Bull Run River

Water Temperature Evaluation

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Preface

Report Purpose

This report is intended to provide supplemental information to Oregon Department of Environmental Quality (DEQ) for consideration in revision of the preliminary draft Total Maximum Daily Load (TMDL) for the Sandy River. The report is also meant to explain the City's analysis of water temperature in the Bull Run River and to outline a proposal for compliance with the Oregon water temperature standard.

This report was developed for DEQ staff already familiar with the City's temperature models and data sets. Only summary information is provided. This report is not intended to be a comprehensive description of the City's water temperature work since 1997.

Report Organization

This report is divided into five parts. These are:

(1) Overview of the Bull Run River system and its historical and current beneficial uses;

(2) Description of the modeled "natural temperature" conditions on the lower Bull Run, that is, temperature conditions assuming no human influences on the system;

(3) Presentation of the effects of the City's water supply infrastructure and operations on the natural Bull Run temperature regime, assuming a "worst case" of no instream releases of reservoir water below the City's water supply intake;

(4) Summary of the experimental releases the City has done since 1997 and an explanation of what the City learned about temperature dynamics in the Bull Run River; and

(5) Explanation of the City's proposed compliance strategy, and description of what the City believes can be achieved with an initial phase of operational changes and a second phase of infrastructure improvements.

Executive Summary

The Bull Run River is a tributary to the Sandy River, which flows into the Columbia River at Troutdale in Northwest Oregon. Bull Run is the primary source of drinking water for the City of Portland (City) and substantial portions of the Portland metropolitan area. The lower reach of the Bull Run River (the 6.5 miles of the river below the City's water supply reservoirs and above the confluence with the Sandy River) does not meet state water temperature standards and is included on Oregon's 303(d) list. Oregon Department of Environmental Quality (DEQ) has under development a Total Maximum Daily Load (TMDL) for the Sandy River watershed, which includes an analysis of the temperature conditions in the Bull Run.

In cooperation with DEQ, the City has conducted extensive data collection, modeling analysis, and water system operational investigations in an effort to better understand the temperature circumstances in the Bull Run River and to seek ways to reduce Bull Run water temperatures. The modeling has been conducted in conjunction with Portland State University, specifically Dr. Scott Wells and Rob Annear. This report represents a summary of that work to date.

As the report will explain, the City has reached several preliminary conclusions:

1. Under natural, undisturbed conditions, temperatures in the lower Bull Run River on a regular basis would have exceeded the regulatory numeric temperature criteria applicable to the designated beneficial uses of the Bull Run River.

2. By managing flow releases in the summer below its reservoirs, the City can substantially improve temperature conditions in the lower Bull Run River beyond the conditions that would prevail if no water was dedicated to instream use. For several years, the City has experimented with various release regimes and has data to demonstrate the improvements.

3. It does not appear possible, given the design of the current water system infrastructure, to alter operations sufficiently to meet either the state numeric temperature criteria applicable to the lower Bull Run or to achieve temperatures comparable to what would be expected under "natural conditions."

4. Further improvements to lower Bull Run temperatures could be achieved if the City changed the design of water intake structures and altered operations to take advantage of those infrastructure changes. The City believes it should be possible to achieve "natural conditions" temperatures with those infrastructure changes in place.

Section 1. Introduction

The Bull Run River and Associated Water Development

The Bull Run River is a tributary to the Sandy River (Figure 1). The Bull Run flows more than 20 miles from its headwaters to the confluence with the Sandy River. The Bull Run watershed is approximately 140 square miles and comprises approximately 30 percent of the land area of the Sandy River Basin. The Little Sandy River is a tributary of the Bull Run River.

In 1895, the City of Portland began diverting water from the Bull Run River for municipal purposes. The diversion location has remained the same since 1895. No other water diversions from the Bull Run River exist upstream of the Little Sandy River, and the City holds all water rights.

In 1921, the City built a diversion dam at its headworks location, thus blocking all further anadromous fish migration above Bull Run River Mile (RM) 6.5. In the ensuing decades the City built two large storage reservoirs and an outlet structure at Bull Run Lake. Dam 2, built between 1958 and 1962, is located just above the diversion dam at RM 6.8. Dam 1, finished in 1929, is located at RM 11.5. Together, the two reservoirs provide about 17 billion gallons of storage, of which about 10 billion gallons is useable for municipal purposes. Bull Run Lake lies at the river's headwaters, at approximately River Mile 25. It can be used occasionally (subject to environmental protection requirements in a USDA Forest Service easement) to supplement the main reservoir supplies with 1-2 billion gallons of water.

The lower Bull Run River historically has also been affected by the operation of a hydropower project currently owned by Portland General Electric (PGE). Since about 1912 PGE and its predecessor have diverted water from the Sandy River (at Marmot Dam) and the Little Sandy River and transported it via tunnel and flume to Roslyn Lake. The water from Roslyn Lake is used to generate hydroelectric power and is then discharged to the Bull Run River at RM 1.5. PGE has submitted paperwork to the Federal Energy Regulatory Commission necessary to decommission its Bull Run project. By 2008 Marmot Dam and the diversion dam on the Little Sandy River will be removed, and Roslyn Lake will be decommissioned. A significant result will be that the Little Sandy will become a free flowing stream, and Sandy River water will no longer be discharged into the lower Bull Run River.

Current and Historical Anadromous Fish Use of the Lower Bull Run

Currently, there are several species that use the lower Bull Run River. Three of these species are listed under the authority of the federal Endangered Species Act (ESA): fall Chinook, spring Chinook, and winter steelhead. Figure 2 presents the life stages and uses for steelhead and Chinook salmon in the lower Bull Run River. In this system, fall Chinook spawn after mid-October, spring Chinook spawn mostly in September and October, and winter steelhead spawn from March to early May.

A number of surveys conducted in the lower Bun Run River between 1973 and 1977 confirm that the fish species present now were also present at that earlier time (USFS 1974; USFS 1975; City of Portland 1977). The mid-1970 surveys indicated the presence of rainbow trout (probably steelhead), cottids, lamprey, and Chinook salmon in the lower Bull Run River.

Historical and Current City Water Supply Operations

Until the mid-1990s, the City operated its system to retain all inflow into the reservoir after summer "drawdown" began. That is, no instream flows were released downstream of Reservoir 2 after the annual date (typically early July) when water diversions for municipal supply exceed reservoir inflows. During the summer drawdown season, Portland relies on Bull Run reservoir storage for a significant portion of the water supply. As the summer proceeds, reservoir surface elevations drop progressively lower.

Since initial experimental releases began in 1997, the City has released water during the summer months to the lower Bull Run River, both to improve fish habitat conditions and to study how best to operate the system for that purpose. Water release decisions take into consideration the following key factors (PWB 2003):

- Spring: Steelhead spawning and reservoir filling
- Summer: Reservoir drawdown, water temperature, and groundwater operation
- Fall: Chinook spawning and reservoir refill forecasting

River Reaches of the Bull Run River

The Bull Run River can be divided, for analytical purposes, into three reaches:

1. RM 0 to RM 6.5—Relatively moderate gradient; lower reach below all reservoirs
2. RM 6.5 to RM 15.5—Relatively low gradient; middle reach containing Reservoirs 1 and 2
3. RM 15.5 to RM 20.3—Relatively high gradient; upper reach above Reservoir 1

Figure 3 shows the longitudinal profile by river mile and Table 1 provides summary information on slopes and channel characteristics for each of these reaches.

The City's studies of temperature focus on part of the lower river (RM 1.5 to RM 6.5). This is where municipal supply operations have the largest influence on downstream water temperatures. Summertime flows in this reach are governed almost exclusively by the amount of water released from Reservoir 2. In addition, this reach is the only location on the Bull Run River where salmonid spawning and rearing have occurred since 1921, when the construction of the headworks diversion dam precluded upstream fish passage beyond RM 6.5.

Water Quality Criteria and Beneficial Uses of the Bull Run

In early 2004, Region X of the U.S. Environmental Protection Agency (EPA) approved Oregon's revised water quality standards for temperature. According to the new standards, the designated use for the lower Bull Run River is core cold-water habitat. Core cold-water habitat is defined as "waters that are expected to maintain temperatures within the range generally considered optimal for salmon and steelhead rearing… during the summer" (OAR 340-041-0002(13)).

Application of the core cold water habitat designation to support spawning in the lower Bull Run River is further broken down into two geographic reaches (Figure 4, spawning periods shown as color codes):

- RM 0 to RM 5.3 - Salmon and Steelhead Spawning from August 15 through June 15
- RM 5.3 to RM 6.5 - Salmon and Steelhead Spawning from October 15 through June 15

Temperature standards to support juvenile rearing apply when the stricter spawning standards do not apply.

Translated into numeric criteria, the water temperature standard requires that the lower Bull Run River meet the standards outlined in Table 2. DEQ's rules also provide that if natural conditions in a stream exceed the biologically-based criteria, the natural condition temperatures become the temperature criteria for the water body. As the City's modeling demonstrates (see Section 2), the natural thermal potential of the lower Bull Run exceeds the numeric criteria.

Section 2.
What were the pre-project (natural) temperature conditions in the lower Bull Run River?

No pre-project river data are available to document natural temperature conditions in the Bull Run River system. Therefore, the City has relied on a series of numerical models using CE-QUAL-W2 (a two-dimensional hydrodynamic and water quality model) originally applied by Portland State University to the Bull Run reservoir system (Annear et al., 1999). These models were used to predict the natural temperature conditions in the lower Bull Run River.

Four CE-QUAL-W2 models, or model components, were created to evaluate the Lower Bull Run (see also discussion of regression model in Section 3). One model represents the upper river reach (as far upstream as the confluence of the Blazed Alder and Bull Run rivers), another model simulates the middle reach system (including the existing two reservoir system), and a third model simulates the middle reach assuming a "free-flowing" river. A final model was developed to represent the lower river reach. Table 3 summarizes attributes used in the model(s) for each reach.

In running the model and judging the output from the models, the focus has been on what is known as the Larson's Site. (Model results reported within this analysis will typically be for the Larson's site.) Larson's Bridge is located at RM 3.8, where data indicate that temperatures typically reach their highest in the lower Bull Run River. The City and DEQ have concurred that temperatures at Larson's Bridge should be used both to identify and characterize the water temperature challenges on the lower Bull Run River.

Data from 2001 are the basis for the model calibration for three primary reasons: (1) the data coincide with DEQ's FLIR and Heat Source analyses in 2001; (2) the City's model development occurred about this time so the recent data were the most readily available; and (3) a subsequent comparison of five years of recent data (1996-2001) indicates that 2001 was the driest of those years and thus challenging for water temperature management.

Modeling to Characterize Natural Conditions

Modeling of natural conditions required a description of pre-project stream channel characteristics. It is impossible, however, to measure most of those stream channel characteristics through the reservoir reach because the streams are inundated and no longer exist. Therefore, to estimate the historical characteristics, data from free-flowing sections were extrapolated to predict river conditions without the reservoirs. The City and PSU undertook considerable efforts to characterize model inputs including stream geometry (width, depth, and length of pool and riffle sections), shading (solar pathfinder estimates of incident radiation, gray card shading estimates), and vegetation characteristics (vegetation height and offset). Beak (1998) and Leighton (2001 and 2002) provide data from field studies.

A number of conditions were simulated to characterize estimated input parameters. Table 4 provides a range of values applied to the key modeling variables: wetted widths, Manning's *n* values, tree heights, and meteorological stations. Each of these variables is discussed in more detail in Attachment A. Attachment A also provides a graphical summary of various model outputs to show the sensitivity of each model input variable at the Larson's site, and presents the alternative choices that City modelers considered but chose not to use.

For the purpose of assessing the suitability of these model inputs, diurnal modeling results for the Bull Run River system were compared against diurnal data from the Little Sandy River. As discussed in detail in later sections of this report, it may not always be appropriate to compare Bull Run River values with the Little Sandy River measurements. However, such a comparison is helpful for evaluating model performance of diurnal fluctuations. Figure 5 suggests that modeling using wider wetted widths and high Manning's *n* values for the Bull Run tend to provide the best agreement with the Little Sandy River for diurnal fluctuations.

Once inputs were chosen and the model was calibrated, the model was used to "predict" what natural temperatures would have been, without the City projects, given the meteorological conditions of 2000 and 2001 (the data sets available when the natural conditions analysis was done). The natural conditions predicted for those two years can also be compared to actual conditions (measured by City data collection) and to "worst case" conditions (conditions had there been no flow releases from the City projects).

Model Results for Natural Conditions

Downstream Variations within Bull Run River

The CE-QUAL-W2 model predicts that, in the absence of the project, the highest elevation station (at RM 15.5 above Reservoir 1) would have the coolest temperatures in the Bull Run River system (Figure 6). As the river flows downstream, the warmest conditions would occur where the river gradient is lowest and the river widths are widest, and where it flows in an east-west orientation.

In addition, warmer temperatures are predicted where large cooling tributaries are absent (between RM 10 and 8.2). For example, maximum water temperatures exceeding 23°C were predicted just above the South Fork confluence (RM 8.2), while the South Fork tributary inputs cool the maximum daily water temperatures by over 2°C between RM 8.2 and RM 6.5.

By the time the river flows past the Larson's site (RM 3.8), temperatures are predicted to increase by <1°C to 2°C above temperatures predicted at RM 6.5. Groundwater return flows in this reach do not appear to mitigate this warming trend. Downstream of Larson's site, the canyon narrows and more shading helps keep temperatures from continuing to rise.

Comparison to Numeric Criteria

Predicted natural temperatures at Larson's site (RM 3.8) are plotted in Figure 7 and compared against the current numeric criterion. During the rearing season (through August 14th), predicted average natural conditions in the lower Bull Run River are 0.7°C cooler than the rearing criteria of 16°C (both expressed as a 7-day average maximum). In contrast, during the spawning season (from August 15th), predicted average natural conditions in the lower Bull Run River are 1.4°C warmer than the spawning criteria of 13°C (again, both expressed as a 7-day average maximum). Pre-project natural water temperatures in this system consistently exceed state spawning criteria from mid-August through late-September. Over the summer period, predicted natural conditions are an average of 0.4°C warmer than the statewide criteria.

Comparison to Little Sandy River Temperatures

Predicted natural temperatures in the Bull Run River are also compared against measured conditions from the Little Sandy River (collected at the USGS gage in the Little Sandy River for 2000 and 2001) in Figure 7. This comparison is intended to help confirm the appropriate CE-QUAL-W2 model inputs, particularly for diurnal fluctuations, and to provide some context for interpreting predicted natural temperatures.

Similar to the Bull Run River, the Little Sandy River has a predominantly east-west orientation that exposes the river to strong solar radiation during the day (Figure 8). However, the Little Sandy River watershed is much smaller than the Bull Run River (in terms of elevation change, drainage area, and length), and summer flows are only 15 to 20 percent of estimated natural flows in the Bull Run River (Table 5). Thus, predicted natural temperatures in the lower Bull Run River will not be exactly the same as the measured temperatures in the Little Sandy River.

Figure 7 shows that during the rearing season (through August 14th) predicted conditions in the lower Bull Run River are 1.1°C cooler than Little Sandy River temperatures. In contrast, during the spawning season (from August 15th), the predicted average natural conditions in the lower Bull Run River are 0.2°C warmer than Little Sandy River temperatures. Predictions using 2000 and 2001 meteorological data show the maximum differences between the lower Bull Run simulated natural temperatures and the Little Sandy River measured temperatures are within 2°C (Figure 9). In early August, the difference is typically less than 1°C. From early September onward into the fall, predicted water temperatures in the lower Bull Run are slightly higher (around 1°C) than the Little Sandy measured values. The variation in differences throughout the summer period (Figure 9) can be attributed to the following:

- In late June and early July, the sun angle is high with limited shading. Given the effect of cool air temperatures in the higher elevations of the upper Bull Run River watershed and the result of snowmelt, cooler water is present in the Bull Run River system in late June and early July.
- In September, the sun angle drops and the relatively more narrow Little Sandy River experiences more shading. This causes the water temperatures to be higher in the Bull Run River system than in the Little Sandy.

Conclusions

The results of the CE-QUAL-W2 model can be used to estimate natural temperature conditions. Predicted natural temperatures during the hotter summer months are consistently above the current statewide spawning criteria (13°C) and periodically above the rearing criteria (16°C). This analysis shows that under natural, undisturbed conditions, temperatures in the lower Bull Run River on a regular basis would have exceeded the regulatory numeric temperature criteria applicable to the designated beneficial uses of the Bull Run River.

Predicted natural temperatures can also be compared to the nearby Little Sandy River, which has similar, although not identical, characteristics to the Bull Run. Both the measured Little Sandy temperatures and the predicted Bull Run "natural conditions," during the summer period, are consistently above the statewide spawning criteria and periodically above the rearing criteria. Figure 7 shows the lower Bull Run River system probably had cooler natural pre-project temperatures than the Little Sandy River during late June and early July (–1.1°C average) and warmer temperatures by September (+0.2°C average).

Section 3.
What effect does the City of Portland water system have on lower Bull Run River temperatures?

Since 2000, the City has provided instream flows throughout the summer to test the effects of flow on downstream temperatures (results of "instream flow" conditions continue to be evaluated and are discussed in more detail in Section 4). Prior to 2000, however, no regular effort was made to provide flows below Dam 2. Thus, the City has undertaken a "project effects" analysis that assumes *no* downstream releases. This analysis describes, in effect, the "worst-case" project effects. "No release conditions" are defined as approximately 5-7 cfs in the lower Bull Run River. These flows result from tributaries entering the river below the City's dams.

The City also collected temperature data at the Larson's site (RM 3.8) during periods when no water was released from the reservoirs in the lower Bull Run (including periods during 1995, 1996, 1998 and 1999). The available data show that under "no release" conditions between 1995 and 1999, maximum water temperatures frequently rose above 20°C, even as a 7-day moving average (Figure 10).

Other trends from data collected from the lower river reach confirm that:

- The majority of warming occurs between the spillway pool discharge (RM 6.8) and the USGS gage (RM 5.3). Additional warming occurs downstream to the Larson's site (RM 3.8).
- The highest temperatures usually occur in late afternoon at the Larson's site (RM 3.8) in July and August .
- The highest temperatures at Bowman's Crossing (RM 2.5) often occur in late evening or early morning, which corresponds to the estimated time of travel of the warmest late afternoon water at the Larson's site (RM 3.8).

Modeling to Characterize "No Release" Conditions

Past monitoring data were used to develop a regression model that predicts water temperatures based on sun angles (for shading) and maximum air temperatures. This model is used to estimate: 1) the predicted "no release" temperatures for 2000 and 2001 (when "no release" data are not available because instream flow releases occurred); and 2) historical temperatures (1973-1977) when the system operated under "no release" conditions but downstream data are not available. These "no release" scenarios can then be compared to predicted natural conditions to determine worst-case project effects.

To evaluate the impacts of the Bull Run River projects on downstream temperature conditions, the regression model is a more suitable tool than the CE-QUAL-W2 model because it relies on empirical data and can more easily evaluate low-flow conditions related to the "no release" operational scenario. While CE-QUAL-W2 models work very well for many applications, their underlying algorithms were developed for larger river systems and sometimes do not function effectively when flows are relatively low.

Modeling Results for “No Release” Conditions

To develop the regression model and predict “no release conditions” for 2000 and 2001, data from 1998 and 1999 were used because these periods coincide with when air temperature data in the canyon are available.[1] Predicted “no release” conditions for 2000 and 2001 compare well with the 1995 through 1999 measured “no release” conditions.

As with the natural conditions, the “no release” conditions from 2000 and 2001 were compared against a number of benchmarks, including predicted natural conditions and Little Sandy River measurements. Figure 11 shows that during the rearing season (through August 14th), average “no release” conditions in the lower Bull Run River are 6.0°C warmer than predicted natural conditions (both expressed as a 7-day average maximum). During the spawning season (from August 15th), average “no release” conditions in the lower Bull Run River are 5.2°C warmer than predicted natural conditions.

For comparison, average “no release” temperatures are 4.9 °C warmer than Little Sandy measurements during the rearing period and 5.3 °C warmer during the spawning period (Figure 11).

Conclusions

In general, the City operated under a “no release” policy for at least the thirty years prior to 1998. Figure 11 is an analytical tool that shows that operating the reservoir system without instream flow releases causes temperatures to be warmer than predicted natural temperatures by 6.0°C during the rearing period and by 5.2°C during the spawning period. Measured and predicted “no release” temperatures are consistently above current statewide spawning criteria (13°C) and rearing criteria (16°C) during the summer period.

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[1] Data from 1995 and 1996 were not used in the regression model because there are no associated meteorological data.

Section 4.
What effects are demonstrated by the experimental instream releases conducted from 1997 to 2003?

Measuring "Instream Release" Conditions

Since 1997, the City has released water during the summer months to the lower Bull Run River, both to improve fish habitat conditions and to study how best to operate the system for that purpose. These operations are referred to as "instream flow" conditions.

History of Instream Flow Releases

Some initial flow releases occurred in 1997. Full scale temperature monitoring began in 1998. The City measured temperatures without releases for 45 days in 1998. Releases occurred for 4 days in mid-August of 1998 and for 7 days in late August/early September. In 1999, the City measured temperatures for 16 days in late July without releases. Over the following 38 days, the City released flow ranging from 10 to 80 cfs. These initial releases were designed to fill key data gaps.

The City began continuous summer flow releases in 2000. Variable flows of 20 to 60 cfs were released from late June to mid July 2000. A relatively constant flow of 30 to 35 cfs was maintained from late July through the end of September. Starting in 2001, the City managed the reservoir releases to "save" cooler water in Reservoir 1 in an attempt to limit the rise in reservoir release temperatures later in the summer. Flows from early July to late September 2001 varied from 30 to 43 cfs. Flows during summer 2002 varied from 20 to 30 cfs, but were increased to 59 cfs for a brief period in August in response to hot weather. Releases during 2003 focused on maintaining the water temperature at Larson's Bridge below 21°C. Flows varied from 17 to 49 cfs, with higher flows (up to 78 cfs) for several days of hot weather in early September 2003.

Regression Model Used to Forecast Temperature Response

Temperature trends and relationships were tested using a step-wise regression model to predict the magnitude of the temperature increase between Headworks (RM 6.8) and Larson's Bridge (RM 3.8) under various instream release conditions. Independent variables used in the analysis included:

> Discharge -- data from the USGS gage (RM 4.8) consists of reservoir releases and accretion flows
>
> Maximum air temperatures – captures both direct magnitude of air temperatures as well as indirect amount of incident radiation

Release temperatures – data from Headworks

Sun altitude – data from noon captures the seasonal change in amount of shading given the vegetation height

Other variables (wind speed, relative humidity, cloud cover, solar radiation, and hours of sunlight) were not used because they are likely of secondary importance and are indirectly captured by the four variables listed above. Sufficient data were available to evaluate the influence on water temperature of flow releases ranging from 15 cfs to more than 60 cfs.

Results of Experimental "Instream Releases"

The measured data indicate that temperature increases in the lower Bull Run River are greater when the following conditions occur:

- River discharges decrease
- Air temperatures increase
- Reservoir release temperatures increase
- Amount of shading decreases (due to sun angle)

Actual flow and temperature conditions observed in the lower Bull Run are plotted for 2000 and 2001 in Figure 12. This comparison confirms that the City's efforts to release water have successfully kept water temperatures lower than they would be if no instream flows were released.

Figure 13 shows that the experimental instream flow releases during 2000 and 2001 caused average temperatures to be cooler than under "no release" conditions by 3.2°C and 1.7°C during the rearing and spawning periods, respectively. Greater cooling is observed during the early summer period than the later summer. This is because the continuous release of cool water from Dam 2 to meet downstream water temperature targets results in less cooler water available for late summer benefits.

"Instream release" temperatures are still warmer than predicted natural temperatures by an average of 2.7°C during the rearing period and by an average of 3.5°C during the spawning period. Measured "instream release" temperatures are also consistently above current statewide spawning criteria (13°C) and rearing criteria (16°C) during the summer period.

Measured temperatures at Larson' Bridge during summer 2003 are shown in Figure 14. The releases were managed in 2003 to stay below 21°C. Flows of up to 78 cfs were needed to reduce water temperatures during the hot weather of late August and early September. September temperatures were above the 13°C numeric criteria for salmonid spawning.

Conclusions

By managing flow releases below the reservoirs in the summer, the City can substantially improve temperature conditions in the lower Bull Run River beyond the conditions that would prevail if no water was dedicated to instream use. For several years, the City has experimented with various release regimes and has data to demonstrate the improvements.

Section 5.
What compliance plan is the City proposing?

The City is attempting to integrate Endangered Species Act and Clean Water Act compliance measures into a coordinated package. The TMDL compliance plan proposed here is a component of those ongoing multi-purpose negotiations.

Applicable Water Temperature Standard for the Lower Bull Run

The recently adopted and EPA-approved Oregon water temperature standard [OAR 340-041-0028] states the following:

> *Where DEQ determines that the natural conditions of all or a portion of a subbasin exceeds the biologically based criteria [in section 4 of the rule], the natural condition supercedes the biologically based criteria, and the natural condition is deemed to be the applicable temperature criteria for that water body.*

Section 2 of this report describes the City's analysis of natural conditions in the lower Bull Run River. This analysis demonstrates that natural conditions exceed the biologically-based criteria for spawning and rearing over the summer period. The natural criteria should be the applicable temperature criteria for the lower Bull Run River system.

Proposed Compliance Approach

Based on analysis of natural conditions in Section 2 and the results of the experimental releases described in Section 4, the City evaluated what could be accomplished with existing infrastructure and what might be accomplished with possible future infrastructure improvements. The City has concluded that it should be feasible to meet a natural temperature standard in the lower Bull Run River. In other words, with infrastructure and operational changes, the system can be operated in a manner that approximates the water temperature regime that would have occurred in the lower Bull Run River before the water system was developed.

The City envisions developing a temperature management plan. The temperature management plan is expected to have two phases. Phase 1 will involve flow releases as defined in Table 6 ("normal years") and Table 7 ("critical years"). These releases will be managed to improve temperatures to the degree possible without new infrastructure. Phase 2 will add construction and operation of new multi-level intake structures at Dam 2. Real-time temperature monitoring equipment will be installed at the beginning of Phase 1.

Phase 1 is envisioned to begin when the temperature management plan is adopted (beginning at a yet to-be-defined date after the TMDL is adopted and before the 18-month deadline for the temperature management plan). Phase 2 would begin after construction of the new intakes is complete.

Proposed Compliance Mechanism

EPA's Region 10 guidance on temperature water quality standards (EPA, 2003) states that natural temperature conditions can be estimated in several ways:

- Using a non-degraded reference stream for comparison,
- Using historical temperature data,
- Using statistical or computer simulation models, or
- Assessing the historical distribution of salmonids.

As described in Section 2, the City has relied on CE-QUAL-W2 and regression modeling to describe and evaluate natural, pre-dam water temperature conditions. For compliance purposes, using a modeled natural condition for the lower Bull Run River that varies day-to-day with weather is problematic. The logistics of predictive modeling to make real-time operation decisions would be cumbersome and would lack the reality check of measured conditions from a reference stream. For these reasons, DEQ has suggested (and the City concurs) that measured Little Sandy temperatures should play a role in the mechanism for Bull Run River temperature compliance.

The City proposes that Little Sandy measured temperatures be used (with adjustments discussed below) as a surrogate for assessing compliance with natural temperatures in the Bull Run. A real-time temperature monitoring station would be constructed and maintained on the Little Sandy River (at a location to be decided in consultation with DEQ and the affected landowners, but likely near the current Little Sandy Dam site), and a second monitoring station would be constructed at Larson's Bridge on the Bull Run River.

The City believes it is not appropriate to use the Little Sandy measurements directly. The Bull Run and the Little Sandy are different streams and react differently to seasonal and weather conditions. To take the differences between Bull Run temperatures and Little Sandy temperatures into account, the City proposes that DEQ employ an adjustment factor or "error bar" around the Little Sandy measured temperatures.

Current analysis suggests that a +/- 1°C variation might be appropriate (see discussion of estimated Phase 2 results below). Table 8 demonstrates a temperature difference within about 1.0°C. Note that the City has more confidence in the 2001 data in Table 8 than the 2000 data because of the longer time period covered in 2001 and the confounding high flow storm conditions during August and September 2000.

An adjustment of +/- 1°C would mean that Bull Run temperatures would be deemed in compliance with the "natural conditions" temperature standards if the measured Bull Run temperature (7 day moving average at Larson's Bridge) is within 1°C of the measured Little Sandy temperature (7 day moving average near the current Little Sandy River dam site). This natural conditions standard would apply when measured Bull Run temperatures exceed the numeric standards -- as can be expected during the summer and early fall. DEQ has suggested that when measured Bull Run temperatures meet or fall below the numeric standards, the City would be in compliance with the temperature standard -- irrespective of modeled "natural conditions" or the temperature of the Little Sandy "surrogate." The City believes this approach allows for better allocation of the limited available cool water and lower river temperatures in the fall season.

The City stands ready to work with DEQ to evaluate this approach. The details of the operating target for Phase 1 and the correction factor mechanism for Phase 2 would be formalized in the temperature management plan.

Results Anticipated from Phase 1 and Phase 2

The City has used data from both experimental releases and modeling to forecast the results anticipated from Phase 1 measures and Phase 2 measures.

Phase 1

Phase 1, as described above, is based on the variable flow release amounts defined in Tables 6 and Table 7. The City will use the multiple level intakes at Reservoir 1 to selectively withdraw water at desired temperatures during the summer season. Early releases will come from upper strata of the reservoir while the temperatures are still cool. As the reservoir warms, releases will be taken from deeper colder strata. Operations will be adjusted in response to the weather.

During Phase 1, the City does not expect to be able to achieve the natural temperature standard, as measured using Little Sandy temperatures and the 1.0°C adjustment. The City proposes an operating target during Phase 1 of 21°C (7 day moving average) measured at Larson's Bridge. As compared to the no release conditions (in Section 3), this is a substantial improvement over conditions prior to 2000.

Figures 15 and 16 show the differences between simulated temperatures in Bull Run and measured Little Sandy temperatures in 2000 and 2001. The Bull Run temperatures are simulated to represent the temperatures we would expect to see under Phase 1 operating conditions. Differences in the 7 day moving averages range from 1 to 5 °C in 2001 weather conditions and from 2 to 4°C during 2002 weather conditions. The maximum temperatures at Larson's Bridge are at or below 20°C most of the time. These results were achieved, however, with flows at times higher than those shown in Tables 6 and 7. Figure 14 also shows that temperatures, even at periodically higher flows, will not be below 21°C at all times (see discussion in Section 4). The City's data indicate at "critical year flows" (Table 7) and 2003 weather conditions, temperatures in late summer could exceed 22°C.

Phase 2

Phase 2 involves construction of multiple level intakes at Reservoir 2. This infrastructure will create two important capabilities: (1) selective withdrawal of water from Reservoir 2 at desired temperatures, and (2) separation of flow going to the water system from flow going to the lower river. The benefits of these changes are as follows:

> ***Selective withdrawal:*** The current intake is only capable of releasing water from the lowest elevations and thus causes mixing of the water column and loss of stratification. By varying the depth of the releases from Reservoir 2, the City should be able to preserve a thermally-stratified reservoir during the summer months.

Water from successively lower depths would then be released to manage downstream temperatures.

Separation of flow: The new intake will also be designed to separate flow into the water system from flow into the lower river. The current intake does not allow this separation. Water diverted to the lower river could then be taken from lower, colder depths while sending somewhat warmer water to the City's water supply system.

Phase 2 actions are expected to achieve the Bull Run natural temperature standard, as described above. Figure 17 shows the differences (based on 7 day moving averages) between simulated natural temperatures at Larson's Bridge and measured temperatures in the Little Sandy during 2003. The simulated Bull Run temperatures are based on minimum flows for normal years described in Table 6. Figure 17 shows the City's forecast that the Phase 2 operations would maintain temperatures below the Little Sandy target, except in September when the Bull Run temperatures would still be within the 1°C adjustment described above. October temperatures on Figure 17 are extrapolations from available data. (See section below about a data gap in October.)

The City has not yet modeled temperatures under the critical flows described in Table 7. The City is also missing key data for October. The City will work with DEQ to fill these information gaps.

Fall Season Data Gap

The City's current data sets contain a gap in the fall season. The City does not yet have complete water temperature data and lower Bull Run canyon air temperatures for October. The data loggers used to monitor the conditions in the lower Bull Run have regularly been retrieved in early fall to prevent their loss during high fall/winter flows and in consideration of employee safety. The City will more fully evaluate the significance of this data gap on model results and will attempt to fill the gap with measured data in the fall seasons of 2004 and 2005. The results will be incorporated, as needed, into the temperature management plan.

This data gap is significant because without the October data, the City's analysis indicates that it might be difficult to meet the Bull Run natural temperature standard in October. This might be true because summer season releases could have exhausted the available cold water in the reservoir by October. If further analysis indicates that the City cannot meet natural temperatures in October, the City will work with DEQ to resolve the related TMDL compliance issues.

Conclusions

Revising reservoir operation practices will significantly improve water temperatures in the lower Bull Run River, even without new infrastructure. The City does not expect, however, to be able to achieve Bull Run natural temperatures during Phase 1. The proposed operating target for Phase 1 remains 21°C.

Further improvements to lower Bull Run temperatures could be achieved if the City re-designs the water intake structures at Reservoir 2 and alters operations to take advantage of those infrastructure changes. The City believes it should be possible to achieve “natural conditions” temperatures with the infrastructure changes envisioned for Phase 2.

Phase 1 and Phase 2 implementation details will be resolved and documented in the temperature management plan.

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Tables

TABLE 1
Bull Run River Slope and Pool Characteristics

River Reach	Average Slope	Number of Identified Pools	Pool Length as Percent of Total
Upper river	0.0215 (220 m drop in 10,000 m)	48 (>1 m) 19 (5 m)	32
Middle river	0.0066 (90 m drop in 13,700 m)	No data	No data
Lower river	0.014 (100 m drop in 7200 m)	22 (>1 m) Spillway pool not included (>5 m)	13

TABLE 2
Current Water Quality Criteria for Lower Bull Run River

River Reach	Time Period	Habitat Use	Numeric Criterion (7-Day Average Maximum)
River Mile 5.3 to 6.5	June 16 to October 14	Salmonid rearing	16°C
	October 15 to June 15	Salmonid spawning	13°C
River Mile 0 to 5.3	June 16 to August 14	Salmonid rearing	16°C
	August 15 to June 15	Salmonid spawning	13°C

TABLE 3
Model Attributes

Modeled Area	Number of Segments	Number of Hydraulic Controls Along Main Stem	Pool Geometry	Range in Slope	Manning's n (original values)
Upper river	46	2	2 pools, 400 m total length, depths of 1.5 m, at 35 to60 cfs	0.007	0.10
Middle river	87	4	3 pools, 1700 m total length, depths of 1 to3 m, at 50 to110 cfs	0.005 to 0.007	0.08
Lower river	99	14	5 major pools, 1400 m total length, depths of 2 to 14 m, at 35 cfs	0 to 0.012	0.09 to 0.21 Ave=0.14

TABLE 4
Simulation Conditions, Middle River Reach

Characteristic	Lower	Higher
River wetted width	Narrow (NW): 27 m	Wide (WW): 55 m
Manning's n	Low (LMN): 0.08	High (MHN): 0.24
Tree heights	30 m	40 m
Meteorological Reference Station	Canyon (CM)	Headworks (HM) Log Creek (LC)

TABLE 5
Comparison of Little Sandy and Lower Bull Run River Natural Flows

Date (Year 2000)	Bull Run at Larson's (cfs)	Little Sandy at Dam Site (cfs)	Little Sandy Flow as percent of Bull Run
June 26	222	39	17.5
July 1	169	30	17.9
August 1	94	16	16.9
August 15	82	14	16.9

NOTE: Bull Run Discharges were estimated from key stations and tributary areas.

TABLE 6
"Normal Year" Flow Rules

From	To	Minimum Flow	% of Inflow	Cap
1-Jan	31-May	120 cfs		
1-Jun	15-Jun	120 cfs		
16-Jun	30-Jun	Ramp down from 120 cfs to 35 cfs at start of drawdown		
1-Jul	30-Sep	20-40 cfs to manage temperature, average 35 cfs		
1-Oct	15-Oct	70 cfs	50 %	400 cfs
16-Oct	31-Oct	70 cfs	50 %	400 cfs
1-Nov	15-Nov	150 cfs	40 %	400 cfs
16-Nov	30-Nov	150 cfs	40 %	400 cfs
1-Dec	31-Dec	120 cfs		

TABLE 7
"Critical Year" Flow Rules

From	To	Minimum Flow	% of Inflow	Cap
1-Jan	31-May	120 cfs		
1-Jun	7-Jun	Ramp down from 120 to 30 cfs, during week of June 1 to June 8, if in drawdown prior to June 15th		
8-Jun	15-Jun	30 cfs		
16-Jun	30-Jun	30 cfs		
1-Jul	30-Sep	30 cfs		
1-Oct	15-Oct	30 cfs		
16-Oct	31-Oct	30 cfs	50%	250 cfs
1-Nov	15-Nov	30 cfs	40%	250 cfs
16-Nov	30-Nov	70 cfs	40%	350 cfs
1-Dec	31-Dec	120 cfs		

TABLE 8
Comparison of Simulated Natural Temperature Conditions in the Bull Run to the Little Sandy

Time Period	Results for 2000	Results for 2001	Comments
July	-1.0 (31 days)	- 0.8 (23 days)	Bull Run is naturally cooler than Little Sandy in July
August	-0.5 (18 days)	-0.1 (26 days)	Excludes days with high flows in Upper Bull Run*
September	1.3 (7 days)	0.5 (25 days)	Excludes days with high flows in upper Bull Run*
September 10th through September 30th, *(subset of above)*	1.3 (7 days)	0.9 (16 days)	Bull Run is naturally warmer than Little Sandy in the fall

* Flow spikes in the Upper Bull Run result in cooler temperatures in the lower Bull Run. Temperatures were 1.2 deg C cooler in the lower Bull Run for 26 days in 2000 and 1.3 deg C cooler for 5 days in 2001. Temperatures on these dates were excluded from the averages above.

Figures

Attachment A

Sensitivity Analysis of CE-QUAL-W2 Input Variables

Attachment A:
Sensitivity Analysis of CE-QUAL-W2 Input Variables

Data from free-flowing sections were extrapolated to predict river conditions without the reservoirs. The City has undertaken considerable efforts to characterize model inputs including stream geometry (width, depth, and length of pool and riffle sections), shading (solar pathfinder estimates of incident radiation, gray card shading estimates), and vegetation characteristics (vegetation height and offset). These efforts are described in more detail below.

Natural Conditions Model Inputs

Wetted Widths

As part of the modeling effort, the City needed to determine a reasonable estimate of wetted widths in the middle reach of the Bull Run River. This is the reach that has long been inundated by the City's reservoirs.

The CE-QUAL-W2 middle reach model relies on larger wetted widths than were measured in the upper and lower reaches at comparable flows (see Tables A-1 and A-2). The literature confirms that it is possible for lower-gradient reaches to have larger widths than higher-gradient reaches (Dunne and Leopold, 1978). This relationship is also consistent with measured narrower widths in the higher gradient upper reach, as compared to measured wider widths in the moderate gradient lower reach at comparable flows (Table A-1). PSU has estimated significantly wider widths of the "natural" reservoir reach (average of 55 m) based on a bathymetric survey of the reservoir bottoms. Unpublished data collected by the Oregon Department of Fish and Wildlife (ODF&W) before Reservoir 2 was constructed suggested an average wetted width of spawning gravels of about 35 m.

For modeling, two wetted width conditions were simulated: 1) PSU's estimated widths from reservoir bathymetry data, and 2) narrower widths representing a 50 percent reduction from the PSU estimates. A total wetted width of 40 m represents a mid-point value between the narrow widths (27 m) and wide widths (55 m) assumed in the model runs at flows of approximately 75 cfs. (At 100 cfs, the average width of the lower reach of the River during the 1999 stranding survey was 40 m.) Thus, the two width values used in the model bracket the likely pre-project conditions.

Manning's *n* Values

Variations in Manning's *n* values (a measure of stream course "roughness") affect travel times and diurnal temperature ranges. PSU set up the middle reach model to use Manning's *n* values of 0.08 (Table 2 in the main text), with Manning's *n* values ranging between 0.09 and 0.21 (average value of 0.14) for the lower reach. ODEQ has had success calibrating their

Heat Source model for the lower reaches using Manning's *n* values ranging from 0.15 to 0.35 (average value of 0.24; Greg Geist, pers. comm.). Higher roughness values are associated with boulders that are typically present in most of the lower reach river channel (Figure A-1).

As higher Manning's *n* values are used, the modeled diurnal variation at the Headworks (RM 6.8) compares well with measured conditions in the Little Sandy River (Figure 5 in the main text). As lower Manning's *n* values are used, the modeled diurnal variation is higher than measured values at Little Sandy River. This is probably attributable to lower volumes of water associated with the simulated river (due to an absence of sufficient pool volume; see Tables 1 and 2 in the main text). As the Manning's *n* value increases, the volume of water in the model increases by 50 percent (average depth of 0.6 m versus 0.4 m), which probably helps explain the better agreement.

Tree Heights and River Shading

The upper and lower reaches in the Bull Run River have been surveyed for tree heights and shading (Beak, 1998: Leighton, 2002). Based on these surveys, the average tree height is approximately 30 to 40 m (90 to 120 feet), as shown in Figure A-2. These values represent the range of tree heights used in the model.

Although tree heights are an important influence on shading, the amount of shading also depends on the wetted width and the distance of the vegetation from the riverbank. Because solar pathfinder diagrams integrate these effects, information on the average amount of solar radiation reaching the water surface was collected from the field (Leighton, 2002). The simulated amount of radiation reaching the water surface in June is close to measured tree heights and wetted widths used in the modeling (Table A-3).

Meteorological Stations

Data from three meteorological stations in the Bull Run River watershed were available:

- Within the canyon in the lower river reach at the USGS gage
- On top of Reservoir 2 near the Headworks
- Above the upper river reach above Log Creek

These stations represent different elevations and site settings, as shown in Figure A-3 and summarized in Table A-4.

To determine which station is the most appropriate to use in the model, the air temperature, wind speed, and relative humidity of these sites were compared for July and August of 2000. The trends can be summarized as follows (Tables A-5 and A-6):

- The maximum air temperatures are lowest at the higher-elevation Log Creek site during cooler days.
- The maximum air temperatures are lowest at the lower-elevation USGS site during warmer days (this site is located within the sheltered riparian zone).
- At the higher-elevation sites (Headworks and Log Creek), maximum air temperatures average 1.5 °C higher than the lower-elevation USGS site.

- The average air temperatures are lowest at the highest-elevation Log Creek site on almost all days.
- Wind speeds are higher at the Headworks and Log Creek sites (both of which are relatively exposed locations). For example, average wind speeds are typically four times higher at these sites than in the relatively well-protected USGS site within the canyon.
- Relative humidity values are not significantly different between sites.

Based on these trends, the USGS and Headworks meteorological sites were both tested to determine which station provided the best modeling input.

Natural Conditions Model Outputs

Figure A-4 compares model output values for predicted water temperatures at the Larson's site (RM 3.8) and provides a sensitivity analysis of various input variables. These results show that the range of conditions is within 3°C on a consistent basis.

In terms of the sensitivity of the input variables, the following trends are noted:

- Using meteorological data from the USGS canyon site generally results in a decrease in predicted temperatures of 0.5°C to 1°C as compared to when meteorological data from the Headworks site are used.
- Using narrow wetted widths generally results in a decrease in predicted temperatures of 0.5°C as compared to when wider wetter width data are used.
- Using lower Manning's *n* values generally results in an increase in predicted temperatures of 0.5°C as compared to when higher Manning's n values are used, as well as larger diurnal swings.

The predicted water temperatures are compared against measured values in the Little Sandy River to provide some context for interpretation and to help evaluate which input variables are most appropriate. In addition, this comparison identifies temporal trends through the summer season. Even if the magnitudes of simulated temperatures do not match exactly, relative differences to the Little Sandy River over time are expected to be correct. This means that the physical differences between the two basins are reflected in the result that temperatures tend to increase more during the summer in the Bull Run compared to the Little Sandy.

Specifically, simulated water temperatures in Bull Run River are generally lower than measured values in the Little Sandy River from mid-June through early August. In early August, the difference is typically less than 1°C. From early September onward, the simulated water temperatures are slightly higher than the measured values in Little Sandy River. The variation in differences throughout the summer period can be attributed to the following:

- In late June and early July, the sun angle is high with limited shading. Given the effect of cool air temperatures in the higher elevations of the upper Bull Run River watershed and the result of snowmelt, cooler water is present in the Bull Run River system in late June and early July.

- In September, the sun angle drops and the relatively more narrow Little Sandy River experiences more shading. This causes the water temperatures to be higher in the Bull Run River system than in the Little Sandy River.

Tables

TABLE A-1
Measured Wetted Width

Source	Flow (cfs)	Number of Cross Sections	Average Wetted Width (m)	Range in Wetted Widths (m)
Upper				
Beak Upper River Survey (Sept 2000)	60-90	118	20 (bank to bank)	10-40 (bank to bank)
Middle				
ODF&W Survey, Pre-Dam 2	(?)	10	33 (of spawning gravels)	27-36 (of spawning gravels)
Lower				
R2 PHABSIM Lower River	75-100 25	13 9	20 15	10-35 10-20
Stranding Study Lower River (1999)	100	6	45	30-70
Beak Lower River Survey (1998)		40	20	3-45

TABLE A-2
Modeled Wetted Width

Source	Flow (cfs)	Number of Cross Sections	Average Wetted Width (m)	Range in Wetted Widths (m)
Upper				
Modeled Upper River	60-90	46	10	8-14
Middle				
Modeled Middle River, narrow widths	75	76	27	5-85
Modeled Middle River, wider widths	75	76	55	10-170
Lower				
Modeled Lower River	30-70	70	15	3-50

TABLE A-3
Measured and Modeled Radiative Heating and Shading, for June

Source	Location	Total Energy Reaching Water Surface
Measured, Solar pathfinder	Upper	56%
Measured, Solar pathfinder	Lower	69%
Modeled, 30 m trees	Upper	56%
Modeled, 40 m trees	Upper	43%
Modeled, narrow width, 30 m trees	Middle	72%
Modeled, wide widths, 40 m trees	Middle	71%

TABLE A-4
Meteorological Station Locations

Location	Elevation (feet)	Setting
USGS	570	Within canyon
Headworks	875	On top of Reservoir 2
Log Creek	2500	Uplands

TABLE A-5
Comparison of Maximum Daily Air Temperatures (July and August 2000 Data)

USGS Temperature Range (°C)	Measured Temperature at Meteorological Station		
	USGS	Headworks	Log Creek
< 20	17.0	17.3	15.6
20-25	23.6	24.6	24.9
> 25	27.7	29.3	29.2

TABLE A-6
Comparison of Meteorological Data for July 23 to August 12, 2000

Parameter	Measured Values at Meteorological Station		
	USGS	Headworks	Log Creek
Average Air Temperature (°C)	17.8	19.5	17.0
Wind Speed (miles/hour)	0.6	2.4	2.3
Relative Humidity (%)	78	70	78