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February 26, 2016

Mr. Mark Wentzel
Texas Water Development Board
P.O. Box 13231
Austin, Texas 78711-3231

Re: Trinity River Water Quality Model
(TWDB Contract No. 1348311642 / RPS #15024.00)

Dear Mr. Wentzel,

Please find attached four (4) copies of the final draft of the water quality model report for the main stem of the Trinity River. Also included is an electronic copy of the HEC-RAS Model and a PDF of the report on a DVD for your use.

Thank you for the opportunity to provide our services on this important water quality project. If you have any questions do not hesitate to contact us.

Sincerely,

A handwritten signature in blue ink, appearing to read 'W. Espey, Jr.'.

William H. Espey, Jr., PhD, P.E.
Senior Vice President



Water Quality Model of the Middle Trinity River

TWDB Contract No:
1348311642

Project Number:
15024.00

Date Submitted:
2/26/2016

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TWDB CONTRACTS

In association with:

AquaStrategies
Water Planning, Science & Engineering

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Table of Contents

Table of Contents	i
List of Figures	ii
List of Tables	iv
1 Background	1
2 Water Quality Goals	1
3 Analysis approach and model description	4
4 Hydraulics	5
5 Water Quality	7
5.1 Run A	7
5.2 Run B	8
5.3 Run C	11
5.4 Comparison of Runs A, B, and C	12
5.5 Run D	14
5.6 Run E	16
5.7 Run F	17
5.8 Run G	19
5.9 Run H	20
5.10 Model Run Summary	22
6 Summary	26
7 References	26

List of Figures

Figure 1 - Model footprint area map with effluent discharges incorporated into model.	2
Figure 2- USGS 0806500 Trinity River near Oakwood, TX (at US-79 bridge)	6
Figure 3 - USGS 0806550 Trinity River near Crockett, TX (at TX-7 bridge)	6
Figure 4 - Trinity River Headwater Flow - USGS Gage 08062500 at Rosser.....	8
Figure 5 - Run B Simulated and Observed Temperature on Trinity River at Oakwood.	9
Figure 6 - Run B Simulated and Observed Temperature on Trinity River at Oakwood.	10
Figure 7 - Run B simulated and Observed Dissolved Oxygen on Trinity River at Oakwood.	10
Figure 8- Run C Simulated and Observed Temperature on Trinity River at Oakwood	11
Figure 9 - Runs A, B, and C Simulated Temperature on Trinity River at Oakwood.....	12
Figure 10 - Runs A, B, and C Simulated Dissolved Oxygen on Trinity River at Oakwood.....	13
Figure 11 - Runs A, B, and C Simulated Temperature on Trinity River at Centerville.....	13
Figure 12 - Runs A, B, and C Simulated Dissolved Oxygen on Trinity River at Centerville.....	14
Figure 13 - Runs D and C Simulated Temperature on Trinity River at Oakwood.....	15
Figure 14 - Runs D and C Simulated Dissolved Oxygen on Trinity River at Oakwood.....	15
Figure 15 - Runs E and C Simulated Temperature on Trinity River at Oakwood.	16
Figure 16 - Runs E and C Simulated Dissolved Oxygen on Trinity River at Oakwood	17
Figure 17 - Runs F and C Simulated Temperature on Trinity River at Oakwood.	18
Figure 18 - Runs F and C Simulated Dissolved Oxygen on Trinity River at Oakwood.	18
Figure 19 - Runs G and C Simulated Temperature on Trinity River at Oakwood.....	19
Figure 20 - Runs G and C Simulated Dissolved Oxygen on Trinity River at Oakwood.	20
Figure 21 - Trinity River Flow Hydrograph at US 287.....	21
Figure 22 - Runs H1 and H2 Simulated Temperature ranges on Trinity River at Oakwood.	21
Figure 23 - Runs H1 and H2 Simulated Dissolved Oxygen ranges on Trinity River at Oakwood.	22

Figure 24 - All model runs A through H Simulated Temperature ranges on Trinity River upstream of Hwy 287. 23

Figure 25 - All Model Runs A through H Simulated Temperature ranges on Trinity River at Oakwood. ... 23

Figure 26 - All model runs A through H Simulated Temperature ranges on Trinity River near Centerville. 24

Figure 27 - All model runs A through H Simulated Dissolved Oxygen ranges on Trinity River upstream of Hwy 287. 24

Figure 28 - All model runs A through H Simulated Dissolved Oxygen ranges on Trinity River at Oakwood. 25

Figure 29 - All model runs A through H Simulated Dissolved Oxygen ranges on Trinity River near Centerville. 25

List of Tables

Table 1 - Instream Flow water quality goals for Trinity River segments 0804 and 0805.	3
Table 2 – Texas Environmental Flow Standards for Trinity River near Oakwood.....	4
Table 3 - Water Quality Kinetic Rates applied in the HEC-RAS Model.....	7
Table 4 - Headwater Boundary Conditions.....	7
Table 5 - Average Wastewater Point Source Loadings	8
Table 6 - Maximum Permitted Wastewater Point Source Loadings.....	11

1 Background

The Texas Instream Flow Program (TIFP) conducts research and analysis of river conditions for four key disciplines: Biology, Hydrology and Hydraulics, Physical Processes and Water Quality. The purpose is to understand relationships between flow cycles and flow patterns (i.e., flow regime) and indicators of a sound ecological environment (TIFP 2008).

This work focuses on evaluating water quality for the Senate Bill 2 (SB2) instream flow study of the middle Trinity River. Flow condition scenarios evaluated as part of this analysis include low flow events occurring in recent low flow summers, and include low-flow conditions consistent with Senate Bill 3 (SB3) adopted Environmental Flow Standards. The methods used to evaluate water quality are consistent with those developed in previous TIFP water quality projects (EC 2010).

Two Trinity River segments are evaluated as part of this project: TCEQ segments 0804 and 0805. The majority of the study area lies within segment 0805 (downstream of Cedar Creek to the headwaters of Lake Livingston). These segments are generally exhibiting good water quality conditions and are meeting SB2 instream flow goals for current conditions. For flow conditions lower than 450 cfs, as evaluated as part of this report, temperature and DO may not achieve the SB2 instream flow water quality goals more frequently than desired.

2 SB2 Water Quality Goals

The overarching SB2 instream flow water quality goals and objectives are (EC 2010):

- To maintain day-to-day conditions that are not anticipated to cause adverse effect on native aquatic species
- To maintain water quality conditions that satisfy current state water quality standards, as determined by the surface water quality standards assessment program (TCEQ 2010b).

Achievement of SB2 goals for water quality can be assessed according to instream flow needs and impact on aquatic habitat, according to specific water quality concentration values (Table 1). Similar to previous projects, three priority tiers have been developed to account for critical instream conditions, for water quality standards, and for long-term trends:

- Tier 1 primary priority SB2 instream flow goals for identified parameters will be assessed for achievement on a day-to-day basis and the goal is for achievement 100% of the time. Tier 1 goals follow SB2 instream flow goals derived in other basins based upon aquatic species tolerances (EC 2011).
- Tier 2 secondary priority SB2 instream flow goals will be screened on a day-to-day basis and long-term trends will be monitored; instream flow goal achievement will be determined by

TCEQ surface water quality assessment program OR by degree of influence on primary priority goals, if any.

- Tier 3 instream flow additional parameters will be monitored for long-term trends. Instream flow goal achievement will be determined by TCEQ surface water quality assessment program OR by degree of influence on primary priority goals, if any.

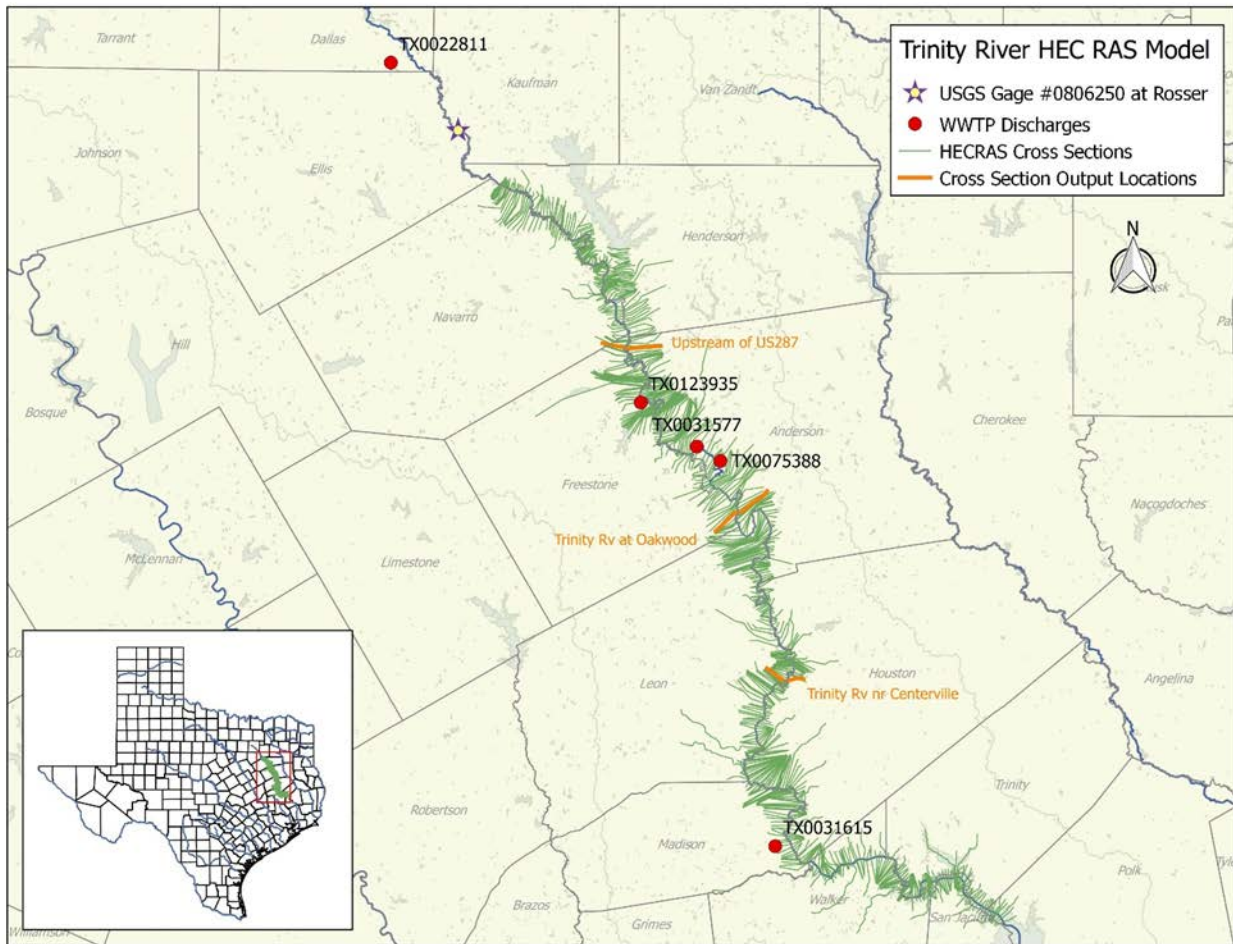


Figure 1 - Model footprint area map with effluent discharges incorporated into model.

Table 1 – SB2 Instream Flow water quality goals for Trinity River segments 0804 and 0805.

Parameter	Instream Flow Goals (Values)	
	Segment 0805 Upper Trinity River before Cedar Creek Reservoir	Segment 0804 Trinity River Above Lake Livingston
Tier 1 Primary priority		
DO* (EC 2010)	<= 12 hours below 3 mg/L	
	<= 2 hours below 2 mg/L	
	> 1.5 mg/L	
Temperature (EC 2010)	<=35°C (95°F)	
Tier 2 - Secondary priority		
DO (2014)	>= 5.0 mg/L daily average	
	=3.0 mg/L minimum for <=8 hours	
	For Spring Condition:	
	>=5.5 mg/L daily average	
	=4.5 mg/L minimum for <=8hrs	
	>=3.5 mg/L when headwater flow at USGS Gage 0804800 is <80 cfs	
Temperature*	<=27°C (80.6°F) Jan - May	
Temperature (2014)	<= 95°F	<= 93°F
TSS	90th percentile	
Nitrate (2010b)	<=1.95 mg/L	
Ammonia (2010b)	<=0.33 mg/L	
Orthophosphate (2010b)	<=0.37 mg/L	
Tier 3 - additional parameters		
E. Coli (2014)	<= 126 org/100mL geometric mean	
Total Nitrogen*	no value	
Nox* (2004)	<= 2.76 mg/L	
Organic Nitrogen*	no value	
Total Phosphorus (2010b)	<=0.69 mg/L	
Chlorophyll-a (2010b)	<=14.1 ug/L	
Salinity*	<=2 ppt	
Chloride (2014)	<=150 mg/L	<=175 mg/L
Sulfate (2014)	<=175 mg/L	<=150 mg/L
Specific Conductance (2010b)	<=3077 uS/cm	
pH (2014)	6.5-9.0	
TDS (2014)	<=600 mg/L	<=850 mg/L

**Preliminary indicator identified by SB2 TIFP stakeholders.*

3 Analysis approach and model description

A modeling approach has been applied to evaluate Trinity River water quality conditions for a range of low-flow scenarios. The following Runs A-H were conducted using various headwater boundary flow regimes and point source discharge conditions. Only point sources with discharge greater than 0.5 MGD are incorporated into the model.

- Run A – Summer 2014 – No WWTP discharges for Summer 2014
- Run B – Summer 2014 – Current conditions WWTP discharges for Summer 2014
 - B1 – August 23, 2014 to August 31, 2014
 - B2 – August 27, 2014 to September 27, 2014
- Run C – Summer 2014 – Fully permitted WWTP discharges for Summer 2014
- Run D – Oakwood Subsistence Summer – Run C with constant headwater at 75cfs
- Run E – Oakwood Subsistence Spring – Run C with constant headwater at 160cfs
- Run F – Oakwood Base Summer – Run C with constant headwater at 250cfs
- Run G – Oakwood Base Spring – Run C with constant headwater at 450cfs
- Run H – Summer 2011 – Fully permitted WWTP discharges for Summer 2011
 - H1 – June 1, 2011 to August 31, 2011
 - H2 – August 1, 2011 to August 11, 2011

The flow levels analyzed are consistent with SB3 base and subsistence flow standards (Table 2) and have not been exhibited in the river in recent years.

Table 2 – Texas Environmental Flow Standards for Trinity River near Oakwood.

USGS Gage 08065000, Trinity River near Oakwood

Season	Subsistence	Base	Pulse
Winter	120 cfs	340 cfs	Trigger: 3,000 cfs Volume: 18,000 af Duration: 5 days
Spring	160 cfs	450 cfs	Trigger: 7,000 cfs Volume: 130,000 af Duration: 11 days
Summer	75 cfs	250 cfs	Trigger: 2,500 cfs Volume: 23,000 af Duration: 5 days
Fall	100 cfs	260 cfs	Trigger: 2,500 cfs Volume: 23,000 af Duration: 5 days

cfs = cubic feet per second

af = acre-feet

To evaluate how flow influences temperature and dissolved oxygen (DO) in the stream, the HEC-RAS one-dimensional hydraulic and water quality model was used (USACE-HEC 2010). The model used for

this project was based upon a HEC-RAS model initially developed by Tarrant Regional Water District (TRWD) for a flood study, and has been modified for this water quality project by adjusting the in-channel bathymetry.

4 Hydraulics

The following section describes how the HEC-RAS model hydraulics were developed and calibrated.

Incorporation of Channel Bottom Survey

Field survey data of the channel bottom collected in 2011 and processed in 2015 by TRA was incorporated into this Trinity River HEC-RAS model to supplement Light Detection and Ranging (LiDAR) data, which was unable to penetrate the water surface of the river. Incorporation of the TRA channel bottom survey data into the model more accurately represents the channel below the surface of the water.

The survey data was imported into ArcMap and each group of survey points were assigned the river station of the closest existing HEC-RAS cross section. A CSV file was generated that contained survey data for 85 channel bottom cross sections, each survey point's ID number, longitude, latitude, elevation, survey station, and river station. This CSV file of 85 cross sections was imported into a new HEC-RAS geometry file, and additional cross sections were interpolated every 100 feet using the cross section interpolation tool within HEC-RAS. The resulting HEC-RAS geometry file served as an index of 9,712 channel bottom cross sections. A composite cross section containing the original cross section geometry from the Trinity River HEC-RAS model and the channel bottom survey index was created. The original HEC-RAS geometry for the Trinity River model was edited using the graphical cross section editor tool in HEC-RAS. Each cross section in the original geometry was manually inspected and overlaid on the closest channel bottom cross section from the index.

Comparison of HEC-RAS Model Results with USGS Data

USGS stream gauges *USGS 0806500 Trinity River near Oakwood, TX* (at US-79 bridge), and *USGS 0806550 Trinity River near Crockett, TX* (at TX-7 bridge) were used to compare with HEC-RAS unsteady hydraulic model results. Stage elevations were computed at HEC-RAS cross sections closest to the USGS stream gauges. Data for three time series were used for comparison: June 1, 2011 through August 31, 2011; August 1, 2013 through September 30, 2013; and June 1, 2014 through September 30, 2014. The following figures illustrate a comparison between computed results and gauge data for the June 1, 2014 through September 30, 2014 at the two gauge sites. Overall, and especially for low flows, the HEC-RAS model is a fair representation of hydraulic conditions as defined at these gauges.

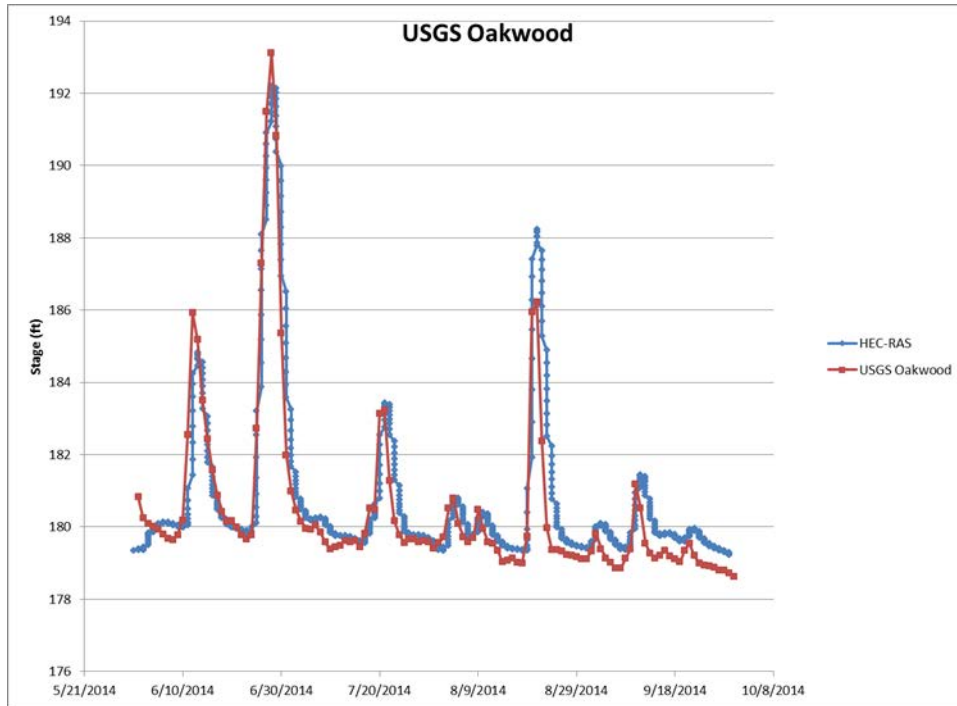


Figure 2- USGS 0806500 Trinity River near Oakwood, TX (at US-79 bridge)

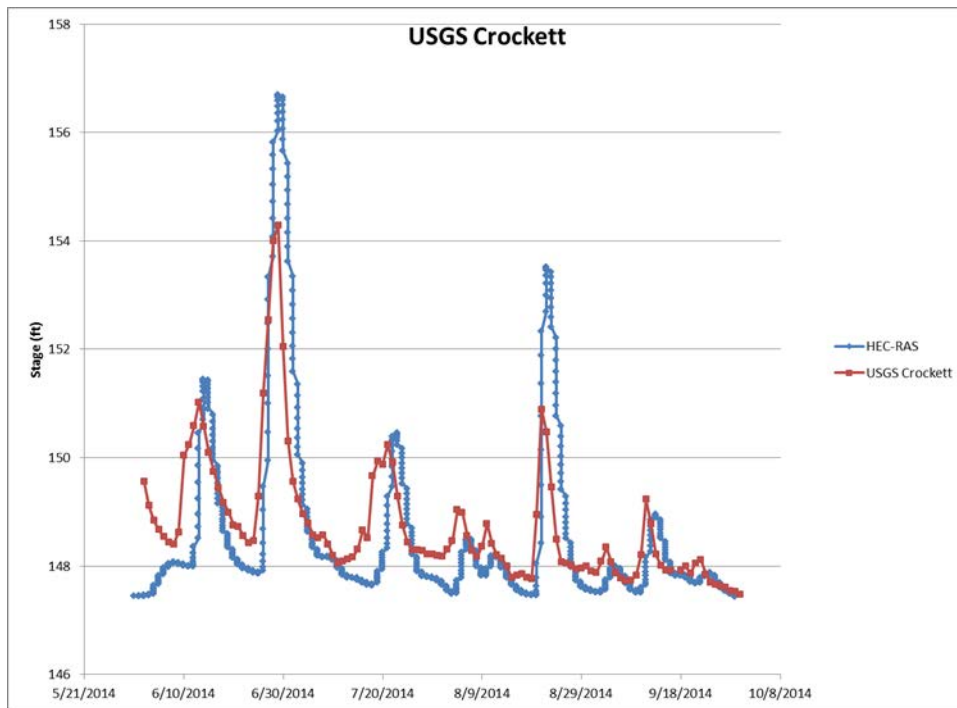


Figure 3 - USGS 0806550 Trinity River near Crockett, TX (at TX-7 bridge)

5 Water Quality

Key water quality kinetic rates applied in the HEC-RAS model are listed in Table 3. These values were held constant for all model runs.

Table 3 - Water Quality Kinetic Rates applied in the HEC-RAS Model

Water Quality Kinetic Rates*

Parameter	Value	Units
Sediment Demand	0.6	/day
CBOD Decay Rate	0.1	/day
CBOD Settling Rate	0	/day
Atmospheric Reaeration	1	/day

*Same for Runs A-H

5.1 Run A

Run A represents a baseline model run that did not include wastewater point source loads (NPDES permitted discharges) from June 1, 2014 to September 30, 2014. The results of this model run are compared to Run B and Run C to establish the impact of the wastewater point source loadings on the water quality of the Trinity River. The headwater boundary conditions for Run A are listed in Table 4. Figure 4 plots the flow headwater boundary condition for the simulation period.

Table 4 - Headwater Boundary Conditions

Headwater BC	Value	Units	Source
Flow	TS*	cfs	USGS Gage 08062500 Trinity nr Rosser
Temperature	TS*	cfs	USGS Gage 08062500 Trinity nr Rosser
DO	TS*	mg/L	USGS Gage 08062500 Trinity nr Rosser
CBOD	5	mg/L	Assumed ultimate CBOD

* TS = Time series data from 6/1/2014-9/30/2014

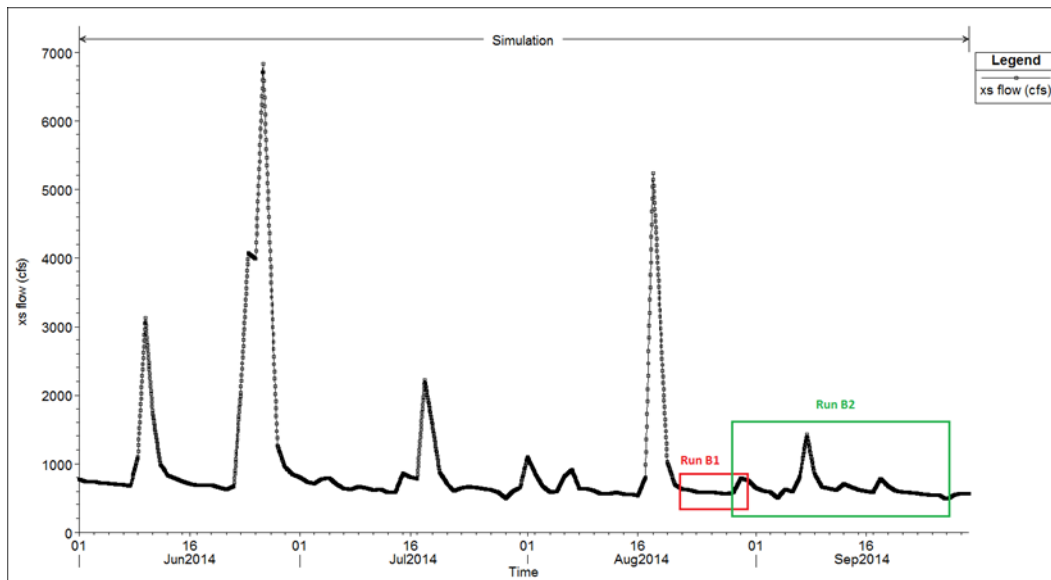


Figure 4 - Trinity River Headwater Flow - USGS Gage 08062500 at Rosser

5.2 Run B

Run B represents the historical condition with average reported wastewater discharge volumes and permitted point source loads (Table 5). The headwater boundary conditions are the same as listed in Table 4 for Run A.

Table 5 - Average Wastewater Point Source Loadings, September 2014

WWTP or discharge		Location X-sec	Point				
			Inflow cfs	Temp C	DO mg/L	cBODu mgO2/L	NH4 mgN/L
TX0022811	TRA Ten Mile	Headwaters	44.6	30	6.1	1	0.3
TX0123935	Freestone Power	1009019	1.5	30	7.54	n/a	n/a
TX0031577	TDCJ Coffield	900194.3	5.3	30	7.05	2.4	0
TX0075388	TDCJ Beto	849825.3	2.7	30	6.98	2.63	0
TX0031615	TDCJ Ferguson	274701.3	1.8	30	4.67	2.1	0.36

Simulated temperature results of the Trinity River at Oakwood for Run B are compared to observed temperature readings collected during a portion of the simulation period in Figure 5. Summary statistics are presented for two time periods for Run B. Period B1 is for the ten day lowest stable flow period (Aug 23, 2014- Aug 31, 2014). Period B2 is coincident with the observation data (Aug 27, 2014 – Sep 27, 2014), and encompasses B1. The flow during these periods are highlighted in Figure 4.

Figures 6 and 7 show the Maximum, Average and Minimum temperature and dissolved oxygen values, respectively, for Periods B1 and B2, and observed values. The range of observed temperature values for the period of time that data was collected is greater than the simulated results, however the average values for temperature are within a few degrees around 30 °C. The application of the climate data (air temperature, solar radiation, wind, cloud cover) within the model has significant effect on water temperature output. The daily range of water temperature fluctuation predicted by the model generally matches the magnitude of daily fluctuations in the observation data (diel fluctuation of 1 to 2 degrees °C). Calibration was conducted to more closely match multi-day trends, but adjustments to climate inputs (particularly to wind) did not yield model temperature predictions that match the observed temperature daily fluctuations during all periods (e.g., Figure 5 near September 18, 2014). The model tends to exaggerate multi-day trends and over predict temperature maximums (Figure 5), compared to observed data (Figure 6).

Simulated dissolved oxygen values were lower and within a smaller range than observed (Figure 7). Algae was not accounted for in the model runs and is likely a factor in DO conditions in the field; since simulated DO is lower without the algae, the model runs are considered conservative.

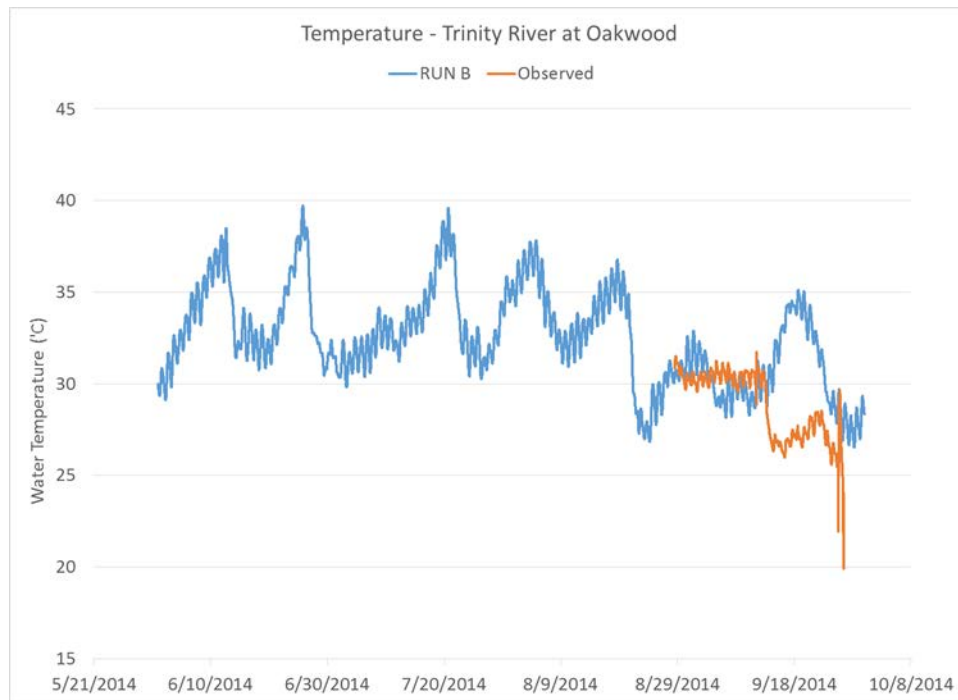


Figure 5 - Run B Simulated and Observed Temperature on Trinity River at Oakwood.

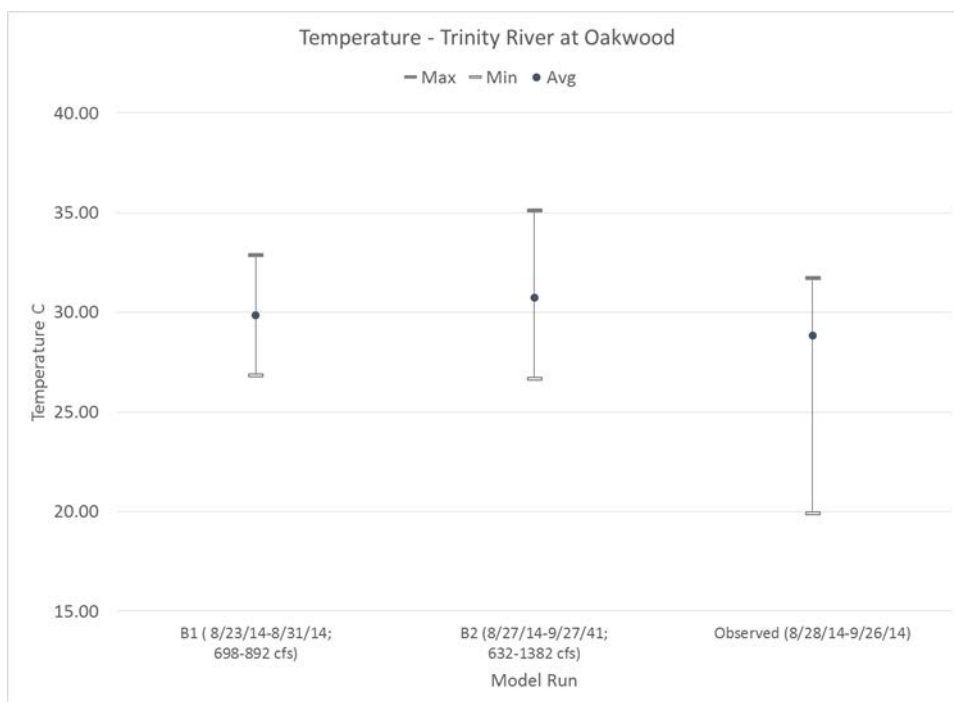


Figure 6 - Run B Simulated and Observed Temperature on Trinity River at Oakwood.

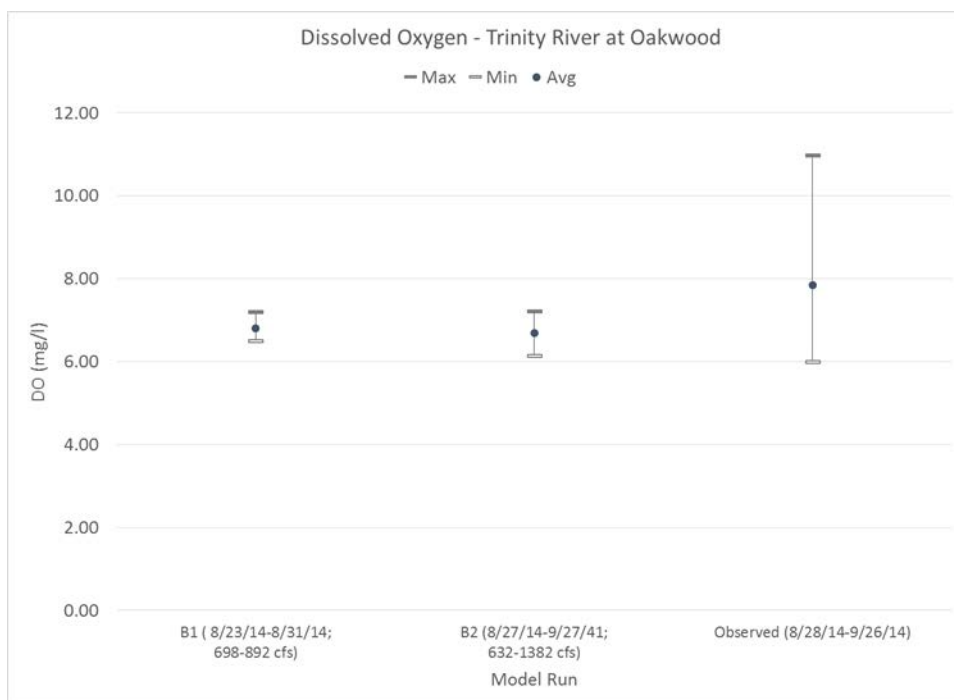


Figure 7 - Run B simulated and Observed Dissolved Oxygen on Trinity River at Oakwood.

5.3 Run C

Run C represents the historical headwater flow from June 1, 2014 to September 20, 2014 with point source loadings at maximum permitted flow and constituent loadings. These values are summarized in Table 6. Figure 8 shows the simulated temperature values for the Trinity River at Oakwood with observed temperature readings.

For the low flow scenario runs D through H, the boundary conditions for Run C are used to account for full future effluent discharges. A comparison of Runs A, B, and C are presented in the next section to explain the rationale for using Run C.

Table 6 - Maximum Permitted Wastewater Point Source Loadings

WWTP or discharge		Location X-sec	Point				
			Inflow cfs	Temp C	DO mg/L	cBODu mgO2/L	NH4 mgN/L
TX0022811	TRA Ten Mile	Headwaters	120.6	30	6	10	3
TX0123935	Freestone Power	1009019	3	30	7.54	n/a	n/a
TX0031577	TDCJ Coffield	900194.3	15.9	30	5	10	2
TX0075388	TDCJ Beto	849825.3	8	30	6	10	2
TX0031615	TDCJ Ferguson	274701.3	1.8	30	4	7	2

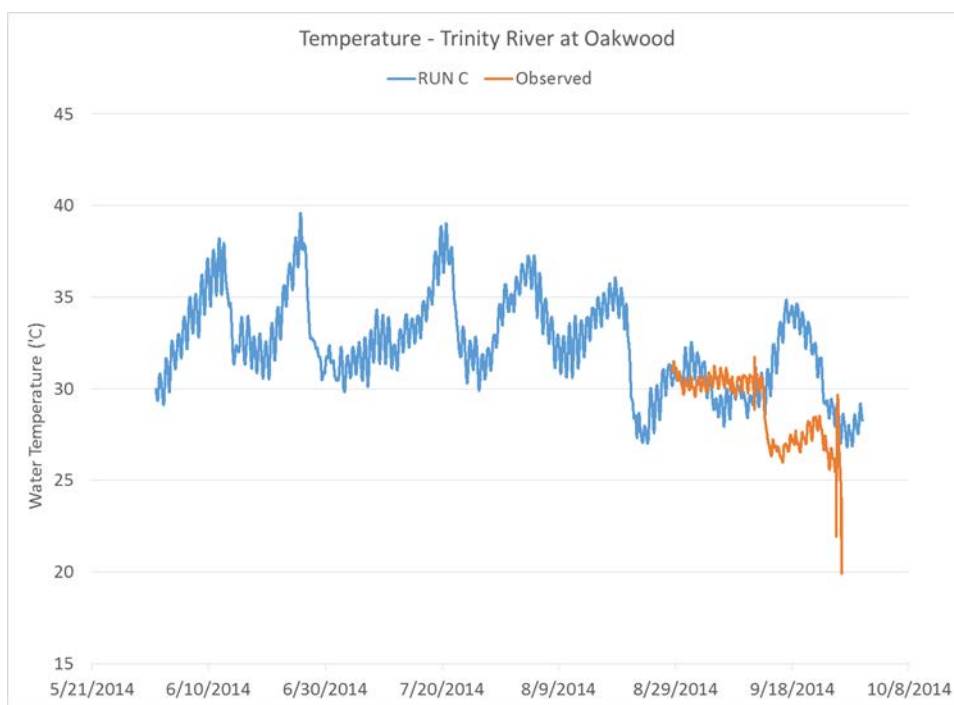


Figure 8- Run C Simulated and Observed Temperature on Trinity River at Oakwood

5.4 Comparison of Runs A, B, and C

The results of model runs A, B and C are compared to demonstrate the rationale for choosing run C for the basis of the remaining model runs D through G. Figures 9 and 10 show the simulated temperature and dissolved oxygen results at Oakwood, respectively, for all three runs. Figures 11 and 12 show temperature and dissolved oxygen results, respectively, at Centerville for Runs A, B, and C. The results from Run A and Run B are indistinguishable from each other (Run B lies directly on top of Run A). This is because existing effluent discharges have nominal effect on river water quality conditions. In Run C, the point sources loadings at the maximum permitted discharge amounts impacted the temperature and dissolved oxygen results. Including the point source discharges at the maximum permitted flows and loadings in Runs D through G should then serve to demonstrate the impact of low flow conditions on water quality in the model under the worst case condition.

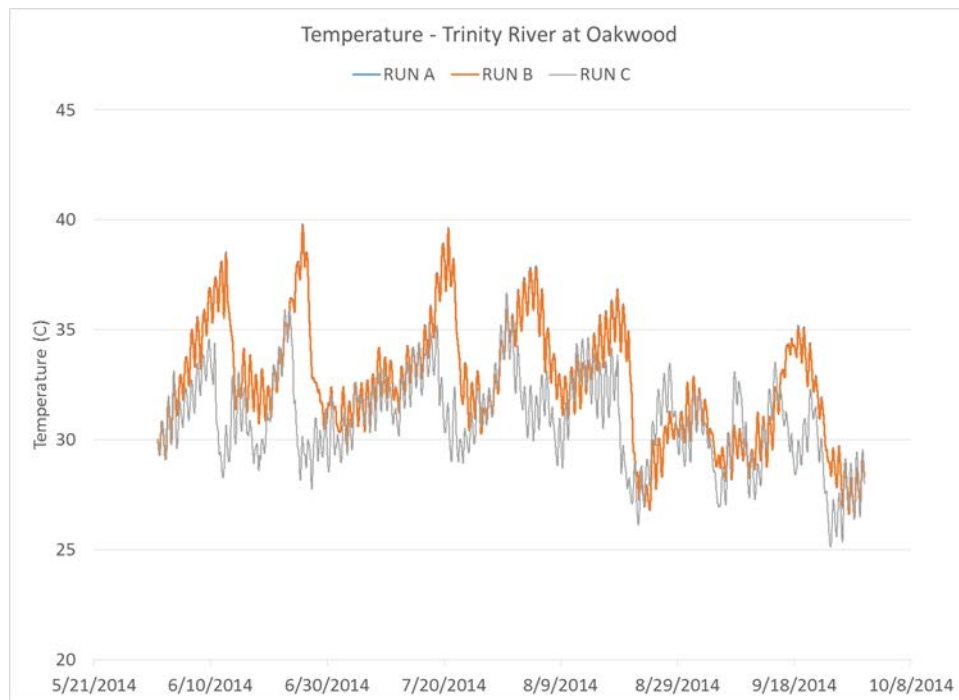


Figure 9 - Runs A, B, and C Simulated Temperature on Trinity River at Oakwood

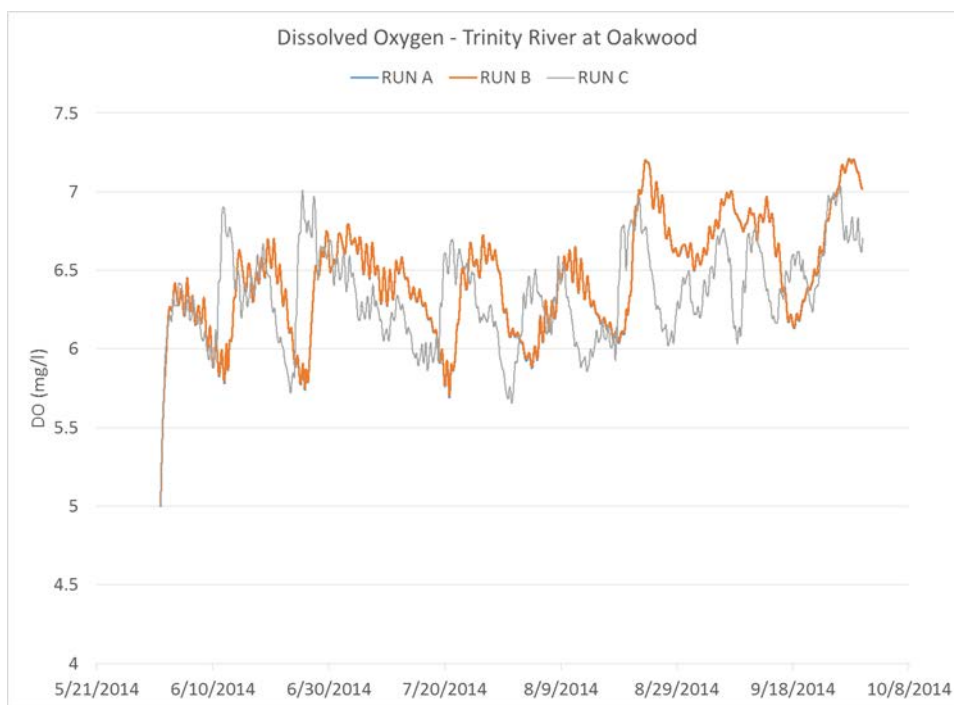


Figure 10 - Runs A, B, and C Simulated Dissolved Oxygen on Trinity River at Oakwood.

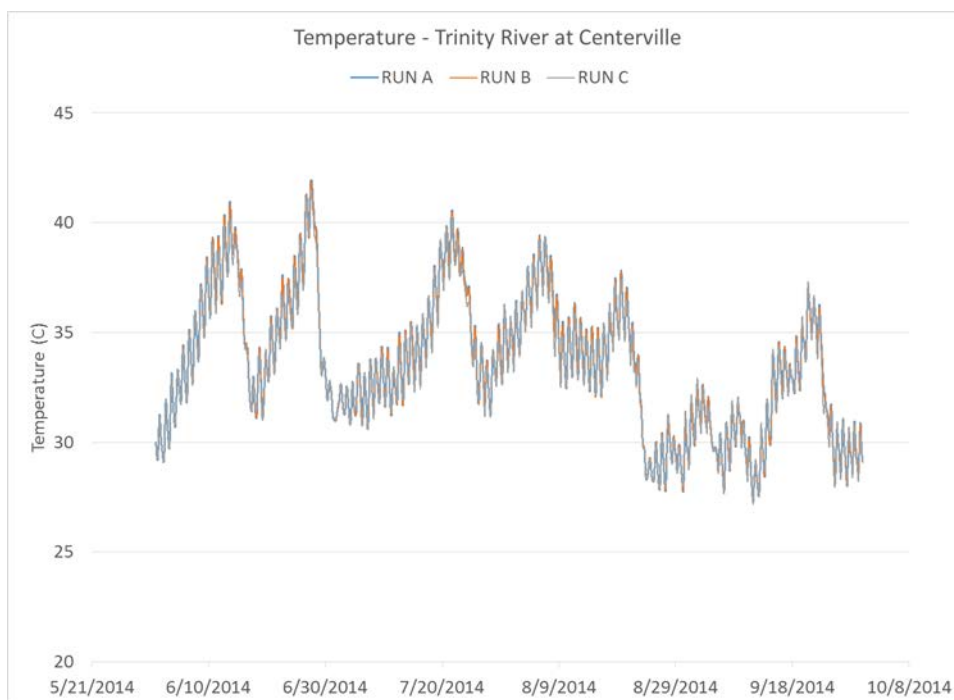


Figure 11 - Runs A, B, and C Simulated Temperature on Trinity River at Centerville

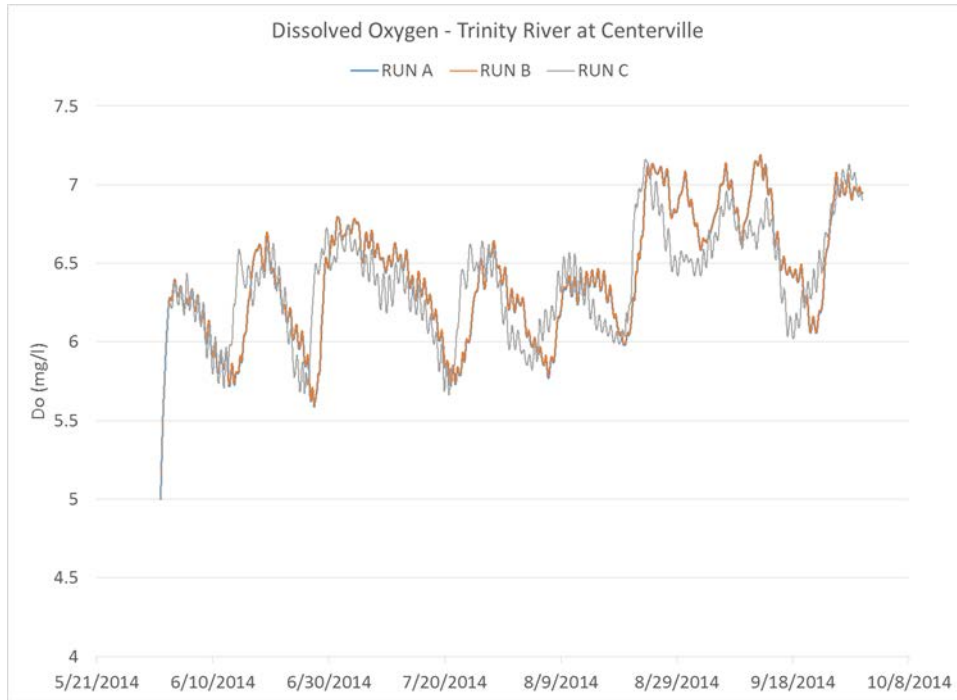


Figure 12 - Runs A, B, and C Simulated Dissolved Oxygen on Trinity River at Centerville.

5.5 Run D

Run D represents subsistence summer conditions with a constant headwater flow at 75cfs and fully permitted point source loads. Temperature and dissolved oxygen results at Oakwood for Run D are compared to results from Run C in Figures 13 and 14, respectively. The shallow depth arising from low flow causes temperatures to exceed the SB2 instream flow goal of 38.9°C (93°F) for much of the simulation period. The high temperature in turn causes DO to drop below the water quality standard (Tier 2 goal) of 5 mg/L during some periods.

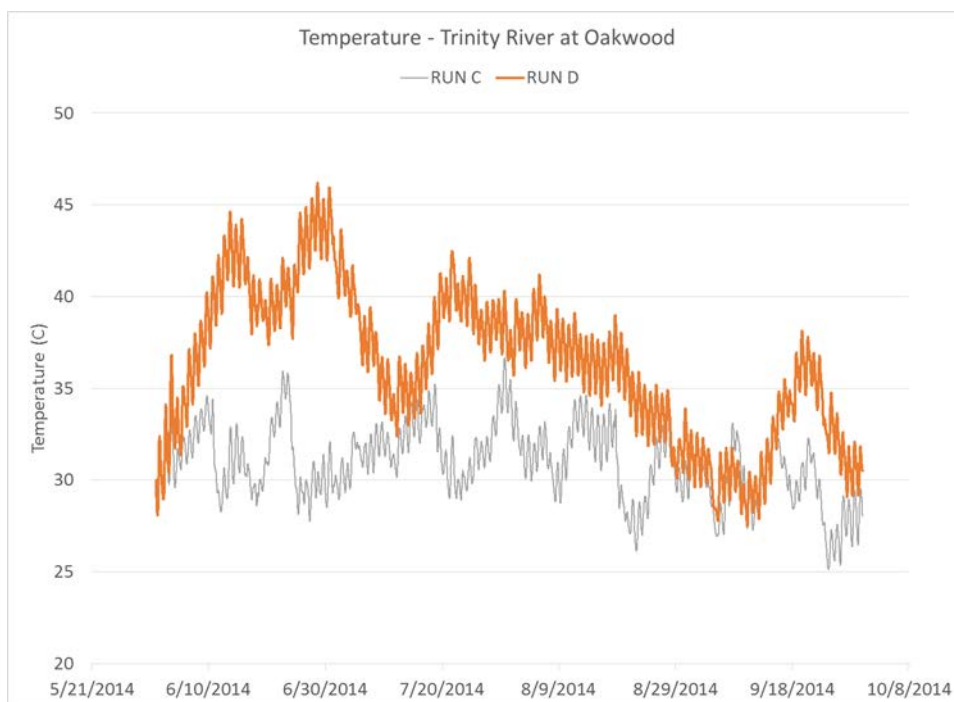


Figure 13 - Runs D and C Simulated Temperature on Trinity River at Oakwood.

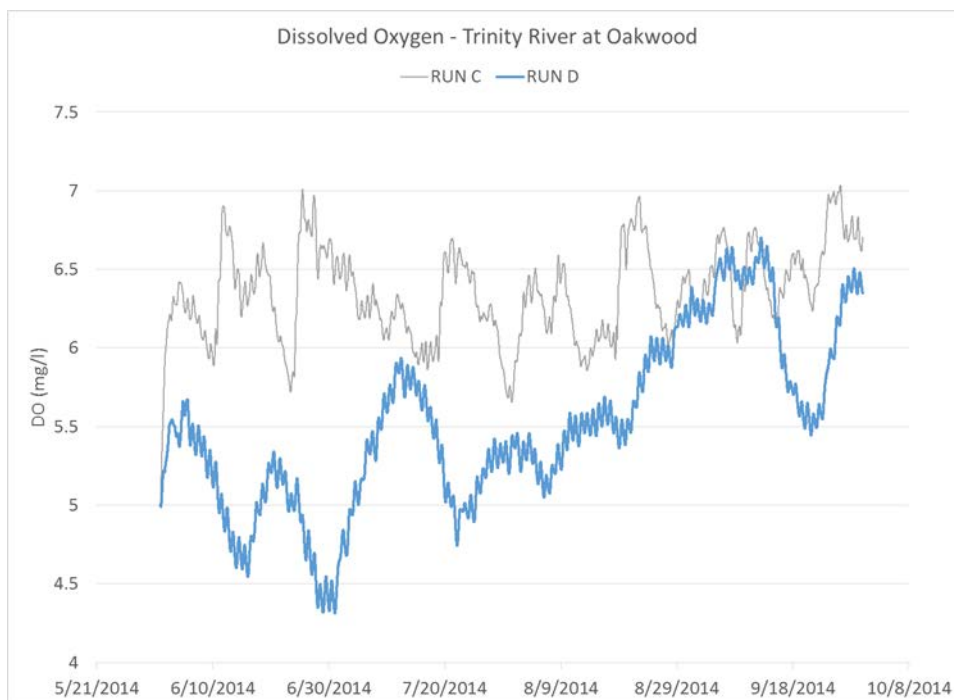


Figure 14 - Runs D and C Simulated Dissolved Oxygen on Trinity River at Oakwood

5.6 Run E

Run E represents subsistence spring conditions with a constant headwater flow at 160cfs and fully permitted point source loads. Temperature and dissolved oxygen results at Oakwood for Run E are compared to results from Run C in Figures 15 and 16, respectively. SB2 goal exceedances for Run E are comparable to those exhibited for Run D.

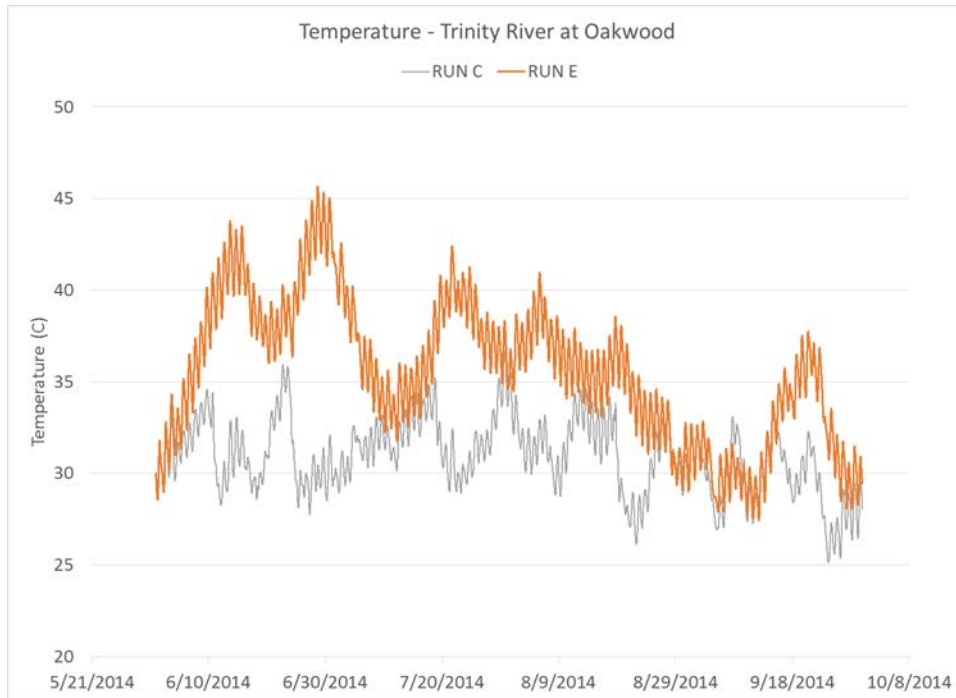


Figure 15 - Runs E and C Simulated Temperature on Trinity River at Oakwood.

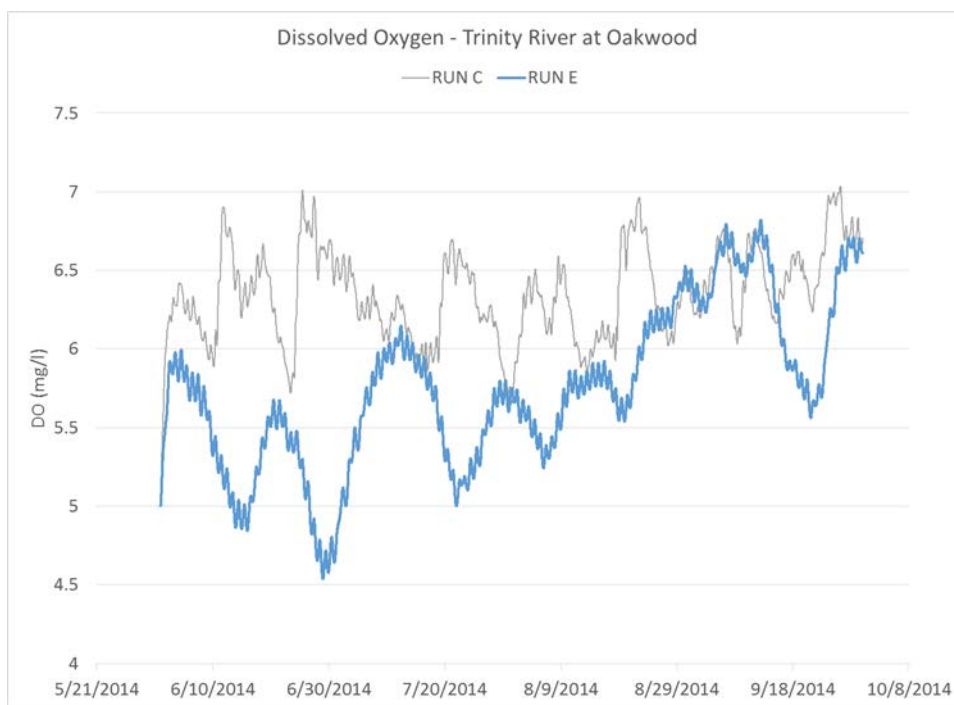


Figure 16 - Runs E and C Simulated Dissolved Oxygen on Trinity River at Oakwood

5.7 Run F

Run F represents base summer conditions with a constant headwater flow at 250cfs and fully permitted point source loads. Temperature and dissolved oxygen results at Oakwood for Run F are compared to results from Run C in Figures 17 and 18, respectively. SB2 goal exceedances for Run F are comparable to those exhibited for Runs D and E.

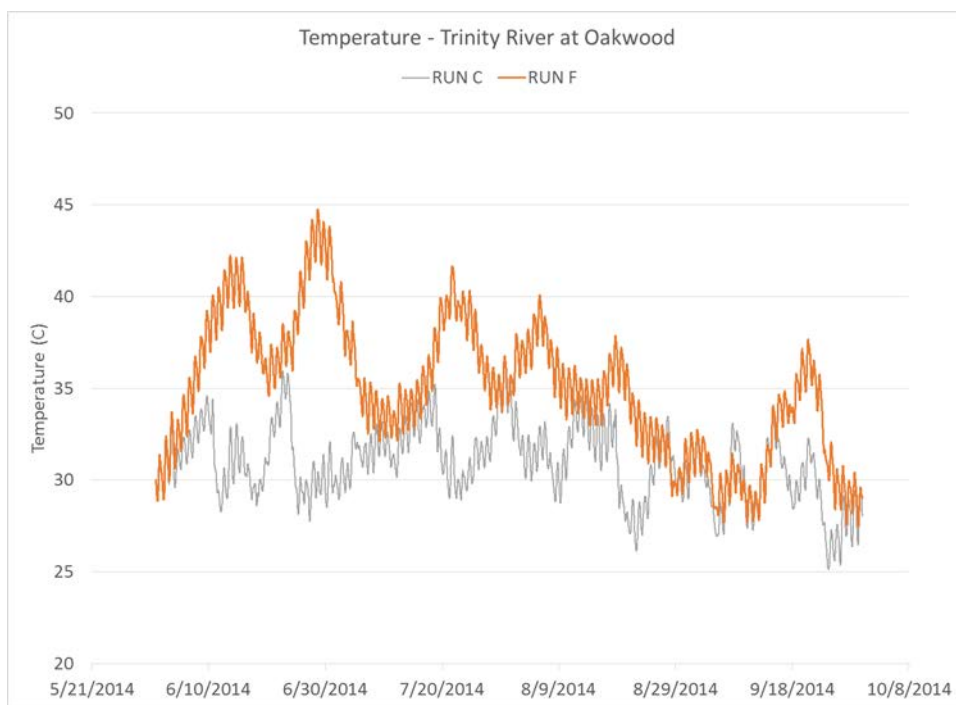


Figure 17 - Runs F and C Simulated Temperature on Trinity River at Oakwood.

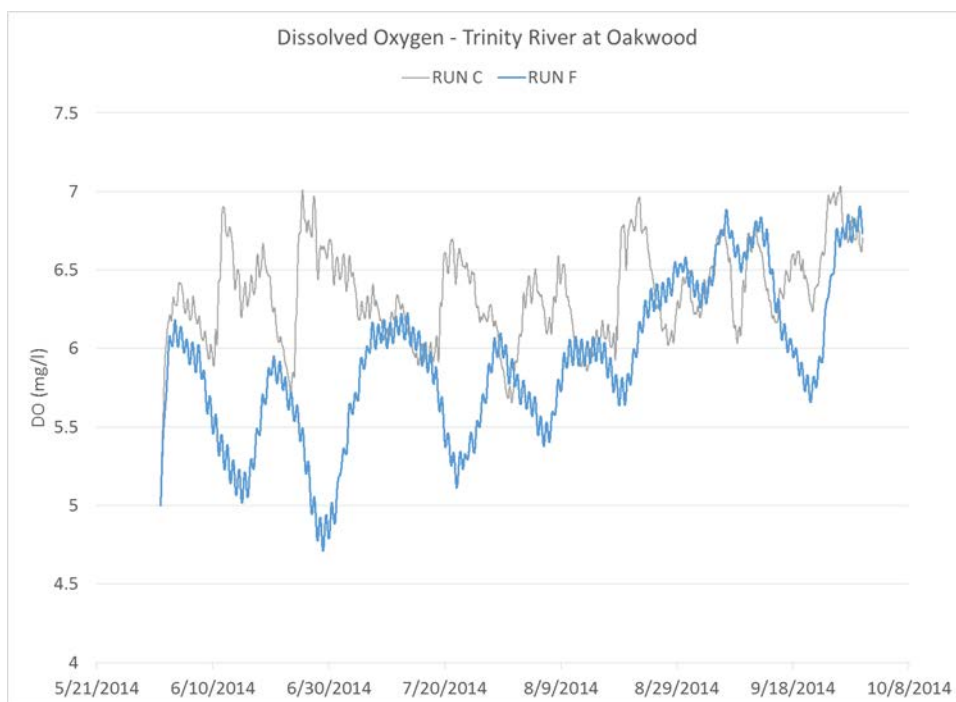


Figure 18 - Runs F and C Simulated Dissolved Oxygen on Trinity River at Oakwood.

5.8 Run G

Run G represents base spring conditions with a constant headwater flow at 450cfs and fully permitted point source loads. Temperature and dissolved oxygen results at Oakwood for Run G are compared to results from Run C in Figures 19 and 20, respectively. SB2 goal exceedances for Run G for temperature are comparable to those for Runs D, E, F, although temperatures are not as high. Because of the lower temperatures, Run G does not cause non-achievement of the DO goal since DO is predicted to stay about 5 mg/L.

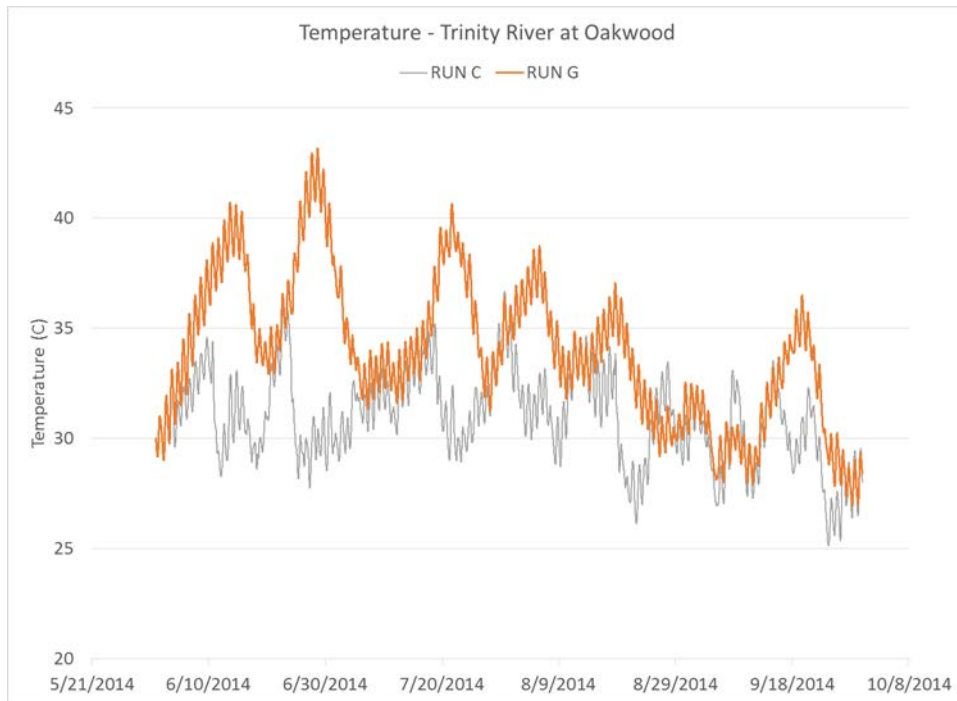


Figure 19 - Runs G and C Simulated Temperature on Trinity River at Oakwood.

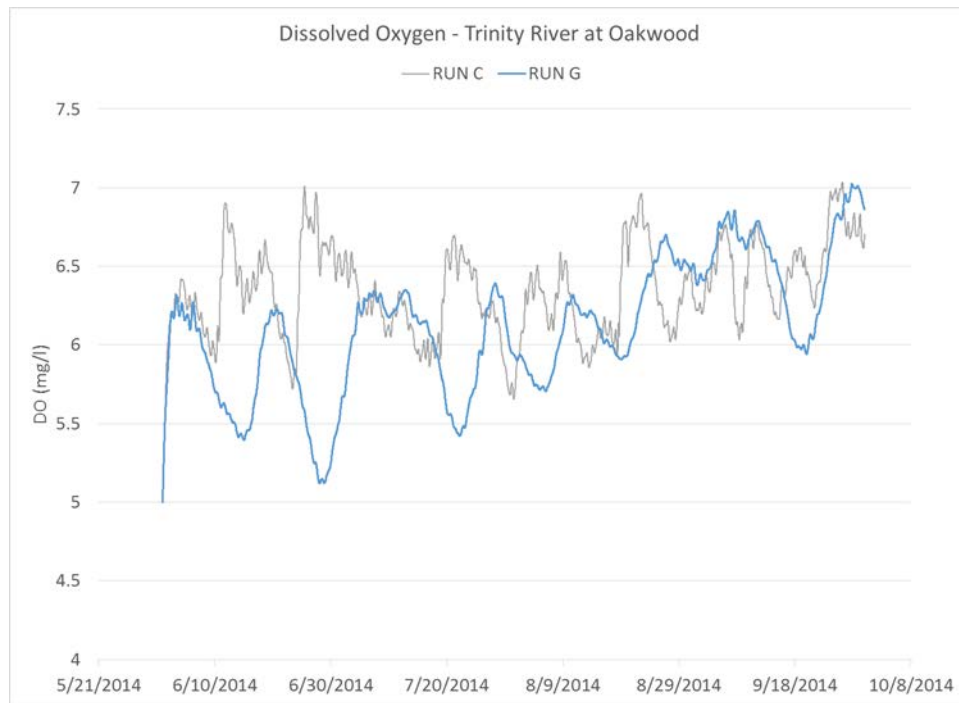


Figure 20 - Runs G and C Simulated Dissolved Oxygen on Trinity River at Oakwood.

5.9 Run H

Run H represents summer 2011 conditions with gaged headwater flow from June 1, 2011 to August 31, 2011 and fully permitted point source loads. Figure 21 shows the flow hydrograph for the Trinity River which is the headwater boundary condition for Run H.

Summary statistics for temperature and dissolved oxygen results are presented for two time periods for Run H. Period H1 includes the entire simulation period from June 1, 2011- Aug 31, 2011. Period H2 is for the ten day lowest stable flow period (Aug 1, 2014 – August 11, 2014) within the timeframe included in H1. Period H2 is coincident with on-site measurements being conducted during the TRA longitudinal survey in 2011. Both are shown in Figure 21. The average values and data ranges for temperature and dissolved oxygen are similar for both H1 and H2 as shown in Figures 22 and 23.

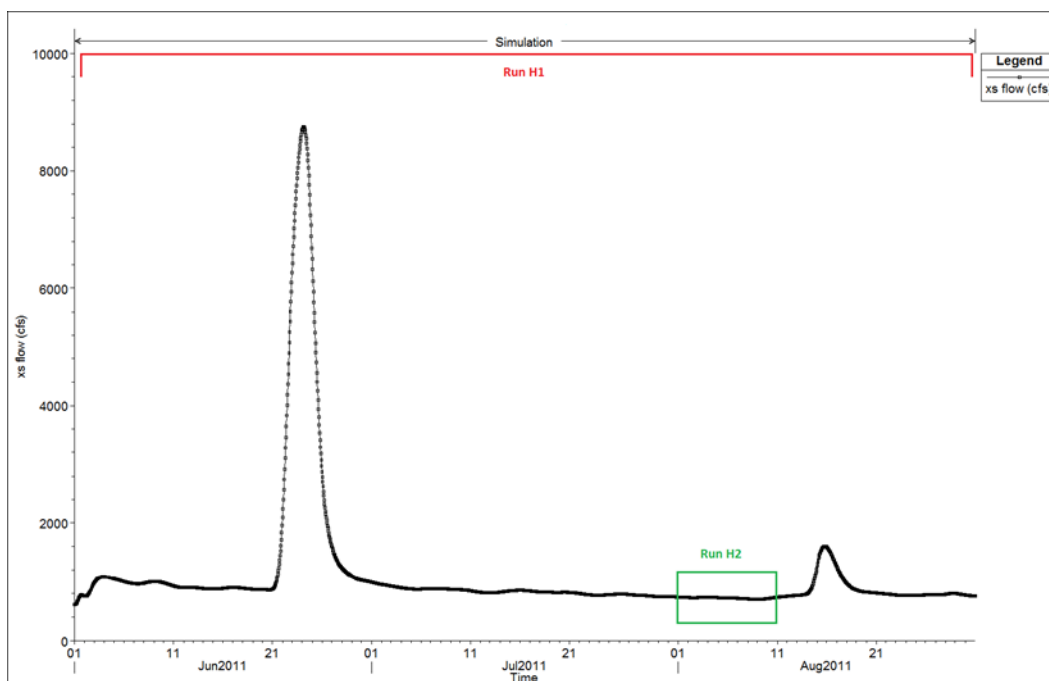


Figure 21 - Trinity River Flow Hydrograph at US 287.

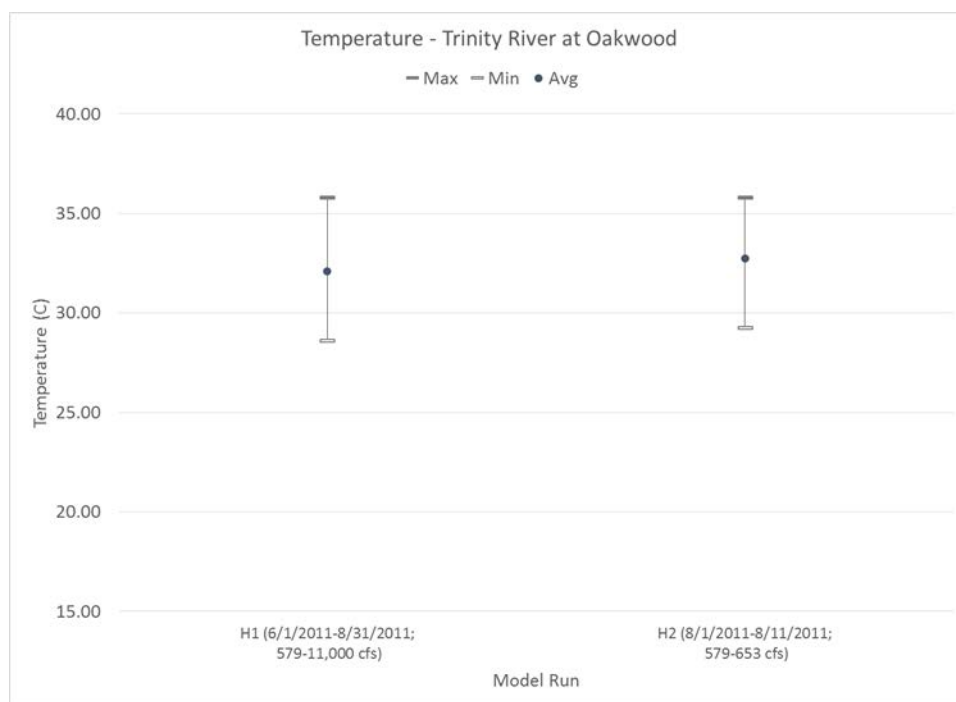


Figure 22 - Runs H1 and H2 Simulated Temperature ranges on Trinity River at Oakwood.

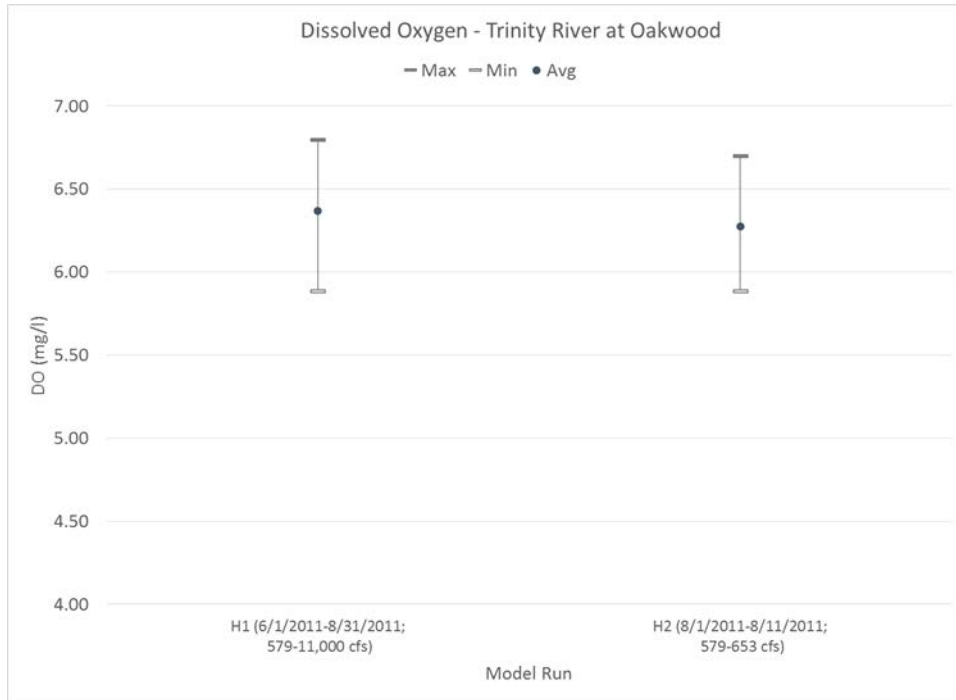


Figure 23 - Runs H1 and H2 Simulated Dissolved Oxygen ranges on Trinity River at Oakwood.

5.10 Model Run Summary

Summary statistics for temperature and dissolved oxygen results are presented for all model runs at three locations in the following six figures. Flow levels at or lower than 250 cfs appear to increase chance and duration of events that are greater than the SB2 temperature goal and lower than DO standard (Tier 2 goal), but not lower than the SB2 DO instream flow Tier 1 goal. Under conditions where wastewater dischargers are operating at fully permitted levels, undesirable conditions may occur at flow levels near 450 cfs.

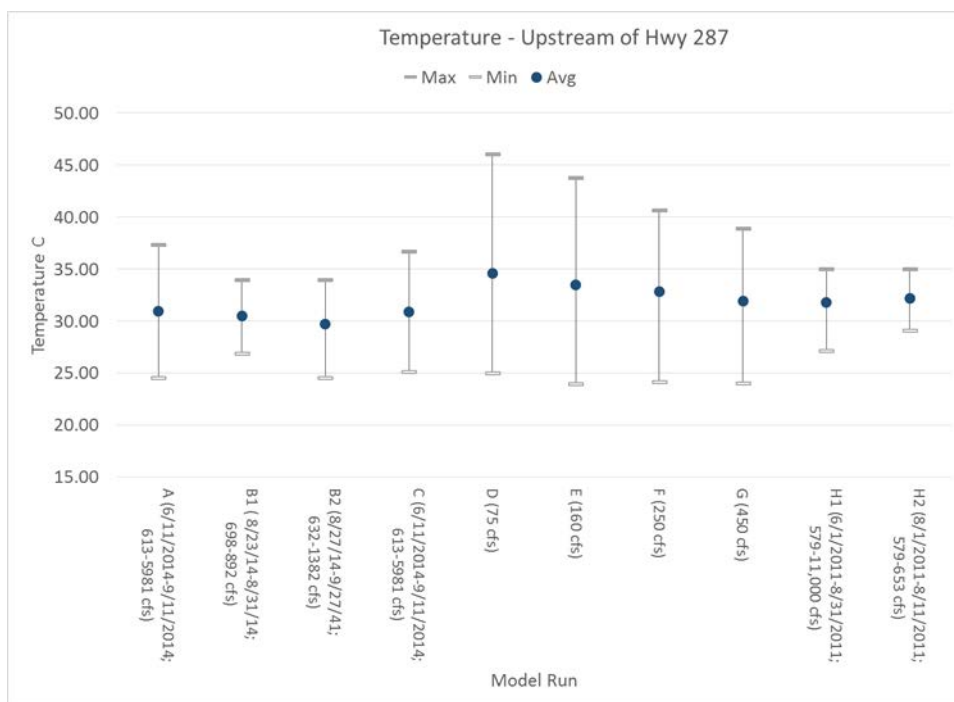


Figure 24 - All model runs A through H Simulated Temperature ranges on Trinity River upstream of Hwy 287.

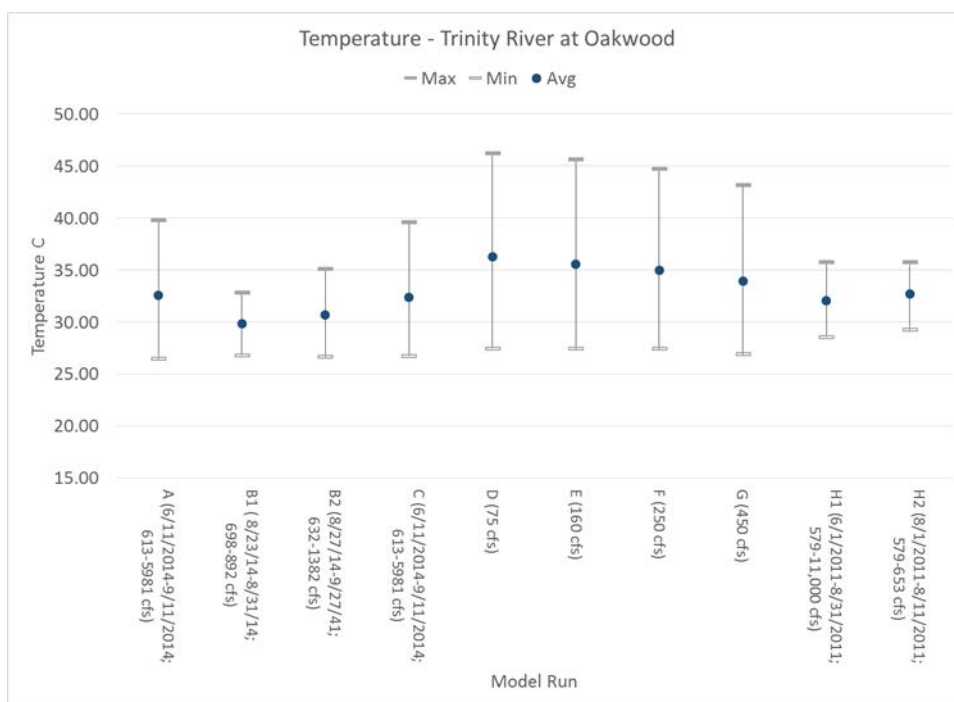


Figure 25 - All Model Runs A through H Simulated Temperature ranges on Trinity River at Oakwood.

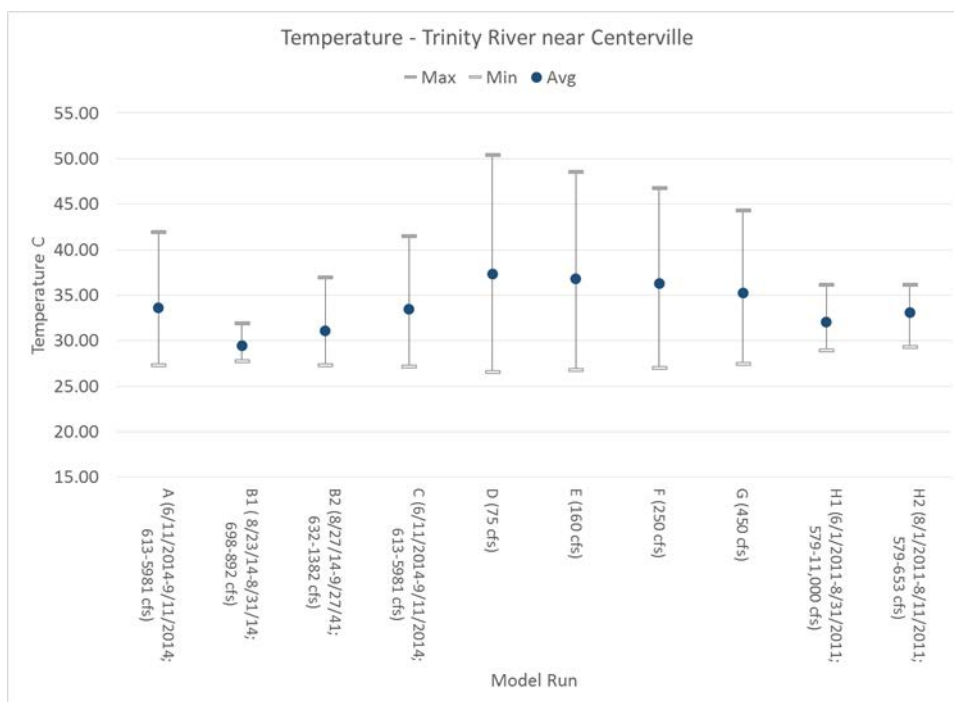


Figure 26 - All model runs A through H Simulated Temperature ranges on Trinity River near Centerville.

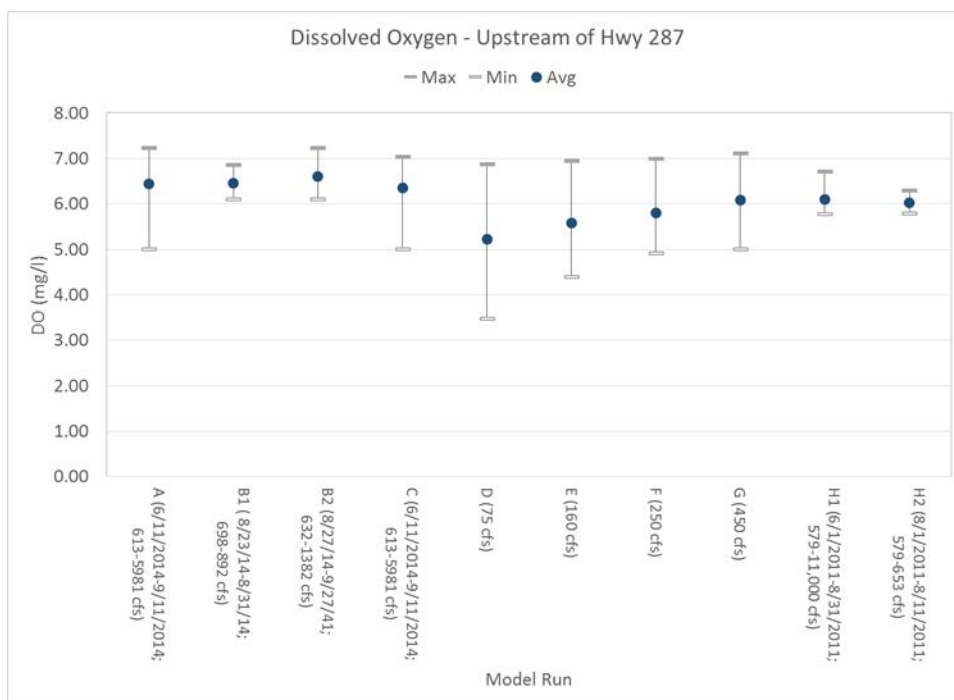


Figure 27 - All model runs A through H Simulated Dissolved Oxygen ranges on Trinity River upstream of Hwy 287.

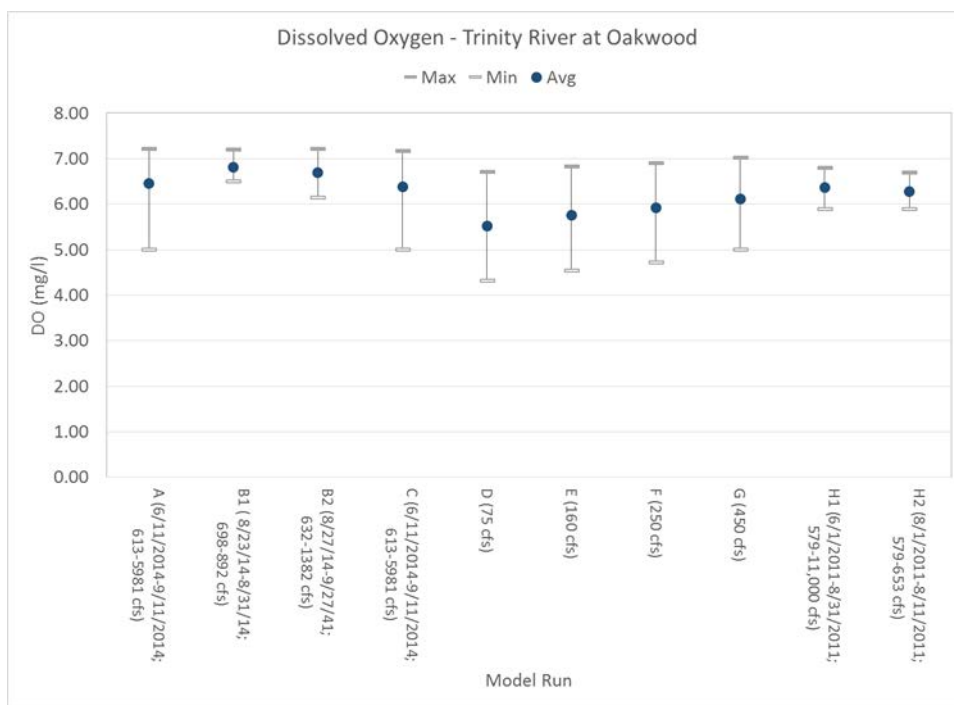


Figure 28 - All model runs A through H Simulated Dissolved Oxygen ranges on Trinity River at Oakwood.

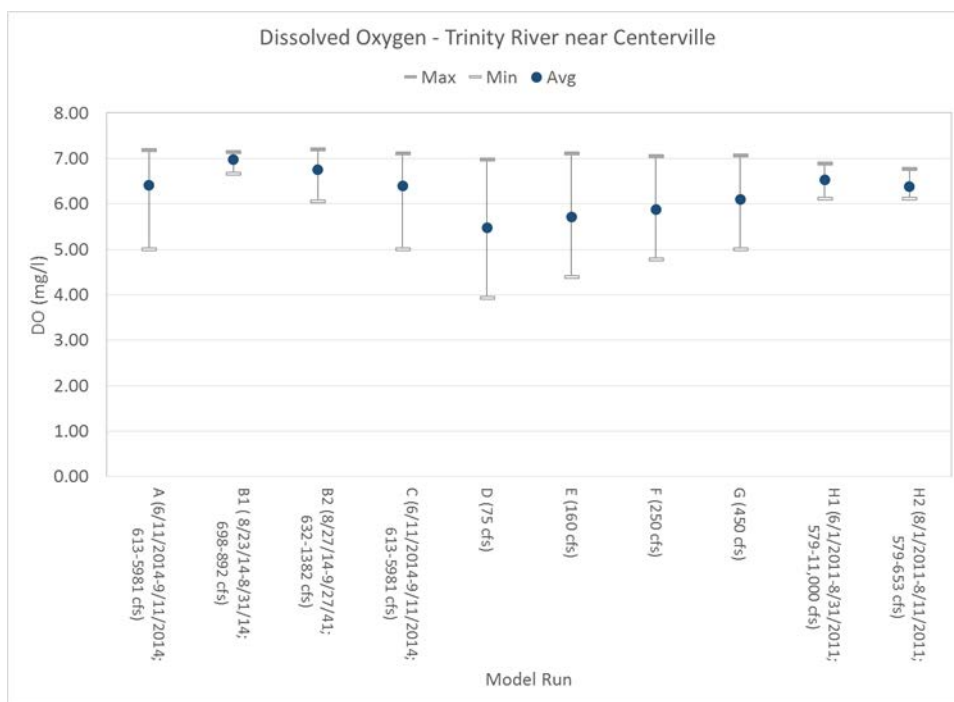


Figure 29 - All model runs A through H Simulated Dissolved Oxygen ranges on Trinity River near Centerville.

6 Summary

The HEC-RAS model was used to characterize hydraulic and water quality conditions across a range of worst-case low flow scenarios in the Trinity River between Rosser and the headwaters of Lake Livingston. Based upon modeling scenarios considering major (>0.5MGD) wastewater discharges into the river, and existing available geometry information, all tiers of the SB2 water quality goals are maintained for flow levels above 450 cfs. For all flows above 75 cfs, the SB2 tier 2 DO goal (equivalent to the TCEQ water quality standard) are maintained.

The high water temperature arising from shallow depths may be an artifact of imperfect bathymetry. For lower flow scenarios than those which have been experienced in recent history, additional work is recommended to verify and refine the channel depths at the low flow conditions.

The model relies upon depth to predict water temperature, and also relies upon temperature to predict DO. Therefore, additional work should focus on a site-specific comparison of HEC-RAS model geometry and depth outputs to available field observations measured at the Trinity River Oakwood site. The degree of difference between model predictions (both depth and temperature) and observations at that site can be an indicator of the degree of difference to expect in other model areas. This should be completed before additional parameters like nutrients and algae are incorporated into this model.

7 References

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