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U. S. GEOLOGICAL SURVEY
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Dear Ms. Newell:

In the early 1990s, the U.S. Geological Survey (USGS) constructed a flow and water-quality model of the Tualatin River in cooperation with the Unified Sewerage Agency of Washington County, now Clean Water Services (CWS). That model was later updated, expanded, and enhanced several times. The latest version of the USGS Tualatin River model has not yet been fully documented, though a report serving that purpose is being prepared for publication.

Earlier this year, the Oregon Department of Environmental Quality (ODEQ) requested that USGS document those aspects of the Tualatin River model related to dynamic shading, including information on model calibration and performance. This letter serves to fulfill that request. Full documentation of the expanded Tualatin River model will be published later as a USGS Scientific Investigations Report.

SUMMARY

The USGS Tualatin River model with dynamic shading is an accurate tool for assessing Tualatin River temperatures. Used to simulate conditions that occurred during May through October of the years 2000 to 2003, the model typically produced a mean error of -0.42°C and a mean absolute error of 0.73°C when compared to measured temperatures. The mean error is a measure of systematic deviation (bias), while the mean absolute error represents the typical difference obtained when comparing measured and simulated temperatures. The error varies somewhat from site to site and over the course of the season. However, the general guidance with temperature models is that if the mean absolute error is less than 1.0°C, then the model is performing well. A mean absolute error of less than 0.5°C is difficult to obtain with any temperature model.

The Tualatin River models use a complex dynamic shading algorithm that, at every time step, computes the position of the sun in the sky, the extent to which topographic features and riparian vegetation cast shadows upon the river surface throughout the modeled reach, and the

corresponding amount of solar radiation blocked from reaching the river. The riparian vegetation information used by the model was derived from ODEQ datasets using methods developed during the construction of the Willamette River temperature Total Maximum Daily Load (TMDL) models. The methods used are up to date and defensible. Given that the models and methods used for the USGS Tualatin River temperature model are the same as or similar to those used in the Willamette River temperature TMDL, it seems that the use of these tools for a revision of the Tualatin River temperature TMDL is justified.

HISTORY— PREVIOUS MODEL VERSIONS

The first version of the USGS Tualatin River flow and water-quality model was built using a modification of version 2.0 of CE-QUAL-W2 (W2 for short), a 2-dimensional, laterally averaged flow and water-quality model from the U.S. Army Corps of Engineers. The code modifications, as well as a detailed description of the model, its calibration, and its application to the Tualatin River, were documented in a USGS Water-Supply Paper by Rounds and others (1999). Other details of version 2.0 of the model can be found in the model's version 2.0 manual (Cole and Buchak, 1995).

Building upon a previous effort by Chris Berger and Scott Wells at Portland State University (PSU) (Berger, 1994), the USGS modeling effort added a large body of field data and experimentation and expanded the time period addressed by the PSU model. The resulting USGS model included the lower Tualatin River from Rood Bridge Road (river mile [RM] 38.4) to the Oswego diversion dam (RM 3.4) and was calibrated and tested for the May through October periods of 1991 to 1993 (Rounds and others, 1999). During a re-evaluation of the Tualatin River TMDL regulations in the mid-1990s, the PSU and USGS versions of the Tualatin River model were compared in detail by a panel of experts appointed by ODEQ (Tualatin Basin Technical Advisory Committee, 1997). That review found that while the PSU and USGS models were constructed a bit differently, their representation of the river resulted in similar conclusions. The USGS model was the more detailed and up-to-date model at that time, and various results from the USGS model were used to update portions of the TMDL.

The USGS Tualatin River model has since been updated and expanded. Rounds and Wood (2001) documented an application of the model to four additional summers, adding the May through October time periods of 1994-1997 so that the model then addressed seven years (1991-1997) of differing hydrologic and point-source characteristics. The modified version 2.0 code was still used, with one new change to address phosphorus/sediment interactions and one update to the ammonia nitrification rate based on field data that were not available during the initial construction of the model for 1991-1993. Goodness-of-fit statistics were computed and graphical comparisons of all measured and simulated parameters, including river temperature, were included in the Rounds and Wood (2001) report.

In the early part of this decade, USGS constructed a W2 model of Henry Hagg Lake on Scoggins Creek, a major tributary to the Tualatin River. That effort was based on version 3.12 of W2 (Cole and Wells, 2003), with modifications by USGS to add zooplankton dynamics (Sullivan and Rounds, 2005). A subsequent modeling effort to assess the potential water-quality effects of increasing the height of Scoggins Dam at Henry Hagg Lake also included some code changes to add new capabilities to the model (Rounds and Sullivan, 2006; Sullivan and Rounds, 2006). Models of Henry Hagg Lake were calibrated for the entire calendar years of 2000-2003.

In order to connect the model of Hagg Lake to the model of the lower Tualatin River, and to simulate that part of the river that flows past the CWS Forest Grove and Hillsboro wastewater treatment facilities, an effort was begun in 2005 to expand the Tualatin River model so that its upstream boundary moved from Rood Bridge Road upstream to Gaston. The lower reaches of Gales and Dairy Creek were included, as well as Scoggins Creek from Scoggins Dam to the Tualatin River. The expanded model was built with the same version (3.12, modified) of W2 as that used for Hagg Lake, and was calibrated and tested for the summers of 2000-2003 to match the calibrated time period for the Hagg Lake model. Some of the code modifications that were implemented for the earlier lower Tualatin River model were, by necessity, applied to the expanded and upgraded model.

Finally, while the upper river model (Gaston to Rood, including Scoggins) was built with dynamic shading, the lower river model still used static shading. To take advantage of the more detailed approach to simulating the river's heat budget offered by dynamic shading, the lower Tualatin River model was upgraded to use dynamic shading. This letter helps to document the model's use of dynamic shading as well as the model's performance characteristics.

Note that a temperature model of the upper Tualatin River was built in the late 1990s by John Risley at USGS (Risley, 1997; Risley, 2000), but that model did not use dynamic shading and was not built to model water quality. It has been superseded by this newer modeling effort.

MODEL STATUS

Currently, two versions of the USGS Tualatin River model are available and can be used for various purposes. First, for simulating flow and water temperature, a version using dynamic shading for both the upper and lower river reaches is available. This is the version that was shared with CWS and presumably is being used to simulate Tualatin River water temperatures for a possible change in the temperature TMDL. Second, a version exists that still uses static shading for the lower river (Rood to Oswego dam). That version also was shared with CWS and can be used for simulations of flow, temperature, and water quality. The use of dynamic shading in the lower river model caused the simulated daily maximum temperatures to be slightly higher than those simulated with static shading, and that slight change had a significant effect on some instream processes such as algal growth and respiration. Though USGS is working on a final water-quality calibration of the dynamic shading model of the lower river, that version is not yet ready for release and use. If water-quality simulations are needed, the version with static shading for the lower river should be used until a new version is available with dynamic shading.

DYNAMIC SHADING

The original USGS Tualatin River model of the lower river (Rood Bridge to Oswego dam) used a static representation of riparian shading. The model was constructed and calibrated assuming that the riparian vegetation at any model location blocked an unchanging fraction of the incoming solar radiation from reaching the river surface. The simulated amount of riparian shade, though it varied by location along the river, was constant regardless of the time of day. The model did attempt to simulate the seasonal leaf-on and leaf-drop transitions from no shading in winter/spring to some shading in summer and back to no shading in the winter (Rounds and others, 1999). The static shading fractions used by the lower Tualatin River model were adjusted during the original model calibration process within reasonable limits set by the width of the river and the height and canopy density of typical streamside vegetation (see Rounds and others, 1999).

While version 2.0 of W2 originally included no riparian shading whatsoever (USGS added the static shading algorithm), version 3.12 introduced a dynamic shading algorithm to calculate the amount of shade caused by both topographic features and riparian vegetation as a function of date and time of day (Annear and others, 2001; Cole and Wells, 2003). The algorithms calculate the position of the sun for every time step of the simulation and accordingly calculate the shadows cast by topographic features and streamside vegetation. The length of those shadows and the density of the vegetation then are used to compute how much solar radiation is blocked from reaching the river surface. Gradual leaf-on and leaf-off transitions were added to the code by USGS.

The dynamic shading algorithms more accurately represent the flux of solar radiation that reaches the river surface over the course of a day and over the course of a season, compared to the estimates provided by static shading. With dynamic shading, the length of the shadows cast by streamside vegetation vary over the course of a day, which should lead to a better representation of the daily maximum river temperature. Similarly, the length of those shadows varies depending on the time of year—shadows are longer in September than they are in July—which again should lead to a more accurate depiction of the river's heat budget than can be obtained with static shading.

W2 SHADE DATA REQUIREMENTS

The dynamic shading algorithms in W2 require the following data inputs:

- date and time of day
- latitude and longitude, for calculating the position of the sun in the sky
- stream aspect (orientation angle) for every location along the river
- tree-top elevation for both the left and right bank and for every location along the river
- distance from center of river to vegetation for both left and right bank and for every location
- summertime fraction of solar radiation blocked by vegetation on both left and right bank at every location
- wintertime fraction of solar radiation blocked by vegetation on both left and right bank at every location
- dates and durations for the leaf-on and leaf-off transition periods
- topographic shading angles in 18 directions (every 20°) for every modeled location

The model determines the location of the sun in the sky, whether topography is casting a shadow on the river, which bank (left or right) may be casting a vegetative shadow, the length of any shadow and the fraction of the river surface covered, and finally the percentage of solar radiation blocked by topographic and vegetative shade. These calculations are performed for every modeled location at every time step in the simulation.

TRANSLATION OF HEAT SOURCE RIPARIAN DATA TO W2 SHADE DATA

Heat Source is a temperature model for small streams that commonly is used by ODEQ in TMDL assessments (Boyd, 1996; Boyd and Kasper, 2003). Extensive procedures and protocols have been established by ODEQ to generate data on riparian vegetation from aerial photography and field verification. Geographic information system (GIS) techniques also were developed by ODEQ to create datasets of riparian vegetation type (height and canopy density, in particular) for use with temperature models such as Heat Source. For version 6.0 of Heat Source, tree height and canopy density data were required in nine zones on both the left and right banks of the river. During the TMDL update that was in progress in the late 1990s for the Tualatin River basin, ODEQ staff used GIS techniques to generate nine-zone datasets of current riparian vegetation (and three topographic inclination angles) along the entire Tualatin River at 100-foot intervals.

Rather than nine zones, W2 requires riparian vegetation data from only one zone on each bank. Therefore, the available ODEQ nine-zone vegetation data for the Tualatin River had to be collapsed to one-zone data. A method was developed for this process by PSU, USGS, and ODEQ staff during the development of the Willamette River temperature TMDL; that modeling effort also used W2 as a river model and relied upon nine-zone ODEQ datasets for riparian vegetation. The methods for translating nine-zone vegetation data into one-zone vegetation data, and for translating three topographic inclination angles into 18, were documented for the Willamette temperature TMDL by Annear and others (2004, see appendix A) and by Sullivan and Rounds (2004). The basic method is reported here for clarity.

Topographic Shading Angles

The Heat Source datasets included three topographic shading angles (east, south, and west) at 100-foot intervals along the Tualatin River. These three angles were interpolated to derive topographic shading angles at 20° intervals in all directions, as needed by W2. These angles then were averaged when the 100-foot spacing of the ODEQ dataset provided more than one point along the length of a W2 model segment.

Riparian Vegetation Data

The first step in assessing the nine-zone vegetative data was to identify the zone with the “controlling” vegetation, or the zone that casts the longest shadow. That zone also can be identified as the zone with the largest ratio of vegetative height to distance from the center of the stream. In figure 1 below, zone 3 does not have the tallest vegetation, but would cast the longest shadow relative to the center of the channel. In this example, then, the distance from the center of the stream to the middle of zone 3 would be set as W2’s centerline distance to the riparian vegetation at that location and for that bank. Once the zone of controlling vegetation has been identified, the tree height in that zone is added to the elevation of the ground surface to obtain the tree-top elevation, another needed data input for W2.

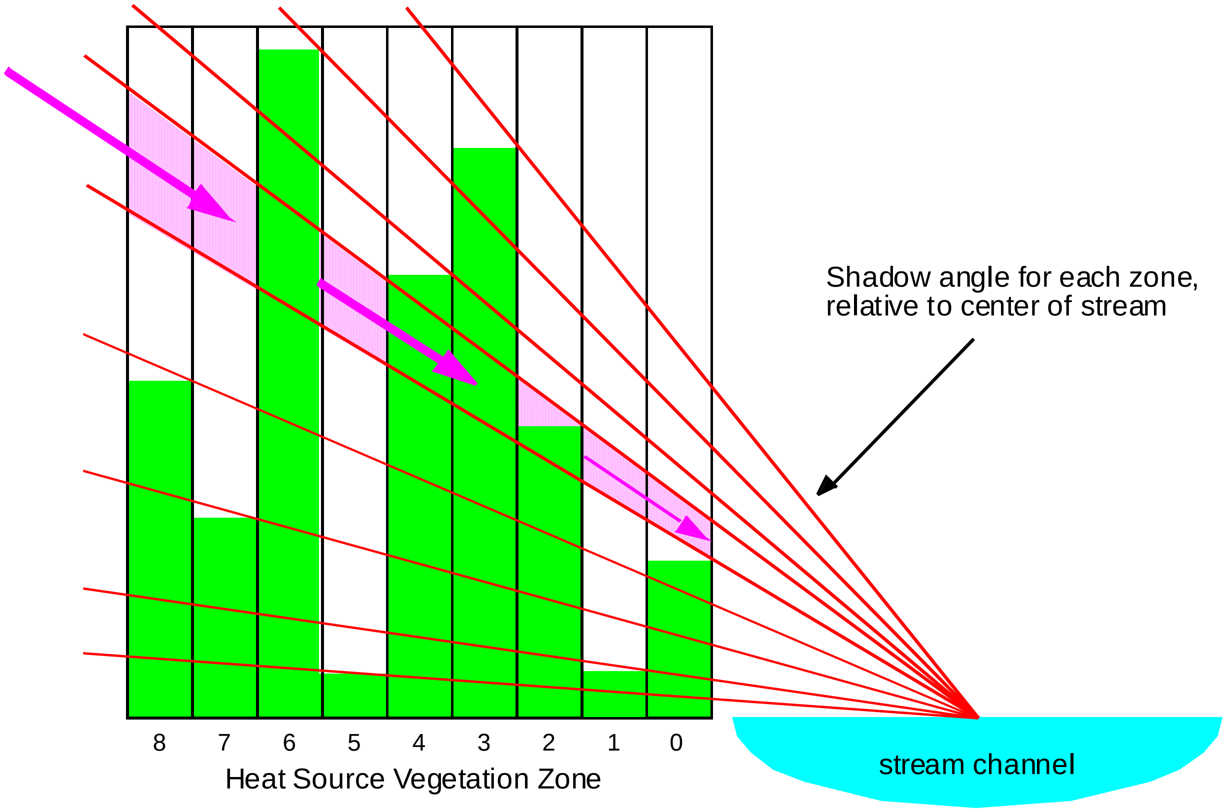

Figure 1. Diagram of the maximum shadow angles cast by the nine vegetation zones used in version 6 of the Heat Source temperature model, relative to the center of the stream. The green bars represent the height of the riparian vegetation in each zone. The red lines are the maximum shadow angle for each zone relative to the center of the stream. The magenta arrows indicate the passage of sunlight through several of the vegetative zones before reaching the stream.

After setting the distance to the vegetation and the tree-top elevation, the last piece of data needed by W2 is the fraction of solar radiation blocked by the vegetation. Several methods of extracting this information from ODEQ’s nine-zone vegetation data were explored during the Willamette temperature TMDL modeling. One simple method is to assign the canopy density from the zone of controlling vegetation as the fraction of solar radiation blocked, making an assumption that the thickness of vegetation is sufficient so that the canopy density parameter used in Heat Source is readily converted to the fraction of solar radiation blocked by the vegetation. This simple approach, however, may not result in an accurate estimate of the aggregate amount of shading. In figure 1, for example, using the canopy density from zone 3 may not be representative of the actual shading because shading from other zones (zone 6, for instance) that may have different canopy densities is not included in the analysis.

Another approach is illustrated in figure 1, where the vegetative shadow is divided into subsections whose boundaries are the shadow angles from each vegetation zone. Using these divisions, the light transmittance through each subsection (one subsection is highlighted in magenta in figure 1) can be calculated. The total light transmittance through all subsections then can be summed and converted to a shading factor for the entire riparian zone. While this approach integrates information from all available zones, it includes shading from zones that may not cast a shadow over the river, depending on the time of day. In an attempt to even out the potential biases involved in these two approaches, the shading factors estimated by both approaches were computed separately and then averaged for use with the W2 model.

Finally, shading fractions were averaged spatially when the 100-foot spacing of the ODEQ dataset provided more than one point along the length of a W2 model segment. W2 vegetative shading factors were set to zero for the winter season (shading in winter is smaller and less important, and model calibration indicated that no shading was necessary at that time). The leaf-on transition was set to occur in early April (day 97, with a 45-day transition period), and the leaf-off transition was set to occur in late September (day 270, 20 day duration). The leaf-on and leaf-off periods were not particularly important to the simulation of temperature in the Tualatin River.

CREATION OF W2 SHADE INPUTS

The translation methods above were encoded into a couple of FORTRAN programs to make the process of creating W2 shade input files easier. ODEQ’s nine-zone Heat Source data files were available for the entire Tualatin River. The only significant task was to merge the ODEQ data with Tualatin River width and elevation data so that these FORTRAN programs could calculate tree-top elevations and the distances between the river’s centerline and the vegetation on either bank.

For the lower Tualatin River, the river elevations used in the Heat Source files were not accurate between RM 10 (Cook Park) and the Oswego diversion dam (see figure 2). Farther upstream, the river channel is highly incised into the surrounding landscape and the water-surface elevations from the USGS model are not representative of the land surface upon which most of the streamside vegetation grows. For those reaches, the ODEQ elevations which were derived from topographic maps were useful as an estimate of the bank elevation where the vegetation resides. Combining the useful parts of both datasets, the resulting hybrid elevations were used as the baseline elevation for the riparian vegetation (figure 2).

The near-stream disturbance zone widths in the Tualatin River Heat Source files were known to be too narrow based on a previous comparison to field data and model simulations by USGS; therefore, those river-width data were discarded in favor of the USGS width data. The ODEQ widths were too narrow probably because the overhang of riparian vegetation in the aerial photographs obscured the edges of the channel; the visible width of the river from aerial photographs was significantly narrower than the actual width. A comparison of the ODEQ widths to USGS modeled widths, which were derived from field measurements of dozens of cross sections, is shown in figure 3.

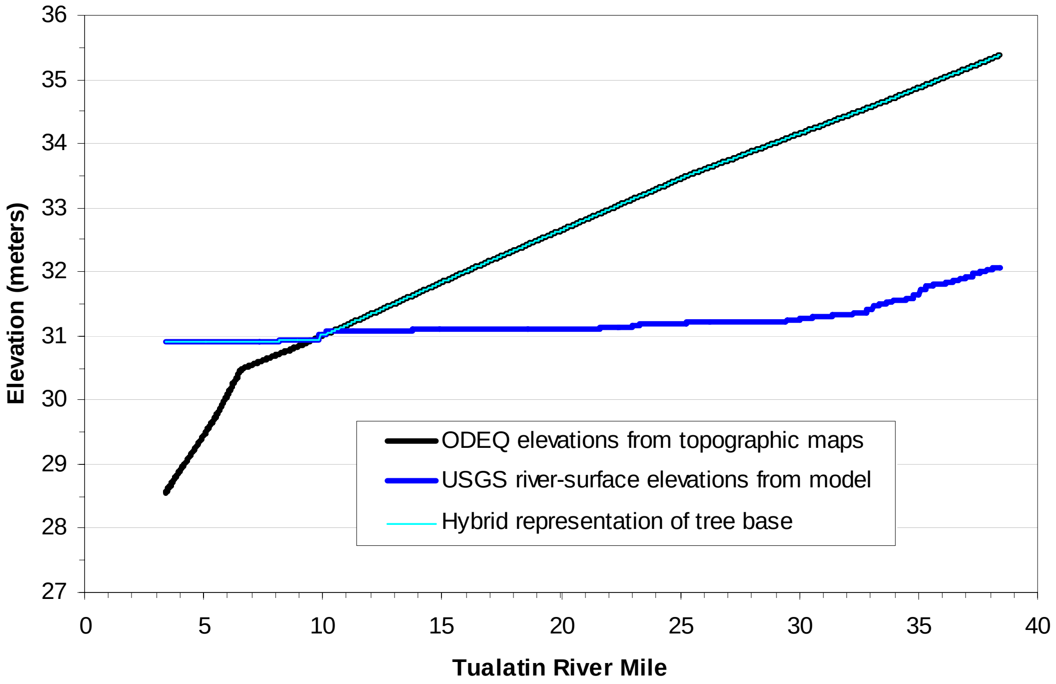

Figure 2. Different sources of elevation data for the lower Tualatin River, including the hybrid dataset that was used to estimate the elevation of the land surface on which the streamside vegetation grows.

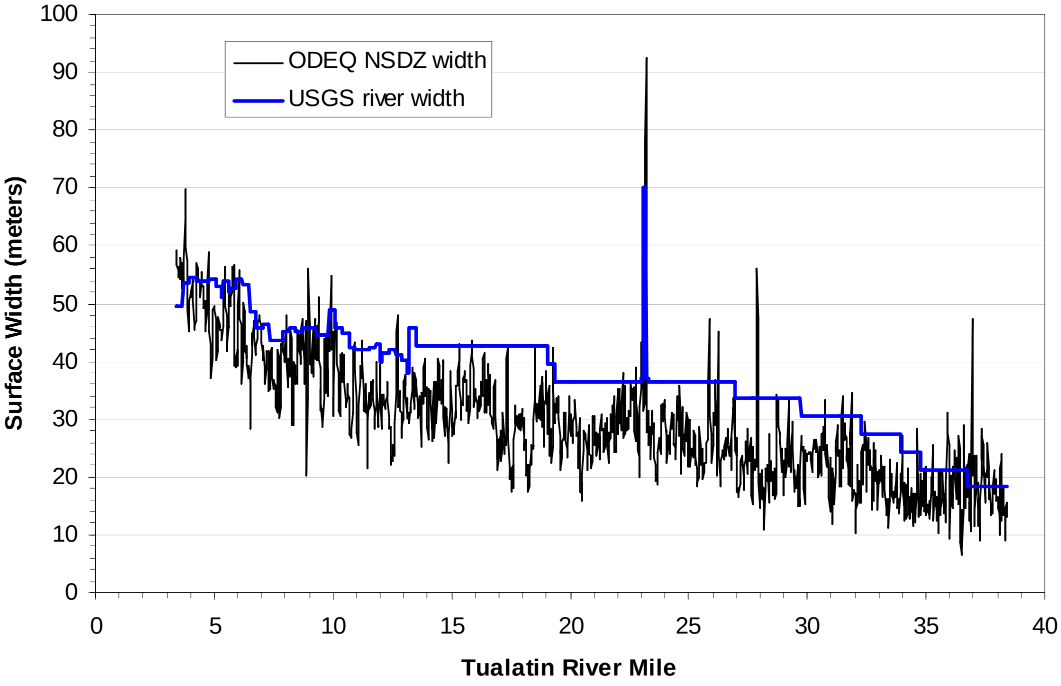

Figure 3. Comparison of two datasets representing the width of the lower Tualatin River. The Oregon Department of Environmental Quality's near-stream disturbance zone (NSDZ) widths were derived from aerial photographs, while the USGS river widths were derived from dozens of cross-sectional measurements.

Using the USGS river widths from figure 3, the hybrid streambank elevations from figure 2, and the nine-zone vegetation data from ODEQ, a shade input file for W2 was created using the methodology described earlier in this letter (see *Translation of Heat Source Riparian Data to W2 Shade Data*). Similar methods were used to create the W2 shade inputs for the upper Tualatin River model, though fewer discrepancies were encountered between USGS field data and ODEQ elevations and widths in the Heat Source files.

CALIBRATION OF WATER TEMPERATURE

Calibration of the Tualatin River dynamic shading model was limited to variations in those parameters that could reasonably be changed. Typically, as long as the input flow and meteorological data are accurate, models of river temperature are calibrated through an adjustment of shading parameters (canopy density, tree height, distance to vegetation) or simulated river widths. Travel times, flow, and stage had already been calibrated, so no adjustment to the river bathymetry or the roughness coefficients was necessary. The static shading model of the lower Tualatin River already was known to accurately predict water temperatures in that reach, so it did not seem reasonable to change the simulated river width. Changing the tree-top elevation and the distance between the vegetation and the river's centerline, however, seemed like a reasonable means of achieving a better match to measured river temperatures, particularly because these data involved some assumptions with connections to other datasets (figures 2 and 3). To preserve the strong connection to the ODEQ nine-zone vegetation dataset, the canopy densities were not varied.

Many scenarios were run in which different land-surface elevations were applied as the base for riparian vegetation, and different combinations of USGS and ODEQ river widths were used to derive the distance to the riparian vegetation. After each scenario was run, a set of goodness-of-fit statistics were computed to assess the performance of each model run relative to measured temperatures. When comparing the simulated water temperatures to measured temperatures, however, none of the new scenarios provided a better overall match to the available data than the original depictions shown in figures 2 and 3 and described earlier. Therefore, the original representation of the lower river's dynamic shading characteristics was retained.

For the upper Tualatin River (Gaston to Rood, plus Scoggins), the calibration process involved an adjustment of the distance from the center of the river to the riparian vegetation, whereby that distance was systematically increased by 25 percent. This was done in an effort to (a) reduce the effects of shading because the simulated temperatures were systematically low, and (b) increase the distance to the vegetation because the original distance appeared to be too small relative to the simulated river widths. This adjustment made a slight difference, and was retained in the final calibration.

MODEL PERFORMANCE

Simulated water temperatures using the dynamic shading model were compared to measured temperatures at nine sites where temperatures were measured continuously during the summer period. These sites and results for two goodness-of-fit statistics are listed in table 1. The mean error (ME) is a measure of systematic deviation (model bias) and can be positive or negative, while the mean absolute error (MAE) is the typical error associated with any data point. Temperature data at these sites were collected by the Oregon Water Resources Department (continuous data) or Clean Water Services (point data), except for the RM 24.5 and Oswego dam sites where the data were collected by USGS.

In general, it appears that the model's results for May through October, averaged over four years and eight sites, are biased slightly low (-0.42°C) and have a typical prediction error of about 0.73°C. These results exclude the comparison at Tualatin Park, where the measured/simulated comparisons appear to have exposed a problem with the measured data. Results for the upper model (3 sites, ME -0.31°C, MAE 0.76°C) are comparable to those from the lower model (5 sites, ME -0.48°C, MAE 0.70°C).

The model's mean error (bias) is small, but might indicate that the simulated amount of shading is slightly too large. Efforts to further reduce the model bias by adjusting tree-top elevation and distance to riparian vegetation were unsuccessful. It is possible that the most important parameter contributing to the bias is canopy density, which was not changed during model calibration in order to preserve the model's connection to the ODEQ vegetation dataset. In any case, the bias is small and at an acceptable level.

Table 1. Goodness-of-fit statistics for the USGS Tualatin River model's dynamic shading simulation of water temperature during the May through October periods of 2000-2003. The dynamic shading version of the lower river model was used in these simulations. All statistics are given in degrees Celsius (°C). The mean error is a measure of bias, while the mean absolute error is a measure of the typical error for any data point.
[RM = river mile; na = measured data not available or too few to use]

Dynamic Shading		May-October Mean Error (°C)				May-October Mean Absolute Error (°C)			
Site	RM	2000	2001	2002	2003	2000	2001	2002	2003
Dilley	58.8	0.28	-0.73	-0.23	-0.18	0.79	0.86	0.85	0.81
Golf Course Road	51.5	-0.17	-0.39	-0.74	-0.61	0.71	0.65	0.78	0.73
Rood Bridge Road	38.4	-0.14	-0.27	-0.09	na	0.68	0.83	0.67	na
Farmington	33.3	-0.29	na	-0.44	-0.55	0.58	na	0.73	0.72
RM 24.5	24.5	-0.56	-0.72	-0.64	-0.78	0.71	0.90	0.80	0.86
Elsner	16.2	-0.37	na	-0.52	-0.60	0.59	na	0.70	0.74
Tualatin Park	9.0	1.34	1.29	1.21	1.02	1.34	1.29	1.21	1.04
Canal headgates	6.7	-0.29	na	-0.22	-0.39	0.65	na	0.64	0.78
Oswego dam	3.4	-0.53	-0.21	-0.48	-0.57	0.69	0.51	0.59	0.70

The typical level of error, as measured by the mean absolute error of the model prediction, is less than 1.0°C and for some comparisons approaches 0.5°C. A useful goal for water-temperature modeling is to minimize the model bias and keep the mean absolute error less than 1.0°C. It is difficult in any temperature-modeling exercise to achieve a mean absolute error of less than 0.5°C, and the fit is considered to be good if the mean absolute error is less than 1.0°C.

These goodness-of-fit statistics also were computed for model results obtained with the static-shading version of the lower Tualatin River model. For those simulations, the upper river model still used dynamic shading. Results are shown in table 2, and indicate that the model bias and typical error for the static shading model (ME -0.50°C, MAE 0.70°C) are similar to those for the dynamic shading model (ME -0.48°C, MAE 0.70°C). In general, the static shading model has a slightly better fit to the data at Farmington and RM 24.5, while the dynamic shading model has a better fit to the data at Elsner, the Oswego Canal headgates, and the Oswego dam. Clearly, both models are representing about the right amount of riparian shade, though the dynamic shading model is likely to better represent how that shade varies over the course of a day and over the course of the summer season.

Table 2. Goodness-of-fit statistics for the USGS Tualatin River model's static shading simulation of water temperature during the May through October periods of 2000-2003. Static shading was used for the lower river model; the upper river model used dynamic shading. All statistics are given in degrees Celsius (°C). The mean error is a measure of bias, while the mean absolute error is a measure of the typical error for any data point.
[RM = river mile; na = measured data not available]

Static Shading		May-October Mean Error (°C)				May-October Mean Absolute Error (°C)			
Site	RM	2000	2001	2002	2003	2000	2001	2002	2003
Farmington	33.3	-0.24	na	-0.39	-0.52	0.56	na	0.70	0.69
RM 24.5	24.5	-0.51	-0.65	-0.57	-0.72	0.67	0.85	0.75	0.81
Elsner	16.2	-0.39	na	-0.52	-0.63	0.57	na	0.72	0.78
Tualatin Park	9.0	1.28	1.22	1.15	0.95	1.28	1.22	1.15	0.97
Canal headgates	6.7	-0.43	na	-0.36	-0.53	0.62	na	0.65	0.78
Oswego dam	3.4	-0.63	-0.31	-0.58	-0.67	0.70	0.56	0.66	0.76

Graphical Comparisons

Figures 4 through 7 show graphs of measured and simulated water temperature at nine sites in the Tualatin River for the years 2000 through 2003. The graphs in those figures overlap somewhat in order to fit them on the same page. The simulated temperatures are displayed in either black or blue, where the black data are plotted against the black temperature axis on the left and the blue data are plotted against the blue temperature axis on the right. The site names for each graph are printed alongside the temperature axis that corresponds to the data.

In addition to showing the relative correspondence between the measured and simulated data, figures 4-7 also show how the temperature changes from upstream to downstream. The sites are plotted from top to bottom according to descending river location, where the most upstream and top-most graph is from the Tualatin River at Dilley, the location nearest to Henry Hagg Lake. It is easy to see in these graphs how the thermal influence of Hagg Lake diminishes, and the influence of local weather increases, as water moves downstream. These comparisons also show that the measured temperatures at Tualatin Park consistently are low relative to the simulated temperatures. Perhaps the sensor at that site was not functioning well or was not properly calibrated. Though I do not have any quality assurance information to either verify or reject those data, it seems reasonable based on the model's agreement with data from other sites to conclude that the measured temperature data from Tualatin Park are not accurate.

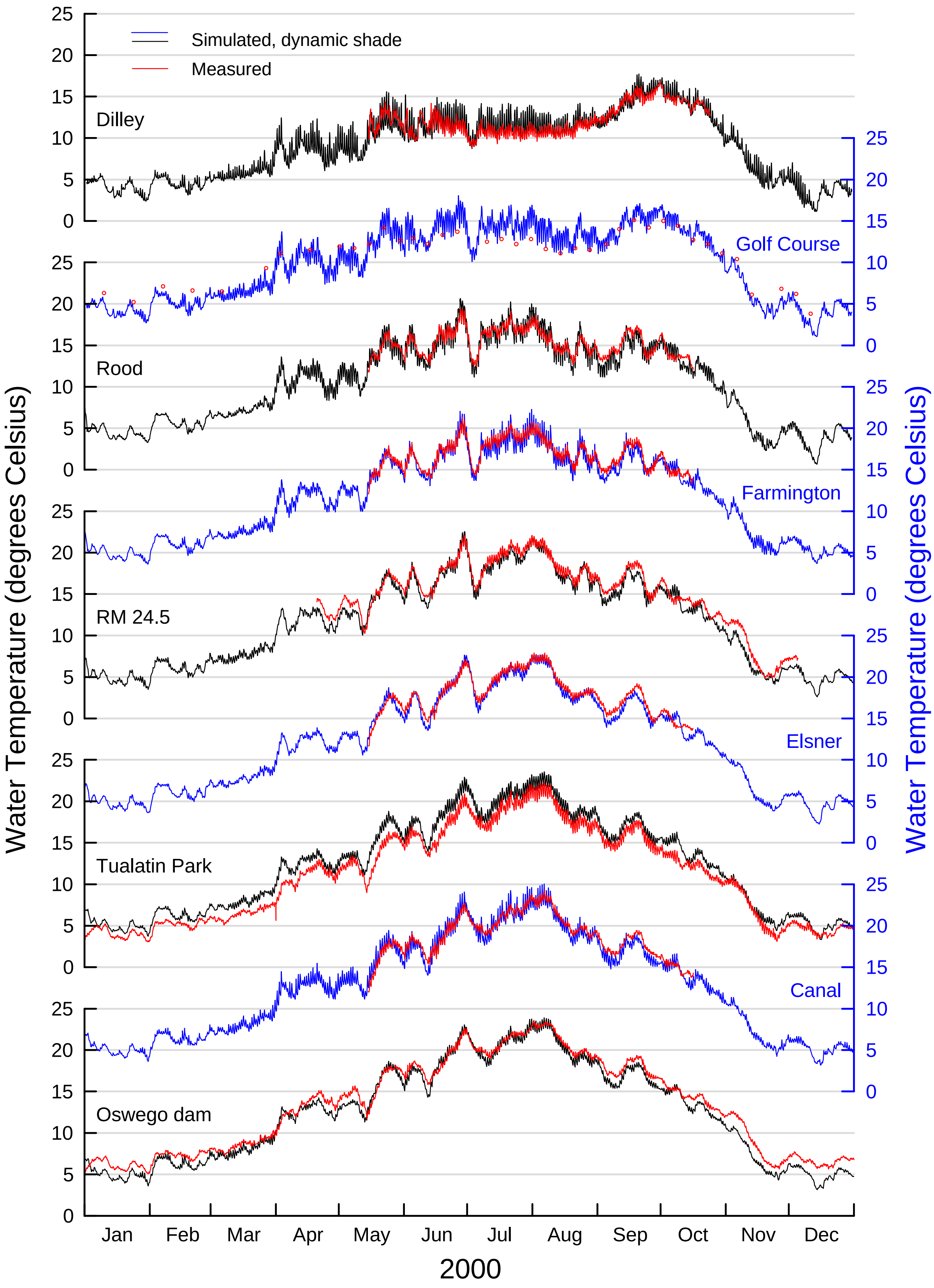

Figure 4. Comparison of measured and simulated water temperatures during 2000 using the dynamic shading model.

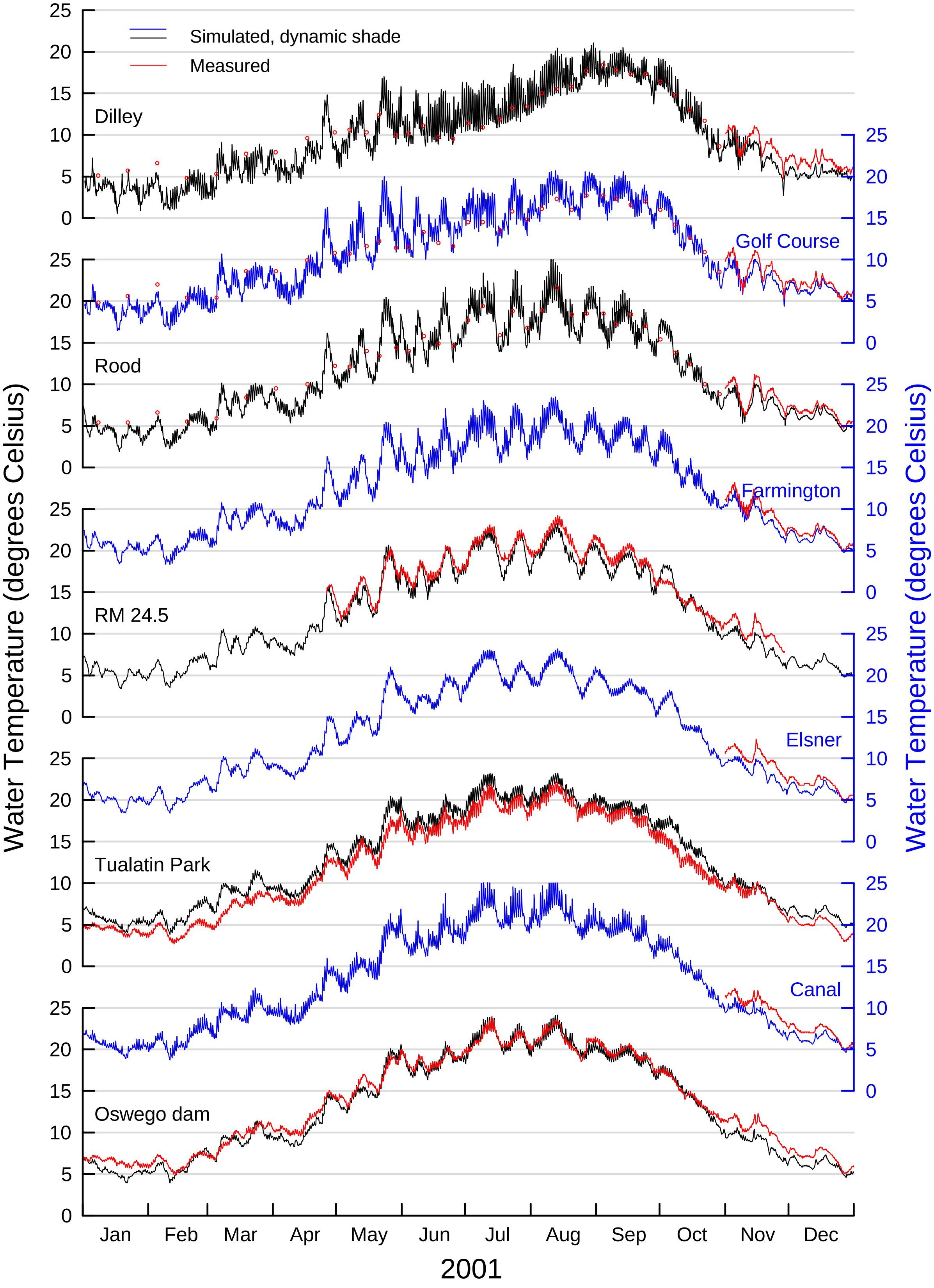

Figure 5. Comparison of measured and simulated water temperatures during 2001 using the dynamic shading model.

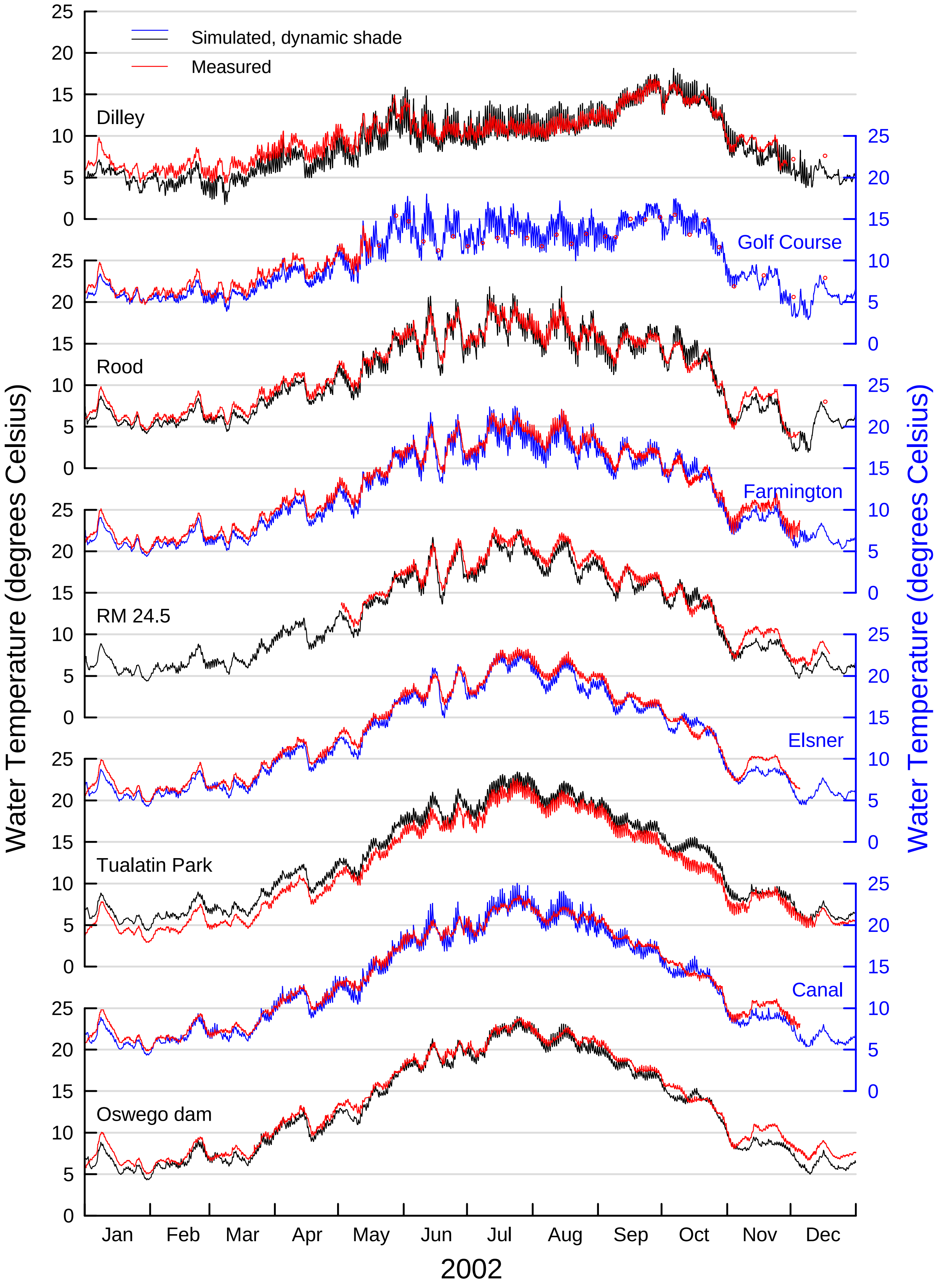

Figure 6. Comparison of measured and simulated water temperatures during 2002 using the dynamic shading model.

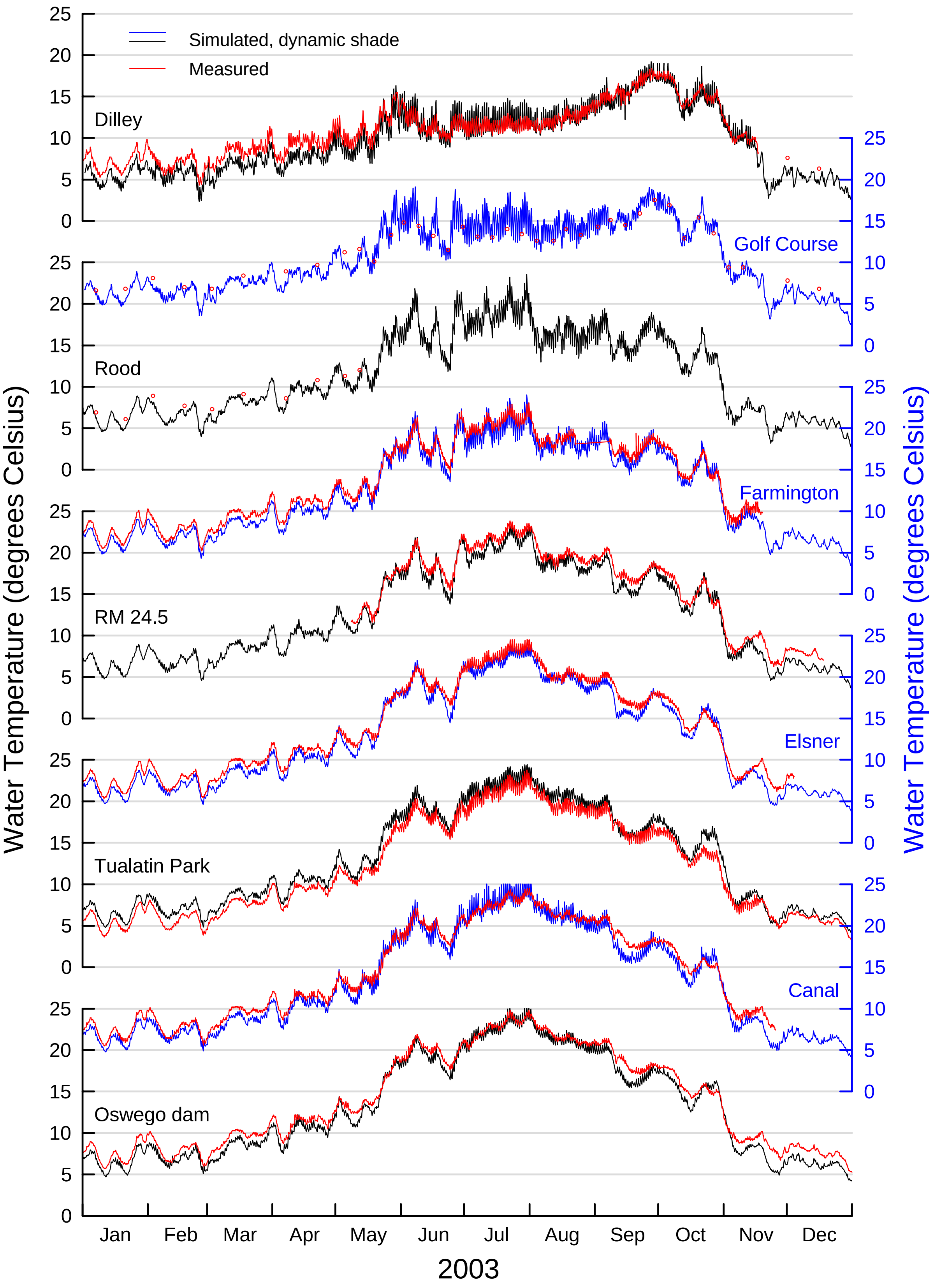

Figure 7. Comparison of measured and simulated water temperatures during 2003 using the dynamic shading model.

Daily Average Effective Shade

A comparison of the daily average effective shade simulated by both the static and dynamic models of the lower Tualatin River was generated for the leaf-on summertime period from May through September. Some results are shown in figure 8. Compared to static shading, dynamic shading produces less shade in mid-summer when the sun angle is high, and produces more shade in September when the sun angle is lower. As a result, mid-summer surface temperatures can be slightly higher and have more daily variation than that produced with static shading. Similarly, surface temperatures in September are slightly cooler. Overall, though, the trends and accuracies for predicting water temperature are similar. Dynamic shading is slightly more accurate than static shading in the early part of the summer, and at the more downstream stations, but is slightly less accurate than static shading in the fall, when the model sometimes predicts a cooler water temperature than indicated by the data. This phenomenon is probably related to the lack of a good sediment-water heat transfer algorithm in the model.

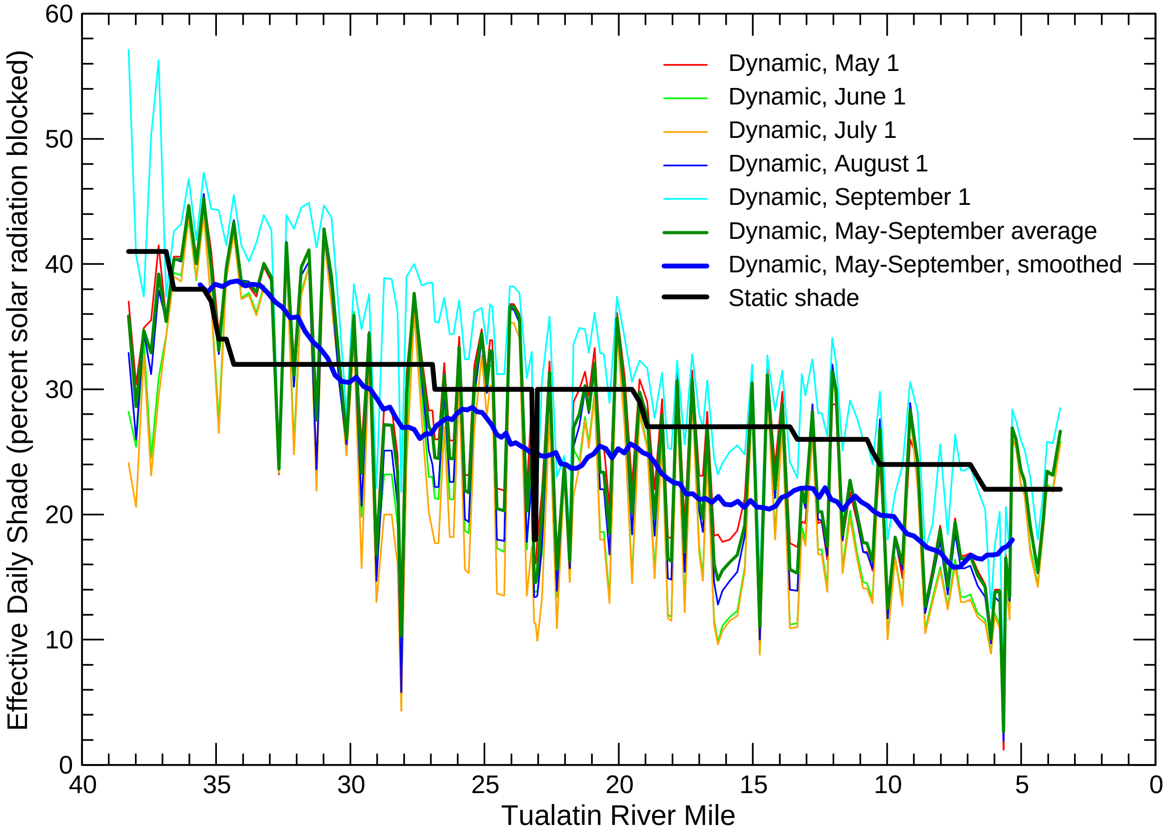

Figure 8. Comparison of daily average effective shade produced by the static and dynamic shading models of the lower Tualatin River. Dynamic shade computations were made for several representative dates during the summertime leaf-on period; those results were then averaged (thick green line) and smoothed with a running average (thick blue line) to provide an overall summertime comparison to the shade produced by the static shading model.

I hope that the information in this letter is useful and is sufficient for your intended purposes. If you have any questions or require further information, please don't hesitate to contact me at 503-251-3280 or by email at sarounds@usgs.gov.

Sincerely,

Stewart Rounds

Stewart Rounds
Hydrologist

cc: Andy Schaedel, ODEQ
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Annett Sullivan, USGS

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