990-1999) for ambient water quality monitoring sites in the Tualatin Subbasin. Activities that degrade water quality in the Tualatin River include logging operations, intensive agricultural and container nursery operations, confined animal feeding operations (CAFOs), industrial operations, municipal WWTPs, urban nonpoint source pollution, and natural hydrological conditions. Because of the low gradient of the primary streams in the subbasin, water flows slowly. Point and nonpoint source pollution is slowly moved downstream and is not readily assimilated. Two advanced tertiary wastewater treatment plants (AWWTP) are located on the Tualatin River: Rock Creek AWWTP at river mile 38.0 and Durham AWWTP at river mile 9.6. Two smaller municipal WWTPs are located on the Tualatin River above Rood Bridge. Inspection of the individual subindices for the monitoring stations reveals very high concentrations of ammonia and nitrate nitrogen and total phosphorus. High concentrations of biochemical oxygen demand, fecal coliform, and total solids also degrade water quality. Low dissolved oxygen concentrations were seen in conjunction with high concentrations of ammonia nitrogen at all sites except the most upstream site, indicating that ammonia was scavenging oxygen for conversion to nitrate nitrogen. Water quality degradation was greater at the monitoring sites downstream of the AWWTPs. Average OWQI scores range from poor to very poor, generally decreasing from upstream to downstream.

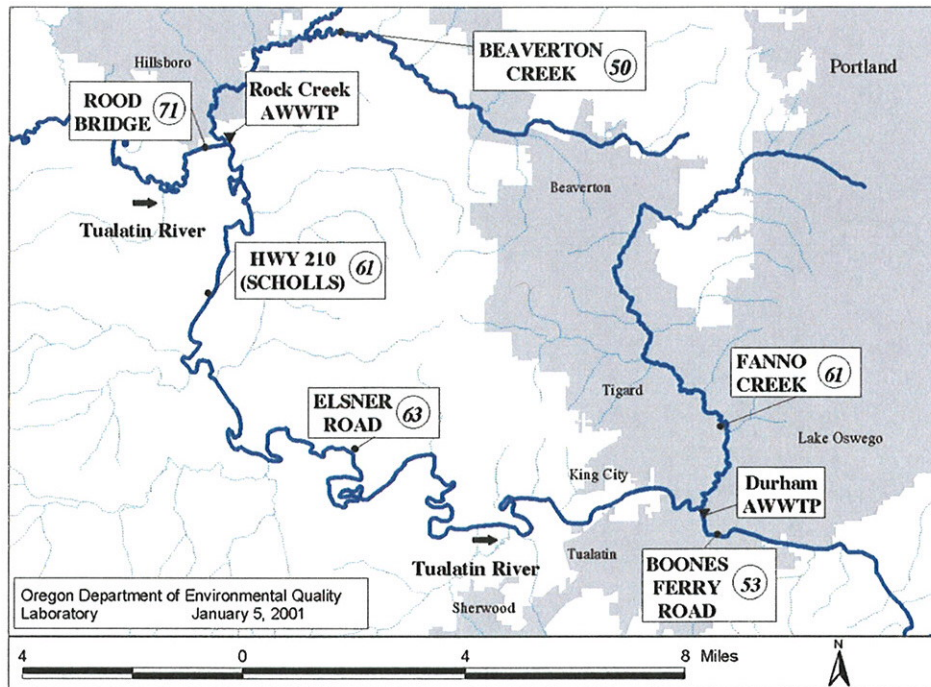


Figure 2 - Tualatin Subbasin OWQI Status (WY 1990 - 1999)

In 1988, a Total Maximum Daily Load (TMDL) was issued limiting the discharge of ammonia and phosphorus to the Tualatin River (Oregon Secretary of State, 1998). The nonpoint source water quality management plan in the TMDL required erosion control for construction activities and storm water control facilities for development. Starting in mid-1989, the Unified Sewerage Agency of Washington County, Oregon, took steps to improve treatment of WWTP effluents. The Rock Creek AWWTP began conversion of effluent ammonia to nitrate in August 1989, and began removal of phosphorus in August 1990. A basin-wide phosphate detergent ban was instituted in February 1991. By 1994, the Durham AWWTP had implemented upgrades similar to those at the Rock Creek AWWTP. Table 2 presents the analysis of water quality trends at Tualatin Subbasin monitoring sites. The Seasonal-Kendall test was performed on data for WY 1990-1999. All sites reported significant improvement in water quality at the 99% confidence level. Seasonal Sen slope (Hirsch, et al., 1982) determines the magnitude of the trend.

The Tualatin Subbasin was the first in Oregon to implement a water quality management plan as prescribed by a TMDL. Although water quality in the Tualatin Subbasin is still "Poor" to "Very Poor", and in spite of rapidly growing populations and pressures on water resources, the Tualatin Subbasin has the most improved water quality in Oregon.

Table 2. Seasonal-Kendall Trend Analysis of OWQI Values for Tualatin Subbasin, WY 1990 - 1999

Monitoring Site	Trend	Magnitude
Tualatin River at Rood Bridge	Increase	+11.2
Beaverton Creek at Cornelius Pass Road	Increase	+12.0
Tualatin River at HWY 210 (Scholls)	Increase	+17.7
Tualatin River at Elsner Road	Increase	+14.8
Fanno Creek at Bonita Road	Increase	+7.4
Tualatin River at Boones Ferry Road	Increase	+42.0

CONCLUSION

Interest groups, the public, and policy makers desire water quality information that is clear, concise, and accurately represents water quality status and trends. The OWQI identifies and compares water quality conditions and trends across space and over time. The OWQI can be used in a variety of ways as an environmental indicator. The OWQI can be used to evaluate the effectiveness of water quality management activities. Most importantly, the OWQI improves comprehension and communication of general water quality issues and illustrates the need for and effectiveness of protective practices.

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