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Water Quality Model of the Middle Brazos River, below Waco to Fort Bend County

Instream Flow Water Quality Model

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In association

AquaStrategies

Client:
Brazos River Authority

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1 Assessment and Modeling

1.1 Model Setup

Similar to an existing downstream Brazos River model (EC 2011), EPD-Riv1 was adopted as the major modeling tool in this project.

The channel geometry for the EPD-RIV1 model could be imported directly from HEC-RAS geometry files of the Brazos River over the model area. Since no up-to-date HEC-RAS files are readily available for the current modeling area, HEC GeoRAS tools in GIS were utilized to generate model cross sections. Digital Elevation Model (DEM) raster data have been investigated and transformed to TIN maps in the project area. Preliminary modeling geometry including stream centerline, bank line, flow path lines and cross section lines are generated in GIS. The geometry file generated in HEC-GeoRAS was imported into HEC-RAS, and then exported into EPD-RIV1 as the start of model setup. The Brazos River EPD-RIV1 model from Waco to Fort Bend County is composed of 55 cross sections in total (Figure 1).

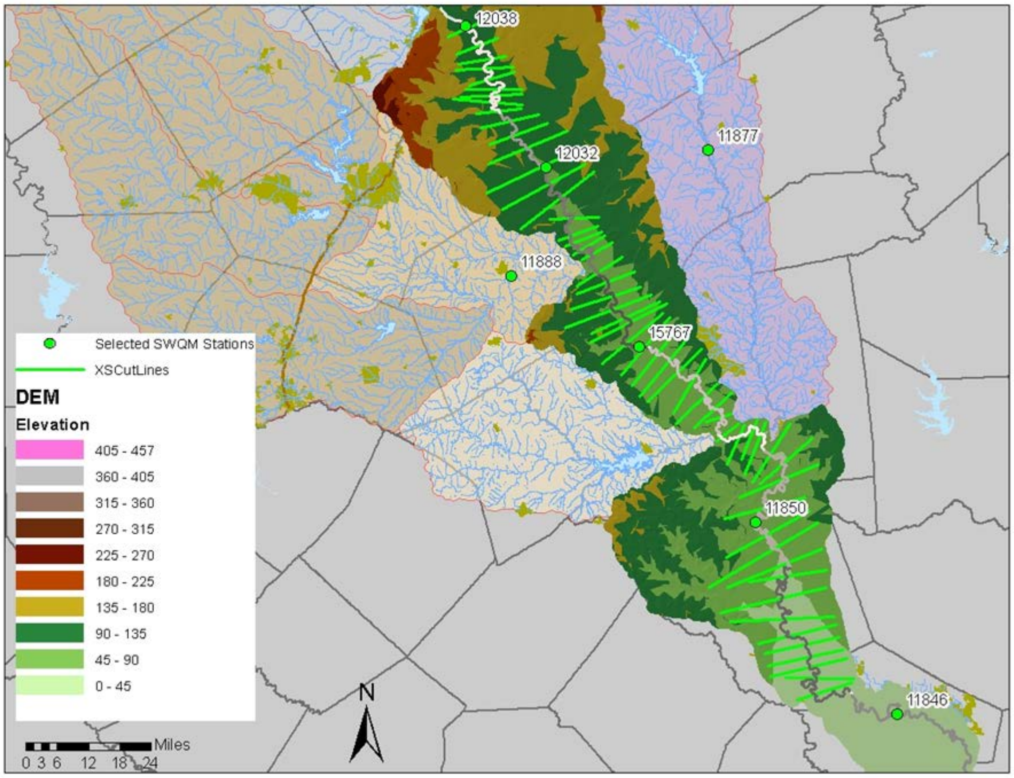

Figure 1 - Map of cross-section locations for Brazos River EPD-Riv1 model

The cross sections generated from DEM files only represent the flood plain without channel details. No funding was provided as part of this contract to collect detailed cross section information within the channel. As part of a separate effort, Texas Water Development Board (TWDB) planned to complete a longitudinal survey of the Brazos River from Waco to the coast. That effort would have provided additional cross sectional data within the channel. However, the longitudinal survey has been delayed and that data is not currently available. TWDB has collected detailed in channel bathymetry for six (6) smaller reaches within the study area (see Figure 2). This data was anticipated to be used to add additional detail to in-channel portions of the cross sections. However, the locations of the collected cross sections provide detailed information for only six (6) of the 55 model cross sections. In lieu of interpolating cross-sectional data collected by the TWDB, into all 55 model sections, a channel shape for low flows is assumed for modeling purposes based upon downstream channel geometry. The dimension of the channel for the modeling area is a trapezoid with 400 feet wide top bank and 30 feet total channel depth (Figure 3). One example of cross section geometry is shown in Figure 4.

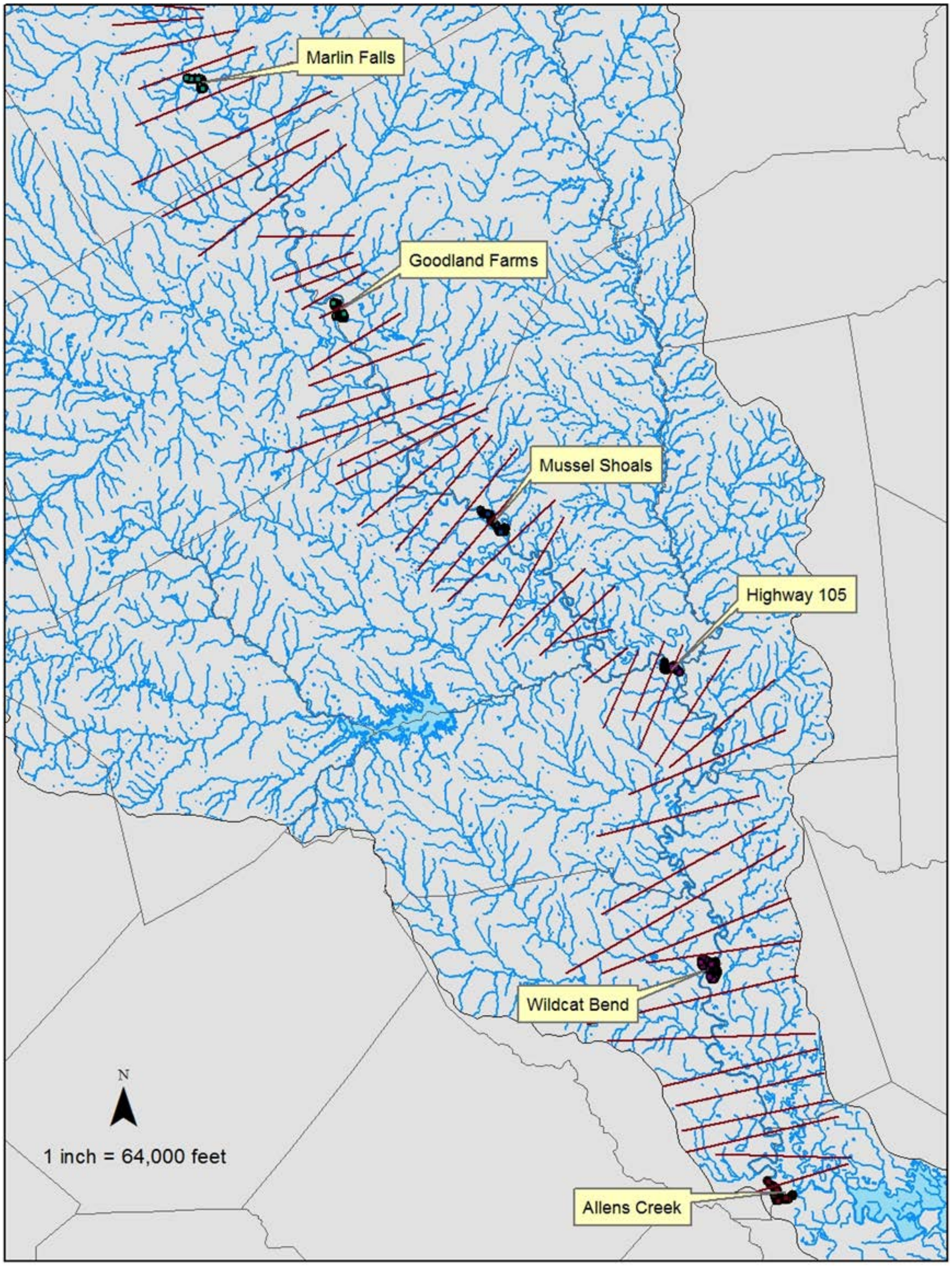

Figure 2 - TWDB Cross Sectional Data Collection Sites

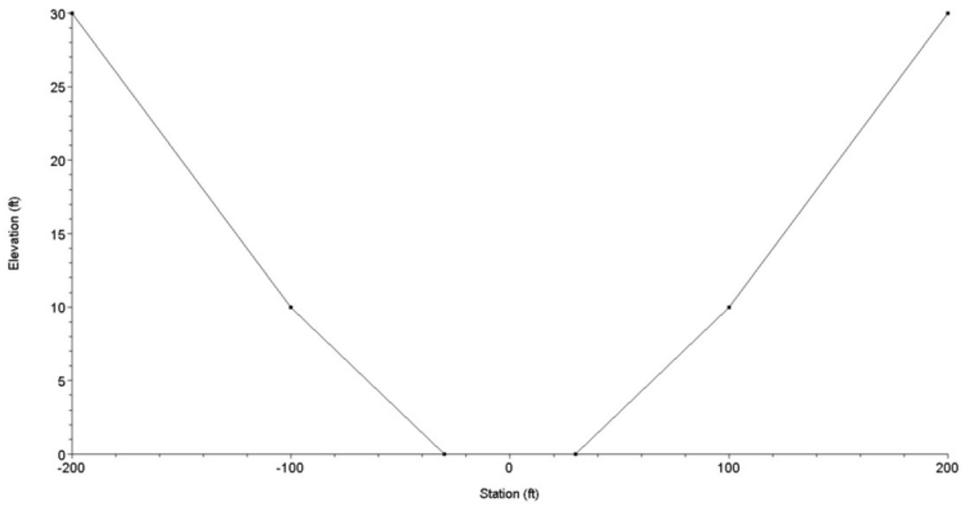

Figure 3 - Channel Shape of Brazos River (in feet)

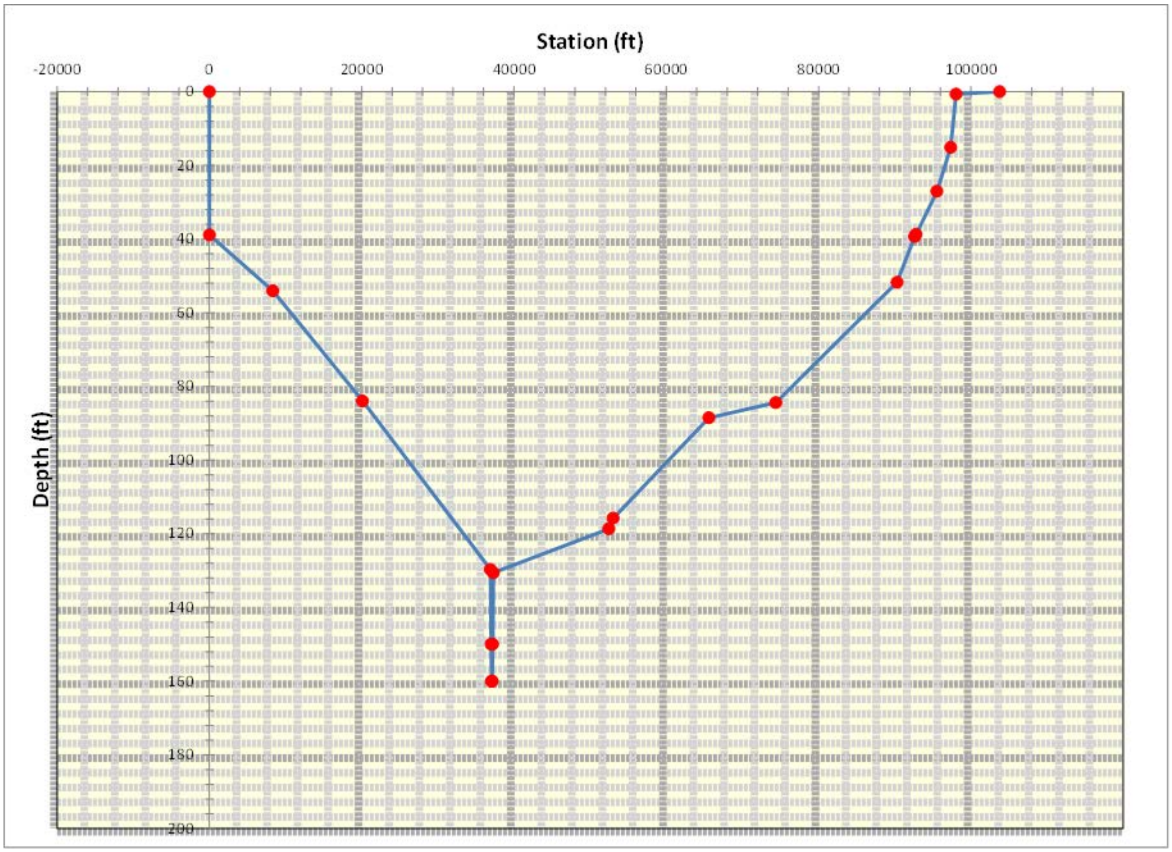

Figure 4 - Example of Cross Section of EDP-RIV1 Model

2 Model Scenarios

Temperature and dissolved oxygen (DO) were modeled for a range of scenarios. The Run A base model was developed and hydrodynamics simulated for the time period May 1, 2009 through June 30, 2009. Allowing a month for hydrodynamic conditions to stabilize, the water quality parameters were simulated June 1, 2009 through June 30, 2009. Run B represents a pulse flow scenario occurring September 2010 through October 2010. Run C includes wastewater discharges into Run A. Run D includes diversions into Run C.

The range of environmental flow low base flow values are captured in Run A model simulation period. Additional constant flow scenarios for Run A were modeled consistent with Senate Bill 3 flow standards (Table 1 and Table 2):

- 56 cfs (Waco subsistence flow)
- 120 cfs (Waco Winter Dry Base flow)
- 510 cfs (Hempstead subsistence flow)
- 2050 cfs (Hempstead Summer Wet Base flow)

Table 1- Environmental Flow Standards, Brazos River at Waco

Figure: 30 TAC §298.480(10)

United States Geological Survey Gage 08096500, Brazos River at Waco

Season	Subsistence	Hydrologic Condition	Base	Dry Condition Seasonal Pulse	Average Condition Seasonal Pulse	Wet Condition Seasonal Pulse
Winter	56 cfs	Dry	120 cfs	1 per season Trigger: 2,320 cfs Volume: 12,400 af Duration: 7 days	3 per season Trigger: 2,320 cfs Volume: 12,400 af Duration: 7 days	2 per season Trigger: 4,180 cfs Volume: 25,700 af Duration: 9 days
		Average	210 cfs			
		Wet	480 cfs			
Spring	56 cfs	Dry	150 cfs	1 per season Trigger: 5,330 cfs Volume: 32,700 af Duration: 10 days	3 per season Trigger: 5,330 cfs Volume: 32,700 af Duration: 10 days	2 per season Trigger: 13,600 cfs Volume: 102,000 af Duration: 14 days
		Average	270 cfs			
		Wet	690 cfs			
Summer	56 cfs	Dry	140 cfs	1 per season Trigger: 1,980 cfs Volume:	3 per season Trigger: 1,980 cfs Volume:	2 per season Trigger: 4,160 cfs Volume:
		Average	250 cfs			
		Wet	590 cfs	10,500 af Duration: 7 days	10,500 af Duration: 7 days	26,400 af Duration: 10 days

cfs = cubic feet per second
af = acre-feet
N/A = not applicable

Table 2 - Environmental Flow Standards, Brazos River at Hempstead

Figure: 30 TAC §298.480(17)

United States Geological Survey Gage 08111500, Brazos River near Hempstead

Season	Subsistence	Hydrologic Condition	Base	Dry Condition Seasonal Pulse	Average Condition Seasonal Pulse	Wet Condition Seasonal Pulse
Winter	510 cfs	Dry	920 cfs	1 per season Trigger: 5,720 cfs Volume: 49,800 af Duration: 10 days	3 per season Trigger: 5,720 cfs Volume: 49,800 af Duration: 10 days	2 per season Trigger: 11,200 cfs Volume: 125,000 af Duration: 15 days
		Average	1,440 cfs			
		Wet	2,890 cfs			
Spring	510 cfs	Dry	1,130 cfs	1 per season Trigger: 8,530 cfs Volume: 85,000 af Duration: 13 days	3 per season Trigger: 8,530 cfs Volume: 85,000 af Duration: 13 days	2 per season Trigger: 16,800 cfs Volume: 219,000 af Duration: 19 days
		Average	1,900 cfs			
		Wet	3,440 cfs			
Summer	510 cfs	Dry	950 cfs	1 per season Trigger: 2,620 cfs Volume: 17,000 af Duration: 7 days	3 per season Trigger: 2,620 cfs Volume: 17,000 af Duration: 7 days	2 per season Trigger: 5,090 cfs Volume: 40,900 af Duration: 9 days
		Average	1,330 cfs			
		Wet	2,050 cfs			

cfs = cubic feet per second
af = acre-feet
N/A = not applicable

2.1 Run A – Low Flow Condition

Run A is a dynamic scenario under low flow condition for which a number of model inputs are supported by observed data. June 2009 is chosen as the modeling period of Run A, with a low average flow of 157 cfs. The stream hydrograph is shown in Figure 5. Run A is performed in EPD-RIV1.

The headwater boundary conditions are set up as time series inputs according to data from US Geological Service (USGS) station 08096500 and Texas Commission on Environmental Quality (TCEQ) Surface Water Quality Monitoring (SWQM) station 12038 near Waco (see Table 3). DO is 11.2 mg/L. Temperature is set as a constant of 34.3°C. These are based on reported SWQM observation values in June 2009. Ultimate Biological Oxygen Demand (BOD) is set as 4.6mg/L (BOD5 = 2 mg/L), which is the detection limit on BOD5 since there is no observation data available for this period.

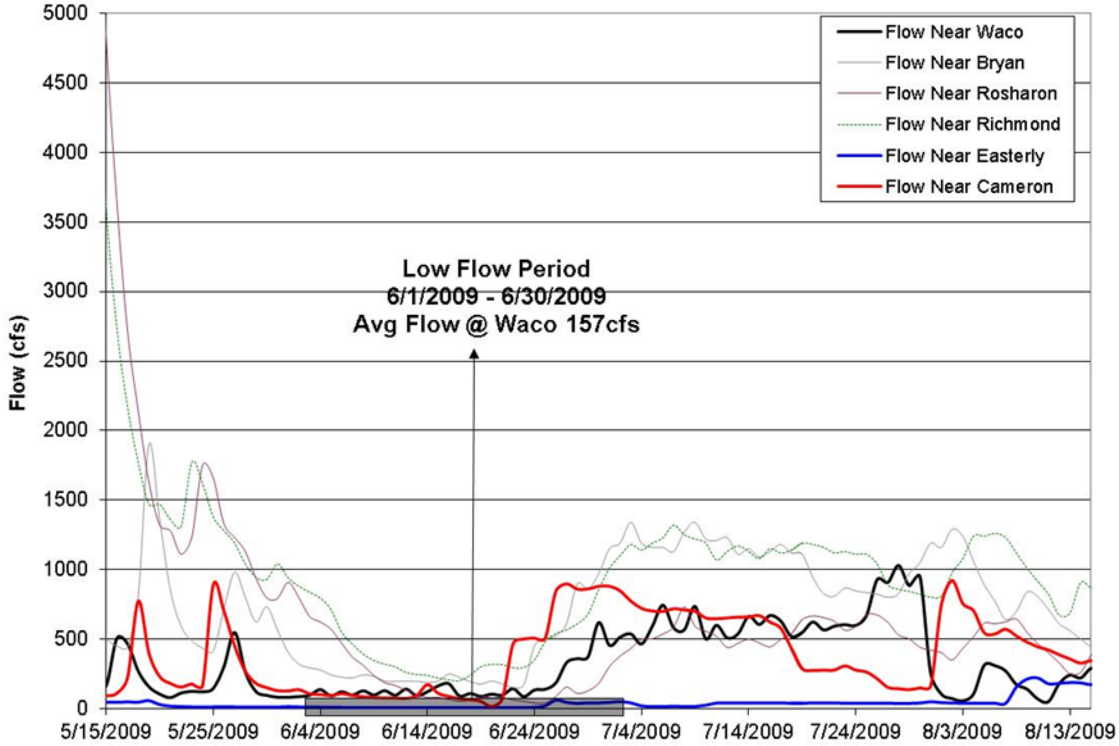

Figure 5 - Flow hydrograph - Run A low flow period

Table 3- Run A - Headwater Boundary Conditions

Headwater BC	*Value*	*Units*	*Source*
Flow	TS	cfs	USGS 08096500
Temperature	34.3	C	Avg SWQM 12038 in modeling period
DO	11.2	mg/L	Avg SWQM 12038 in modeling period
CBODu	4.6	mg/L	Detection Limit of SWQM 12038

No lateral inflows from waste water treatment plants (WWTP) were utilized for this low flow scenario. Lateral inflows from tributaries are included in this modeling run. Modeling results for Little River and Navasota River, and USGS gage flows for Yegua Creek are included in this low flow scenario. However, no incremental inflows are included in this or any modeling run.

DO and BOD are major parameters in water quality modeling. DO concentration at boundaries, re-aeration and Sediment Oxygen Demand (SOD), and BOD kinetic coefficients were set up in this model (Table 4). DO re-aeration coefficients are “Texas equation” used by TCEQ in QUAL-TX modeling efforts. SOD and BOD decay rates are consistent with values used in Texas in the same (QUAL-TX) modeling efforts (communication with Rudolph 2007).

Table 4 - Run A - Water Quality Kinetic Rates

Parameter	Value	Units
SOD	0.6	g/m2-day
BOD Decay Rate	0.1	/day
Reaeration Coefficient AG	1.923	
Reaeration Coefficient K1	0.273	
Reaeration Coefficient K2	0.894	

Hydrodynamic modeling results are shown in Figure 6 and Figure 7 as follows. Before major tributary inflows, at the Highbank gage location, similar values were shown in model predictions and USGS gage observations (Figure 6). However, at downstream locations, for example Hempstead gage, model predictions are relatively lower compared with gage observations (Figure 7). This may be due to the drainage area incremental flows and local rainfall events. Daily rainfall data at Limestone (near Waco) are shown in Figure 8 in Run A modeling period.

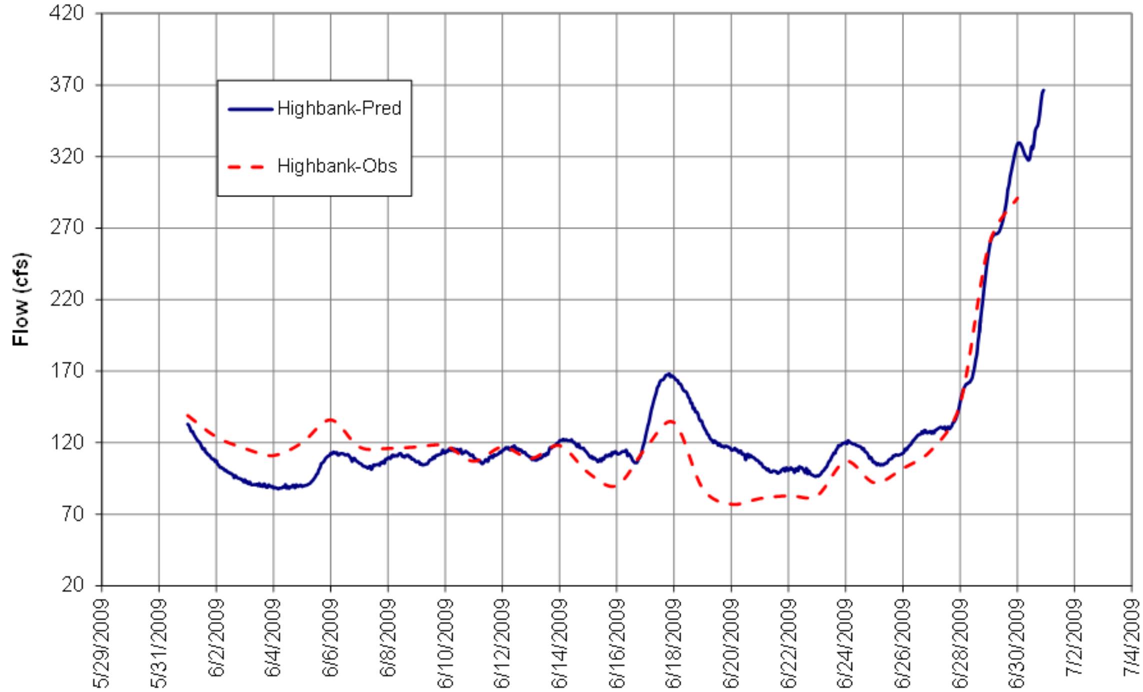

Figure 6- Run A - EPD-RIV1 - Flow at Highbank

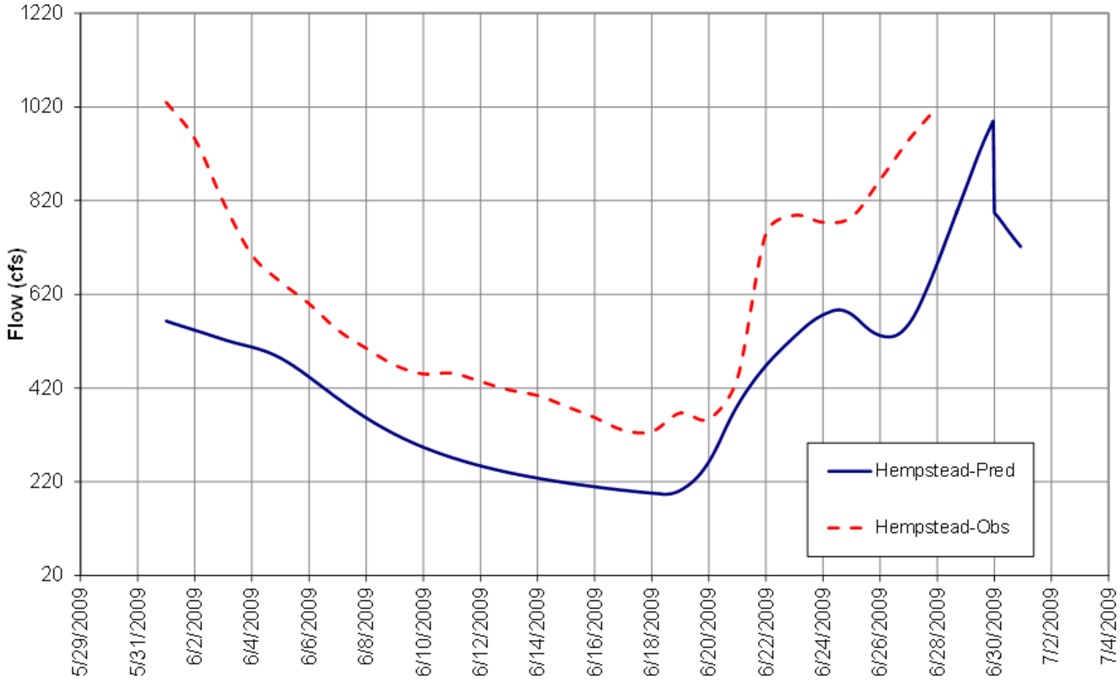

Figure 7 - Run A - EPD-RIV1 - Flow at Hempstead

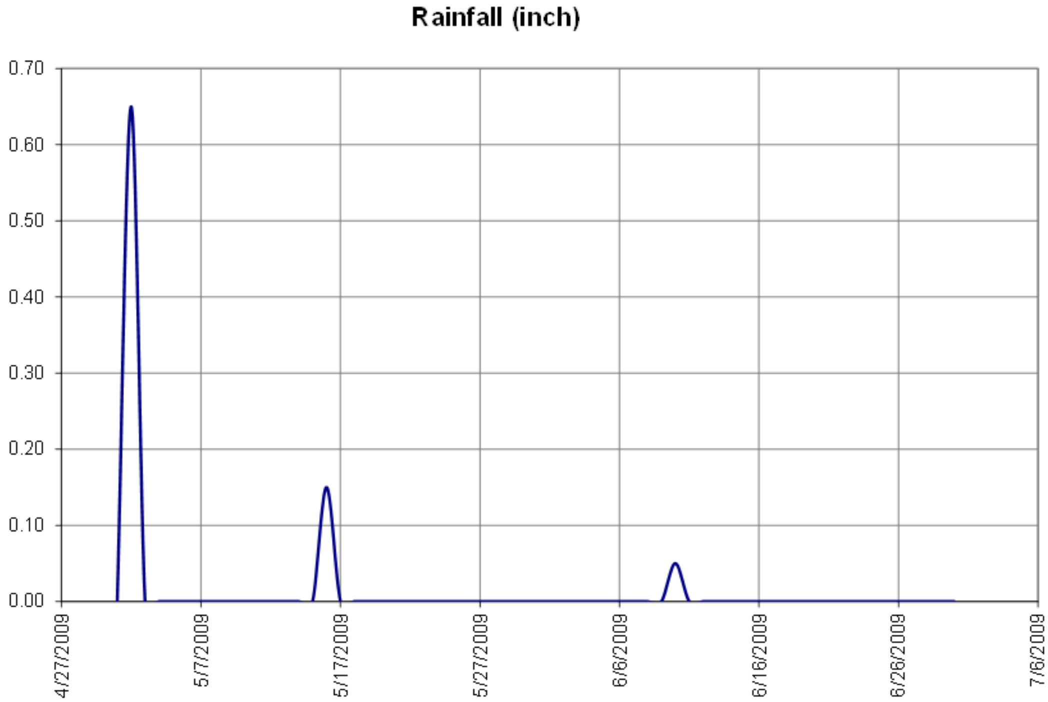

Figure 8 - Daily Rainfall at Limestone

2.2 Run B – Pulse flow condition

Run B is a dynamic scenario representing a pulse flow condition for modeling periods September to October 2010. Run B is performed in EPD-RIV1. The stream hydrographs are shown in Figure 9.

The headwater boundary conditions are set up as time series inputs according to data from USGS station 08096500 and TCEQ SWQM station 12038 near Waco (see Table 5 for details). DO and Temperature are based on SWQM observation in each modeling period. Ultimate BOD is set as 4.6mg/L (BOD5 = 2 mg/L), which is the detection limit on BOD5 since there is no observation data available for this period.

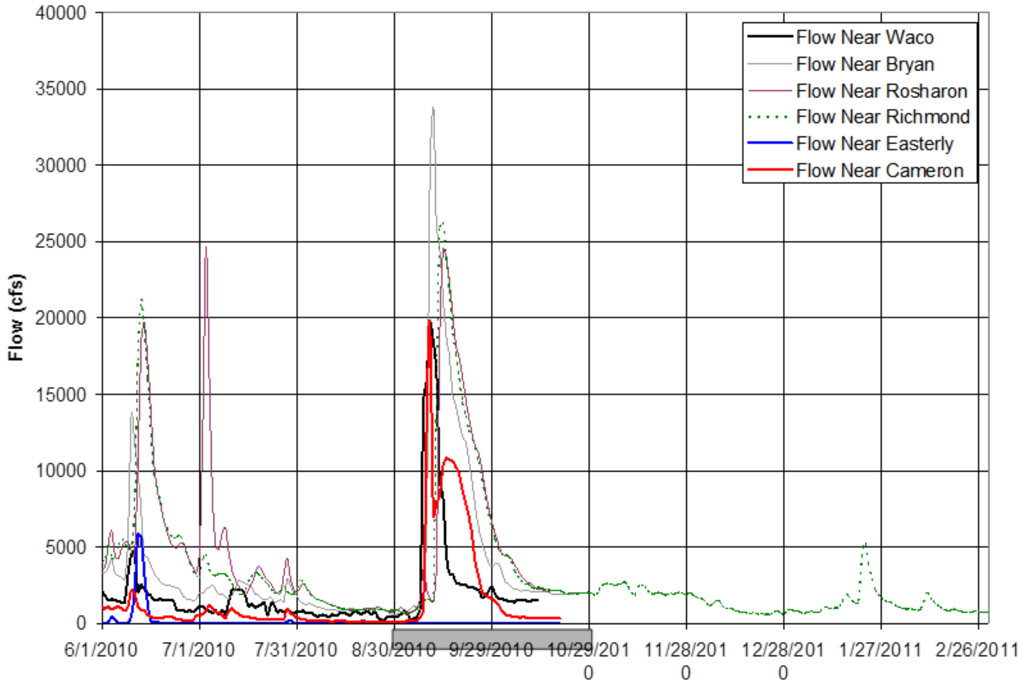

Figure 9 - Flow Hydrograph - Run B 2010

Table 5- Run B - Headwater Boundary Conditions 2010

Headwater BC	Value	Units	Source
Flow	TS	cfs	USGS 08096500
Temperature	24.15	C	Avg SWQM 12038 in modeling period
DO	9.15	mg/L	Avg SWQM 12038 in modeling period
CBODu	4.6	mg/L	Detection Limit of SWQM 12038

No lateral inflows from WWTP were utilized for this pulse flow scenario. Lateral inflows from tributaries are included in this modeling run. Modeling results for Little River and Navasota River, and USGS gage flows for Yegua Creek are included in this low flow scenario. However, no incremental inflows are included in this or any modeling run.

Hydrodynamic modeling results are shown in Figure 10 and Figure 11 as follows. Before major tributary inflows, at Highbank gage location, similar values were shown in model prediction and USGS gage observation (Figure 10). However, at downstream locations, for example Hempstead gage, model predictions are relatively lower compared with gage observations (Figure 11). This may be due to the drainage area incremental flows and local rainfall events. Daily rainfall data at Limestone (near Waco) are shown in Figure 12 in Run B modeling period.

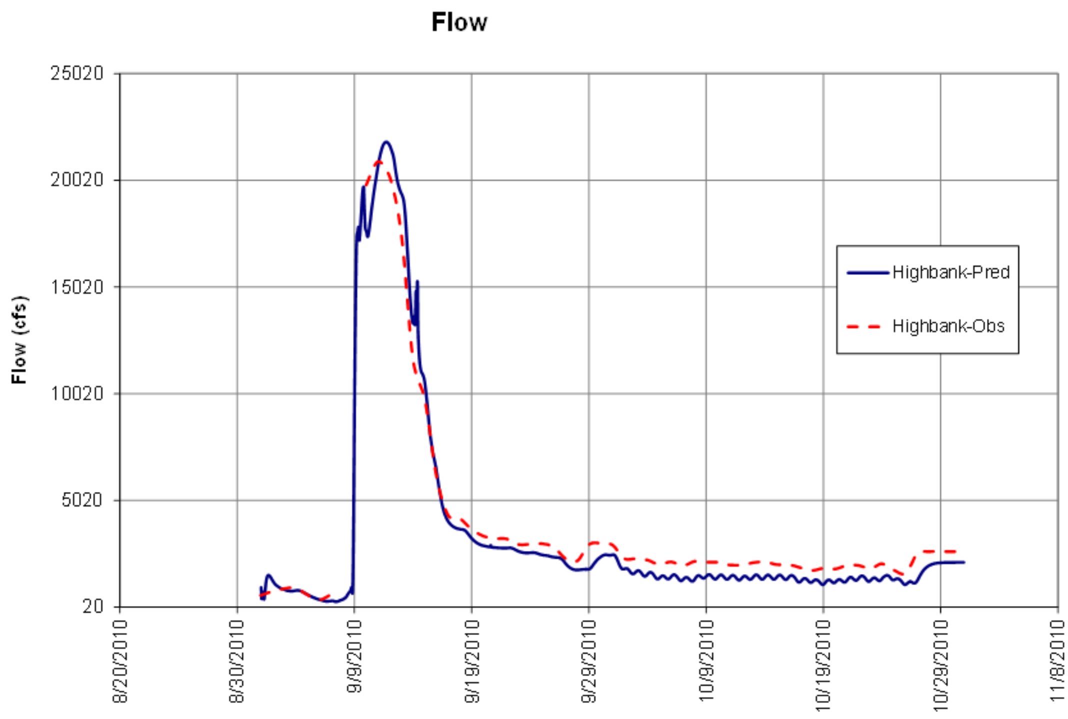

Figure 10 - Run B - EPD-RIV1 - Flow at Highbank

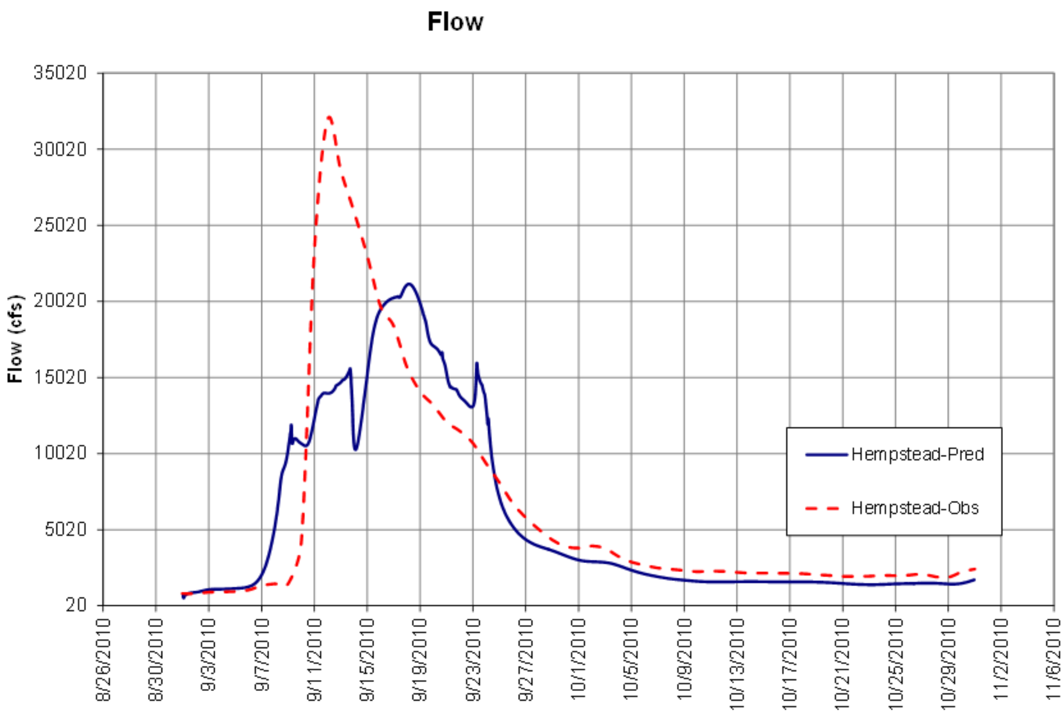

Figure 11 - Run B - EPD-RIV1 - Flow at Hempstead

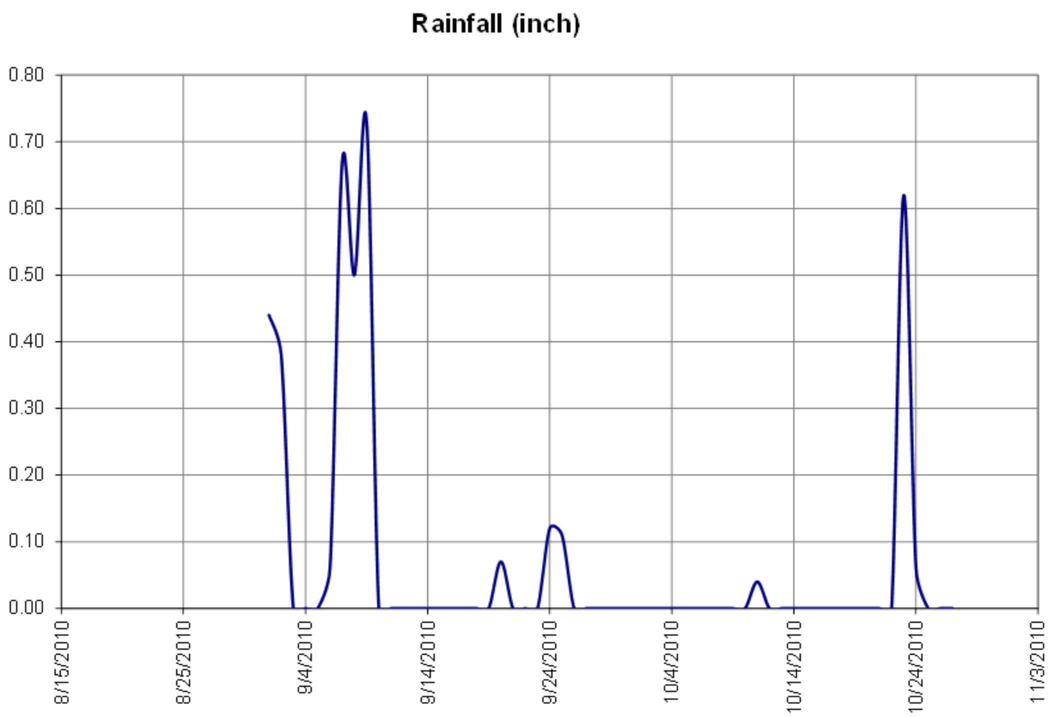

Figure 12 - Daily Rainfall at Limestone

2.3 Run C – Low flow condition w/ Current Lateral Inflows (WWTP discharges)

Run C is a dynamic scenario under low flow condition. Same period as Run A (June 2009) is chosen as the modeling period, with a low average flow of 157 cfs. The stream hydrograph is shown in Figure 5.

The headwater boundary conditions are set up as time series inputs according to data from USGS station 08096500 and TCEQ SWQM station 12038 near Waco (see Table 6 for details). Temperature is set as a constant of 34.3°C. DO and Temperature are based on SWQM observation in June 2009. Ultimate BOD is set as 4.6mg/L (BOD5 = 2 mg/L), which is the detection limit on BOD5 since there is no actual observation data available.

Table 6- Run C - Headwater Boundary Conditions

Headwater BC	*Value*	*Units*	*Source*
Flow	TS	cfs	USGS 08096500
Temperature	34.3	C	Avg SWQM 12038 in modeling period
DO	11.2	mg/L	Avg SWQM 12038 in modeling period
CBODu	4.6	mg/L	Detection Limit of SWQM 12038

The current discharges from WWTP were included for this low flow scenario, while diversion was not incorporated. The point source flows, DO, and BOD concentrations are based upon observed current values in the modeling period (Table 7). The observed ammonia concentrations are included in Table 7, while nitrogen concentration was not considered in this DO model scenario. When multiple discharges flow into Brazos River at the same location, the sum of the observed discharges and the flow-weighted average of the observed concentrations were used (see X-sec A2 etc. in Table 7). The bold values listed in Table 7 are observed/reported data values or are calculated from observed data, such as DO at station TX0026506. All other values are assumed values. For stations without temperature data, temperature is assumed as boundary condition temperature 34.3°C. For stations without DO data, 80% of saturated DO concentration at reported or assumed temperature was used in the model.

DO (BOD) modeling was conducted for Run C. DO and BOD are major parameters considered for the water quality modeling case. DO concentrations at boundaries, re-aeration and SOD, and BOD kinetic coefficients were set up in this model. The kinetic rates shown in Table 4 are used in Run C.

Table 7 - Run C - Point Source Loadings

	Location	Point				
		Inflow	Temp	DO	cBODu	NH4
WWTP	X-sec	cfs	C	mg/L	mgO2/L	mgN/L
TX0026506	A2	31.90055	34.30	6.7	4.62	0.14
TX0021725	A10	1.184	34.3	5.30	0.00	0.00
TX0101168	A15	1.550	34.3	5.64	22.50	0.00
	A30-Total	5.537	34.30	6.14	16.51	2.03
TX0025071	A30	2.03205	34.3	6	5.31	0.35
TX0113603	A30	1.95455	34.3	6.7	23.00	3
TX0128554	A30	1.55	34.3	5.64	23.00	3
	A32-Total	2.68	34.30	5.94	10.85	0.49
TX0090883	A32	0.496	34.30	4.27	14.08	0.49
TX0108146	A32	2.1855	34.30	6.32	10.12	0.49
TX0025470	A43	3.013	34.3	6.00	6.90	1.61
TX0111201	A47	0.690	34.3	7.20	4.83	0.21

2.4 Run D – Low flow condition w/ Later Inflows and Diversions

Run D is a dynamic scenario under low flow condition. Same period as Run A (June 2009) is chosen as the modeling period, with a low average flow of 157 cfs. The stream hydrograph is shown in Figure 5.

The headwater boundary conditions are set up as time series inputs according to data from USGS station 08096500 and TCEQ SWQM station 12038 near Waco (see Table 6 for details). Temperature is set as a constant of 34.3°C. Ultimate BOD is set as 4.6mg/L (BOD5 = 2 mg/L).

The current condition lateral inflows from WWTP were included for this low flow scenario (same as Run C, Table 7).

The fully permitted diversions were considered in the model; however, those diversions would be large enough to “dry up” the river and introduce an error into the model. Therefore, a diversion value equivalent to 20% of the maximum diversion was used for this model scenario (Table 8). For permits with multiple allowable diversion locations, the diversion flow was divided among the possible diversion locations as shown. If additional scenarios are identified at a later date, diversions can be modified and adjusted at the diversion locations already built into the model.

Both thermal and DO (BOD) modeling were conducted for Run D. Thermal modeling included temperature as the major water quality parameter. The meteorological conditions are set up according to hourly climate data (including water temperature, dry bulb temperature, wind speed and pressure etc.) at Sugar Land Regional Airport. DO and BOD are major water quality parameters considered for the DO modeling case. DO concentrations at boundaries, re-aeration and SOD, and BOD kinetic coefficients were set up in this model. The kinetic rates shown in Table 4 are used in Run D.

Table 8 - Run D - Large diversions along Modeling Area

X-sec	Diversion	
	Permitted (ac-ft/yr)	Model (cfs, 20% offully permitted)
A2	67200	18.56
A3	10000	2.76
A30	55708	15.39

3 Instream Flow Water Quality Goals

The primary priority water quality goals for dissolved oxygen (DO) and temperature for Brazos River TCEQ Segment 1242 (Table 9) are the same as for Segment 1202 (from the Navasota River to Fort Bend County and on to the Brazos River tidal segment). These goals are to meet 3 mg/L DO concentration and 35°C temperature.

Table 9 - Brazos River Instream Flow Water Quality Goals (see EC 2011)

Brazos River, downstream of Waco to Navasota River
1242 (BR-3 and BR-4)

Parameter	Instream Flow Goals (Values)
Tier 1 - Primary priority	
DO* (EC 2010d)	<= 12 hours below 3 mg/L <= 2 hours below 2 mg/L >1.5 mg/L
Temperature* (EC 2010d)	<= 35' C (95 'F)
Tier 2 - Secondary priority	
DO* (2010a)	>= 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 <= 8 hours
Temperature*	<= 27` C (80.6`F) Jan - May
Temperature* (2010a)	<= 95 'F
TSS *(90pctl)*	<= 160.3 mg/L
Nitrate (2010b)	<= 1.95 mg/L
Ammonia* (2010b)	<= 0.33 mg/L
Orthophosphate* (2010b)	<= 0.37 mg/L
Tier 3 - additional parameters	
E. Coli* (2010a)	<= 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 (2010a)	<= 350 mg/L
Sulfate (2010a)	<= 200 mg/L
Specific Conductance (2010b)	<= 3077 uS/cm
pH (2010a)	6.5 - 9.0
TDS (2010a)	<= 1000 mg/L

* = Preliminary indicator identified by SB2 TIFP stakeholders

4 Model Results

Model results for temperature and dissolved oxygen are presented for the Highbank (cross-section X13) and Hempstead (X43) locations. Since the upstream boundary condition is located at the Waco SB3 measurement point, Highbank was chosen as a nearby downstream location representative of the Waco reach that is sufficiently downstream to avoid boundary condition influence.

Model calibration was limited since the model depths are based upon assumed geometry, and the assumed geometry will likely have impact on the temperature conditions, which will in turn affect the DO concentrations. The model results are the best available at this time.

4.1 Run A – Low Flow

The model predicts temperature and DO conditions to be above instream flow goals (Table 9) for a range of baseflow conditions occurring during the summer (June) of 2009 (Figure 13). The model may be generally over predicting the diel range of temperature based upon diel observation data measured during the summer of 2011, but the prediction is consistent with the point observation measurement at Hempstead (Figure 14). The range of diel DO fluctuations are not captured by the model because photosynthesis and respiration of algae is not being simulated (Figure 15). The DO simulation does consider nutrient concentrations and kinetics. Despite some differences in model predictions compared to observations, the average temperature is within range of observations, and the predicted DO is lower than observations suggesting a conservative model. The model is used in this project to compare relative predictions across a range of flow scenarios.

For low range base flow conditions between 56 cfs and 510 cfs (Figure 16, Figure 17, Figure 18), the temperature goal is predicted to be maintained and only the 56 cfs scenario results in a DO below the tier 2 instream flow goal that is equivalent to the 5.0 mg/L DO water quality standard near Hempstead (Figure 16); however, the dip below 5.0 mg/L occurs downstream at the Hempstead location where flow is not anticipated to be as low as 56 cfs because of intermediate gains and inflows between Highbank and Hempstead.

For a higher base flow at 2,050 cfs, the temperature is maintained and DO falls below the instream flow tier 2 goal of 5.0mg/L near Hempstead (Figure 19).

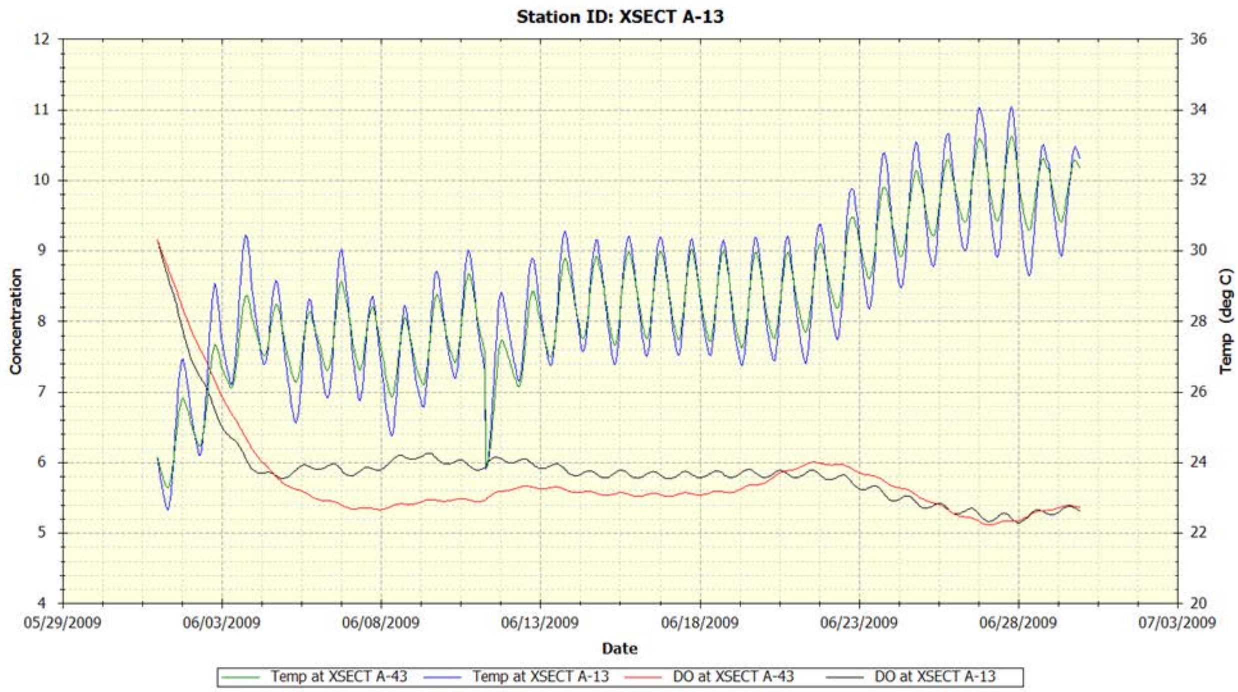

Figure 13 - Run A - DO and Temperature results

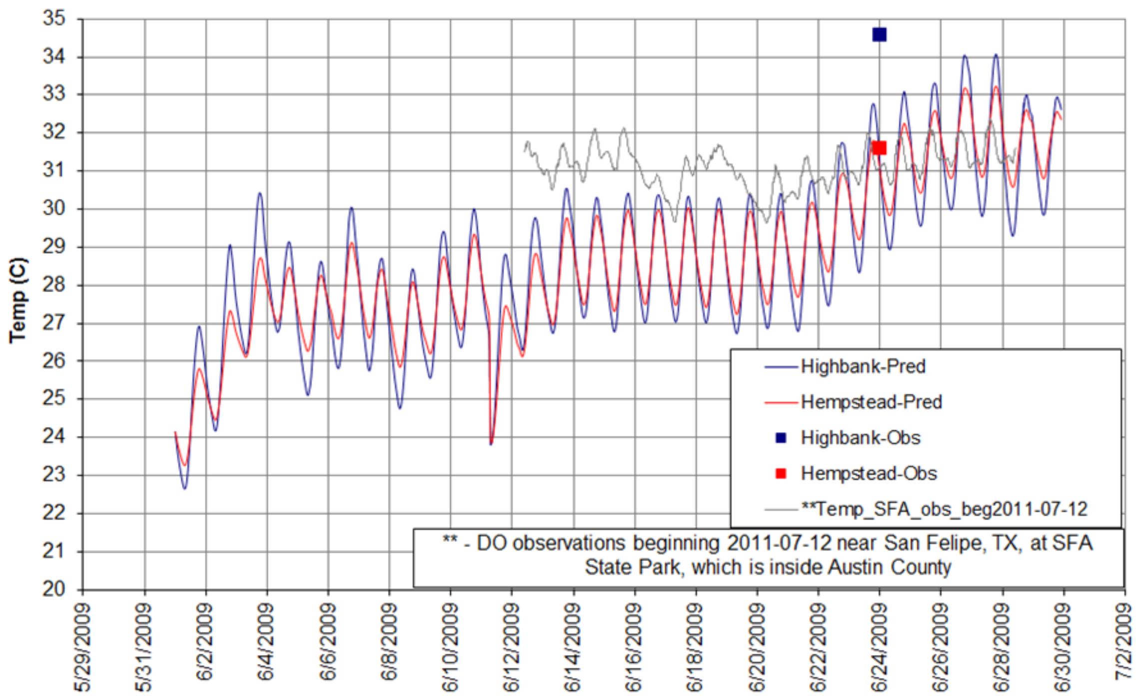

Figure 14 - Run A - Temperature results with observations to compare range

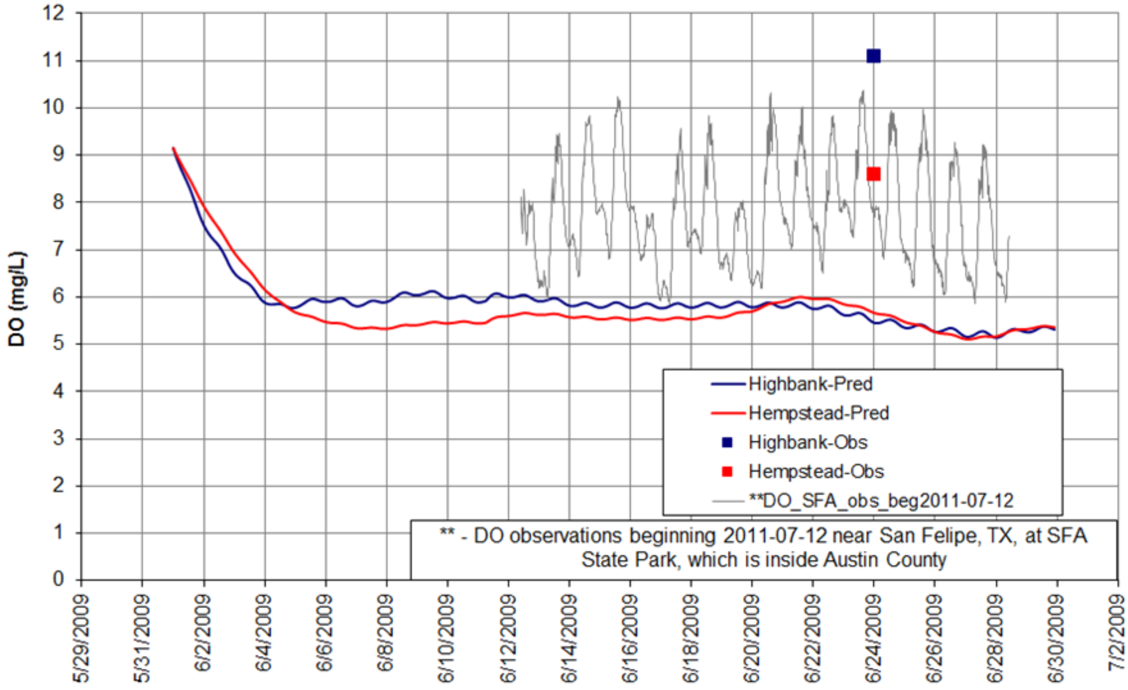

Figure 15 - Run A - DO Results with observations to compare range

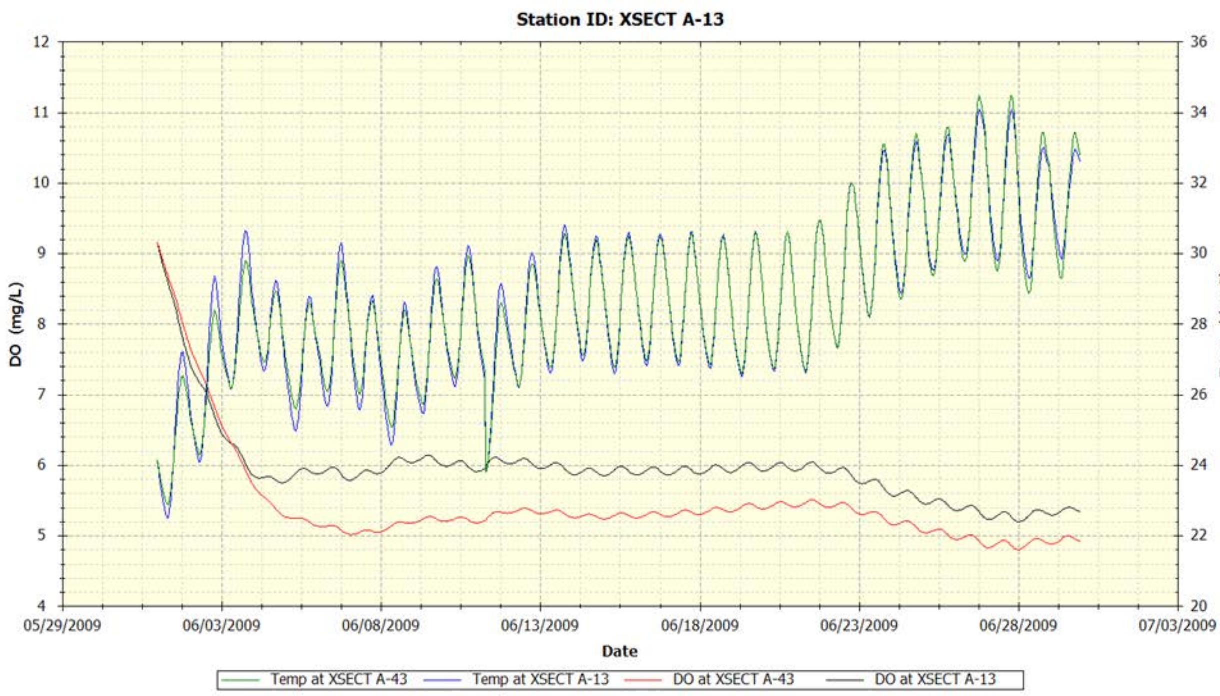

Figure 16 - Run A1 - 56 cfs - DO and Temperature results

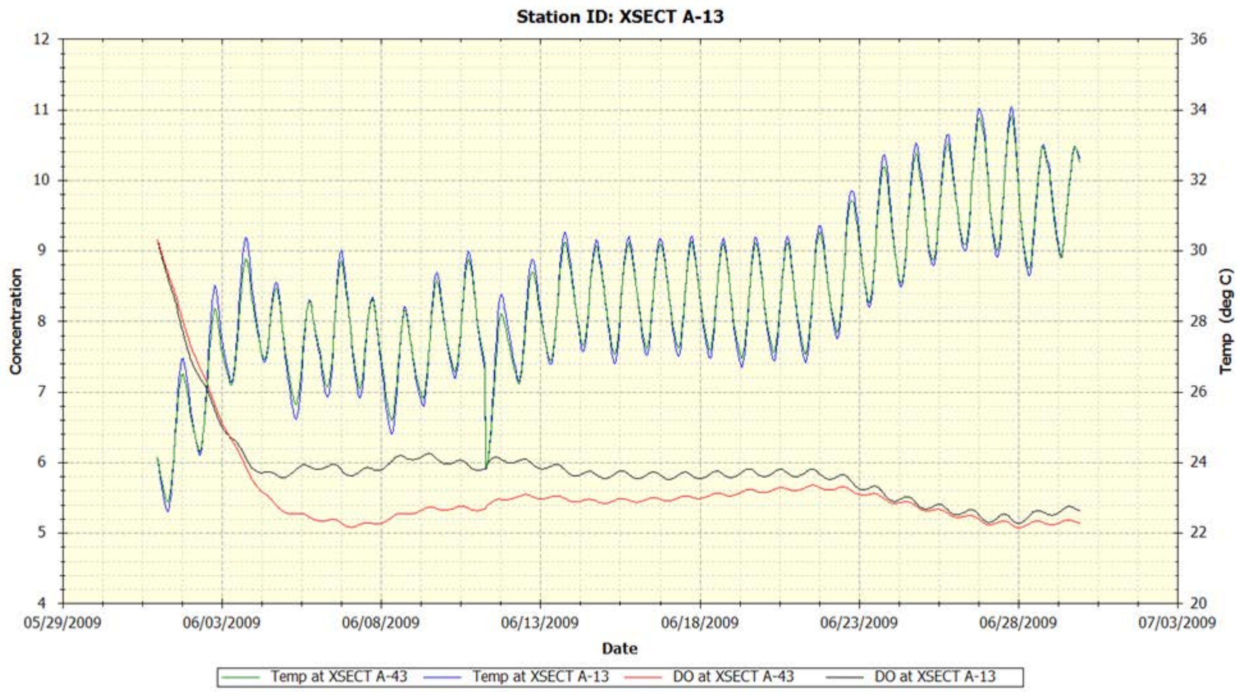

Figure 17 - Run A2 - 120 cs - DO and Temperature results

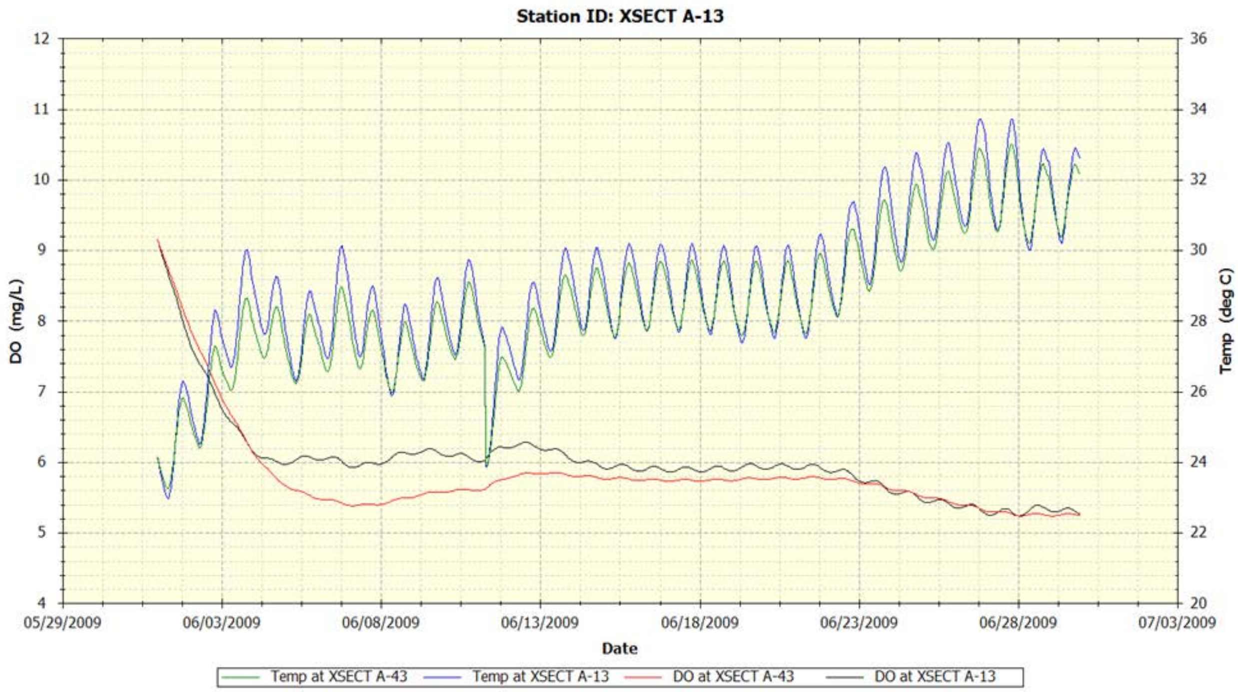

Figure 18 - Run A3 - 510 cfs - DO and Temperature results

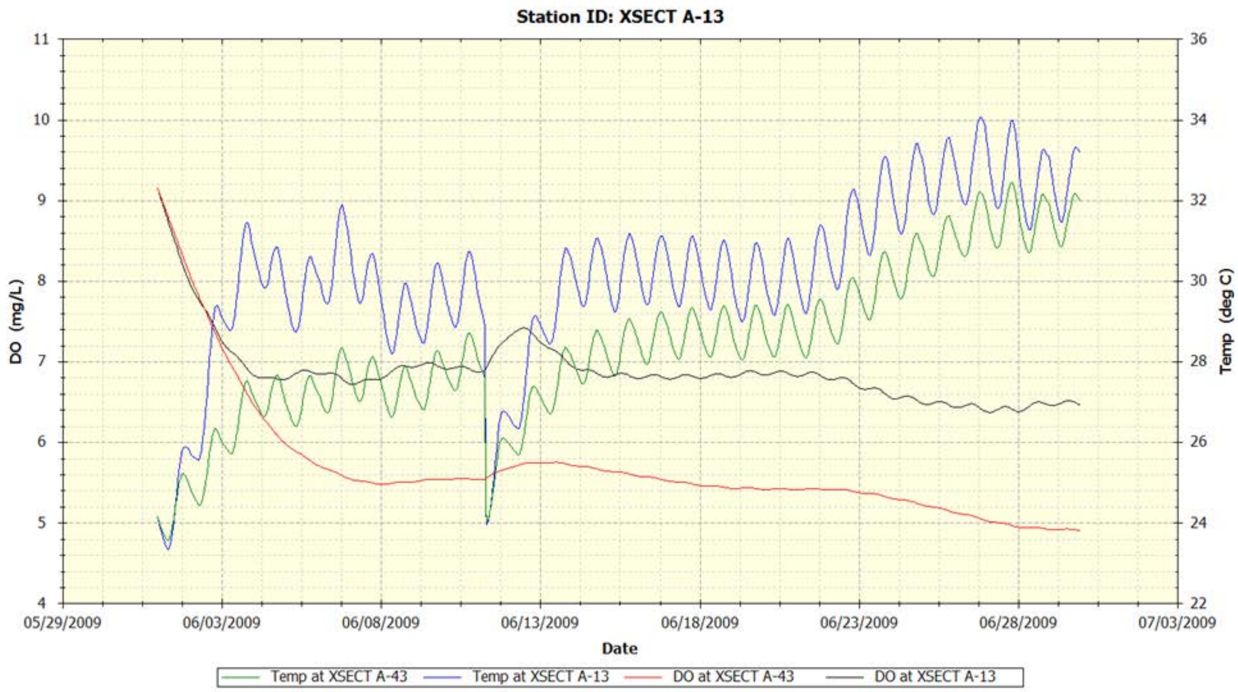

Figure 19 - Run A - 2050 cfs - DO and Temperature results

4.2 Run B – Pulse Flow

While the hydrodynamics model was able to run, as shown in Section 2.2, the water quality model proved unstable for dissolved oxygen after October 5. However, subsequent to the pulse flow event occurring during September (Figure 20), the DO did not reduce below 5 mg/L (Figure 21).

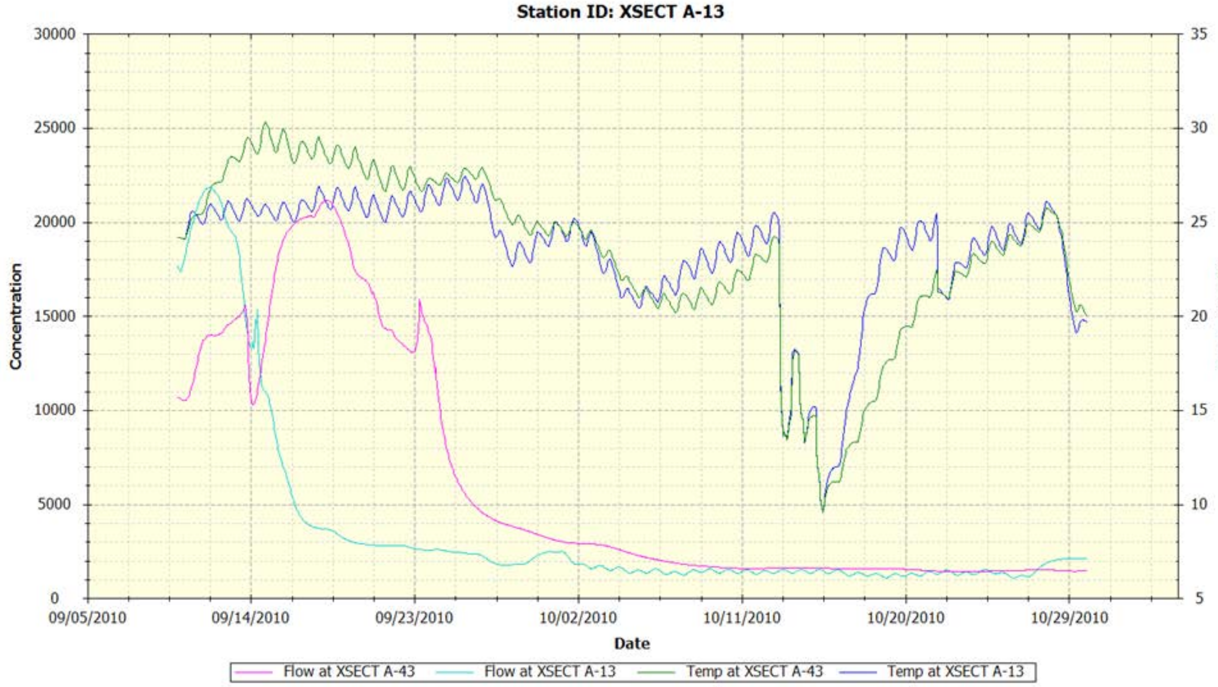

Figure 20 - Run B - Flow, with Temperature results

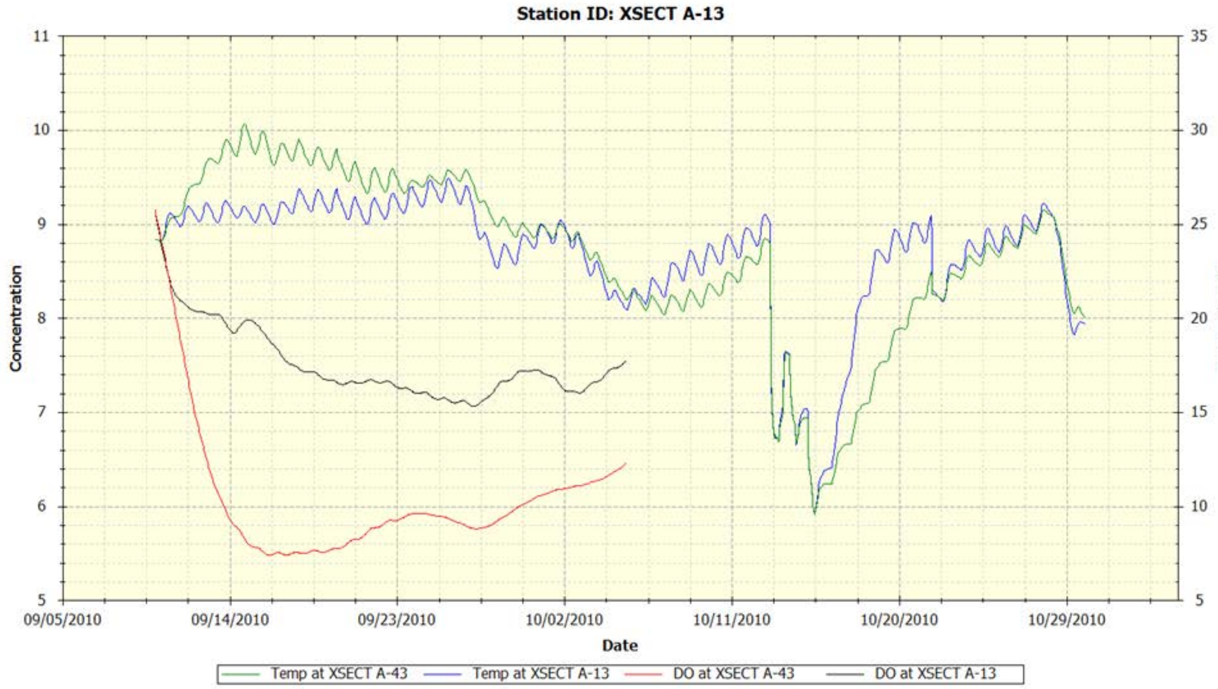

Figure 21 - Run B - DO and Temperature results

4.3 Run C – WWTP inflows

While the hydrodynamics model was able to run, the water quality model proved unstable for dissolved oxygen after 6/20/09. Including the waste loads did not significantly impact the DO concentrations (Figure 22) compared to Run A. Temperature is lower at Hempstead as a result of the discharges.

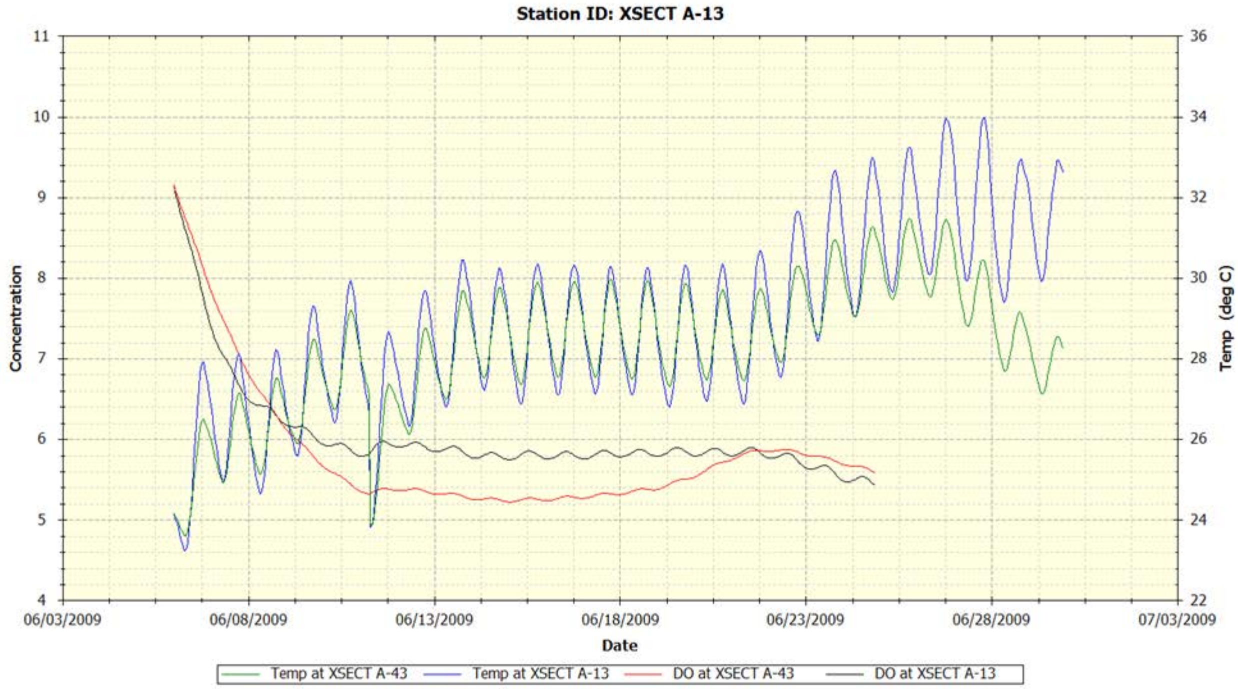

Figure 22 - Run C - DO and Temperature results

4.4 Run D – WWTP inflows and diversions

While the hydrodynamics model was able to run, the water quality model proved unstable for dissolved oxygen. Temperature results (Figure 23) do not indicate any significant difference from Run C. Dissolved oxygen results are presented for a constant temperature scenario (24.3°C) since the model was unstable when both temperature and dissolved oxygen calculations were activated at the same time. DO results indicate values higher than 5.0 mg/L (Figure 24).

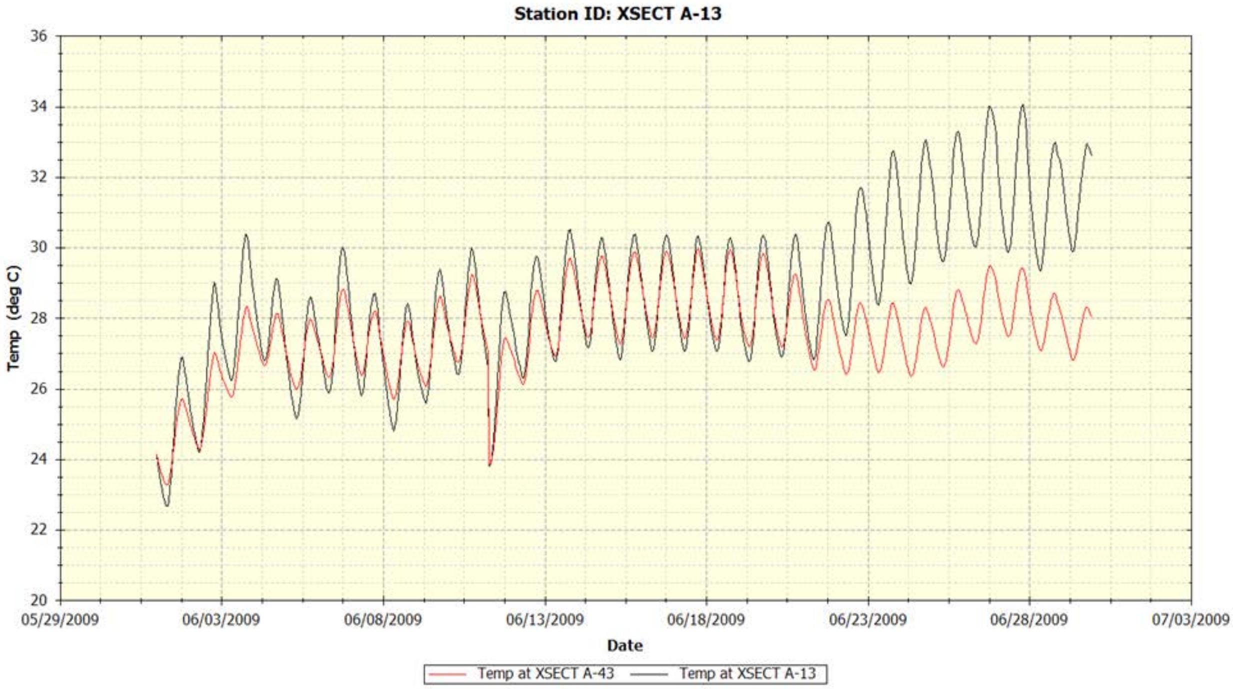

Figure 23 - Run D - Temperature results

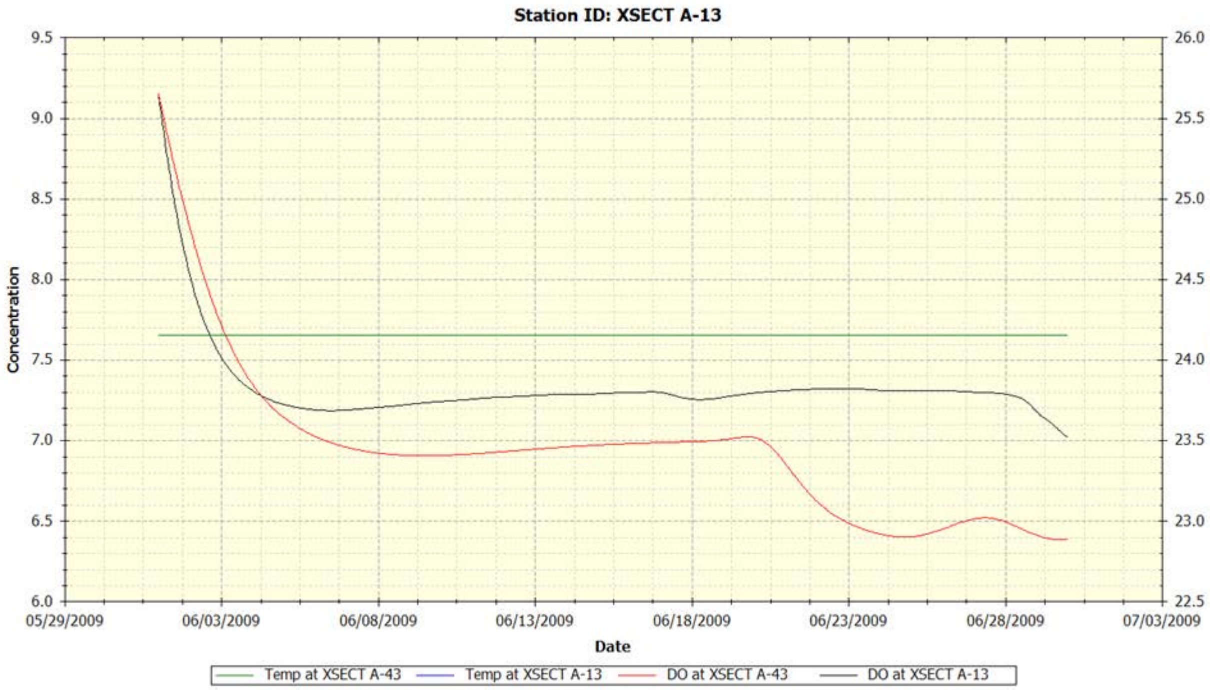

Figure 24 - Run D - DO results

5 Summary

The EPD-RIV1 model was used to simulate water flow and quality conditions in the Brazos River between Waco, TX and Fort Bend County, TX. The model developed for this project is an extension to a model developed under a previous project (EC 2011).

For all conditions simulated, the model predicted that DO and temperature conditions in the Brazos River would satisfy Tier 1 primary priority instream flow water quality goals. For a very low flow at Hempstead, lower than subsistence level flows applicable to that location, predicted DO drops below the Tier 2 secondary instream flow water quality goal.

Based upon available topography data (DEM data), channel stream lines and assumed in-channel geometry, this model is preliminary and should be updated when additional in-channel geometry data becomes available.

6 References

[EC] Espey Consultants. 2011. Brazos River Instream Flow Program Instream Flow Water Quality Evaluation, Volume 1 – Brazos River downstream of Waco, TX. Submitted to Brazos River Authority and Texas Commission on Environmental Quality, October 8, 2012.

Water Quality Model of the Middle Brazos River, below Waco to Fort Bend County

Instream Flow Water Quality Model Operation Instructions

- Install EPD Riv1 version 1.2
- Install WRDP version 6.0

- Open the EPD Riv 1 program
- Open the *.prj project definition file (each subdirectory [e.g., "RunA_Lowflow_510"] contains its own prj file)
- Allow the model to change file paths to the current path (first time to open only)
- Run hydrodynamics
- Run water quality

- Open the WRDB program
- Click the DATA button to open the *-H.bmd file to plot hydraulic outputs
- Click the DATA button to open the *-Q.bmd file to plot water quality outputs