Blackstone River WLA and Qual2K Model

The second design project for CEE 577 is a Wasteload Allocation (WLA) and Qual2K model Study for the Blackstone River in central MA and RI. Please work in groups of 3. You may choose to keep your team from the first design problem. I'll ask you to show graphical data and discuss in class various sub-sections of the assignment as they are completed. These will be used by your group in the final report.

Problem Statement

The Blackstone River originates in the Worcester hills in central Massachusetts, and flows southeasterly into Rhode Island, discharging eventually into Narragansett Bay. Like many major waterways in the New England region, the water and sediment quality of the Blackstone River watershed was historically impaired by intense industrial development and urbanization, resulting in the discharge of untreated industrial and domestic wastes. The presence of numerous dams along the river, with at one point as many as one dam for every one mile of river, significantly impacted the fate and transport of these historical contaminants. The river continues to be plagued today by contaminated sediments trapped upstream of these impoundments.

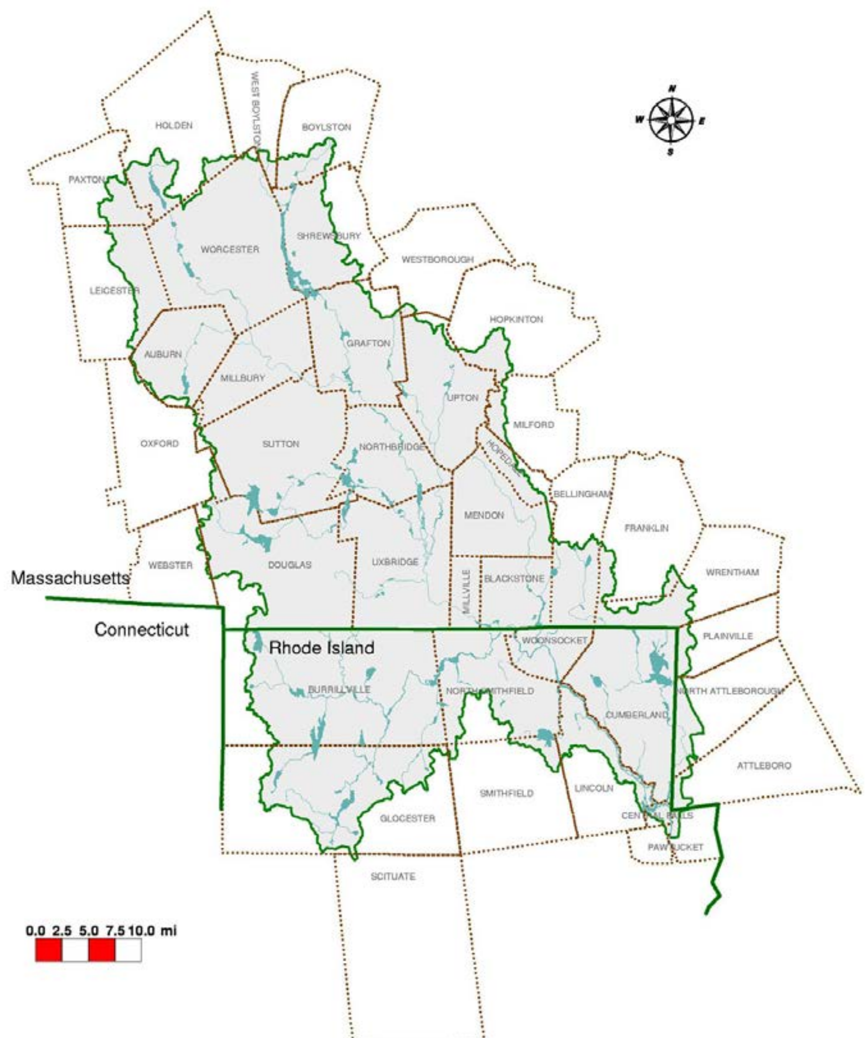
Significant improvements in the overall water quality of the Blackstone River have been made in the past 30 years as a result of the Clean Water Act and the other pollution reduction initiatives. Despite this, the entire mainstem Blackstone River in the Massachusetts portion of the basin is impaired (defined as partial support and non-support) with respect to aquatic life and primary/secondary use attainment (MADEP 2002 303(d) List). Additionally, segments of the Blackstone River in Rhode Island fail to meet that state's water quality standards. According to the 2002 303(d) List of Impaired Waters prepared by the Rhode Island Department of Environmental Management (RIDEM), causes of impairment include biodiversity, excess algal growth, lead and copper, low dissolved oxygen concentrations, and pathogens.

Background

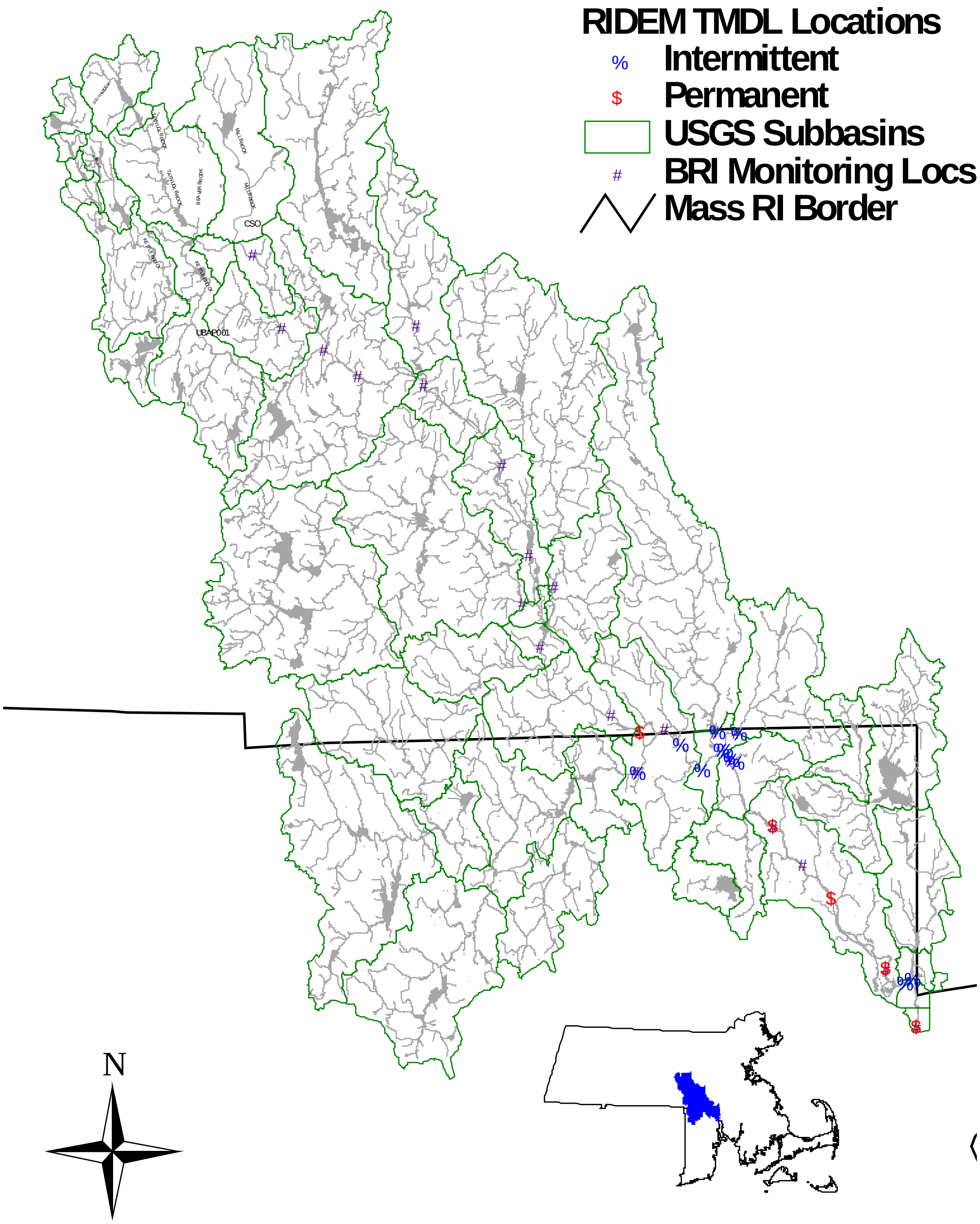
The Blackstone River watershed encompasses an area of approximately 475 square miles in Rhode Island and Massachusetts, as typically defined by the U.S. Geological Survey (USGS); it should be noted that the exact drainage basin area depends upon the watershed delineation point, and therefore varies somewhat between organizations. Some twenty-nine communities in central Massachusetts and northern Rhode Island are contained within the watershed. The Blackstone River is formed by the confluence of the Middle River and Mill Brook in Worcester, Massachusetts. From there, the River flows approximately 48 miles south into Rhode Island where it becomes the Pawtucket River at the Main Street Dam in Pawtucket, Rhode Island. For the purposes of this

Blackstone River Watershed Assessment Study, the primary focus of the program will be defined as the watershed area upstream of this dam. The Pawtucket River flows to the Seekonk River and then to the Providence River, which eventually empties into the Narragansett Bay.

The mainstem Blackstone River is joined by six major rivers- the Quinsigamond River, the Mumford River, the West River, the Mill River, the Peters River, and the Branch River- in addition to many smaller tributaries. The watershed consists of over 1300 acres of lakes and ponds including the largest, Lake Quinsigamond. Several reservoirs in the northwest portion of the basin are used along with out-of-basin sources for the City of Worcester, Massachusetts water supply.



We will be modeling a portion of the Blackstone watershed starting 1.2 miles upstream of of the Upper Blackstone Water Pollution Abatement District's (UBWPAD) outfall to a mile below the USGS gaging station in Millville. This covers 27.6 miles (44.4 km) of the Blackstone mainstem. Within this reach there are 5 wastewater treatment plant discharges and 3 major rivers flowing into the Blackstone.



Project Guidance

1. Preliminary modeling

1.A. Download and Run Qual2K

1. Visit the Tufts website and download the Qual2K zip file. Un-zip the package.
   http://qual2k.com/

2. Create a sub-directory called "DataFiles" within the directory that contains Qual2K on your computer.

3. Launch the main Qual2K excel file, named "Q2KMasterv2_12b1" or something close to this.
   a. Enable macros, if this feature is disabled on Excel.
   b. Change the directory path in the first worksheet, cell 10B, so that it points to your newly created "DataFiles" subdirectory.

4. Run a test and examine the results
   a. Click on the "Run Fortran" button. The program comes pre-loaded with an example input file. At this point a DOS window should appear. It will show that the program is running, passing through multiple iterations and it should finish in a matter of a few seconds to a minute. It gives you a Q2K Fortran alert that the program has finished. If you get to this point, you can probably conclude that the installation was successful.
   b. Click "OK", then a screen appears offering you some plot options. You can just click OK to the first option. It will allow you to view the excel file that now contains several dozen plots of the model output (pink tabs). You should look through these just to become familiar with the types of output Qual2K normally gives you.

1.B. Streeter-Phelps Model and simplified WLA

1. Prepare a highly simplified model using the analytical solution to the extended Streeter-Phelps (SP) equation. Divide the Blackstone mainstem into two reaches, one from UBWPAD outfall at MP 44.6 (71.8 Km) to the outfall of the Millbury WWTP at MP 40.8 (65.66 Km). The second reach should flow from this point downstream until the recovery zone is reached (where DO has reached its minimum and starts to rise again). Note that we are using the MP designations as adopted by the Blackstone River Initiative, which differ by as much as 4 miles from some earlier MA DEP designations. Don't be stingy with your element lengths. You should probably use river length increments of 0.3 mile (0.5 km) or shorter so as not to lose important spatial resolution.

2. <u>Conduct WLA based on Simplified Method</u>[1]: For this you should use the design conditions (flow, temperature). The design flow is the usual 7Q10 approach as determined by MA DEP in 1983 (see table below). For the design temperature, we will use 20°C for simplicity. For other key rates or parameters (e.g., CBOD oxidation rate; ammonia nitrification rate), please use the recommended levels from the *"Simplified Method for Waste Load Allocations"*. For this purpose, assume the Blackstone has an entirely rocky bottom.

   The initial testing and WLA will require that you consider at least two loading scenarios from the UBWPAD: (1) assume it to be a secondary treatment plant with effluent quality typical of a conventional activated sludge plant, (2) use expected effluent quality based on values from the *"Simplified Method for Waste Load Allocations"*. Instead of using all the procedures from the simplified method as written, I'd like you to depart from them in at least two ways. First, for both wastewater sources assume a 20°C bottle constant of 0.2 d^{-1}. Second, use the Covar approach for selecting reaeration coefficients. Also, please ignore any SOD for the purposes of this first assessment.

Table 1. UBWPAD Effluent Characteristics

Parameter	Scenario #1	Scenario #2	Units
Flow	1.087	1.087	m^3/s
	38.386	38.386	Cfs
$CBOD_5$	30	Variable	mg/L
Ammonia-N	10	Variable	mg/L
Dissolved Oxygen	6	6	mg/L

Table 2. Millbury WWTP Effluent Characteristics

Parameter	Scenario #1	Scenario #2	Units
Flow	0.01933	0.01933	m^3/s
	0.598	0.598	cfs
$CBOD_5$	30	Variable	mg/L
Ammonia-N	10	Variable	mg/L
Dissolved Oxygen	6	6	mg/L

Table 3. Headwater parameters for the 7Q10 conditions

[1] Note that the UBWPAD design flow is larger than should be used with this method based on EPA criteria. However, for the purpose of this exercise, we will use it.

Parameter	Value	Units
Upstream Flow (above UBWPAD)	0.2226	m^3/s
	7.86	cfs
CBODult	0.89	mg/L
Ammonia-N	0	
Dissolved Oxygen	7.08	mg/L

Table 4. Simple Model: First segment Parameters (71.78 km -65.66 km)

Parameter	Value	Units
Depth	1.219	m
	4	ft
Velocity	0.1568	m/s
	0.5146	ft/s
DO saturation	8.95	mg/L

Table 5. Simple Model: Second segment Parameters (65.66 km – 29.29 km)

Parameter	Value	Units
Depth	0.610	m
	2	ft
Velocity	0.271	m/s
	0.889	ft/s
DO saturation	8.95	mg/L

This section of the Blackstone River is designated as a warm water fishery. As such the ambient water quality standard is 5mg/L for dissolved oxygen and 0.006 mg/L for unionized ammonia.

1. C. Qual2K evaluation

1. Use QUAL2K (Q2K) to run the same model as above. This is intended as a test of both the streeter-phelps (SP) calculations, and the QUAL2K model code itself. You'll need to scale the computer model down to the steady-state SP basics. To help with this, I've prepared a"Blackstone simple" file for this initial evaluation. This file has been posted on the dp#2 area on the course website and can be downloaded in a zip format. This file differs substantially from the input file provided with Q2K. A few points to note:
   - Hourly input variables are all the same so that time variable responses are suppressed
   - Air temperatures are elevated to force Q2K to keep the water temperature at 20°C (to counter evaporative heat loss (?) that I can't seem to turn off)

- The dependence of CBOD deoxygenation rate on the dissolved oxygen level must be suppressed. There are many ways to do this. The approach I used was to select the “exponential” model (blue “rates” tab) and set K_{socf} to a very large number (1000 L/mg-O_2).
- CBOD loading and rate parameters should be applied to the “Fast CBOD” and not the “Slow CBOD”. The latter is a new feature to Q2K which allows for CBOD that must first undergo a slow hydrolysis step prior to oxidation.
- Use the Covar approach for selecting reareation coefficients. In Q2K, this requres that you select “Internal” under the heading “Oxygen: reaeration model” in the blue “rates” worksheet.

At the very least, you’ll need to enter the point source effluent concentrations in the blue “point sources” worksheet. You may run into problems if your DO level gets too low. Q2K always shuts its biological processes (especially nitrification) down when the DO starts to become limiting, but SP doesn’t. So, to avoid this you might need to reduce your CBOD or NBOD loads so that the DO never drops below 2 or 3 mg/L.

2. Verify that the two models (SP and Q2K) give identical results. To do this, you should prepare a set of 4 graphs showing (a) travel time, (b) CBOD, (c) ammonia nitrogen, and (d) dissolved oxygen versus river kilometer. The x-axis should run from the high kilometer point (KP) to low KP, so that you move downstream from left to right. Plot predictions from both models on the same graph for each. Do this in a way that makes comparison easy. For example, I plotted the SP results using black open circles and the Q2K in simple straight red line segments. When I got it to work properly, the red lines essentially bisected the black circles.

2. Full model implementation

2. A. Setup Input File

1. Download and open the full model file called “Blackstone 577 dp2”. This has been set up with the 15 reaches used by BRI in their Q2E code as well as 4 major dams which must be now incorporated as separate reaches in the Q2K program.
2. Determine Rating Curves based on the 1980 survey (see June, August & October data, Table 6 below) for the first 5 regular reaches (#1, 2, 3, 4, and 6). In the BRI project, rating curves for MA reaches were based on these older data, and RI reaches were determined by URI in a later study.
3. Run model making sure that there are no errors and that the output looks plausible

Table 6. Data For Establishing Rating Curves

CEE 577		15-Oct-80			10-Jun-80			5-Aug-80		
Reach #	station#	Q (cfs)	H (ft)	t (hr)	Q (cfs)	H (ft)	t (hr)	Q (cfs)	H (ft)	t (hr)
1	10	57.98	1.3	1.64	106.54	1.5	1.21	90.27	1.4	1.31
2	11	62.01	1.2	5.33	109.08	1.4	4.29	91.86	1.3	4.56
3		68.72	2.6		113.24	3		94.51	2.8	
4	12	72.9	4	12.22	115.73	4	10.15	96.75	4	10.79
6	13A	80.39	2	15.26	120.74	2.4	12.79	99.71	2.2	13.61

Table 7. Accompanying Information on Location Descriptions and Reach Numbers

CEE 577	2001 BRI designation				
Reach #	R #	upstream description	downstream description	RM - up	RM - down
1	1	Millbury St. Worcester	McCracken Rd, Millbury	48.5	44.0
2	2	McCracken Rd, Millbury	Riverlin St., Millbury	44.0	41.4
3	3	Riverlin St., Millbury	Millbury WWTP	41.4	40.8
4	4	Millbury WWTP	Singing Dam, Blackstone St., Sutton	40.8	39.8
6	5	Singing Dam, Blackstone St., Sutton	Pleasant St., Grafton	39.8	38.2

Table 8. Point Source Input Data for July 1991 Sampling Date (part 1)

#	Description	location (mile)	location (km)	discharge (ft3/s)	dischage (m3/s)	Diss. O2 (mg/L)	BOD (mg/L)	Cons1 Chloride (mg/L)
1	UBWPAD	44.6	71.78	38.4	1.0874	6	2	91.2
2	Milbury WWTP	40.8	65.66	0.598	0.0169	6	44	282
3	Quinsigamond River	36.6	58.90	8.95	0.2534	6.33	0.5	68.13
4	Grafton WWTP	35.4	56.97	1.64	0.0464	6	9	102
5	Northbridge WWTP	29.2	46.99	1.78	0.0504	6	6.2	45
6	Mumford River	25.6	41.20	13.15	0.3724	8.08	0.63	20
7	West River	24.4	39.27	7.18	0.2033	6.59	0.63	43
8	Uxbridge WWTP	22	35.41	3.875	0.1097	6	5	102

Table 8. Point Source Input Data for July 1991 Sampling Date (part 2)

#	Description	Chl-A (ug/L)	Org-N (mg/L)	Org-N (ug/L)	NH3-N (mg/L)	NH3-N (ug/L)	NO3-N (mg/L)	NO3-N (ug/L)	Diss-P (mg/L)	Diss-P (ug/L)
1	UBWPAD	0	0.75	750	0.44	440	5.4	5400	0.9	900
2	Milbury WWTP	0	0	0	21	21000	3	3000	4.13	4130
3	Quinsigamond River	1.5	0.514	514	0.07	70	0.14	140	0.07	70
4	Grafton WWTP	0	0	0	2	2000	3	3000	4.3	4300
5	Northbridge WWTP	0	0	0	5.97	5970	3	3000	2.3	2300
6	Mumford River	1.2	0.436	436	0.05	50	0.15	150	0.16	160
7	West River	1.45	0.466	466	0.04	40	0.1	100	0.01	10
8	Uxbridge WWTP	0	0	0	0.23	230	3	3000	3.67	3670

2. B. Test Against WLA Scenarios

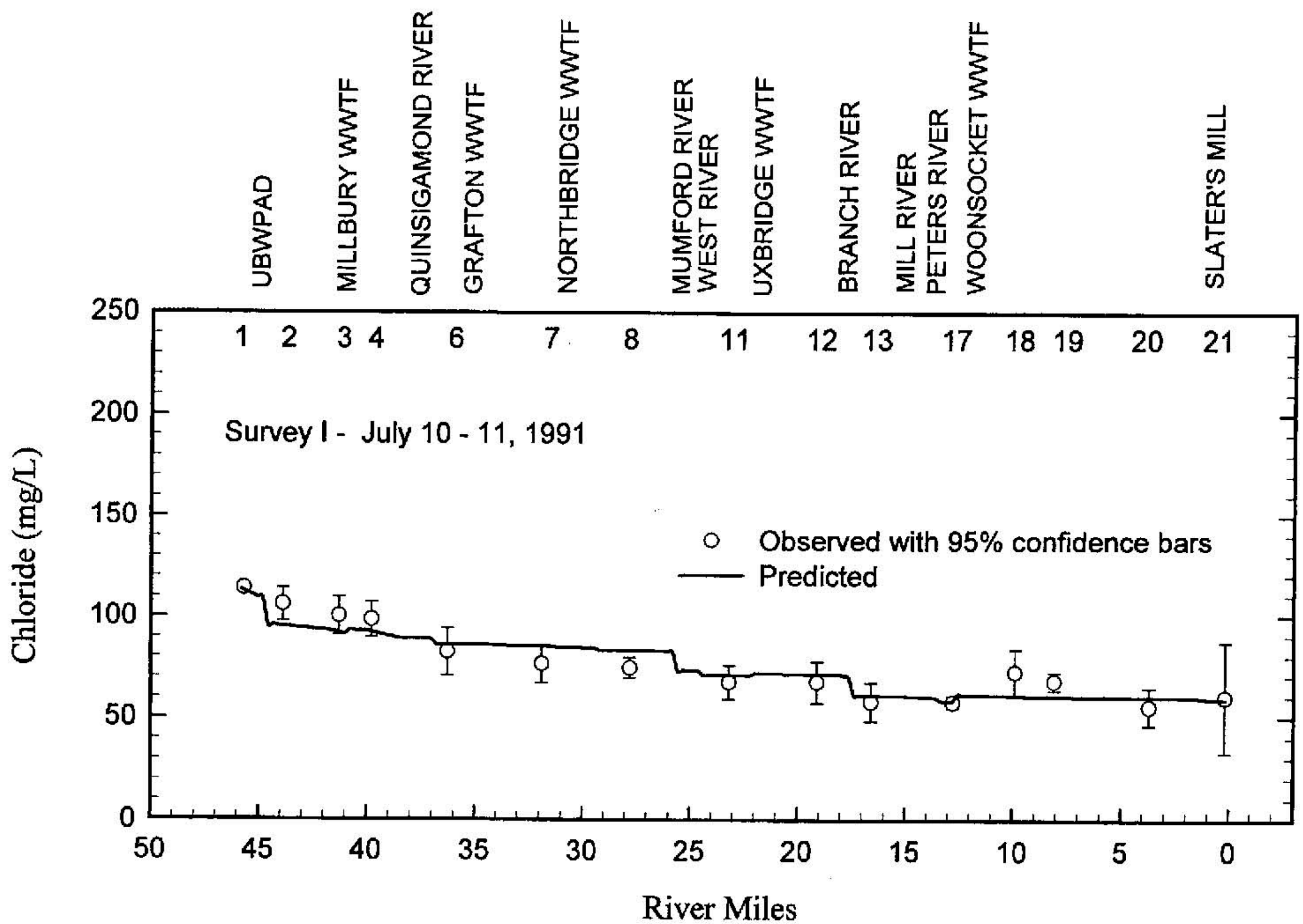
1. Run the Model for the minimum level of treatment allowable for the UBWPAD discharge based on the ammonia criteria from your prior calculation
2. Examine possible DO non-compliance downstream, paying special attention to the impoundments
3. Propose solutions to any non-compliance including reductions in loads and removal of dams
4. Show your results and conclusions in the form of a graphical display of DO and BOD concentrations versus river KM.

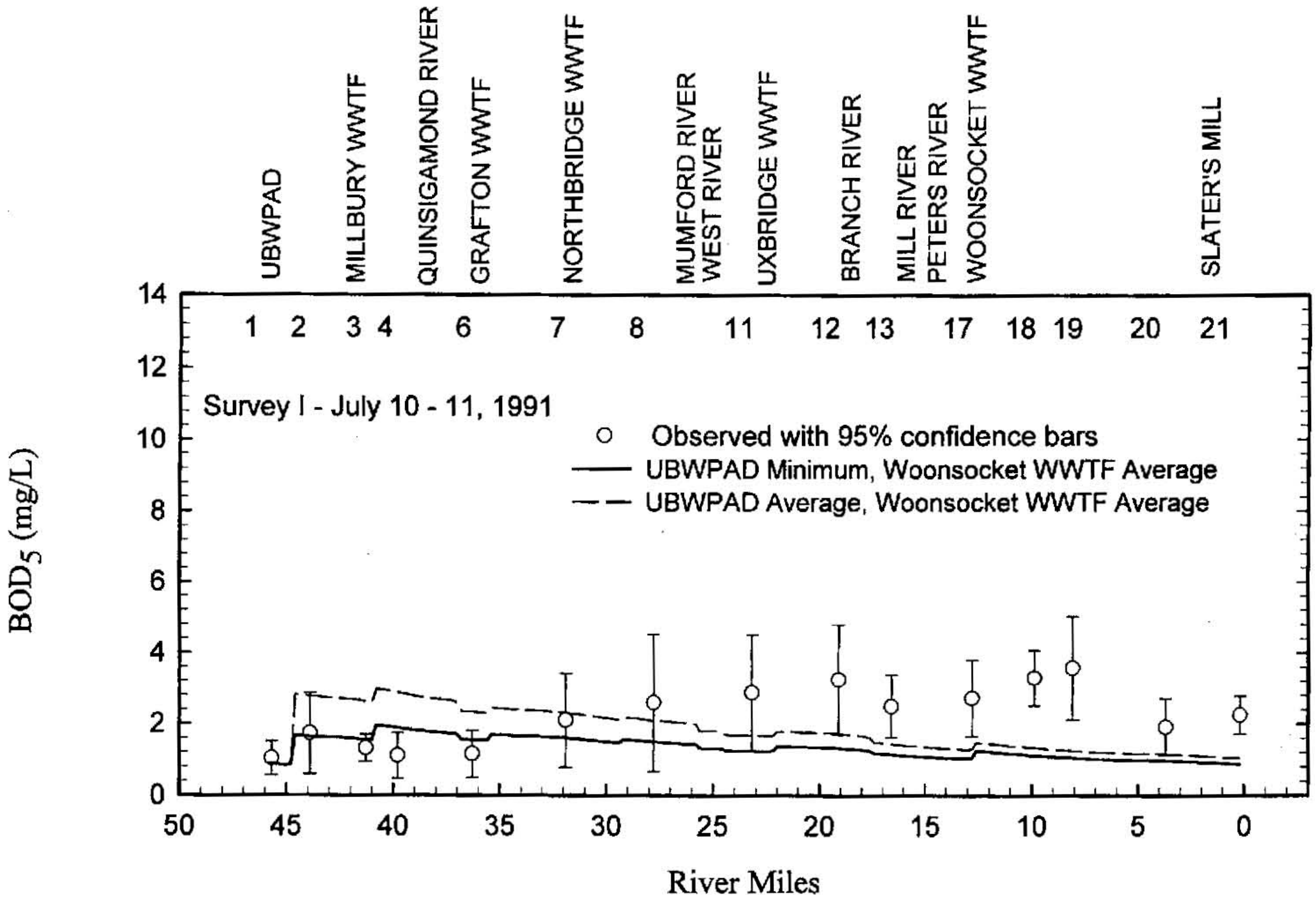
2. C. Test Model Against July 1991 Data & Sensitivity Analysis

1. Run the Model for the July 1991 Conditions and Compare with actual measurements. The observed in-stream values have been added to the input file. They are also reproduced in Tables 8-11 below, for your convenience. The attached figures show the BRI model results using Qual2E vs in-stream measurements.
2. Does your model match the actual data as well as BRI's did? If not, what would you do to improve prediction?
3. Pick one important model parameter (e.g,. reaeration coefficient) and perform a sensitivity analysis to see its overall impact on the model predictions. In doing this you will want to increase and decrease the value (but keep it within the plausible range) and run model simulations to see the effect. Present the results graphically. What is your conclusion on the importance of this variable? Should it be studied further before imposing new effluent or non-point source controls?

3. Schedule:

Task	Deliverable	Date
1.A. Download & Run Program	Discuss in class	Nov 29
1.B. WLA with S-P	Discuss in class	Dec 1
1.C. Q2K evaluation	Show graphs in class	Dec 6
2.A. Full Model Setup	Show rating curves in class	Dec 8
2.B. Test against WLA Scenarios	Discuss required treatment levels in class	Dec 11
2.C. Test against Data & Sensitivity	Show graphs of sensitivity analysis in class	N/A
Final Report	Hand in group reports	Dec 22


UBWPAD
MILLBURY WWTF
QUINSIGAMOND RIVER
GRAFTON WWTF
NORTHBRIDGE WWTF
MUMFORD RIVER
WEST RIVER
UXBRIDGE WWTF
BRANCH RIVER
MILL RIVER
PETERS RIVER
WOONSOCKET WWTF
SLATER'S MILL
1 2 3 4 6 7 8 11 12 13 17 18 19 20 21
Survey I - July 10 - 11, 1991
Observed with 95% confidence bars
Predicted
Chloride (mg/L)
250
200
150
100
50
0
50 45 40 35 30 25 20 15 10 5 0
River Miles


UBWPAD
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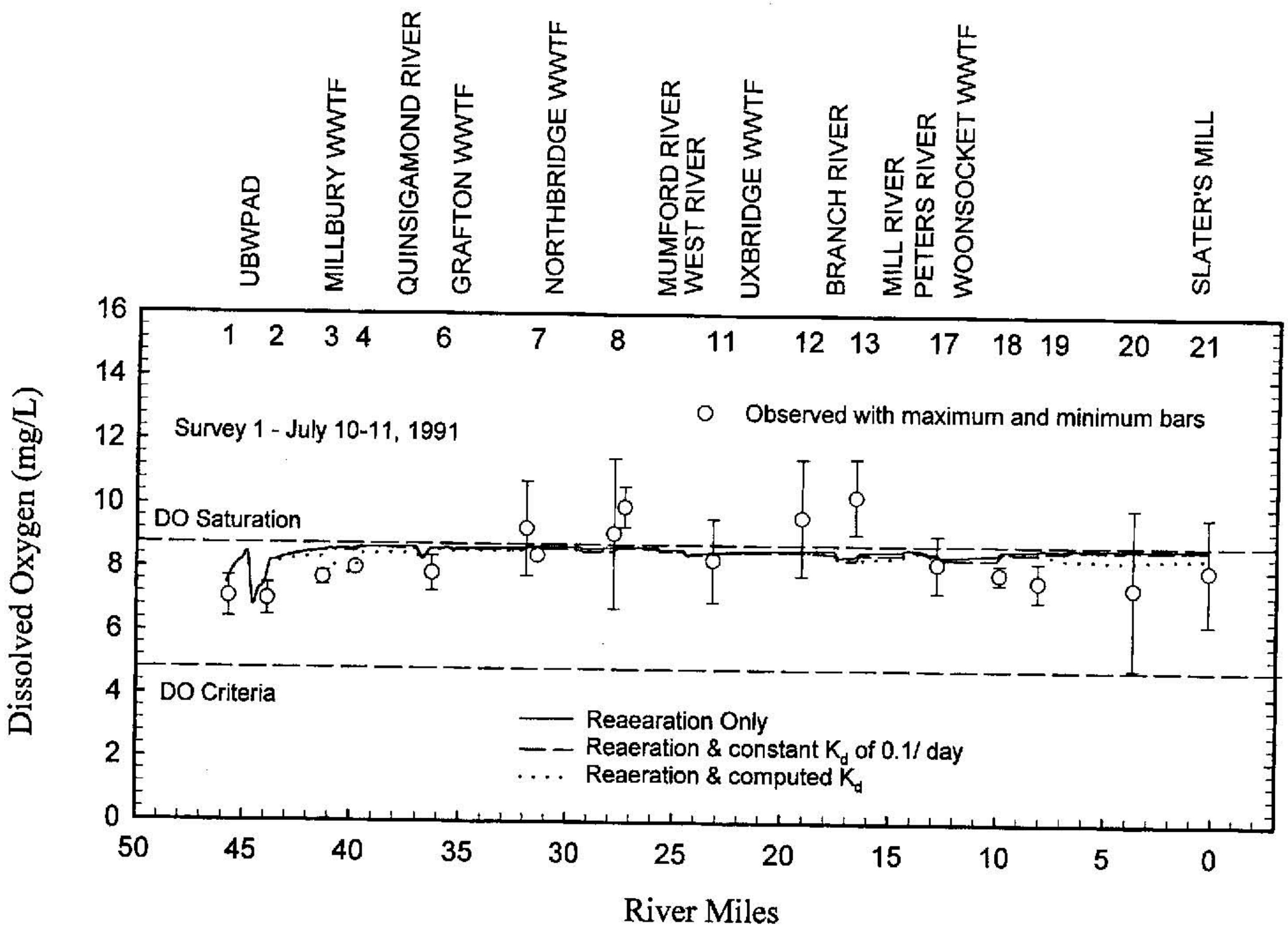
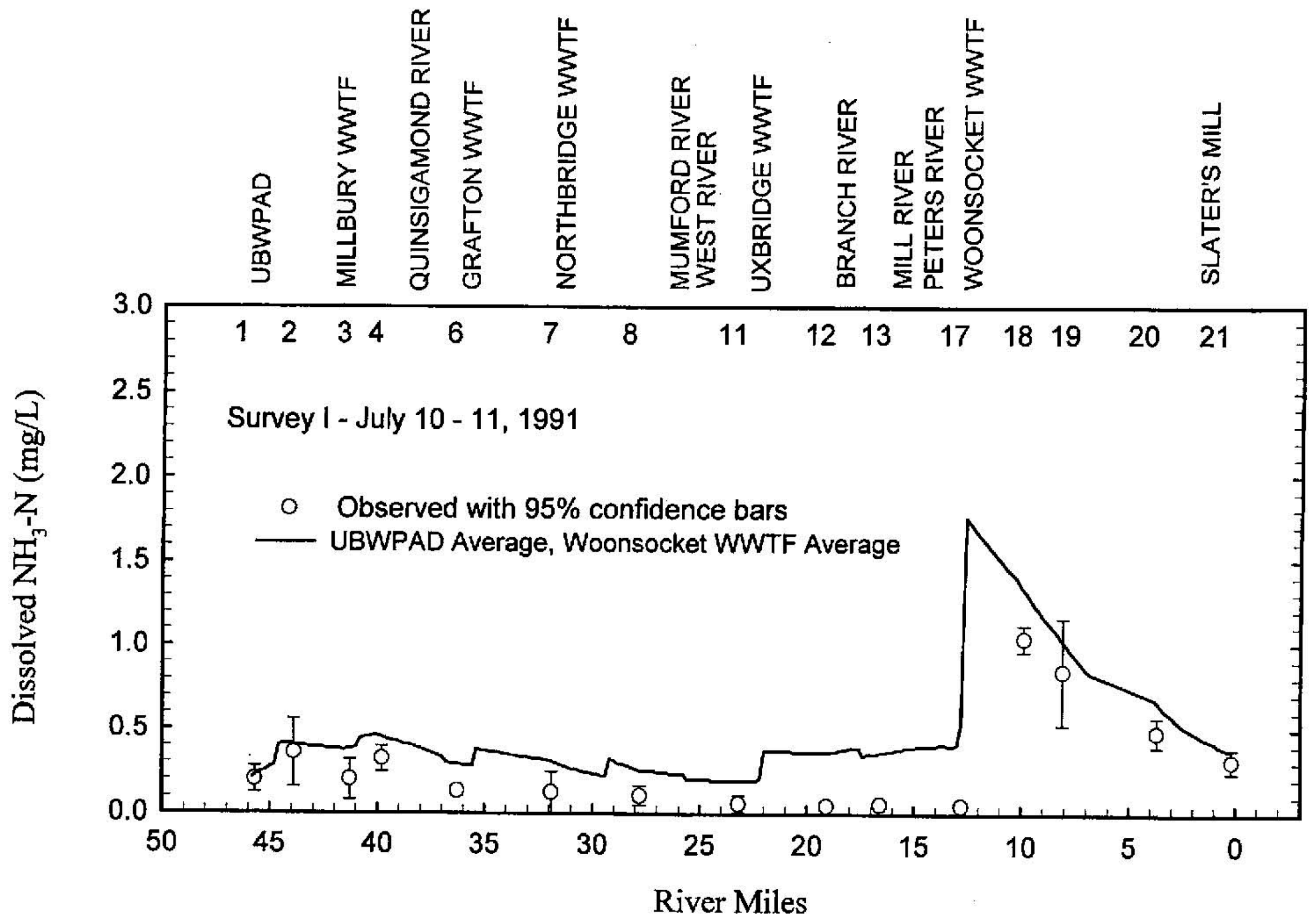
QUINSIGAMOND RIVER
GRAFTON WWTF
NORTHBRIDGE WWTF
MUMFORD RIVER
WEST RIVER
UXBRIDGE WWTF
BRANCH RIVER
MILL RIVER
PETERS RIVER
WOONSOCKET WWTF
SLATER'S MILL
1 2 3 4 6 7 8 11 12 13 17 18 19 20 21
Survey I - July 10 - 11, 1991
Observed with 95% confidence bars
UBWPAD Minimum, Woonsocket WWTF Average
UBWPAD Average, Woonsocket WWTF Average
BOD5 (mg/L)
0
2
4
6
8
10
12
14
50
45
40
35
30
25
20
15
10
5
0
River Miles


UBWPAD
MILLBURY WWTF
QUINSIGAMOND RIVER
GRAFTON WWTF
NORTHBRIDGE WWTF
MUMFORD RIVER
WEST RIVER
UXBRIDGE WWTF
BRANCH RIVER
MILL RIVER
PETERS RIVER
WOONSOCKET WWTF
SLATER'S MILL
1 2 3 4 6 7 8 11 12 13 17 18 19 20 21
Survey 1 - July 10-11, 1991
Observed with maximum and minimum bars
DO Saturation
DO Criteria
Reaearation Only
Reaeration & constant K_d of 0.1/ day
Reaeration & computed K_d
Dissolved Oxygen (mg/L)
River Miles
16
14
12
10
8
6
4
2
0
50 45 40 35 30 25 20 15 10 5 0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QUINSIGAMOND RIVER
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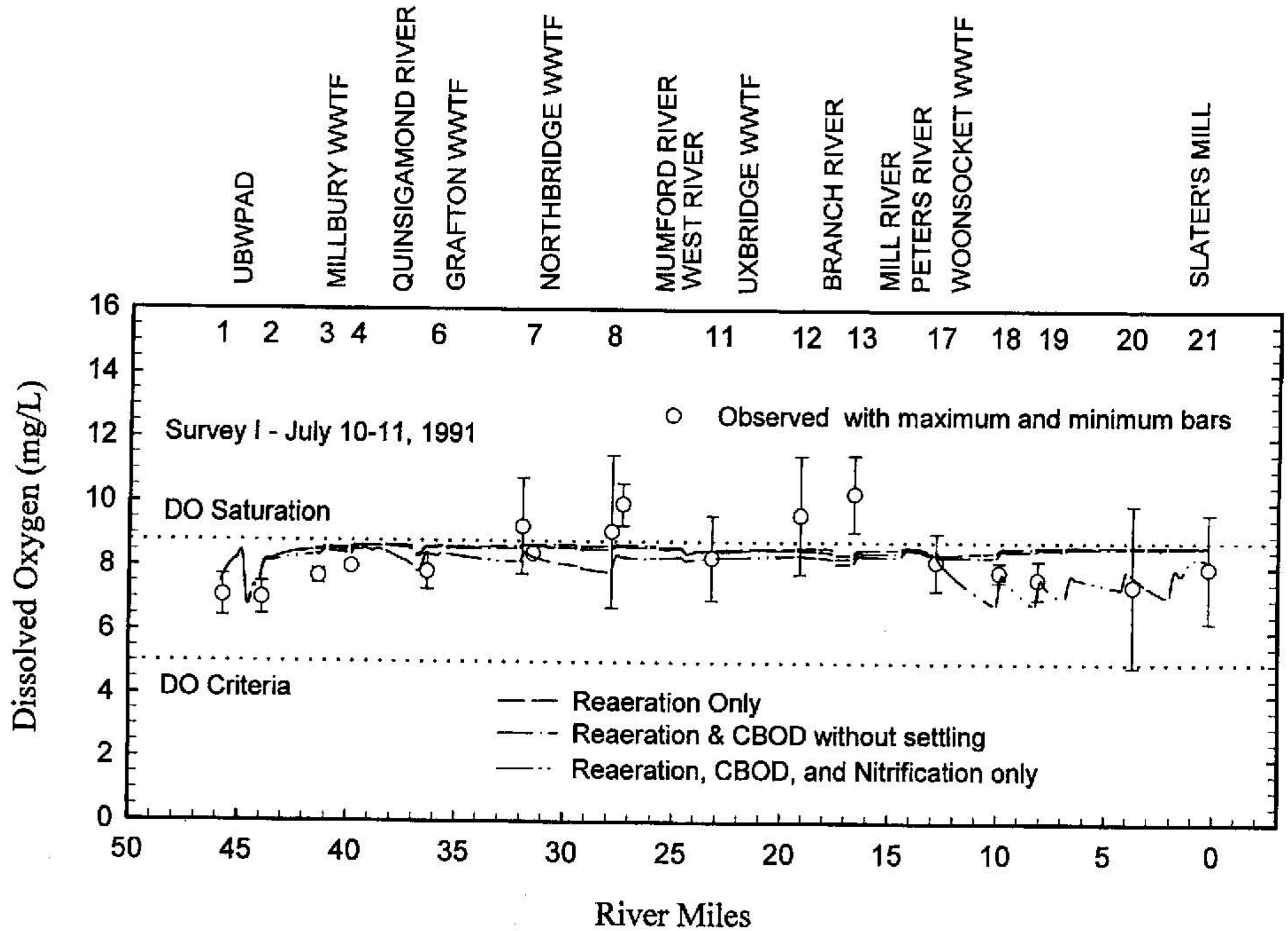
NORTHBRIDGE WWTF
MUMFORD RIVER
WEST RIVER
UXBRIDGE WWTF
BRANCH RIVER
MILL RIVER
PETERS RIVER
WOONSOCKET WWTF
SLATER'S MILL
1 2 3 4 6 7 8 11 12 13 17 18 19 20 21
Survey I - July 10 - 11, 1991
Observed with 95% confidence bars
UBWPAD Average, Woonsocket WWTF Average
Dissolved NH3-N (mg/L)
3.0
2.5
2.0
1.5
1.0
0.5
0.0
50 45 40 35 30 25 20 15 10 5 0
River Miles


UBWPAD
MILLBURY WWTF
QUINSIGAMOND RIVER
GRAFTON WWTF
NORTHBRIDGE WWTF
MUMFORD RIVER
WEST RIVER
UXBRIDGE WWTF
BRANCH RIVER
MILL RIVER
PETERS RIVER
WOONSOCKET WWTF
SLATER'S MILL
1 2 3 4 6 7 8 11 12 13 17 18 19 20 21
Survey I - July 10-11, 1991
Observed with maximum and minimum bars
DO Saturation
DO Criteria
Reaeration Only
Reaeration & CBOD without settling
Reaeration, CBOD, and Nitrification only
Dissolved Oxygen (mg/L)
River Miles
16 14 12 10 8 6 4 2 0
50 45 40 35 30 25 20 15 10 5 0

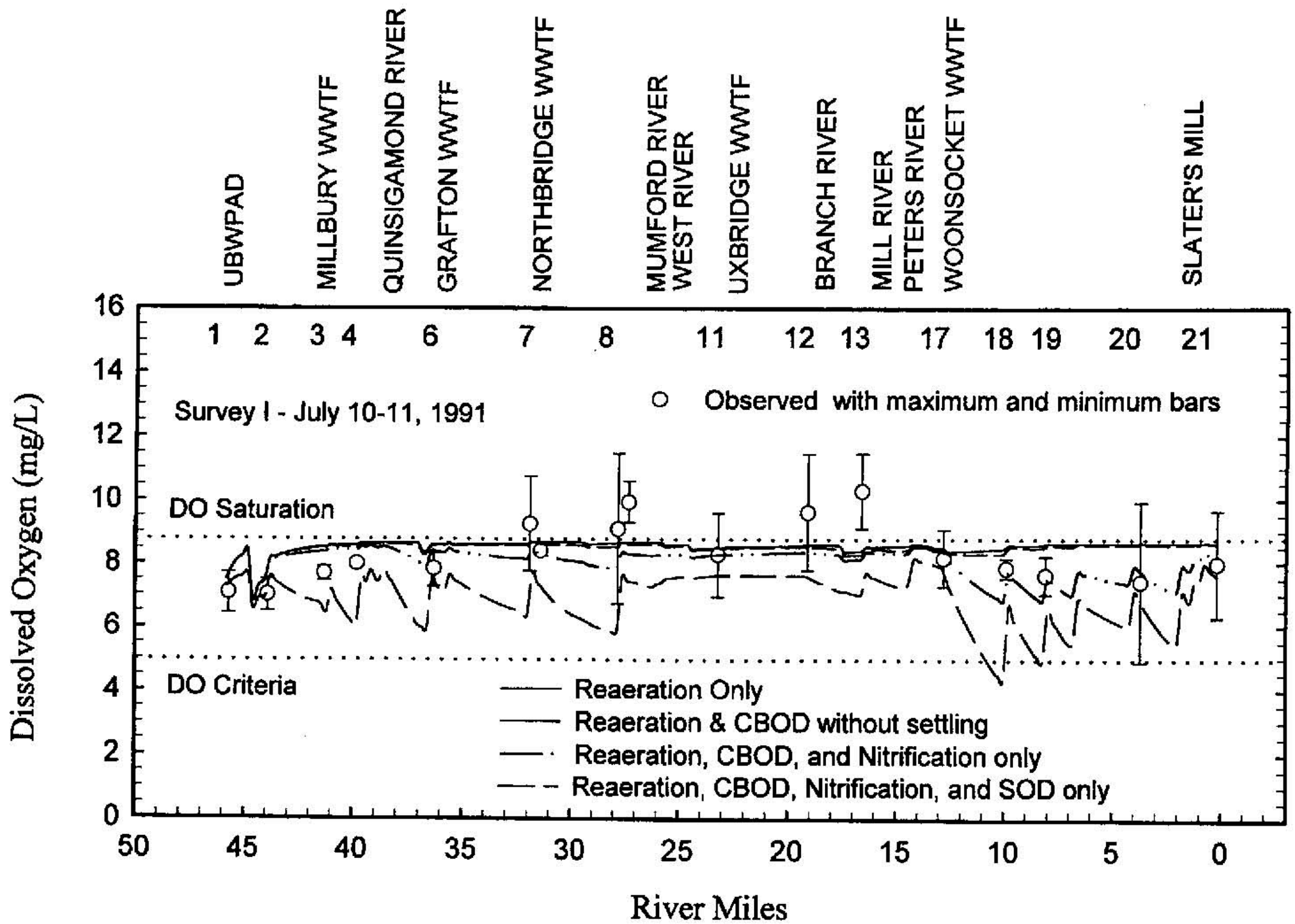

UBWPAD
MILLBURY WWTF
QUINSIGAMOND RIVER
GRAFTON WWTF
NORTHBRIDGE WWTF
MUMFORD RIVER
WEST RIVER
UXBRIDGE WWTF
BRANCH RIVER
MILL RIVER
PETERS RIVER
WOONSOCKET WWTF
SLATER'S MILL
1 2 3 4 6 7 8 11 12 13 17 18 19 20 21
Survey I - July 10-11, 1991
Observed with maximum and minimum bars
DO Saturation
DO Criteria
Reaeration Only
Reaeration & CBOD without settling
Reaeration, CBOD, and Nitrification only
Reaeration, CBOD, Nitrification, and SOD only
Dissolved Oxygen (mg/L)
River Miles
0
2
4
6
8
10
12
14
16
50
45
40
35
30
25
20
15
10
5
0

Table 8: BOD Data from the July 10-11, 1991 Survey of the Blackstone River

Station #	MP	KP	BOD5 (mg/L)						
			Obs#1	Obs#2	Obs#3	Obs#4	**Average**	low bar	high bar
1	45.8	73.7	0.75	0.75	1.2	1.4	**1.03**	0.53	1.52
2	44	70.8	1	1.3	2	2.6	**1.73**	0.65	2.80
3	41.4	66.6	1.7	1.2	1.1	1.3	**1.33**	0.93	1.72
4	39.8	64.1	0.75	0.75	1.6	1.4	**1.13**	0.46	1.79
6	36.4	58.6	0.75	0.75	1.6	1.4	**1.13**	0.46	1.79
7	32	51.5	1.2	1.7	3.1	2.4	**2.10**	0.86	3.34
8	28	45.1	1.6	2.6	4.3	2	**2.63**	0.84	4.41
11	23.2	37.3	1.5	2.9	3.8	3.4	**2.90**	1.40	4.40
12	19.2	30.9	1.9	3.5	4.3	3.4	**3.28**	1.77	4.78

Table 9: Chloride Data from the July 10-11, 1991 Survey of the Blackstone River

Station #	MP	KP	Chloride (mg/L)						
			Obs#1	Obs#2	Obs#3	Obs#4	**Average**	low bar	high bar
1	45.8	73.7	114	114	114	148	**122.5**	97.0	148.0
2	44	70.8	109	109	NS	100	**106.0**	97.0	115.0
3	41.4	66.6	104	105	92	100	**100.3**	91.4	109.1
4	39.8	64.1	97	105	92	100	**98.5**	90.3	106.7
6	36.4	58.6	82	82	74	92	**82.5**	71.4	93.6
7	32	51.5	78	82	68	78	**76.5**	67.5	85.5
8	28	45.1	75	79	71	74	**74.8**	69.8	79.7
11	23.2	37.3	67	75	63	65	**67.5**	59.6	75.4
12	19.2	30.9	70	75	60	65	**67.5**	57.8	77.2

Table 10: Ammonia Data from the July 10-11, 1991 Survey of the Blackstone River

Station #	MP	KP	Ammonia (μg/L)						
			Obs#1	Obs#2	Obs#3	Obs#4	**average**	low bar	high bar
1	45.8	73.7	140	170	240	240	197.5	121.6	273.4
2	44	70.8	480	260	240	450	357.5	170.0	545.0
3	41.4	66.6	290	210	110	180	197.5	85.7	309.3
4	39.8	64.1	380	290	280	330	320	251.8	388.2
6	36.4	58.6	120	130	120	160	132.5	104.1	160.9
7	32	51.5	210	160	50	80	125	15.1	234.9
8	28	45.1	120	50	140	110	105	46.9	163.1
11	23.2	37.3	60	60	100	20	60	11.0	109.0
12	19.2	30.9	40	50	50	60	50	37.8	62.2

Table 11: Dissolved Oxygen Data from the July 10-11, 1991 Survey of the Blackstone River

Station #	MP	KP	Dissolved Oxygen (mg/L)										
			4 hr	10 hr	16 hr	22 hr	28 hr	34 hr	40 hr	46 hr	**average**	low bar	high bar
1	45.8	73.7	6.4	7.7	7.8	6.4	6.4	7.1	8.4	6.5	**7.08**	6.29	7.86
2	44	70.8	6.2	7.2	7.2	6.3	6.7	7.2	8.1	6.6	**6.94**	6.33	7.54
3	41.4	66.6	7.5	7.8	8.0	7.3	7.2	7.9	7.8	7.4	**7.61**	7.33	7.89
4	39.8	64.1	8.0	8.0	7.9	7.8	7.7	7.9	7.8	8.0	**7.87**	7.76	7.98
6	36.4	58.6	7.0	8.3	8.4	7.2	7.0	8.0	8.6	7.2	**7.72**	7.05	8.40
7	32	51.5	7.3	7.6	10.0	9.2	7.9	10.5	12.7	8.7	**9.23**	7.43	11.02
8	28	45.1	6.0	9.8	13.0	6.8	5.9	10.2	12.9	7.9	**9.08**	6.22	11.94
11	23.2	37.3	6.5	9.6	9.5	6.4	6.9	9.5	10.1	7.4	**8.22**	6.63	9.81
12	19.2	30.9	6.8	11.1	11.5	8.0	6.9	11.9	11.8	8.3	**9.56**	7.31	11.80

Tables 8-11 present some important in-stream data from the July 10-11, 1991 survey. These data and a general report on the survey can be found in the MA DEP report, "Blackstone River Initiative: Phase 1, Dry Weather Assessment, Interim Report of Data 1991, Appendices". The upper and lower limits on the error bars (columns labelled "low bar" and "high bar") were calculated as the mean plus and minus three times the standard error of the mean for BOD, chloride and ammonia. For dissolved oxygen I used the mean plus and minus one times the standard deviation of the eight 48-hour measurements.

Table 12: Headwater parameters for the 1991 conditions[2]

Parameter	Value	Units
Upstream Flow (above UBWPAD)	0.388	m^3/s
	13.7	cfs
BOD	0.89	mg/L
Dissolved Oxygen	7.08	mg/L

[2] These are already incorporated in the 577 dp2 input file. They are reproduced here for your information only.