Scientific Status of Willamette River TMDLs*

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Introduction

Total Maximum Daily Loads (TMDLs) are a regulatory management strategy to partition waste load allocations (WLAs) among various dischargers to keep concentrations within limits in the receiving water body. They are a step beyond the National Pollution Discharge Elimination System (NPDES) permitting system for point source discharges by incorporating a broader perspective. Water quality management can be improved by using a comprehensive watershed approach that reflects cumulative effects of activities within a drainage basin.

Under this new comprehensive strategy addressing water quality problems, DEQ attempts to evaluate water quality of the entire river and basin rather than whether a specific discharge meets its permit requirements. DEQ calculates pollution load limits—the TMDLs—for each pollutant entering a body of water. TMDLs describe the amount of each pollutant a waterway can receive without violating water quality standards. TMDLs take into account the pollution from all sources, including discharges from industry and sewage treatment facilities; runoff from farms, forests and urban areas; and natural sources such as decaying organic matter or nutrients in soil. TMDLs include a safety margin for uncertainty and growth to accommodate future discharges to a river or stream without exceeding water quality standards.

This discussion will focus specifically on the most recent Willamette River TMDLs for bacteria, mercury, and temperature because this is the first attempt by DEQ to define a whole-basin approach. Individual river subbasins (e.g., Tualatin) have had TMDLs prepared; eventually they will be incorporated into the whole-basin approach.

Beginning in the Calapooia Range of the Cascade Mountains, the Willamette River drains a basin between the Cascade Mountains and the Coast Range which is approximately 187 miles (303 kilometers) long and 100 mi (162 km) wide, encompassing 11,478 square miles (29,728 km^2). Approximately 70 percent of the basin is forested (largely tributary basins), about 22 percent is farmed, and the remaining 8 percent is urbanized or in other uses. Streams on the west side of the basin tend to be more sluggish, with lower base and minimum discharges and higher temperatures than streams on the east side of the basin where the influence of geology and snowpack make for more uniform temperature and flow rates.

The Willamette River is the 10th largest river in the conterminous U.S. in terms of stream flow and produces more runoff per unit of land area than any of the larger rivers. Annual average discharge at the river's mouth is 24 million acre-ft (3 million ha-m), accounting for 15% of the total flow in the Columbia River. Between 1941 and 1969, the U.S. Army Corps of Engineers built 11 major water storage reservoirs on tributaries to the Willamette River to provide irrigation water and inexpensive power and, most importantly, minimize the Willamette's damaging floods. Operation of the dams has lowered peak flows in the river during winter, and increased summer low flows, significantly altering the natural hydrological dynamics of the river. Throughout the basin there are more than 16,000 miles (25,900 km) of streams and rivers. The smallest headwater reaches and ephemeral channels are not shown on topographic maps so it is difficult to calculate an accurate total length.

The size of the basin, the length of streams and rivers draining it, and limits of budget and personnel restrict the quantity of data available for DEQ to apply to regulatory and compliance decisions. These are the fundamental science aspects that affect the quality of the current state of TMDLs in Oregon. This raises the question of numeric modeling as a tool for generalizing insight gained from limited data. If a model is sufficiently general to accommodate all the variability within 16,000 miles of streams and rivers draining 11,500 square miles of land surface, then it is not sufficiently specific to apply to any one point or stream reach. Similarly, if a numeric model is constructed to realistically represent the physical, chemical, biological, or ecological dynamics of a specific reach (for example, an stream adjacent to two agricultural fields, or the immediate vicinity of a POTW[1], then it is not applicable to an entire river system and the basin it drains. The generic model requires fewer and less detailed data for input and can make broader assumptions about coefficients and rate variables; the specific model requires more data to produce results that track the real world. This is an inherent limitation of numeric models. It also places restrictions on the strength of regulatory decisions based on them.

Bacteria

There are four science concerns with the bacteria TMDL proposed in the draft document:

1. Where and when the numeric criterion is not met.
2. Data adequacy based on spatial and temporal variables.
3. Determination, assignment and value of reduction amounts from non-point source lands along tributaries.

[1]Publicly Owned Treatment Works; that is a Sewage Treatment Plant.

4. Suitability of QUAL2E as a model for the entire Willamette River system.

Location and Timing of Non-Compliance

The bacterial indicator species is *Escherichia coli*, which replaces the broad category of "fecal coliform bacteria" which used to be the pollution indicator. According to page 2–3 in the draft TMDL document, water runoff from agricultural lands are a nonpoint source of the bacterium. The loading capacity of 126 organisms per 100 milliliters of water is accepted as the threshold for human recreational contact. The nonpoint source load allocations are expressed as the percentage reduction necessary to achieve the target concentration.

On page 2-2 we read, "[v]iolations are common in creeks that drain urban and agricultural land and discharge to the Willamette River," and that the "2002 303(d) list identified river miles (RM) 0 to about 149 of the Willamette River as not attaining the applicable bacteria criteria . . . during fall-winter--spring months." But, we also read, "[o]bserved fall-winter-spring water quality violations in the Willamette River above Willamette Falls are very subtle, and are limited to rare violations of the single-sample maximum concentration at a few sites."

"Violations are common" is inconsistent with "violations are subtle and rare." Most of the mainstem river was listed as out of compliance with the bacterial water quality standard in 2002, but above the falls violations are rare both spatially and temporally. Do rare violations at a few sites justify listing on the bi-annual list of quality impaired waters? This inconsistency needs to be resolved. It may be related to the adequacy of data upon which decisions are made. The situation is not clarified by the statement on page 2-5 that, "[v]iolations near the mouth of the river occurred in approximately 30 to 40% of samples, while violations decreased to 12% of samples at river mile (RM) 131 near Corvallis." The frequency of upriver violations—12 percent—is not what is usually considered as "rare."

It is also difficult to comprehend how bacterial count violations above Willamette Falls can be "very subtle." Numeric thresholds define crisp sets. If the count of *E. coli* is less than 126 per 100 milliliters of water then the sample is in compliance with the bacterial standard. If the count is greater than 126 organisms per 100 milliliters of water then the sample is not in compliance with the standard. The TMDL does not explain what is subtle about that.

There is also inadequate justification for having listed RM 0–149 on the mainstem Willamette River as non-compliant with the bacterial water quality standard if the violations are common in the tributaries but the bacterial concentrations are diluted by the confluence of tributary waters with the mainstem river.

From the science perspective, these inconsistencies and subjective language weaken the rationale that there is a bacteriological problem in the Willamette River system that requires calculation of a TMDL and compliance enforcement with partitioned waste load allocations.

Data Adequacy

Page 2-9 of the draft TMDL reports that bacteria samples have been collected at 10 stations along the mainstem Willamette River since 1996. These locations are presented in Figure 2-2 and form the basis for the following discussion.

DEQ reasoning on the distribution of bacterial counts that exceed the numeric standard does not follow from the location of the sampling stations. Other than the station at RM 161.2 the bacterial sampling locations are located upriver from a municipal POTW outfall. In addition, with the exception of the station at RM 165.3 these locations also capture urban runoff and water transported down river along the main channel. Only the site at RM 34.4 (Canby) is immediately downriver from the confluence of a major tributary (the Molalla/Pudding Rivers, in this case). Adding to the technical insufficiency upon which a regulatory decision for a TMDL was made, Figures 2-1 and 2-2 differ in the extent of bacterial non-compliance in the river.

No sampling location is at the mouth of a major tributary so it is difficult to follow your reasoning that the tributaries carry bacterial concentrations above the numeric criterion. Location of sampling stations only along the mainstem Willamette River does not provide sufficient data on bacterial loads in various tributaries at different seasons. And, with the most up-river, mainstem station at RM 131.4 there is no rationale for continuing the red marking on Map 2-1 of 303(d) limited waters beyond the confluence of the Long Tom River.

There are fiscal constraints in establishing sufficient locations along 187 miles of river, and taking samples at frequent and consistent time intervals. However, the limited data raise concerns regarding the conclusions drawn from a highly limited, not-well-dispersed set of data collection locations.

The scientific basis for a bacterial TMDL for the Willamette River system would be enhanced by a discussion of the sampling protocol used at each site. The river is too wide and deep to wade at each of these locations so it would be very useful to know just how samples were collected. For example, was a "sample" pooled from multiple points across the width of the channel? Were samples that of surface water, an integrated depth sample, or taken at 60 percent of the depth (a standard rheological location assumed to represent the water column at that point for most streams and rivers)? What volume of water represents a sample? Since each location was sampled only once per month (or every other month), justification for the number of samples taken at each visit, and their ability to fairly represent the cross-section and discharge dynamics of the river at that location are important in interpreting the numbers produced.

On page 2-9 we read in the section on fall-winter-spring data that "the 10 stations with sufficient data were ... analyzed." This statement needs explanation. There are only 10 stations and all data are presented in Figure 2-3, so which stations or data were not analyzed? There appears to be more data points incorporated into Figure 2.3 than are incorporated into the summer plot, Figure 2-2.

The first paragraph in the same section reports that data suggest the entire river is in compliance with the numeric criteria during the non-summer months. Page 2-12 repeats this conclusion that water quality criteria are met most months at most stations during the period of record. These are inconsistent with the statement earlier in the chapter that the river is out of compliance during these same months. It is also puzzling that the collected data "were not able to capture certain patterns in bacterial concentrations." If the patterns could not be captured, how does DEQ know that those patterns exist? Further, if monthly or bi-monthly sampling intervals are too coarse then TMDLs based on those data cannot be supported as reasonable and prudent.

The two issues of where/when data were collected and the adequacy of those data to support regulatory decisions need to be better addressed in the TMDL document for the Willamette River system.

Tributary Nonpoint Source Runoff

On page 2-3 of the draft Willamette River bacterial TMDL the nonpoint sources load allocations are "expressed as a percent reduction necessary to meet the numeric criteria." However, on page 2-13 also states,

> "There were no reported violations in ODEQ data during summer in the entire river through the period beginning in 1996 to present. ODEQ data indicate rare violations of the single sample maximum criterion (406 MPN/100 milliliter) and **no violations of the geometric mean criterion** (126 MPN/100 milliliters) in recent years in the fall-winter-spring period above Willamette Falls." (Emphasis added.)

This raises the question of what percentage reduction is required to meet the geometric mean criterion and how can one predict—and, therefore, prevent—the rare single-sample criterion violation?

In several places within Chapter 2 the Department writes that a lot of the nonpoint source bacterial load is transported to the mainstem river by tributaries, but there is no explanation how this conclusion comes from the presented data. The sampling locations are neither on tributaries nor surrounding the confluences of tributaries with the mainstem river.

The Water Quality Management Plan (Chapter 14) repeats that nonpoint source load allocations will be reduced via specified management strategies in order to meet designated criteria. For agricultural lands the Oregon Department of Agriculture (ODA) is the designated management agency and acts via the Senate Bill 1010 water quality management plans. The reader does not know what this means to those sectors of the agricultural industries within the Willamette River basin because the presented data indicate that the upper river meets the bacteria concentration criteria all year with the rare and unpredictable single-sample spike. There is nothing in the ODA 1010 plans that can predict these rare spikes, nor is there a mechanism that uses DEQ sampling locations and time intervals to document that the agriculture community is not causing *E. coli* bacteria concentrations to exceed determined limits at any place or time.

Suitability of the QUAL2E Model

While the "E" version of this model was replaced in 2004 by the "K" version, most of the core functionality is the same. The discussion of the application of this model beginning on page 2-14 raises a number of questions which need to be answered and incorporated into a final Willamette River TMDL A useful reference to learn about this water quality model is located at `http://www.epa.gov/athens/wwqtsc/html/qual2k.html`; and related sites on the World Wide Web that can be found searching with Google.

The QUAL2E model is one-dimensional; it assumes the channel is well-mixed both vertically and laterally. Such simplification may be appropriate for a very coarse initial screening, but not for the purpose of setting regulatory thresholds. The mainstem Willamette River is sinuous and has a well-defined *thalweg*[2]. In these reaches the flow velocity is much higher in the thalweg but much lower along the opposite bank. This flow difference results in the creation of lateral and point gravel bars along the river bank. Such vertical and lateral differences in flow sort sediments by weight which is an indication that the waters are not well-mixed for dissolved chemicals or bacteria, either. Then there are major morphometric changes such as the 30-mile long Newberg Pool which is much deeper than the river further south, and Willamette Falls which certainly does provide a mixing action to water-borne constituents as they flow from higher to lower elevation at this location. The mainstem also has backwater sloughs, eddy currents on the downriver side of large woody debris and other large obstructions in the channel, and the confluences of tributaries. The non-uniform, non-well-mixed nature of the river is acknowledged by the designation of a "mixing zone" for point source discharges. In summary, the assumption of vertical and lateral uniformity is an over-simplification not suitably rigorous for setting load allocations, particularly for nonpoint source reaches along tributaries or the mainstem of the river.

QUAL2E also segments the river system into equally-sized reaches. This results in reach calculations that do not account for changes in slope, sinuosity, width, tributary inflow or other fluvial geomorphic variables. The uniform-size reach works well with the steady-state hydraulic assumption that the flow is steady but not uniform longitudinally. Again, these coarse assumptions are adequate for initial screening decisions but they are not sufficiently robust to support load allocation decisions.

DEQ should clarify the statement on page 2-14: "Given the model is steady-state a reasonable worst case scenario was developed." First, what has non-uniform, steady flow to do with worst case scenarios? Second, how does a "reasonable worst-case" differ from an "unreasonable worst-case?" Such imprecision results in uncertainty and unpredictability by the regulated community in demonstrating compliance with all water quality criteria under the TMDL water quality management plan.

Continuing discussion of model application, we read that the Department's

[2]The deepest part of the channel with the highest flow velocity. Located at the outside of meander bends and crosses the channel between bends.

"ambient monitoring network provided *E. coli* data for tributaries and the main stem calibration sites," but Figure 2-2 shows a total of 10 sites all on the mainstem of the river and none on tributaries or at the confluences. The same map does not show the stations that are "near the mouths of rivers." There is a definite need for more comprehensive maps and tables that indicate the full extent of the ambient monitoring network and data collection frequencies and specific locations within the channel. The text of the document continues by stating that the monitoring network is distributed across the entire state but does not explain how these data in other basins are relevant to TMDL determinations within the Willamette River drainage.

Considering the four areas of scientific concern, the current state of the bacterial TMDL for the Willamette River system is not sufficiently healthy to be considered technically sound.

Mercury

From the scientific and technical perspective there are serious difficulties associated with sampling metallic and organic mercury, particularly when concentrations are near the lower detection limits. There area also difficulties associated with partitioning total amounts by their particular sources or locations. Therefore, the Department's caution in developing controls or numeric criteria is both warranted and technically sound.

Future Sampling

Given the difficulties and uncertainties of defining sources, pathways and methylation processes within the entire Willamette River basin, the identification of sampling locations and frequency in Chapter 3 needs to be better defined. DEQ may continue to use the existing 18 sampling stations or add more locations so as to refine the spatial resolution of the data. Sampling frequency should be increased from once per quarter to monthly (or semi-monthly) to better capture the flow regime and its variation over the next four years. In brief, it would be beneficial to the affected public to learn in advance how the Department plans to overcome some of the current data limitations. The next interim TMDL, in 2009, should be more confident of mercury dynamics within the basin than is the current version.

Temperature

A lot of time and effort went into examining many variables and finding input data to the CE-QUAL-W2 model used for water temperature. Many comments on the first draft TMDL document focused on this element. Early in 2006 revisions to the temperature chapter were released for public review and comment. The two aspects revised are the use of different flow data to determine the river's capacity for assimilating heat and a new method for determining temperature limits for wastewater discharges to the river.

Changing physical parameters of the model put the focus on how well the model predicts the physical environment of the river. However, the reason for designating temperature as a water quality factor that requires compliance standards and management via a TMDL is the biology of fish, specifically cold water anadromous salmonids in the Willamette River system that are listed as threatened under the Endangered Species Act (ESA). Therefore, the major scientific deficiencies of the temperature TMDL are:

- The lack of linking measurements and model outcomes to salmonid fish distribution and behaviors.
- The exceptional difficulties in relating fractional-degree changes of a 7-day average of maximum daily water temperatures to the aquatic biota.
- The problems associated with applying model results in a regulatory environment.

DEQ needs to incorporate knowledge from qualified fish biologists, stream ecologists, and fluvial geomorphologists as the document is revised during the next three years. One important principle to keep in mind is that statistical significance does not always reflect biological significance. With regard to this principle, water temperature may not be a limiting factor for salmonid populations in the Willamette River. A numeric standard might be exceeded but have no influence on the number of fish nor their vigor individually or as populations.

Model Use

One of the serious problems associated with the use of complex numeric models is producing output for factors that the model can simulate even if the real world will not support the effort. The most glaring example of this in the draft TMDL is the discussion of channel complexity (pages 4-80 ff). This section begins with the statement that any relationship between channel complexity and surface water temperature is only a hypothesis. This is true, and immediately raises the question of why it is included in the draft TMDL. Just because CE-QUAL-W2 has the capability to include a channel complexity component in simulations is not sufficient reason to use it on the Willamette River system. Furthermore, the physical space, state budget and social will to restore sufficient channel complexity to the river system is essentially non-existent. We do not know if channel complexity is related to surface water temperature and we are not going to recreate a braided-channel system such as existed in 1850 or 1895, so the Department should not have bothered modeling the variable and spending the time and effort to write it up with illustrations.

Another way that numeric models seduce us into releasing our mental grip on scientific reality is by the number of significant digits they provide in the output values. Consider Table 4-11 (page 4-66). The table shows increases of a few thousandths of a degree in the mainstem river if the tributary has a 0.3^oC rise in temperature. These data are meaningless; they contain no usable information that leads to knowledge and understanding, particularly in a regulatory context.

It is not even a difference of $0.001 - 0.5^oC$ at one place and time, but the calculated difference in the mean maximum daily temperature over a moving window of 7 days. While such a small change can be calculated, it has no biological meaning to the fish and their use of the river. Fish will not notice such a minor change in the moving 7-day average of maximum daily temperatures in the overall river system, particularly since the daily temperature range in small streams can be as high as 6^oC.

Two other considerations from the real world intrude on the model's results. One is the behavioral dynamics of salmon in the mainstem Willamette River and its tributaries, the other is how the Department measures water temperatures to determine compliance.

Fish Population Dynamics

The multi-agency efforts to collect adequate and suitable data for the CE-QUAL-W2 certainly makes for higher quality results. However, there are some contradictions and apparent lack of connections between collected data and fish that ought to be resolved as soon as practical.

On page 4-4 we read, "...that the Willamette River and its major tributaries exceed the temperature criteria for a number of months in the summer and early fall." This is an overly-broad statement that does not reveal whether or not this has any meaning for listed salmonids in the system. Where are fish located during this period? Are they in the small tributary streams where eggs hatched and alevins, fingerling's or fry are reared? Are the fishes found in the larger tributaries and main stem Willamette River only when actively migrating toward the ocean? Research has been conducted by both ODFW and a private consultant[3] on salmonid diurnal use of the main stem in the mid-reaches of the mainstem Willamette River. The results obtained by the Department and by the consultant differ because of when they went looking for fish.

ODFW biologists would seine juvenile salmonids only in off-channel refugia, under cut-banks and hidden in pools in back-water areas, not in the main channel of the river. They worked only during their regular, daylight hours. The consultant, on the other hand, began sampling around sunset and discovered more fish in the main channel than in off-channel areas shortly after that time. The fish were actively feeding and migrating at night while avoiding predators and higher water temperatures during the day. The nocturnal behavior of the juvenile fish has as much to do with feeding (if not more) than temperature. The aquatic insects which are the food resource for these young

[3]Chip Andrus, Water Works Consulting, Independence, OR

fish drift downstream with the current in the main channel starting about one-half-hour after sunset. There is another peak in numbers around midnight on nights with a full moon. This is a normal population response of the insects and why the salmonids feed then: their food is more easily captured with a lower energy expenditure than having to hunt for insects. The behavior of the juvenile salmonids was synchronized with the behavior of their invertebrate food base. The implications for water temperature TMDLs should be clear: if the fish are not present in those specific areas where the water temperature exceeds the standard, then they are not at risk. While this is acknowledged in the temperature standard criteria, it is easy for it to become lost in the complexity of compliance decisions of the TMDL.

This is why the last sentence in that paragraph, "Slower moving streams warm up faster than faster moving streams because the water is exposed to more solar warming over the same amount of time", makes no sense in the context of the main stem of the Willamette River and its larger tributaries. How slow is slow? What is faster? Where, within the Willamette River, does this statement apply? These are questions of scientific relevance that need to be addressed in the Willamette River temperature TMDL.

There is an error in the following paragraph (pages 4-4 and 4-5) discussing the main stem river temperature effects of dam operations. Before the dams were constructed the river hydrograph would show annual low flows in late summer which coincided with higher water temperatures. The hypolimnetic (bottom layers) release of waters from the dams during late summer results in both higher flows and cooler temperatures than would be found without the dams. The combination of altered hydrograph and temperature caused the fishes to change their behaviors, too. That fish are still using these reaches and successfully migrating downriver and into the Columbia River testify to the high degree of adaptability exhibited by anadromous salmonids.

Water Temperature Measurements

The approach to setting waste load allocations for the nonpoint source reaches of river are dependent upon a surrogate technique of potential shading, and were modeled using System Potential 1. One of the interesting statements on page 4-6 is the predicted temperature reduction in the main stem of the river if full potential shading is realized: perhaps 1^oC in the upper reaches and less than 0.5^oCdownriver from Albany.

First, in relation to the discussion of diurnal fish behavior presented above, it is not reasonable to expect changes of $< 0.5 - 1^oC$ in the average *maximum* water temperature over 7 days to have biological significance.

Second, from the perspective of enforcement of the temperature waste load allocation it is important to consider how monitoring is done by DEQ at ambient monitoring locations. We assume that any additional sites for TMDL compliance would use the same techniques. These procedures are defined in the DEQ Laboratory Division/Watershed Assessment Section's Mode of Operations Manual (MOM), version 3.1 (03-LAB-0036-SOP, dated March 2004).

Water sampling at larger reaches of tributaries and the main stem river is done from highway bridges using a pair of stainless steel buckets attached to ropes. The paired buckets are thrown from the bridge, allowed to fill with water and retrieved. A portable meter is used to measure the temperature. However, that measurement represents an undefined grab that could be from the surface, some distance below the surface or anything else. It is not consistent from place to place or time to time. While this is perfectly satisfactory for coarse screening of water quality when the check is for highly unusual values, it does not inspire confidence that calculations of 7-day average maximum daily temperature differences of 1^oCor less have any biological or ecological meaning. Certainly they are completely inadequate for supporting either regulatory action or determining whether or not any activities are changing water temperatures meaningfully from the point of view of the fish.

Conclusions

A very large amount of time and effort went into developing and validating the CE-QUAL-W2 model for the Willamette River system. The correlation between measured temperatures and predicted temperatures is impressively close. Unfortunately, it appears that the staff who worked so diligently on this TMDL did not check their assumptions with the reality of fish behavior and the pragmatic details of the continuing monitoring program that will be used for regulatory compliance among potential temperature input from point or nonpoint sources. The quality of the Willamette River temperature TMDL can be improved if DEQ coordinates their work with ODFW to bring into analyses and policy decisions information about fish use within the system.

About The Author

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