Harpeth River Water Quality Model Comparison

PURPOSE

The purpose of this modeling task is to use available tools to help quantify the likely impacts of the Franklin IWRP on water quality and flow in the Harpeth River. The aim is not to provide a definitive statement about whether or not the IWRP will achieve water quality standards, as such determinations would be hampered by known data gaps (e.g. instream organic matter, nonpoint source pollutant loads, etc.), by scientific uncertainty inherent in any representation of natural hydrologic systems, and by factors beyond the control of the City of Franklin (such as upstream watershed pollutant loads, climate variability, etc.). Rather, the tools will be adapted as needed and used to compare the IWRP alternatives with respect to their impacts on water quality and river flow. Results will be interpreted in conjunction with professional judgment in a probabilistic context (for example: Most likely to meet state standards, likely to meet state standards, compliance uncertain, not likely to meet standards).

This memorandum compares the two available models of the hydraulics and water quality in the Harpeth River, and recommends the tool(s) that are best suited to this IWRP study.

Client

Franklin, TN

Integrated Water Resources Plan

Key Team Members

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Date

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DRIVING QUESTIONS

To date, water quality in the Harpeth River has been addressed in the IWRP process only through estimation of changes to pollutant loads into the river, and not on instream fate and transport of pollutants. As the process moves toward the selection and implementation of alternatives, specific questions about instream water quality must be addressed:

- Which IWRP alternative is likeliest to yield the best water quality in the Harpeth River in Franklin and downstream?
- What are the likely water quality impacts of the selected alternative?
- If water quality upstream of Franklin meets TN standards, how will Franklin's IWRP affect the river?
- If water quality upstream of Franklin does not meet standards, how will Franklin's IWRP work toward improvements?

AVAILABLE TOOLS

There are currently two separate, existing models of the Harpeth River. A suite of models of the watershed loading, river hydraulics, and water quality processes was developed by EPA Region 4 as part of a TMDL for the river in 2004. Another model of the hydraulics and water quality processes has been developed and maintained by TVA (River Management System, or RMS). Both models have strengths and weaknesses, and both will need to be modified and updated for use in the IWRP. The following figure illustrates the watershed and identifies key river mile locations that are referenced in the model descriptions:

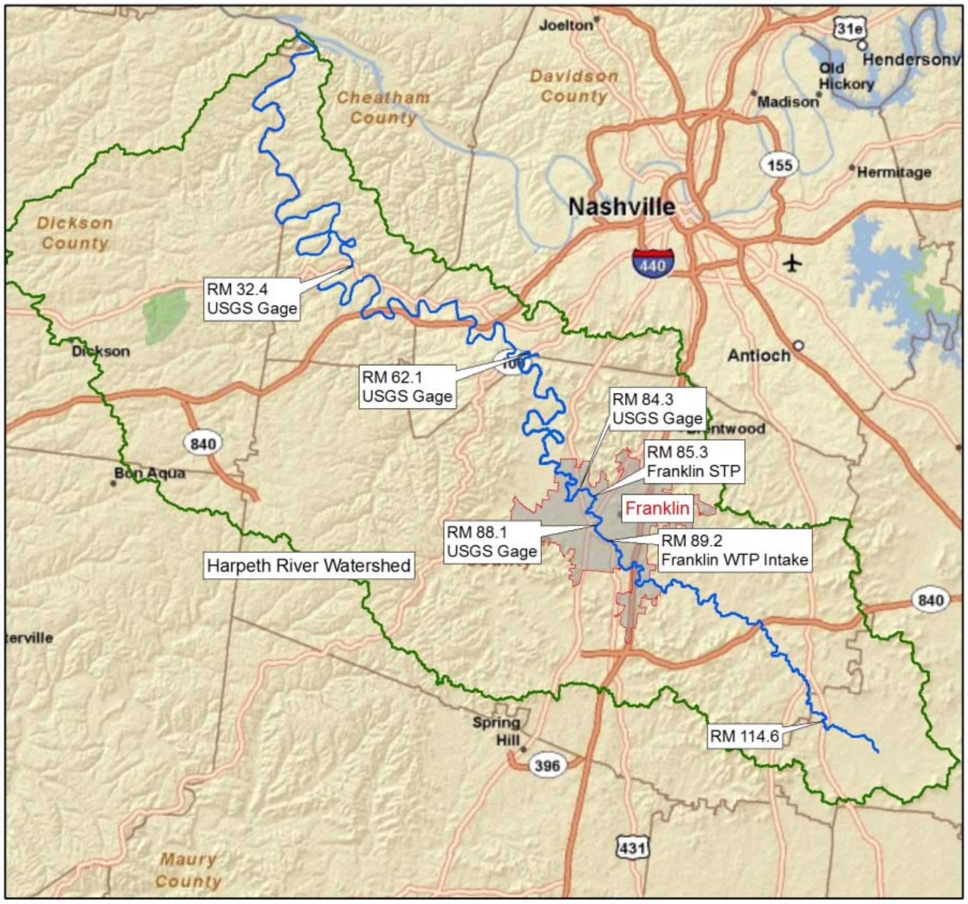

Figure 1 - Harpeth River Watershed and Key River Mile Locations

The TMDL models use the following software, and cover river mile 32.4 to river mile 88.1:

- Loading Simulation Program C++ (LSPC) for overland flow and watershed loading
- CE-QUAL-RIV1 (CE-QUAL) for river hydraulics
- Water Quality Analysis Simulation Program (WASP) for instream water quality
- QUAL2E for dissolved oxygen upstream of river mile 89.2

The TVA model is coded in the River Management System (RMS) framework, and covers river mile 32.4 to river mile 114.6. It is comprised of the following analytical modules:

- ADYN for the river hydraulics
- RQUAL for the instream water quality

The RMS model has not yet been applied to studies of the Harpeth River.

METHOD OF TOOL SELECTION

The tools used for evaluation of future water quality and flow conditions in the Harpeth River will be selected and adapted based on their ability to address the driving questions outlined above. A four-step process was employed to evaluate and compare the alternative tools and formulate a recommendation to the City. Ultimately, the recommendation of which tool(s) to apply will be based on observed scientific credibility and professional judgment regarding the functionality of the tools and their applicability to the IWRP process.

1) Review existing reports

    a. Strengths and weaknesses from past peer reviews were noted.

    b. Calibration records were examined for consistency across ranges of flows and seasons, and for overall scientific credibility.

2) Review input files

    a. Parameters were reviewed against available data and published literature values for inland rivers.

    b. Hydraulic and water quality processes (e.g. the nutrient cycle) were examined for appropriate level of detail with respect to available data. *Note that complete representation of physical, biological, and chemical processes is not necessarily a criterion, as sometimes the ability to distinguish causes and effects is obscured when detail is added but cannot be substantiated.* We looked for a representation of the system that can reproduce *and explain* observed phenomena. Clarity in the causal relationships and their sensitivity was more important than complete and accurate reproduction of all end results.

3) Run the models

    The models were evaluated for:

    a. Ease of scenario definition

    b. Ranges of conditions over which they can be run

    c. Sensitivity to the types of projects comprising the IWRP alternatives

    d. Numerical stability

    e. Required conversions to new versions

4) Observed Performance

    a. Based on the types of scenarios proposed, more emphasis was placed in this comparison on instream processes (channel hydraulics and water quality) than on watershed processes such as rainfall-runoff relationships and nonpoint source pollution loading. This is because surrogates are readily available for watershed processes, in the form of USGS streamflow records, existing water quality data, and published values on land use loading rates for relevant pollutants. Furthermore, none of the IWRP alternatives are aimed at improving conditions in the upstream watershed (as this is beyond the purview of the City of Franklin), and available data will be more credible than synthesized inputs to the model of the actual river. Therefore, a brief review of key model performance features was conducted, focusing specifically on time of travel over varying flow conditions and simulated dissolved oxygen levels (both daily average and diurnal fluctuations).

OBSERVATIONS

Calibration/Performance

Flow and Time of Travel

Both existing models have been configured to simulate flows in the river in August 2000 (a period of low flows), allowing for comparison of hydraulic and water quality model performance against observed data for that time period. In addition, the ADYN hydraulic model was configured to run for April 2001, in order to compare the results under a higher flow regime.

The Harpeth River experiences times of extremely low flow (less than 1 cfs) during average summer months, which presents a challenge in hydraulic modeling. Under such low flows, the river can be dry in some places and flow as a series of trickles and pools in others. Neither ADYN nor CE-QUAL is designed to simulate such flows with a high level of precision because channel features are generalized over reaches of several thousand feet, and under low flow conditions, localized variations in geometry can restrict flow where higher flow would be unaffected. While the flows in the model output match gaged records, the simulated velocities can be greater than what would be observed in the river, therefore resulting in decreased travel times under extreme low flow conditions. Figures 2 and 3 show the gaged flows for August 2000 and April 2001 as compared with the simulated flows from the ADYN and CE-QUAL hydraulic models.

Both models use the 15-minute flow data from the USGS Gage at Franklin (03432350) as a boundary condition. There are unexplained differences in the gage data and the existing CE-QUAL model boundary condition input, specifically spikes in flow in late August 2000 in the model input that do not appear in the observed data. The source of the input flow data (from tributaries and intermittent runoff) is different for the two models. The existing CE-QUAL model uses flows generated by a watershed rainfall-runoff model (LSPC), while the ADYN model input flows were derived using existing gage data and conservation of mass principals. The latter approach results in better matching of peaks at the gaged locations, and is sufficient for the purposes of this study, where simulation of overland flow and loading is not a principal focus (stormwater pollutant loads can be estimated outside of modeling frameworks). The USGS gages on the Harpeth River also provide adequate data over the past several decades to simulate a wide range of flow conditions with this approach. Without converting the CE-QUAL model to its successor software, EPD, it is not possible to examine how that model would respond to input flows generated using a mass balance approach.

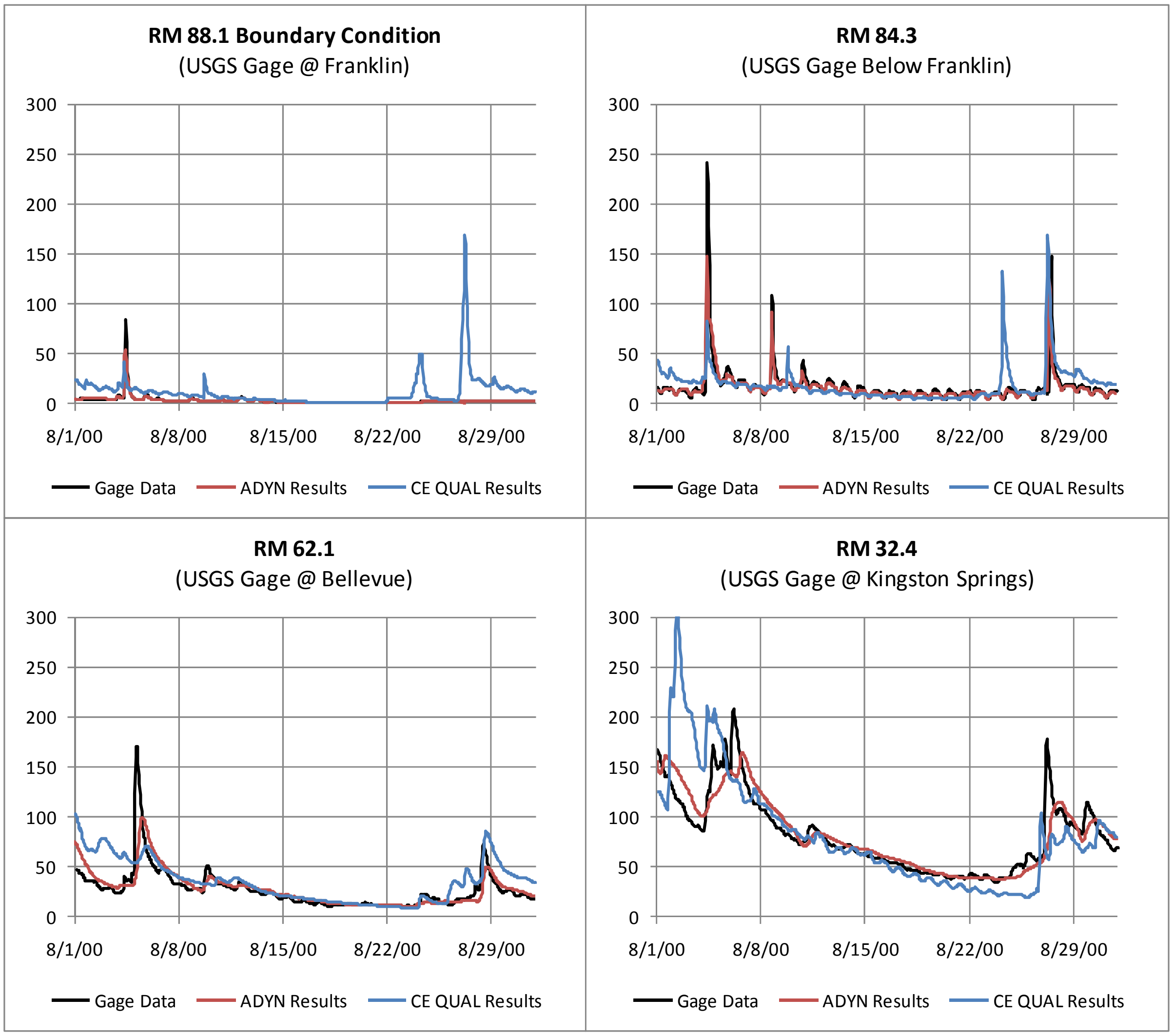

Figure 2 - Gaged and Simulated Streamflow Comparison – August 2000

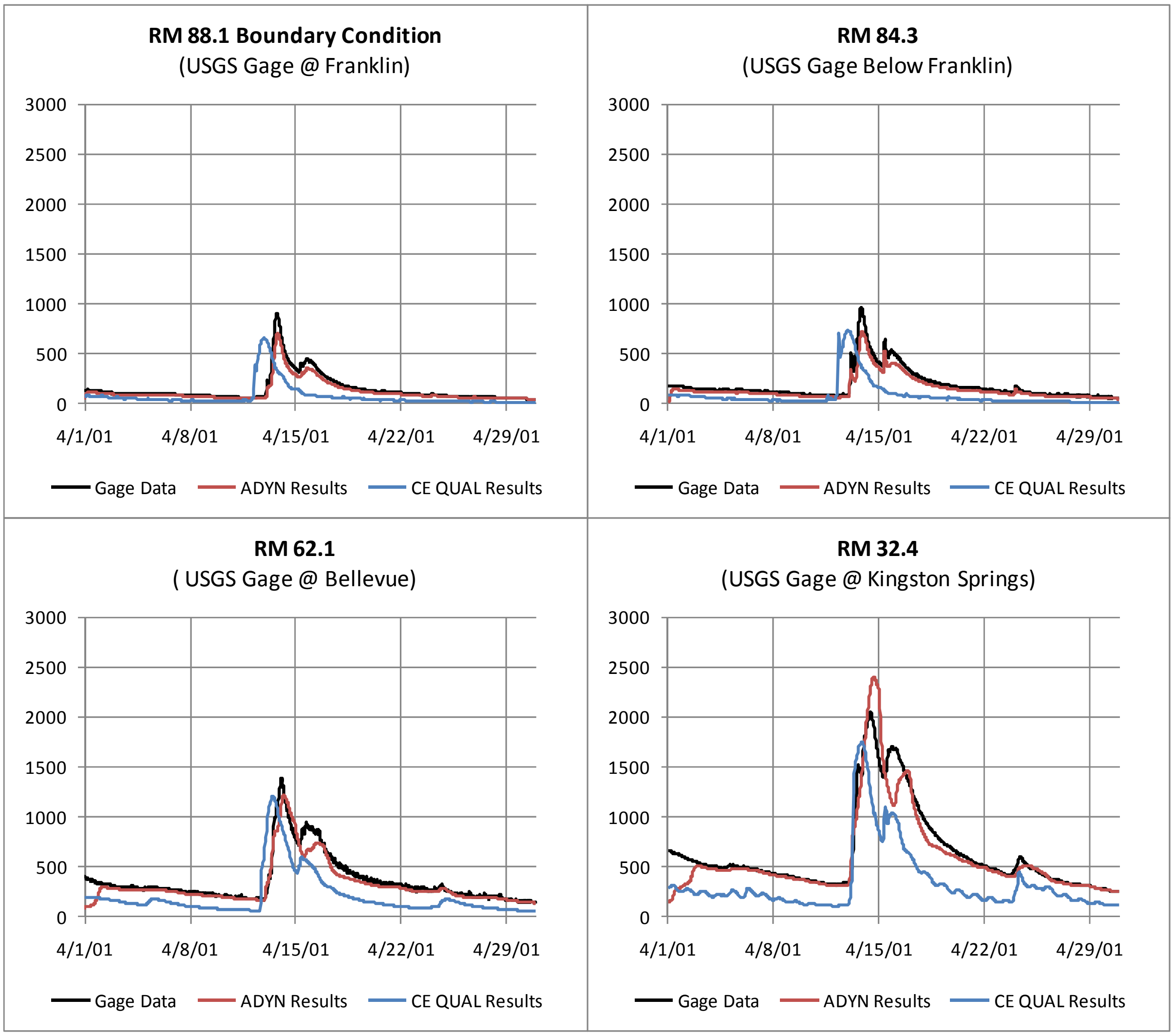

Figure 3 - Gaged and Simulated Streamflow Comparison – April 2001

EPA conducted two time of travel studies on the Harpeth River in August 2000 and April 2001. The results are reported in graphical form only in the Harpeth River Watershed Modeling Effort: A Tool for TMDL Development Report (July 2002). The velocity and time of travel results from the August 2000 study conflict (pp. 40 and 47), and therefore will be omitted from the model comparison in this memorandum.

Both models match the time of travel data from the April 2001 study fairly well (see Figure 4). The CE-QUAL model tends to simulate lower velocities (greater times of travel), likely due to assumptions of variable roughness coefficients (discussed in the section on model parameterization). A separate comparison between times of travel of storm peaks shows that both models produce reasonable results as compared with gaged data. Figure 5 shows the flow (at the upstream gage) versus time of peak travel for several rain events in August 2000 and April 2001. This comparison shows that both models reasonably predict time of travel in the river over a range of flow conditions, not including extreme low flows. The lowest observable peak in the gage hydrographs was approximately 50 cfs, which is well above the extreme low summer flows of below 1 cfs that have been observed in the Harpeth River.

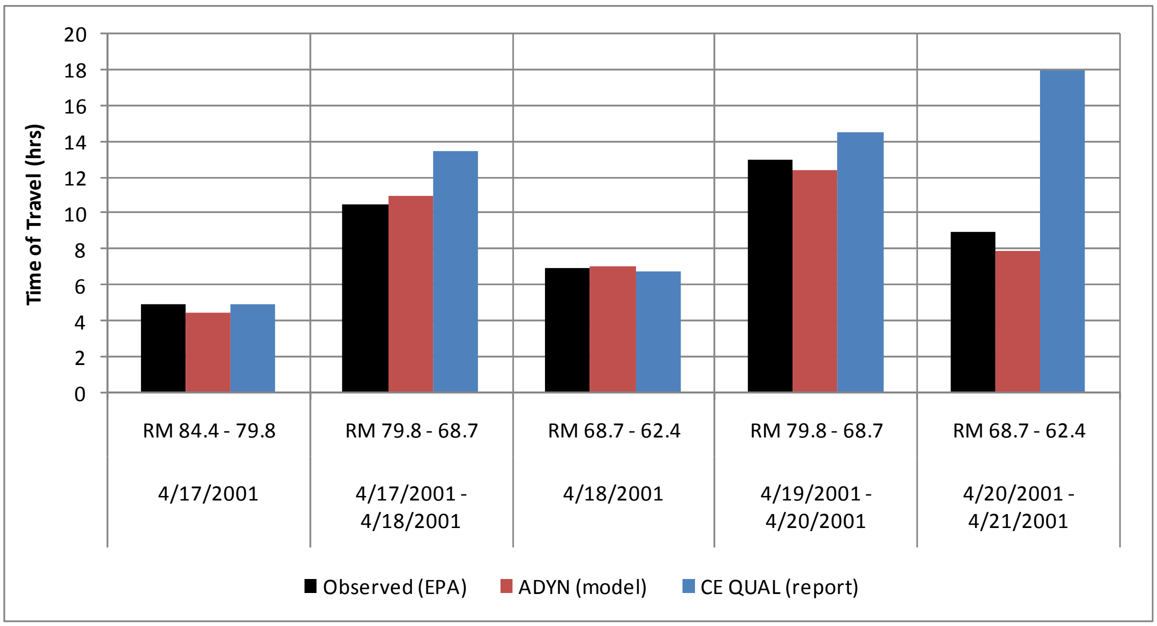

Figure 4 - Time of Travel Comparison – April 2001

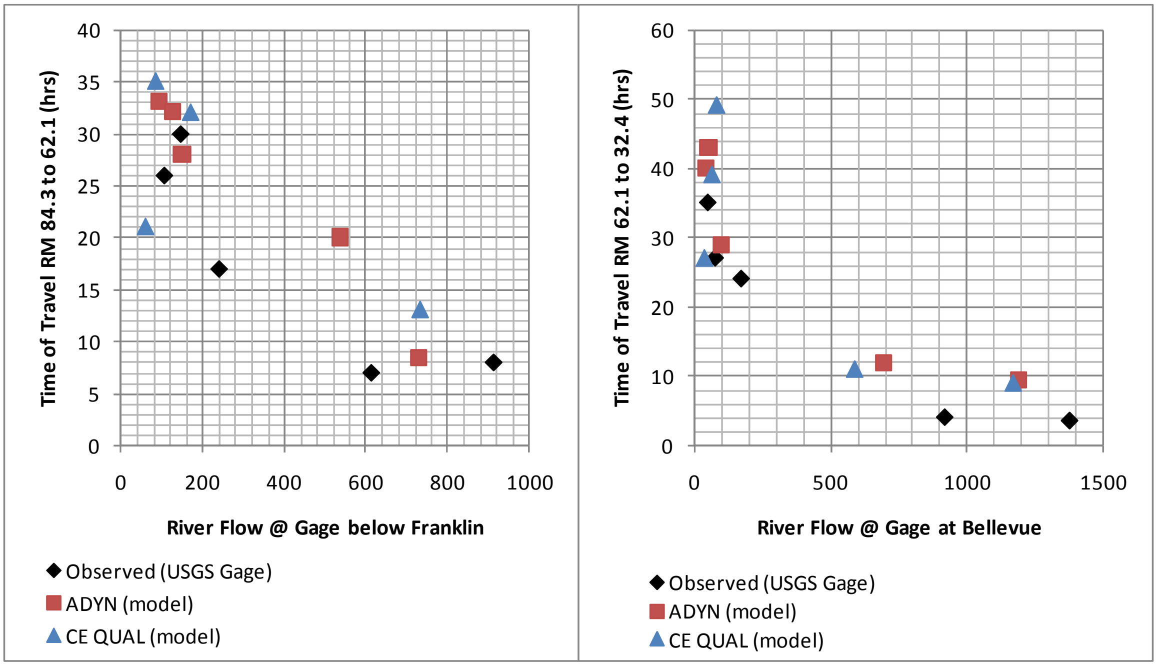

Figure 5 - Comparison of Flow vs. Time of Peak Travel for August 2000 and April 2001 Storms

Dissolved Oxygen

Dissolved oxygen levels in the Harpeth River were measured by EPA in August 2000 at seven locations: two upstream of Franklin, two in or near Franklin, and three downstream of Franklin. The measurements were taken continuously at 30 minute intervals over four days, August 22 to August 25. The comparison of dissolved oxygen levels between measured values and the WASP simulation was included in the TMDL Development Report and is presented in Figure 6 and 7. The comparison between measured dissolved oxygen and the RQUAL simulation was extracted from the August 2000 model run, and is presented in Figure 8. The RQUAL comparison figures show the average dissolved oxygen and diurnal fluctuations for each river location where data were available.

Both water quality models match the magnitude of dissolved oxygen concentrations in the river relatively well. The RQUAL model more successfully matches the diurnal timing pattern than the WASP model, based on the plot of river mile 88.1 from the TMDL Development Report. This location in the river is of particular interest in the IWRP study, as it will be necessary to examine the effect of various water and wastewater management strategies on the dissolved oxygen levels within the Franklin reach of the Harpeth River, where the stream is currently impaired. The current calibration of the RQUAL model predicts slightly greater dissolved oxygen values than were observed at this location, but the model parameters are largely set to default values. Based on the accuracy of the timing of diurnal fluctuations, and the very close match to observed data at downstream locations, the RQUAL model appears to be the preferred tool to use in water quality simulations for the IWRP study.

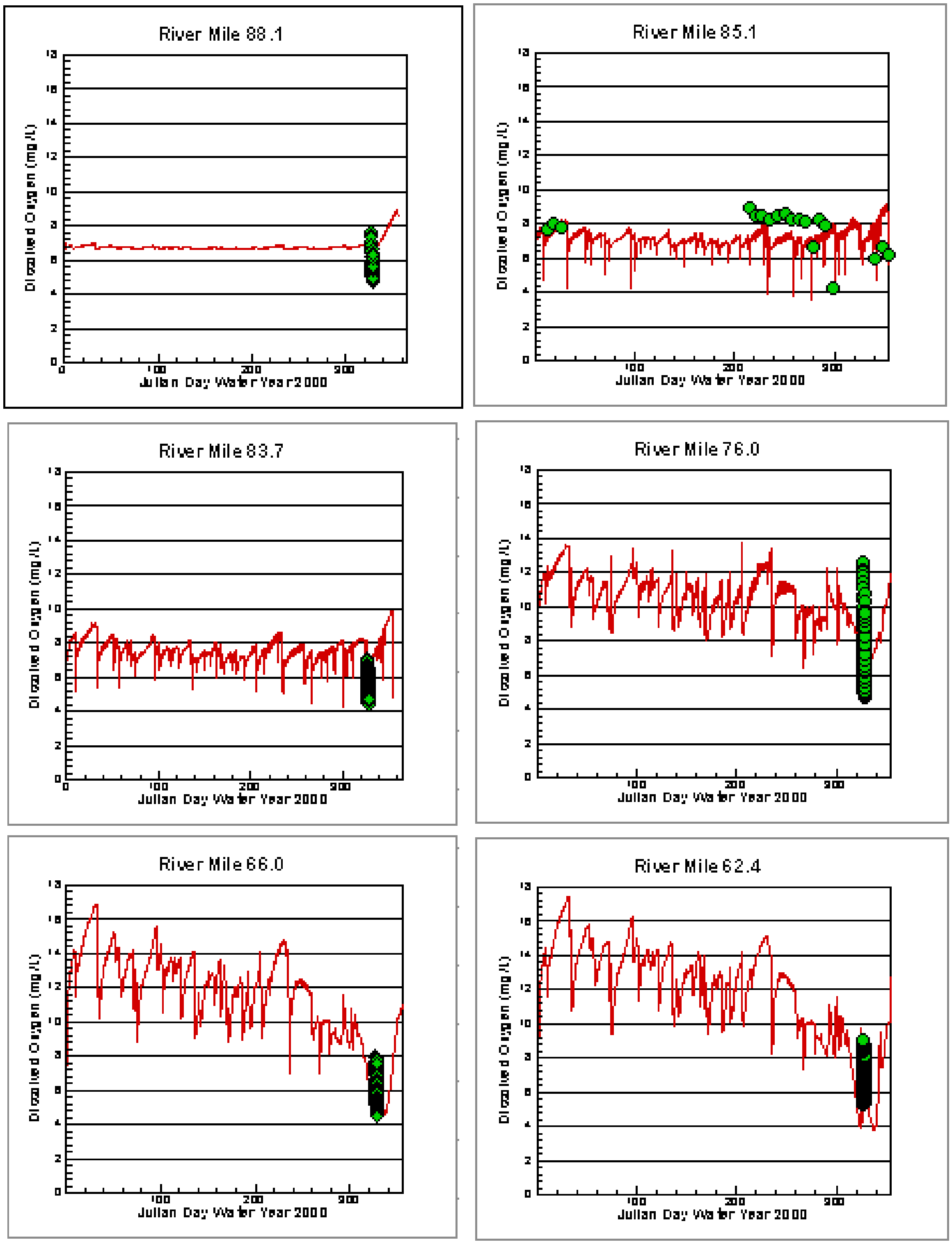

Figure 6 - Comparison of Observed and Simulated Dissolved Oxygen, WASP Model

(Excerpted from: Harpeth River Watershed Modeling Effort: A Tool for TMDL Development Report (EPA, July 2002)

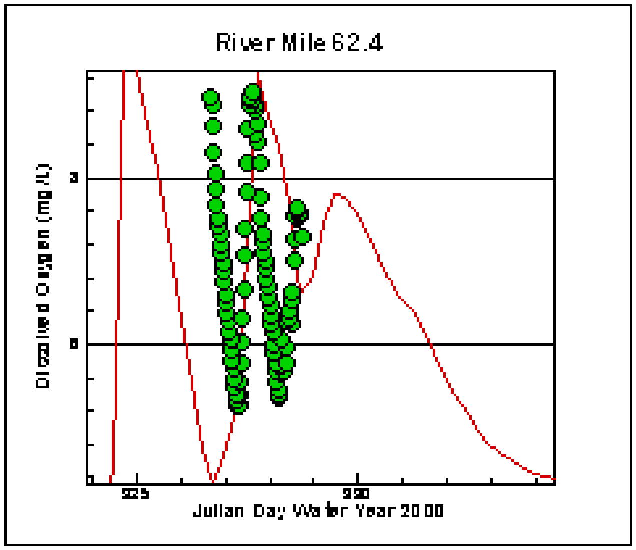

Figure 7 - Comparison of Observed and Simulated Dissolved Oxygen Diurnal Fluctuations, WASP Model

(Excerpted from: Harpeth River Watershed Modeling Effort: A Tool for TMDL Development Report (EPA, July 2002)

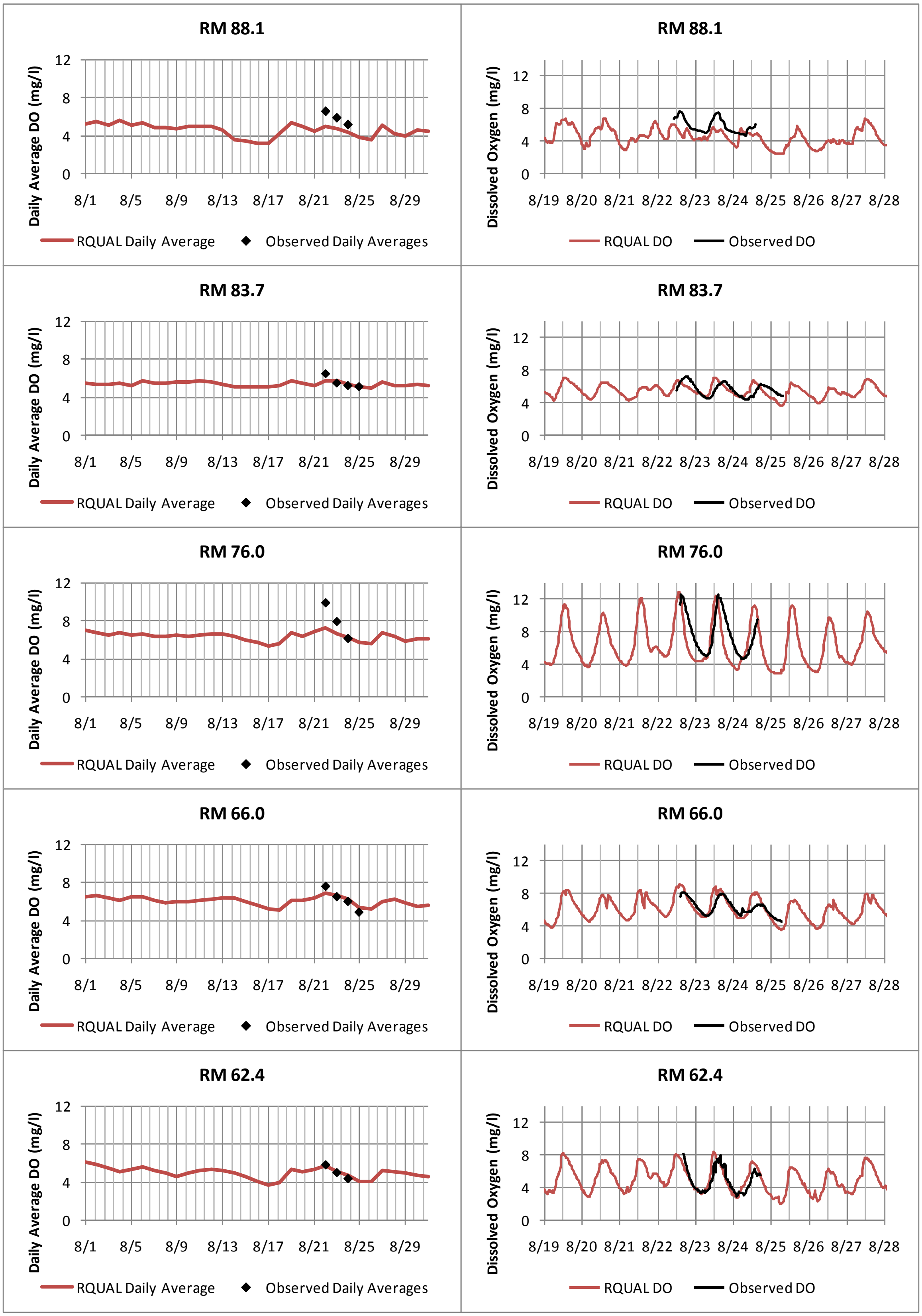

Figure 8 - Comparison of Observed and Simulated Dissolved Oxygen, RQUAL Model

Notes From Past Peer Reviews

CDM reviewed the TMDL model in 2002 and discovered the following issues:

- The 1992 land use data used in the LSPC watershed model is outdated.
- The hydraulic model needs refinement in streambed elevations, using local digital elevation models.
- The hydraulic model is unstable or inaccurate at very low flows (less than 1 cfs).
- Periphyton is not considered in the water quality model.
- The time of travel calibration is inadequate for the purposes of the TMDL study.
- The diurnal fluctuations represented in the model are inadequate for the purposes of the TMDL study.

A complete memorandum on the CDM review of the TMDL model was issued to EPA on September 30, 2002. It is important to recognize that the modeling for the IWRP study is not intended to recommend permit limits or load/wasteload allocations. Hence, weaknesses in certain areas, while critical to a TMDL study, are not necessarily fatal flaws with respect to comparative analysis for IWRP planning (refer to the fundamental questions outlined at the beginning of this document), but are still important considerations in the selection of a tool.

The RMS model of the Harpeth River was developed by TDEC for internal purposes, and has not been peer-reviewed at this time.

Current Model Parameterization

Hydraulic Parameters

The primary parameters of the channel hydraulic simulation are the roughness coefficients for the channel itself and its overbank areas. For fast-flowing streams that are constrained by numerous constrictions such as culverts and wide bridge piers, contraction and expansion head loss coefficients can also be important parameters to adjust in a hydraulic model. However, the Harpeth River, under most flow conditions, cannot be generally characterized that way, and so the most important hydraulic parameters are the roughness coefficients. These control the velocities at which water flows through the channel, the associated depth, and backwater behavior, and are the most important parameters in the accurate simulation of travel time, water depth, and flow velocity.

Roughness coefficients can range from values of approximately 0.013 (smooth, concrete channels) to 0.13 – 0.15 (swampy areas with severely restricted or impeded flow pathways). Generally, channels such as the Harpeth River with flat bottoms of rocks, sand, and gravel are characterized by roughness coefficients ranging from 0.030 – 0.040. Overbank areas that are marked by tree roots and heavy vegetation, such as characterize the channel banks along the Harpeth River, generally have higher roughness coefficients to represent the flow restrictions.

The CE-QUAL hydraulic model of the Harpeth River applied depth-variable roughness coefficients to simulate the slowing down of river flow during low-flow conditions, when uniform flow in the channel is replaced with more stagnant pools and riffles (even puddles). At zero depth, the roughness coefficient is 0.15 (almost fully restricted), and this decreases linearly with increasing depth to 0.030 at 4 feet of depth, a common value for rocky-bottom channels like the Harpeth. This was done as a calibration step, to slow the water velocity down at extremely low flows, when small rocks and gravel can act more like boulders would in a larger stream. However, the depth-roughness relationship is not necessarily physically based, and the channel should begin to behave like a normal, gravelly river at depths well below 4 feet. (4 feet of depth corresponds to flows much higher than extreme low flow conditions), Functionally, however, this approach is useful in representing the ways in which the channel's restrictive characteristics act differently on low flows than on higher flows. With respect to the overbank areas, the roughness coefficients in this model do not appear to vary from the channel coefficients, which is somewhat unusual and not necessarily physically representative of the dense vegetation that lines the river banks of the Harpeth.

The ADYN model applies constant roughness coefficients of 0.030 for the channel and 0.090 for the overbank areas. These values are physically based and commonly applied for rivers characterized by flat, gravelly bottoms and vegetated, rooty banks and floodplains. These values are considered to be more defensible than those in the CE-QUAL model because they are physically linked to actual channel characteristics, though for extremely low flow conditions, travel times may be faster than in the actual channel

Water Quality Parameters

While the mathematical representation of the physical, biological, and chemical processes in the WASP model and the RQUAL model are reasonably similar, the parameterization of the models differs in many cases. This makes a direct comparison of the appropriateness of parameters somewhat difficult, and so each of the tools was evaluated for its water quality parameterization independently. Full summary tables of parameter values are available but this section focuses on a general evaluation of key parameters and apparent philosophies of calibrating the two models.

Many of the basic parameters are equivalent or similar between the two models, and fall within the range of expected values for this type of river. An example are the Sediment Oxygen Demand rates (SOD), set at 2 $g/m^2/day$ in WASP and varying between 2 and 2.3 $g/m^2/day$ in RQUAL (higher at the upstream end). Neither model demonstrates major changes in SOD, which is encouraging – drastic variations would suggest that SOD may have been a localized calibration parameter, and with as much uncertainty as there is in the Harpeth concerning nutrient loads, periphyton, etc., it is preferable *not* to compensate for one uncertainty with a high degree of variability in another uncertain variable. It is best to keep variables such as SOD reasonably constant unless field data suggest other trends. Other basic parameters, such as temperature correction factors, are also similar between the two models.

However, some of the key parameters that govern the nitrogen cycle are very different. For example, the nitrification rate constant is set at 0.4 in the WASP model, and 0.1 in the RQUAL model. Similarly, the denitrification rate in WASP is set at 0.03, while in RQUAL it is 0.1. Because organic growth in the Harpeth River is assumed to be primarily limited by nitrogen, care will be required to vet these constants to other calibrated river models, and understand their sensitivities (for whichever model is selected).

Many of the variables in the WASP model fall within the range of published literature values. However, in the WASP model, many of the nutrient and phytoplankton (floating algae) coefficients are set at or above the maximum recommended value. It is very possible that this is because the WASP model does not account for fixed organic growth (attached algae, or periphyton) and compensates for the oxygen depleting effects by over-emphasizing the impacts of nutrients and their interactions with floating algae (Note that a newer version of WASP, WASP7, includes simulation options for periphyton, but the Harpeth model was created in an older version which did not have this functionality). Generally, observing so many coefficients set at or above the maximum recommended rate is a sign that the processes being simulated are not necessarily represented in a physically defensible way.

In the RQUAL model, most of the parameters for the Harpeth River are set at default values, generally within published literature ranges Notable exceptions include the photosynthetic and macrophyte respiration rates, which were adjusted to replicate presumed impacts of periphyton, based on dissolved oxygen measurements. The RQUAL model does not simulate periphyton explicitly, but the photosynthetic and respiration processes associated with fixed organic growth, such as macrophytes, can be used approximately as a surrogate.

Therefore, RQUAL is the preferred tool with respect to water quality parameterization:

- RQUAL uses parameter values that generally fall within published literature ranges, whereas the calibrated WASP model applies parameter values at or above the recommended maximum for many nutrient and algae processes, suggesting that other processes (perhaps fixed/rooted organic matter) are not adequately represented.

- Periphyton is a known issue in the Harpeth River. RQUAL represents this by simulating photosynthesis and respiration of fixed aquatic plant growth (macrophytes), which is a reasonable surrogate if interactions with sediment nutrients is de-emphasized, especially in the absence of field data. The original WASP model did not include periphyton simulation, though the latest version (WASP7) includes this functionality. The WASP model would need to be converted and upgraded to simulate periphyton.

Before application, the full suite of parameters in the RQUAL model will be further examined and adjusted if defensible and necessary.

Functionality and Ease of Use for IWRP Analysis

The table below compares the two modeling packages for overall functional characteristics and efficiency / effectiveness for IWRP analysis. Recall that these models are *not* being used in this study to establish discharge permit limits or Total Maximum Daily Loads (TMDLs) or new FEMA-certified flood elevations. Rather, the selected tool will be used to compare the IWRP alternatives and help identify which alternatives are likely to produce the best water quality conditions in the river, and how likely any of the alternatives will be to achieving Tennessee state water quality standards on a relative basis.

Qualitative assessments of the functionality of each evaluated tool toward these ends are provided in the table below. For each criterion, the preferred tool is shaded, with darker shading indicating strong preference and lighter shading indicating only a moderate preference.

Table 1 - Comparison of Functionality and Ease of Use

Criteria	CE-QUAL / WASP	RMS: ADYN / RQUAL
Ease of scenario definition and output review	Hydraulic scenarios are difficult without the user interface for EPD, which requires conversion of the input files from CE-QUAL. WASP scenarios are easy to define and manage. The need to port output from EPD to WASP requires generation of .HYD files, which is straightforward, but not seamless.	Scenarios are easy to define and manage with the available user interface, and the two models are designed to run together as two modules of a single package. Output review is very easy with the interface.
Ranges of conditions over which model can be run	Possible to run long-term scenarios. Boundary conditions and input flows currently developed in external LSPC watershed model, but could be replaced with available gaged flows.	Currently set up to run 1-month scenarios. Longer-term simulations are possible, though model array size may pose a problem. The current time-step limit is unknown. There is the possibility of working with the developer to increase the array size. Boundary conditions and input flows derived from known gaged flows.
Sensitivity to the types of projects comprising the IWRP alternatives	Can easily introduce changes in flow and load from lateral confluences. Can simulate altered channel hydraulics. Existing model may not have a reliable background simulation of the nutrient cycle and local oxygen levels without periphyton (would require conversion to WASP 7, additional parameterization, and recalibration). End result may be slightly more physically-based periphyton representation than RQUAL, but without field data, high precision is not possible anyway.	Can easily introduce changes in flow and load from lateral confluences. Can simulate altered channel hydraulics. Already simulates fixed organic growth (periphyton) for better representation of background dissolved oxygen levels so that sensitivity of IWRP projects can be better grounded (representation of macrophyte growth is used as a surrogate for all fixed organic growth).
Numerical Stability	Hydraulic model cannot simulate river flows below 1 cfs. These flows are known to occur during periods of interest for IWRP analysis, but any simulation of flows this low are questionable because of the inability of hydraulic models to accurately account for pooling and riffling and the amplified restrictions of gravel at severe low flows.	Hydraulic model is stable below 1 cfs, but as explained to the left, any simulation of flows in this regime should be used with caution.

Required conversions	CE-QUAL-RIV1 has been replaced by EPD-RIV1. EPD will read CE-QUAL input files, but the user interface necessary for efficient scenario setup and output review requires file conversion. WASP would require upgrading to WASP7 and recalibration to distinguish between floating and fixed algae.	No conversions needed.
Technical Support	Has been difficult getting data and support	TDEC worked with TVA in the development of this model and has willingly provided assistance in this evaluation and will continue to provide technical support and review during the IWRP.

RECOMMENDATION

Recommended Tool

Based on the model review described herein, CDM recommends that the RMS modeling tool be used for the IWRP Harpeth River technical analysis. The following table summarizes the preferred models for each category of observations. A dot in both model columns indicates that there was insufficient information to make a definitive preference of one model over the other.

Category	**CE-QUAL / WASP**	**RMS (ADYN / RQUAL)**
Hydrologic / Hydraulic Calibration/Performance		•
Dissolved Oxygen Calibration/Performance		•
Peer Reviews	•	•
Hydraulic Parameterization		•
Water Quality Parameterization		•
Functionality		•

The RMS modeling package is preferred in all categories where enough information was available to make such a determination. The hydraulic performance of the ADYN (RMS) model appears better than the CE-QUAL model. However, the discrepancies between observed and simulated flows seem to be caused in part by input flows and boundary conditions. Without comparing the simulated flows of both models using the same input and boundary condition flows, it is not possible to fully evaluate their performance relative to each other. In the Peer Review category, only one model was subject to a complete peer review, so there is insufficient information to determine a preference of one model over the other.

Required Enhancements

The RMS model was developed internally by TDEC and not for use on a particular study. Most parameters are set to default values and the model is only fully set up to run one month (August 2000). The following enhancements will be required to bring the model into a fully functional and usable state for the IWRP technical analysis. This list is a starting point; there are likely additional enhancements needed that have yet to be discovered. These enhancements are based on the model review performed to date and the previous peer review of the TMDL model.

Known required model enhancements:

- Evaluate and possibly revise model streambed elevations using local digital elevation models
- Test the sensitivity of the model to algae and macrophyte growth and decay parameterization
- Configure model to run long-term scenarios, of one year or longer (exact dates to be determined)
- Examine and possibly revise the water quality parameterization in relation to regional and literature values
- Compare model scenario runs to other existing data collected since the TMDL study

Attachment: Water Quality Model Parameterization

RMS – RQUAL Parameters

Water Quality Process Coefficients				
NAME	TYPE	DESCRIPTION	VALUE	NOTES
THR	Real	temperature correction coefficient for reaeration	1.024	
THB	Real	temperature correction coefficient for CBOD decay	1.047	
BK20	Real	deoxygenation rate at 20 °C for CBOD (1/day)	0.2	
THN	Real	temperature correction coefficient for NBOD decay	1.09	
NK20	Real	deoxygenation rate at 20 °C for NBOD (1/day)	0.3	
THS	Real	temperature correction coefficient for SOD	1.065	
EXCO	Real	light extinction coefficient (1/m)	0.1	fairly clean water
HMAC	Real	average weed height from bottom of channel (ft)	0	
THPR	Real	temperature correction coefficient for macrophyte photosynthesis and respiration	1.08	
IK2EQ	Integer	flag for reaeration equation choice (-1 to 7)	5	Reaeration equation: Tsivoglou
Algal Kinetic Coefficients				
NAME	TYPE	DESCRIPTION	VALUE	NOTES
AG	Real	algal growth rate (1/day)	2.2	range 1.0-5.0
AM	Real	algal mortality rate (1/day)	0.3	range 0.0-0.5
AR	Real	algal dark respiration rate (1/day)	0.2	range 0.0-.5
AS	Real	algal settling rate (1/day)	0.01	range 0.0-0.5
ASAT	Real	half-saturation coefficient for light (W/m2)	20	range 10-50
EXOM	Real	extinction due to organic suspended solids (m2/g)	0.17	suggest 0.17

Algal Rate Coefficients				
NAME	TYPE	DESCRIPTION	VALUE	NOTES
AT1	REAL	Lower temperature for algal growth	10	
AT2	REAL	Lower temperature for maximum algal growth	20	
AT3	REAL	Upper temperature for maximum algal growth	30	
AT4	REAL	Upper temperature for algal growth	40	
AK1	REAL	Fraction of algal growth rate at AT1	0.1	
AK2	REAL	Fraction of maximum algal growth rate at AT2	0.99	
AK3	REAL	Fraction of maximum algal growth rate at AT3	0.99	
AK4	REAL	Fraction of algal growth rate at AT4	0.1	
Organic Matter Kinetic Coefficients				
NAME	TYPE	DESCRIPTION	VALUE	NOTES
DOMDK	REAL	Labile dissolved organic matter decay rate (1/day)	0.2	range 0.0-0.5
POMDK	REAL	Particulate organic matter decay rate (1/day)	0.2	range 0.0-0.5
POMS	REAL	Particulate organic matter settling rate (1/day)	0	range 0.0-0.5
SDK	REAL	Settled organic matter decay rate (1/day)	0.05	range 0.0-0.3; SDK>0.05 causes SED to go negative
Organic Matter Rate Coefficients				
NAME	TYPE	DESCRIPTION	VALUE	NOTES
OMT1	REAL	Lower temperature for organic matter decay	10	
OMT2	REAL	Lower temperature for maximum organic matter decay	15	
OMK1	REAL	Fraction of organic matter decay rate at OMT1	0.1	
OMK2	REAL	Fraction of organic matter decay rate at OMT2	0.99	

Phosphorus				
NAME	TYPE	DESCRIPTION	VALUE	NOTES
AHSP	REAL	Half-saturation constant for phosphorus (g/m3)	0.009	range 0.001-0.01
Ammonium				
NAME	TYPE	DESCRIPTION	VALUE	NOTES
NH4DK	REAL	Ammonium decay rate (1/day)	0.1	range 0.0-0.5
AHSN	REAL	Half-saturation constant for nitrogen (g/m3)	0.05	range 0.0-0.2
Ammonium Rate Coefficients				
NAME	TYPE	DESCRIPTION	VALUE	NOTES
NH4T1	REAL	Lower temperature for ammonium decay	5	
NH4T2	REAL	Lower temperature for maximum ammonium decay	20	
NH4K1	REAL	Fraction of nitrification rate at NH4T1	0.1	
NH4K2	REAL	Fraction of nitrification rate at NH4T2	0.99	
Nitrate				
NAME	TYPE	DESCRIPTION	VALUE	NOTES
NO3DL	REAL	Nitrate decay rate (1/day)	0.1	range 0.0-0.15
Nitrate Rate Coefficients				
NAME	TYPE	DESCRIPTION	VALUE	NOTES
NO3T1	REAL	Lower temperature for nitrate decay	5	
NO3T2	REAL	Lower temperature for maximum nitrate decay	20	
NO3K1	REAL	Fraction of denitrification rate at NH4T1	0.1	
NO3K2	REAL	Fraction of denitrification rate at NH4T2	0.99	

Stoichiometry Coefficients				
NAME	TYPE	DESCRIPTION	VALUE	NOTES
O2NH4	REAL	Oxygen stoichiometric equivalent for ammonium decay (gO2/ gNH4)	4.57	
O2OM	REAL	Oxygen stoichiometric equivalent for organic matter decay (gO2/gOM)	1.4	
O2AR	REAL	Oxygen stoichiometric equivalent for dark respiration (gO2/gA)	1.4	
O2AG	REAL	Oxygen stoichiometric equivalent for algal growth (gO2/gA)	1.4	
BIOP	REAL	Stoichiometric equivalent between organic matter and phosphorous (gP/gOM)	0.005	
BION	REAL	Stoichiometric equivalent between organic matter and nitrogen (gN/gOM)	0.05	
Oxygen Limit				
NAME	TYPE	DESCRIPTION	VALUE	NOTES
O2LIM	REAL	Dissolved oxygen concentration at which anaerobic processes begin (g/m3)	0.1	suggestion 0.1
Water Quality Process Coefficients				
NAME	TYPE	DESCRIPTION	VALUE	NOTES
BS20	REAL	CBOD settling rate (1/day)	0	see manual
O2KM	REAL	DO half-saturation value to reduce respiration at low DO	0	see manual
QSAT	REAL	saturation light intensity for macrophytes	0	see manual
Weir Aeration Coefficients and Formulation (Franklin Weir @ RM 89.0)				
NAME	TYPE	DESCRIPTION	VALUE	NOTES
WFAC	REAL	Weir aeration equation multiplication factor	1	free overflow weirs
WLEN	REAL	weir crest length (ft)	76	
NEVQ	Integer	#points on user-defined Q vs. E15 curve	0	ignored

SOD Rates vs. River Mile			
NAME	TYPE	DESCRIPTION	VALUE
SFAC	REAL	factor to multiply all SK20 in reach to test sensitivity	1
RMI	REAL	river mile (exact match to model node)	see table
SK20	REAL	SOD rate (g)2/m2/day)	see table
VALUES			
RMI	SK20		
114.60	2		
89.00	2		
88.10	2.3		
83.98	2.3		
75.95	2		
66.00	2		
62.40	2		
35.50	2		
32.40	2		

Photosynthesis Rates vs. River Mile			
NAME	TYPE	DESCRIPTION	VALUE
PFAC	REAL	factor to multiply all PMAX20 in reach to test sensitivity	1
RMI	REAL	river mile (exact match to model node)	see table
PMAX20	REAL	photosynthesis rate (gO2/m2/hr)	see table
VALUES			
RMI	PMAX		
114.60	0.2		
89.00	0.2		
88.10	0		
76.17	0.4		
75.95	0.4		
66.00	0.3		
62.40	0.5		
32.40	0.5		

Respiration Rates vs. River Mile				
NAME	TYPE	DESCRIPTION	VALUE	NOTES
RFAC	REAL	factor to multiply all RESP20 in reach to test sensitivity	1	
RMI	REAL	river mile (exact match to model node)	see table	
RESP20	REAL	weed respiration rate (gO2/m2/hr)	see table	should be about 0.1 to 0.3 times PMAX20
VALUES				
RMI	RESP			
114.6	0.02			
89	0.02			
88.1	0			
76.17	0			
75.95	0			
66	0			
62.4	0.05			
32.4	0.05			

WASP Parameters

Phytoplankton Constants				
DESCRIPTION	ON/OFF	VALUE	MIN	MAX
Phytoplankton Maximum Growth Rate Constant @20 °C (per day)	1	2	0	3
Phytoplankton Growth Temperature Coefficient	1	1.07	0	1.07
Include Algal Self Shading Light Extinction in Steele (0=Yes, 1=No)	0	0	0	1
Exponent for Self Shading (Mult * TCHLA^Exp)	0	0	0	1
Multiplier for Self Shading (Mult * TCHLA^Exp)	0	0	0	1
Phytoplankton Self Shading Extinction (Dick Smith Formulation)	0	0	0	0.02
Phytoplankton Carbon to Chlorophyll Ratio	1	60	0	200
Phytoplankton Half-Saturation Constant for Nitrogen Uptake (mg N/L)	1	0.05	0	0.05
Phytoplankton Half-Saturation Constant for Phosphorus Uptake (mg P/L)	1	0.05	0	0.05
Phytoplankton Endogenous Respiration Rate Constant @20 °C (per day)	1	0.8	0	0.5
Phytoplankton Respiration Temperature Coefficient	1	1.08	0	1.08
Phytoplankton Death Rate Constant (Non-Zooplankton Predation) (per day)	1	1	0	0.25
Phytoplankton Zooplankton Grazing Rate Constant (per day)	0	0	0	5
Nutrient Limitation Option	0	0	0	1
Phytoplankton Decay Rate Constant in Sediments (per day)	0	0	0	0.02
Phytoplankton Temperature Coefficient for Sediment Decay	0	0	0	1.08
Phytoplankton Phosphorus to Carbon Ratio	1	0.24	0	0.24
Phytoplankton Nitrogen to Carbon Ratio	1	0.43	0	0.43
Phytoplankton Half-Sat. for Recycle of Nitrogen and Phosphorus (mg Phyt C/L)	1	1	0	1

Light Constants				
DESCRIPTION	ON/OFF	VALUE	MIN	MAX
Light Option (1 uses input light; 2 uses calculated diel light)	1	1	1	2
Phytoplankton Maximum Quantum Yield Constant	1	500	0	720
Phytoplankton Optimal Light Saturation	1	320	0	350
Background Light Extinction Multiplier	0	0	0	10
Detritus & Solids Light Extinction Multiplier	0	0	0	10
DOC Light Extinction Multiplier	0	0	0	10
Dissolved Oxygen Constants				
DESCRIPTION	ON/OFF	VALUE	MIN	MAX
Water body Type Used for Wind Driven Reaeration Rate	0	0	0	3
Calc Reaeration Option (0=Covar, 1=O'Connor, 2=Owens, 3=Churchill, 4=Tsivoglou)	0	0	0	4
Global Reaeration Rate Constant @ 20 °C (per day)	0	0	0	10
Elevation above Sea Level (meters) used for DO Saturation	0	0	0	15000
Reaeration Option (Sums Wind and Hydraulic Ka)	0	0	0	1
Minimum Reaeration Rate, per day	0	0	0	24
Theta -- Reaeration Temperature Correction	0	0	0	1.03
Oxygen to Carbon Stoichiometric Ratio	1	2.67	0	2.67
Use (1 - On, 0 - Off) Total Depth of Vertical Segments in Reaeration Calculation	0	0	0	1
CBOD (Ultimate) Constants				
DESCRIPTION	ON/OFF	VALUE	MIN	MAX
BOD (1) Decay Rate Constant @20 °C (per day)	1	0.07	0	5.6
BOD (1) Decay Rate Temperature Correction Coefficient	1	1.047	0	1.07
BOD (1) Decay Rate Constant in Sediments @20 °C (per day)	0	0	0	0.0004
BOD (1) Decay Rate in Sediments Temperature Correction Coefficient	0	0	0	1.08
BOD (1) Half Saturation Oxygen Limit (mg O/L)	1	0.5	0	0.5

Fraction of Detritus Dissolution to BOD (1)	0	0	0	1
Fraction of BOD (1) Carbon Source for Denitrification	0	0	0	1
SOD Parameters				
DESCRIPTION	ON/OFF	VALUE	MIN	MAX
SOD (gram/m²/day)	1	2.0		
SOD Temperature Correction Factor	1	1.04		