Aroostook River Modeling Report
Final
Sept 2004

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DEPLW-0622

Executive Summary

1. A study of the Aroostook River from Ashland to the USA / Canada border (58 miles) began in the summer of 2001 involving the DEP and a number of stakeholders such as wastewater treatment personnel from Washburn, Presque Isle, McCain Foods, Fort Fairfield, and the Aroostook Band of MicMacs.
2. Two data sets were collected in August of 2001 to calibrate and verify a water quality model. The lack of runoff prior to the survey, presence of low flow conditions (second data set collected at 7Q10 flow), and utilization of good QA/QC measures resulted in excellent quality data to calibrate the water quality model.
3. Dissolved oxygen criteria were met at all Aroostook River and tributary sites with the exception of the three Presque Isle Stream sampling locations. Chlorophyll a results exceeded the algae bloom threshold (8 to 12 ug/l) at some Aroostook River locations from the Caribou dam to Fort Fairfield. For detailed descriptions of the data, one should consult the Aroostook River Data Report (MDEP, May 2002).
4. MDEP's version of the EPA supported model, QUAL2EU; (QUAL2MDEP) was used to model the Aroostook River and two tributaries (Presque Isle Stream and Little Madawaska River). Some important changes to QUAL2EU include the addition of a periphyton module and benthic BOD component, an enhanced dissolved oxygen saturation calculation that adds salinity as a dependent variable, and alteration to phosphorus output units to the nearest 0.1 ppb.
5. The model was calibrated and verified with comparisons of the model output of BOD, phosphorus, nitrogen, chlorophyll-a and dissolved oxygen to the data observed in the summer of 2001. Good comparisons resulted.
6. The model prediction runs at worse case conditions of 10-year low flow, high water temperatures, and point sources inputted at licensed loads predicts that both minimum dissolved oxygen criteria and monthly average dissolved oxygen criteria (6.5 ppm) should be met everywhere on the Aroostook River. Algae blooms are projected to occur in 13 to 23 river miles from Presque Isle to Fort Fairfield.
7. Point sources inputted at licensed conditions account for about 87% and 96% of the total BOD and total phosphorus (TP) loads, respectively, that enter the Aroostook River at 7Q10 flow conditions.
8. Collective point source phosphorus reductions of greater than 50% from current amounts are needed to eliminate algae blooms. The most important sources to reduce are McCain Foods and Presque Isle. Effluent TP treatment that reduces TP concentrations to 0.5 to 1 ppm may be necessary to alleviate bloom conditions.
9. Data taken in the summer of 2002 indicates that the algae also cause pH to exceed the maximum allowable level of 8.5.
10. Non-point source best management practices should be implemented on priority tributary watersheds.
11. An additional data set should be taken at reduced point source phosphorus inputs. McCain Foods and Presque Isle should target TP levels of 1 ppm. Fort Fairfield should implement phosphorus pollution prevention during this data collection effort
12. Total phosphorus license allocations for point sources should be re-evaluated by the model after the collection of the additional data set recommended and nutrient criteria development are final.

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Introduction

The Aroostook River Basin is the largest sub basin of the St John River lying almost entirely within the state of Maine. It has a drainage area of 2353 square miles at the international border of U.S. and Canada. The river segment of interest on the Aroostook begins in Ashland (River Mile 58) and flows to Washburn (RM 37), Presque Isle (RM 28), Caribou (RM 14), Fort Fairfield (RM 3) and eventually the international border (RM 0). In Canada, after an additional 4.6 miles, the Aroostook joins with the St John River.

A water quality model has been developed to update a prior effort. A model calibration data set was collected in 1987. A water quality model was setup on the USEPA supported model, QUAL2EU, but an additional verification data set to complete the model was never collected. The two low flow data sets collected in the summer of 2001 were used to calibrate and verify the water quality model. The model is then typically used to predict worst case (low flow, high water temperature) water chemistry of such parameters as dissolved oxygen, algae, or nutrients. Regulatory measures on both point and non-point source pollutant inputs may be necessary if the model predictions for dissolved oxygen are lower than statutory requirements.

The data collection effort involved stakeholder participation from the towns of Washburn, Presque Isle, Fort Fairfield; McCain Foods; the Aroostook Band of MicMacs; and personnel from MDEP, Augusta; and the Northern Maine Regional Office of DEP in Presque Isle.

In the river segment of interest, seven point source discharges are licensed to discharge organic waste loads to the Aroostook River. Point source discharges and their permitted licensed flows are as follows[1]: Ashland (0.3 mgd), Washburn (0.28 mgd), Presque Isle (2.3 mgd), Caribou (1.41 mgd), Loring (2.5 mgd), and Fort Fairfield (0.6 mgd). McCain Foods' waste discharge license is structured with two production tiers. Tier I is the current production level in which flow is limited to 2.5 mgd and tier II is a future production level expansion in which flow will be limited to 4.0 mgd. One should consult table 1 for a summary of allowable BOD and total phosphorus loads as specified in the waste discharge licensed issued by DEP[2].

Two dams significantly impound water in this segment. The Caribou dam is located approximately 15 river miles upstream of the international border and impounds water 4.5 river miles above the dam. The Tinker dam is located in Canada, but still impounds water 5 river miles upstream of the international border. Non-point source (NPS) inputs related to agricultural and forested land uses are also possible relevant pollution sources to the Aroostook watershed.

[1] There is also an overboard discharge (Town and Country Apartments) not included in the modeling analysis due to its very small size (.085 mgd) and small potential for impact to the Aroostook River.
[2] Presque Isle's allowable loads in table 1 specify limits for a discharge to Presque Isle Stream. These loads should be somewhat relaxed after re-location of the outfall to the Aroostook as required by the waste discharge license by the summer of 2007.

Table 1 Permitted Limitations of Point Sources to Aroostook River Basin						
		Flow	BOD5 Mo Ave	BOD5 Weekly Ave	BOD5 Daily Max.	TP Weekly Ave
		mgd	PPD	PPD	PPD	PPD
Ashland		0.3	75	113	125	
Wasburn		0.28	70	105	117	
Presque Isle		2.3	168	168	168	3.8
McCain Foods	Tier I	2.5	497	N/A	1335	91
	Tier II	4.0	794	N/A	2077	91
Caribou		1.41	880	N/A	1595	
Loring		2.5	626	938	1043	

Summary 2001 Data

The data collection effort is described in detail in the Aroostook River Data Report (May 2002). Some highlights are repeated here for convenience. The overall quality of both the data sets collected in 2001 is considered excellent due to good QC measures utilized throughout the sampling effort that involved such practices as cross checking of dissolved oxygen meters and duplicate sampling. The three-day intensive surveys, that were undertaken on the Aroostook River during August 14 ,15, and 16 and August 28,29,and 30 were specifically for calibration and verification of the water quality model. It is desirable to collect the model calibration data sets under conditions of low flow and high water temperature. This represents conditions of worse case when river dissolved oxygen levels are most likely to be the lowest. At low river flow, the dilution of waste loads is reduced resulting in river pollutant concentrations of higher strength. At high water temperatures, dissolved oxygen saturation decreases and biological activity increases resulting in a greater amount of oxygen demand in the water column as BOD (biochemical oxygen demand) and greater amount of oxygen demand from bottom sediments (SOD). Thus water column dissolved oxygen depletion is maximized under these conditions.

A goal of sampling at less than 390 cfs as measured at the USGS gage in Washburn (90% flow duration) was the specified target flow in the Work Plan for the three-day intensive survey. This goal was met in both intensive surveys. The three-day average flow was 145 and 127 cfs for the first and second data set, respectively. When considering 7-day low flows, the first data set represents about a 6-year event and the second data set a 10-year event. The 7-day 10-year (7Q10) flow is used for calculating the river’s assimilative capacity. Hence the river was sampled under ideal flow conditions.

Another preferable sampling condition is having no runoff during and prior to the survey. Runoff is undesirable due to the difficulty of quantifying it as input to the model. The first data set had minimal rainfall prior to and during the survey. The second data set had some precipitation events a week prior to sampling which resulted in about a 10% rise in river flow at Washburn over two days. In addition, there were precipitation events during the second survey, which resulted in the river flow at Washburn rising 24% over the three day period. This is still within the limits specified in the work plan in which flow increases from runoff should not 50% for the data to be considered acceptable for model calibration.

The dissolved oxygen data are characterized by large diurnal fluctuations due to the significant growths of both bottom-attached (benthic) and floating algae (phytoplankton). There is similarly a trend of greater fluctuation in the shallower flowing sections and less fluctuation in impoundments (figure 6). There is also a trend of less fluctuation above the significant point source discharges. In the segments above major point source discharges (first five upstream locations and background tributary) average diurnal DO fluctuations are generally around 1 to 2 ppm. Below major point source discharges, average diurnal DO fluctuations range from 5 to 9 ppm in the shallower flowing segments and 1 to 4 ppm in impoundments.

The 2001 data indicated that minimum statutory dissolved oxygen criteria were met and often greatly exceeded at all river and tributary locations, except in Presque Isle Stream. Of significance, however was the fact that point source discharges were collectively at only 4% of their licensed permitted BOD5 (five-day biochemical oxygen demand[3]) limits. Hence the potential for lower dissolved oxygen levels than measured is possible, and worse case levels must be determined by the model.

A chlorophyll-a[4] level in the range of 8 to 12 ug/l is currently being used by MDEP as the threshold level indicating the occurrence of an algae bloom. When chlorophyll a levels approach this threshold, the water may begin to appear green tainted from plankton that are floating in the water. The plankton may also be visible within the water column. Both data sets experienced chlorophyll a levels exceeding the upper range of this threshold from above the Caribou dam to the international border.

Although not quantitatively sampled, large levels of benthic algae were observed in the Aroostook River during both surveys. The benthic algae were evident from the confluence of Presque Isle Stream to the head of the Caribou dam impoundment, but most abundant from below the Caribou dam to the head of the Tinker Dam impoundment in Fort Fairfield. Benthic algae were also observed in Presque Isle Stream.

[3] Biochemical oxygen demand (BOD) is a laboratory test estimating the amount of oxygen demanding substances in water samples. The oxygen depletion of a water sample is measured over a time increment. The five-day test or BOD5 is typically used to measure BOD in effluent samples from wastewater treatment plants. Hence, this test measures the potential of discharges to deplete oxygen within a river.

[4] The chlorophyll-a test is used as an indicator to quantify the amount of phytoplankton or floating algae within a water sample. MDEP lakes program and EPA's Nutrient Criteria Technical Guidance Manual use 8 ug/l chl-a as an algae bloom threshold. More recently MDEP has been using a range of 8-12 ug/l chl-a on rivers as a threshold level for an algae bloom.

Water Quality Model

The EPA supported model, QUAL2EU was used in the analysis of the Aroostook. Steady state flows and load inputs are required and major transport mechanisms of advection and dispersion must be one-dimensional. The lack of significant runoff that was previously discussed satisfies the steady state condition. The uniformity of the dissolved oxygen and temperature readings in the vertical profiles indicates that the Aroostook is a well-mixed system and hence one-dimensional flow occurs. The Aroostook River should be well suited to this model.

Many changes were recently incorporated into MDEP's version of QUAL2EU or more appropriately named QUAL2MDEP. The changes are as follows:

1. Addition of a periphyton module with links to the nutrient and dissolved oxygen modules. A major shortcoming of QUAL2EU is bottom attached algae can not be directly modeled. The majority of impacts now experienced in rivers involve low early morning dissolved oxygen from bottom attached algae. The QUAL2MDEP model can now be used to model bottom attached algae and the resulting diurnal dissolved oxygen swings.
2. Addition of a benthal BOD component. QUAL2EU models the direct oxygen demand from bottom sediments, but the sediment may also add BOD to the water column. This is particularly significant in long river systems like the Aroostook with long travel times to accurately model non-point source impacts.
3. Enhancement of the dissolved oxygen saturation calculation. QUAL2EU calculates dissolved oxygen saturation as a function of temperature. This results in unnecessary error in marine situations, since salinity also affects dissolved oxygen saturation. Salinity is now included into the dissolved oxygen saturation calculation.
4. Alteration to phosphorus output units. QUAL2EU's output for organic phosphorus and dissolved phosphorus is rounded off to the nearest 10 ppb. This has been changed in QUAL2MDEP so the output for phosphorus components are now rounded off to the nearest 0.1 ppb.
5. Revisions to the simulation output formats. The diurnal output was enhanced so that all dynamic output can now be observed. An EXCEL VBA post processor was created. The output for a dynamic model run is quite large and not easily managed. The postprocessor allows the selection of specific output specified by the user, which can be transferred to an EXCEL spreadsheet for observation and easy plotting.

The first step in the model setup is to divide the river into segments of similar physical and chemical properties called reaches. The model has 26 reaches, and 12 point source inputs (figure 1). The water quality classifications are illustrated in Figure 2. Presque Isle Stream and the Little Madawaska River are modeled as tributaries with junctions containing three and five reaches, respectively. The other major non-point source tributary inputs are modeled as point sources. There are 7 point source inputs and 5 major tributary inputs. The minor tributaries are grouped into incremental inputs or inputs with flow distributed throughout the reach. Phytoplankton as chlorophyll-a, nutrients as nitrogen and phosphorus, carbonaceous BOD, periphyton, and dissolved oxygen were simulated as the chemical parameters of interest.

Figure 1 Aroostook River QUAL2EU Model Setup

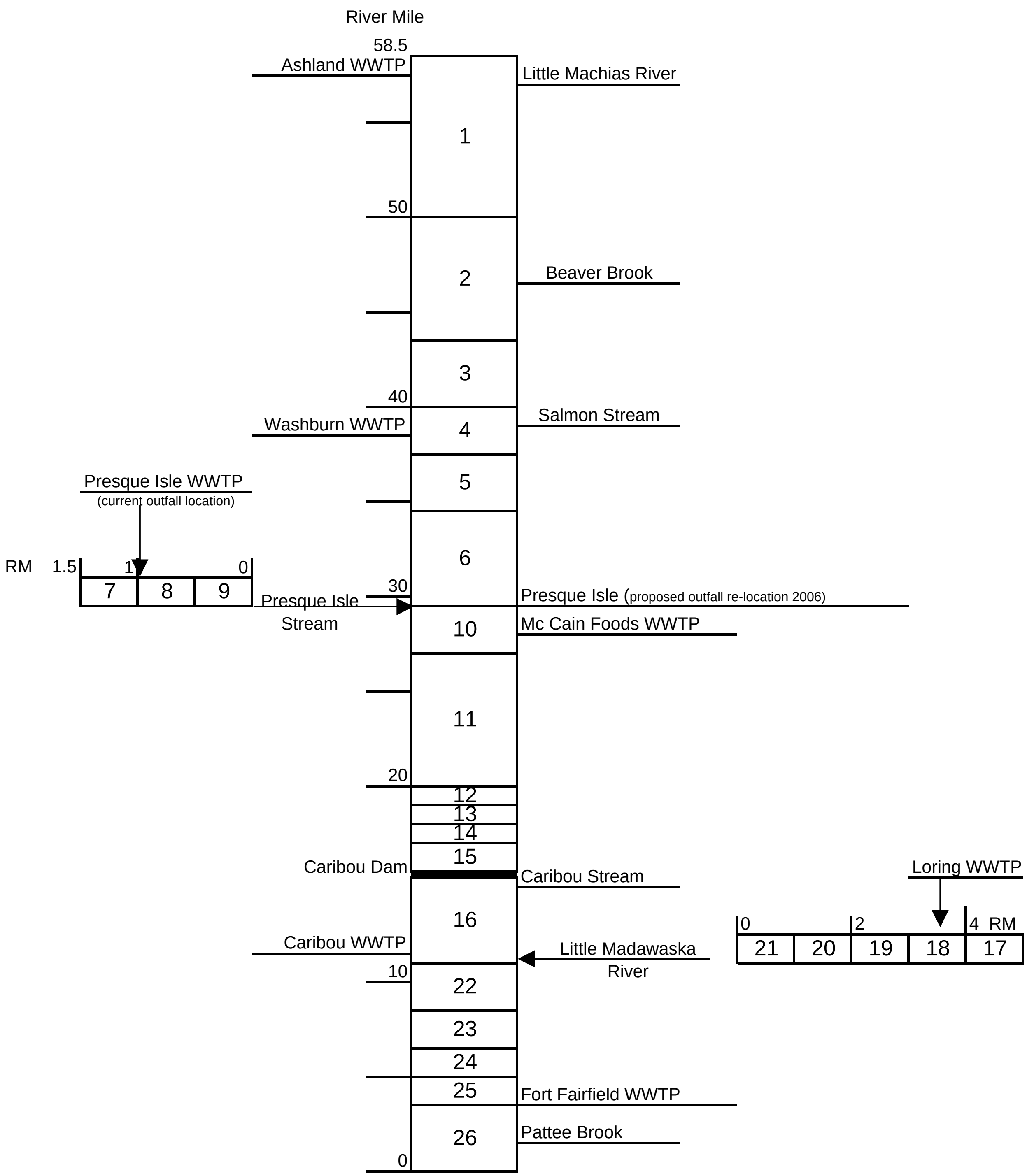
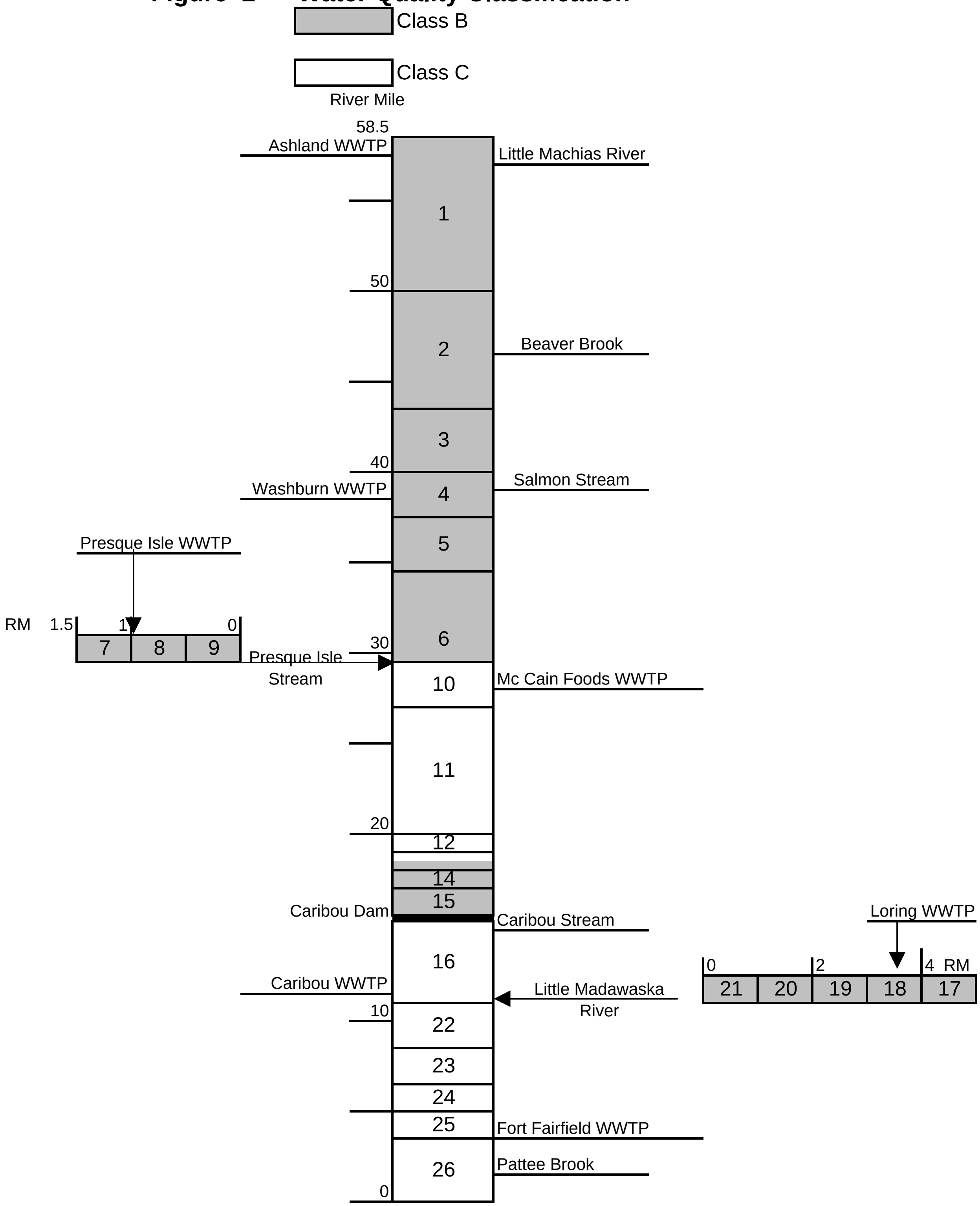


Figure 2 Water Quality Classification



Model Transport

In the hydraulic component of the model, river velocity and depth relationships are developed as a function of flow. Transect and time of travel data are used as a basis for deriving the relationships. QUAL2EU offers two options for the transport of pollutant parameters; a power equation and the Manning equation for open channel flow. The power equation option was chosen for the Aroostook River model. This computes velocity and depth as a function of flow with the following equation:

$$\mathbf{V = A_1Q^{B}{}_1 \text{ and } D = A_2Q^{B}{}_2}$$

where V = velocity; D = depth; Q = flow, and A_x, B_x are coefficients that are empirically derived from transect and time of travel data

Two sources of information were available for developing hydraulic relationships (Table 2). A dye study sampled at three river flows from Washburn to Fort Fairfield was undertaken by the NMRO of DEP in 1971. Little information is available on this study other than travel times at the specific flows (Figure 3). Transect data was undertaken at a number of dates and locations. The transect data for the Tinker Dam impoundment were collected in the early 1990's. Transect measurements were taken in 2001 at 24 locations and were supplemented with additional data taken in 2002 at 19 locations.

The indicated river velocities are somewhat different when comparing the transect and dye study information. The velocity from both sources of information was averaged as input for the model (Figure 4). In the river segment from Ashland to Washburn and Fort Fairfield to the international border no dye study information was available. In these areas, the transect data were used as the source for determining river velocities.

Flow data is available at two USGS gages on the Aroostook River; one at Masardis and the second at Washburn. In addition, flow was gaged on the following tributaries during the survey; Caribou Stream, the Little Madawaska River and Presque Isle Stream. A flow balance was calculated for the watershed (table 3) using this available flow information and a proration of watershed drainage area for tributary inputs to the Aroostook. The larger tributaries were input to the model as point sources and the smaller tributaries were grouped as incremental flow inputs or distributed loads.

Chemical Calibration of the Water Quality Model

The chemical calibration of the model involves inputting measured tributary and treatment plant effluent as point source loads, measured upstream boundary conditions and measured water temperature as initial conditions. The model output of various parameters, such as BOD, chlorophyll a, and dissolved oxygen are compared to measured values and adjustments are made to the model parameter rate coefficients until a good match of model and observed values occur. The model parameter rates that are adjusted include many inputs (see Tables 4, 5). Default values are used as initial estimates and adjusted within the ranges recommended in the literature until satisfactory results are achieved. The model is verified after satisfactory results are obtained from a comparison

Table 2 Aroostook River Model Hydraulic Coefficients

V = Velocity in fps
D = Depth in ft
Q = Flow in cfs

$V = A_1 Q^{B_1}$ $D = A_2 Q^{B_2}$

Model Reach #	Reach Description	River Miles	Velocity Coefficients		Depth Coefficients	
			A_1	B_1	A_2	B_2
1	Ashland	58.5 - 50.0	0.102	0.35	0.175	0.45
2	Pudding Rock	50 - 43.5	0.115	0.35	0.15	0.45
3	Donelly Island	43.5 - 40.0	0.129	0.35	0.125	0.45
4	Washburn	40 - 37.5	0.09	0.35	0.176	0.45
5	Crouseville	37.5 - 34.5	0.08	0.35	0.179	0.45
6	Presqus Isle above P I Str	34.5 - 29.5	0.071	0.35	0.182	0.45
7	Presque Isle Stream #1	1.5 - 1	0.0701	0.6	0.6476	0.3
8	Presque Isle Stream #2	1 - 0.5	0.0701	0.6	0.6476	0.3
9	Presque Isle Stream #3	0.5 - 0.0	0.0538	0.6	0.6263	0.3
10	Presque Isle below P I Str	29.5 - 27.0	0.111	0.35	0.102	0.45
11	Maysville	27.0 - 20.0	0.0867	0.35	0.126	0.45
12	Caribou Dam Impoundment Upper	20.0 - 19.0	0.000718	1	4.8	0
13	Caribou Dam Imp. McGraw	19.0 - 18.0	0.000407	1	6	0
14	Caribou Dam Imp. Middle	18.0 - 17.0	0.000255	1	8.64	0
15	Caribou Dam	17.0 - 15.5	0.000161	1	11.97	0
16	Caribou Dam to L Madawaska R	15.5 - 11.0	0.1013	0.35	0.11	0.45
17	Little Madawaska R #1	5.0 - 4.0	0.3971	0.26	0.221	0.45
18	Little Madawaska R #2	4.0 - 3.0	0.3971	0.26	0.221	0.45
19	Little Madawaska R #3	3.0 - 2.0	0.4844	0.18	0.1184	0.47
20	Little Madawaska R #4	2.0 - 1.0	0.3057	0.28	0.1803	0.48
21	Little Madawaska R #5	1.0 - 0.0	0.3326	0.28	0.1638	0.46
22	Below L Madawaska R	11.0 - 8.5	0.081	0.35	0.16	0.45
23	Goodwin	8.5 - 6.5	0.047	0.35	0.135	0.45
24	Stevensville	6.5 - 5.0	0.034	0.35	0.208	0.45
25	Tinker Dam Imp Upper	5.0-3.5	0.00314	0.6	1.166	0.3
26	USA / Canada Border	3.5 - 0.0	0.000162	1	10.16	0

Figure 3
Summary of 1978 Dye Study

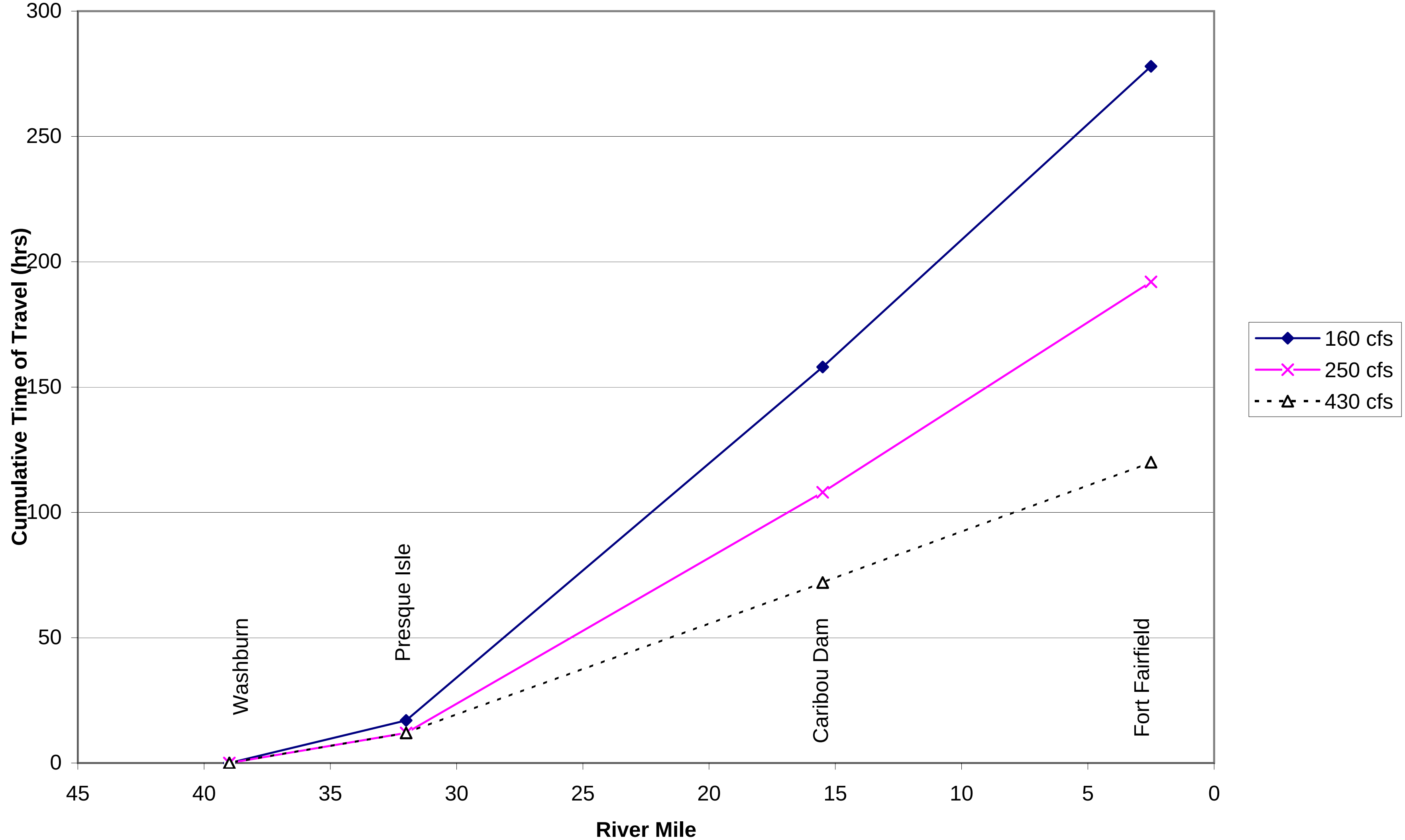


Figure 4
Aroostook River Time of Travel
Dye Study and Transects Compared to Model
160 CFS at Washburn

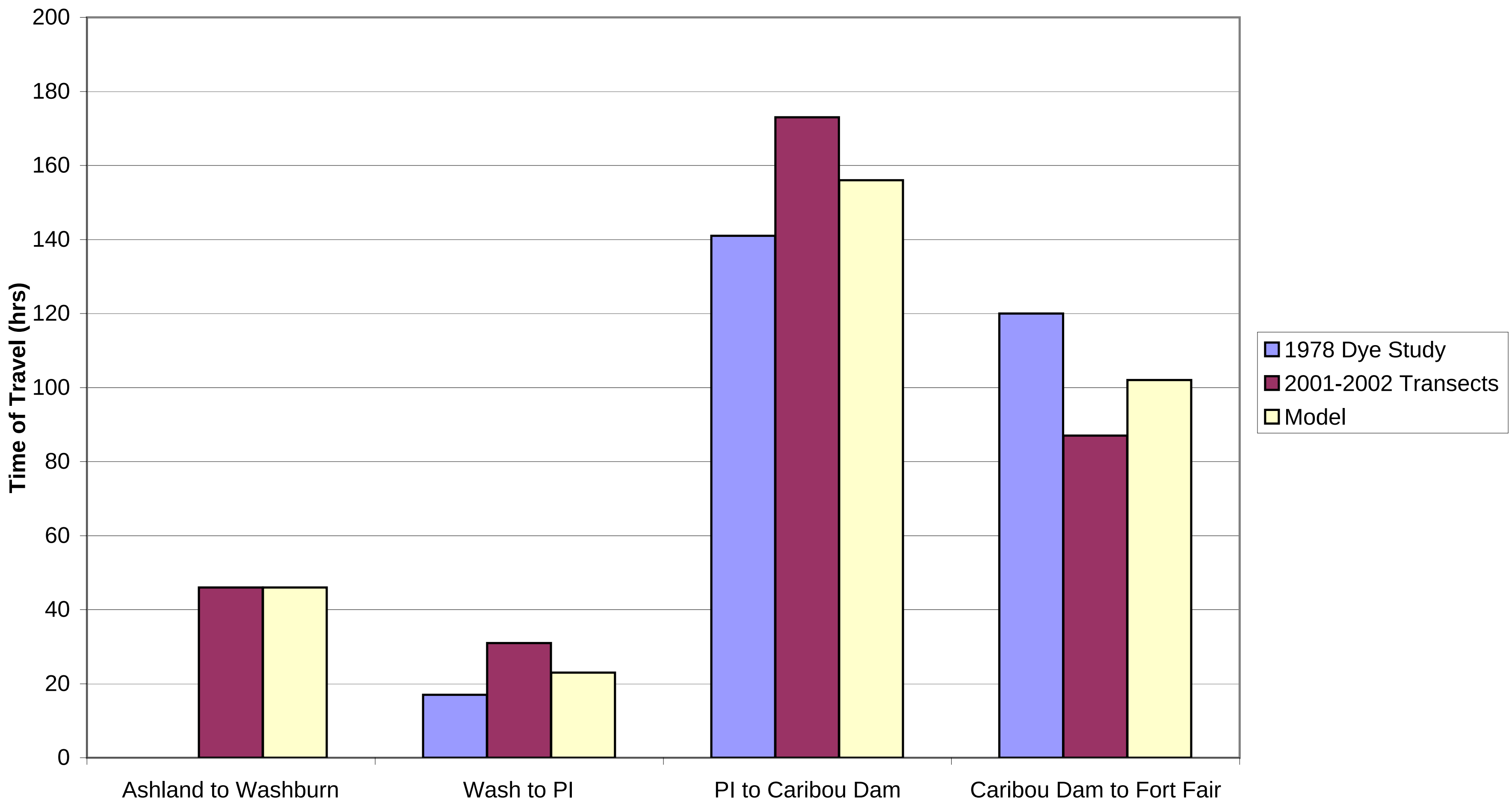


Table 3 Flow Balance of Aroostook River

Reach	Description	Reach River Miles		Drainage Area (Mi^2)		Flow Inputs	Input DA (mi^2)	Flow (cfs) 8/02-16/01		Flow (cfs) 8/09-30/01	
		Begin	End	Begin	End			Incremental	Head of Rch	Incremental	Head of Rch
1	Ashland	58.5	50	1338	1459	L Machias R	63	8.6	180.2	5.1	116.1
						Incremental	58	7.9		4.7	
2	Pudding Rock	50	43.5	1459	1577	Beaver Br	103	14.0	196.7	8.3	125.8
						Incremental	15	2.0		1.2	
3	Donnelly Island	43.5	40	1577	1599	Incremental	22	3.0	212.8	1.8	135.4
4	Washburn	40	37.5	1599	1659	Salmon Br	55	7.5	215.8	4.4	137.2
						Incremental	5	0.7		0.4	
5	Crouseville	37.5	34.5	1659	1681	Incremental	22	3.0	224	1.8	142
6	Presque Isle	34.5	29.5	1681	1889	P I Stream	197	8.0	227.0	4.6	143.8
						Incremental	11	1.5		0.9	
10	Presque Isle	29.5	27	1889	1900	Incremental	11	1.5	236.5	0.9	149.3
11	Maysville	27	20	1900	1915	Incremental	15	2.0	238.0	1.2	150.2
12	Caribou Dam Upper	20	19	1915	1922	Incremental	7	1.0	240.0	0.6	151.4
13	McGraw	19	18	1922	1929	Incremental	7	1.0	241.0	0.6	151.9
14	Caribou Dam Middle	18	17	1929	1936	Incremental	7	1.0	242.0	0.6	152.5
15	Caribou Dam Lower	17	15.5	1936	1943	Incremental	7	1.0	242.9	0.6	153.1
16	Grimes Mill	15.5	11	1943	2253	Caribou Str	50	6.1	243.9	4.1	153.6
						L Madaw R	243	40.4		28.5	
						Incremental	17	2.3		1.4	
22	Below L Madaw R	11	8.5	2253	2271	Incremental	18	2.5	292.7	1.5	187.6
23	Goodwin	8.5	6.5	2271	2291	Incremental	20	2.7	295.1	1.6	189.1
24	Stevensville	6.5	5	2291	2296	Incremental	5	0.7	297.9	0.4	190.7
25	Tinker Dam Upper	5	3.5	2296	2301	Incremental	5	0.7	298.5	0.4	191.1
26	Tinker Dam Lower	3.5	0	2301	2328	Pattee Br	27	3.7	299.2	2.2	191.5
						Incremental	25	3.4		2.0	
						End			306.3		195.7
						USGS Masardis	892		116		78
						CFSM Masardis-Washburn			0.136		0.081

Presque Isle Stream

7	Downtown Presque Isle	1.5	1
8	WWTP to Bypass Bridge	1	0.5
9	Bypass Bridge to Confluence	0.5	0

Little Madawaska River

17	Bowles Rd	5	4
18	Rte 89	4	3
19	Island #1 to Island #2	3	2
20	Island #2 - S Curve	2	1
21	S Curve - Confluence	1	0

of modeled Vs observed values of a second independent data set. After this process, the model can then be reliably used for model predictions of water quality.

The traditional approach used by modelers when assigning parameter rates is to use the same rate for model calibration and verification whenever possible. This makes the selection of which rates one should use for the prediction runs easier, since the same rates can be used that were used for calibration / verification. In reality, the rates are somewhat variable. The rates assigned for the algae component of the model are the ones that are most likely to vary. The high levels of algae result in a very unstable environment that is very dynamic. In these situations, it may sometimes be more appropriate to assign a range rather than a single number for describing river kinetics.

The approach used for the Aroostook model is to use a constant rate for model calibration and verification whenever possible. In 33 of the 37 rates assigned, constant rates were used for both data sets (Table 4). Variable rates were used for the benthic CBOD rate, organic phosphorus settling rates, orthophosphorus uptake rate, and the algal loss coefficient in some of the model segments (Table 5). When variable rates are assigned to the calibration and verification, an average of these rates can be used in the prediction model runs and the range also plugged into the model as the range of prediction, given the variability in the environment and the data limitations. Although some would argue that this is not a true calibration / verification of the model, in DEP's opinion, if the majority of the parameter rates were held constant, it is still a valid calibration / verification. In the Aroostook model, 96% of the rates were held constant when considering the segment length and number of parameter rates, so this most certainly qualifies as a majority of the model and a valid calibration / verification.

The data collected primarily on August 28, 29, and 30 in the Aroostook River and major tributaries were used to calibrate the Aroostook River water quality model. These data were collected under lower flow conditions than the data collected earlier that month and should have a higher sensitivity to parameter rate adjustments. The data collected primarily on August 14, 15, and 16 30 in the Aroostook River and major tributaries are used to verify the model. The model calibration / verification are plotted for each chemical parameter (figures 5 to 11) in a river mile Vs chemical parameter format. The model output is displayed as a line and the data as an average (unshaded triangle) and range (high and low error bars).

Data collected on other dates than the three days mentioned in each of the data sets is also used in the modeling. For example, tributaries and effluent sampling began one day before the three-day river surveys and ended one day prior to the end of river sampling. In addition all of the available data over the river travel time or the total excursion time over the study reach should be used to describe data observations. Hence the first data set should use a 2 week average and the second data set a three week average of available data. Hence the observed data plotted for the calibration data set is actually an average of the first data set and second data set. River flows and treatment plant flows and loads are also averaged over a three and two week period, respectively for calibration / verification. Throughout the report, the calibration / verification data set dates will refer to the river

Table 4 Environmental Constants and Parameter Rates Used in Aroostook River Model Constant by Model Reach

Literature Source - Help and Limit Screens for Eutrophication Preprocessor for EPA WASP4/Eutro4 Model, Tetra Tech, 8/8/1991.

-Computer Program Documentation for the Enhanced Stream Water Quality Model QUAL2E , USEPA, 8 / 1985.

Constants — Cannot be Varied by Reach in Qual2e

	Literature				
Algae as Phytoplankton	Range	Default	Aroostook Model	Units	Considerations and Logic Used
Maximum Growth Rate	1 - 4	1.8	1.8	1 / day	Calibration of chlorophyll a.
Algal Respiration Rate	.05 - .5	0.15	0.3	1 / day	Calibration of chlorophyll a, DO
Algal Death Rate	0 - .25	0.05	See settling rate Table 6	1 / day	Assigned as settling rate. Qual2e has no input for algae death.
Oxygen Uptake by Algae	1.6 - 2.3	2	2	mg-O / mg-A	Default
Oxy. Production by Algae	1.4 - 1.8	1.6	20		High rate needed to calibrate DO.
Nitrogen Content of Algae	.07 - .09	0.085	0.085	mg-N / mg-A	Default range.
Phosphorus Content of Algae	.01 - .02	0.014	0.01	mg-P / mg-A	
N-Half Saturation Constant	.001 - .15	0.025	0.025	mg/l	Default
P-Half Saturation Constant	.001 - .05	0.001	0.001	mg/l	
Light Saturation Coef	.02 - .10	0.06	0.06	BTU / ft^2-min	Default
Algae as Periphyton					
Maximum Growth Rate	.3 - 2.25		1.5	1 / day	Calibration of model phosphorus, dissolved oxygen
Periphyton Respiration Rate	.01 - .8		0.01		
Periphyton Death Rate	0 - .8		0.001		
Oxygen Uptake by Periphyton	1.6 - 2.3	2	2	mg-O / mg-AP	Default
Oxy. Production by Periphyton	1.4 - 1.8	1.6	6		High rate needed to calibrate DO.
Nitrogen Content of Periphyton	.07 - .09	0.08	0.08	mg-N / mg-AP	Default
Phosph. Content of Periphyton	.01 - .02	0.01	0.01	mg-P / mg-AP	
Chl-a Content of Algae	5 - 10	7.5	10		Calibration of model phosphorus, dissolved oxygen
N Half- Sat. Constant Periphy.	.01 - .766		0.02	mg/l	
P Half -Sat. Constant Periphy.	.001 - .08		0.006	mg/l	
Light Saturation Coef Periphy.	.01 - .10	0.05	0.1	BTU / ft^2-min	
Periphyton Density Satur. Coef	3 - 6	4.5	4.5	mg-chl-a / ft^2	Default

Parameter Rates — Varied by model reach in Aroostook model. See Table 5 for reach specific rates.

Sediment Oxygen Demand	9 - 900	Variable	10 - 150	mg / ft2-day	Consistent with measured reates in impoundments
Reaeration Rate	.01 - 100	Variable	.25 - 20.4	1 / day	Modified method of Covar
PO4-P Uptake Rate	Variable		.01 - 3.0	mg / ft^2-day	Assigned as negative flux rate to calibrate PO4-P.
Algae Settling Coefficient	0.3 - 59	1.6	.1 - 1.5	ft / day	Includes algae death. Qual2e has no direct input for algae depth.
Benthal CBOD Source	Variable		10-80	mg / ft2-day	BOD calibration / See text for details
OP decay	.01 - .7	0.22	.05 - .25	1 / day	OP calibration
ON Settling	0.001 - 0.10	0.05	.01 - .50	1 / day	ON, OP calibration. Very high loss rate in Aroostook
OP Settling			.01 - 20		

Parameter Rates — Can be varied by model reach in Qual2e but were assigned as constants in Aroostook model

NH3-N Benthal Source	Variable		0.05	mg / ft2-day	Nitrogen, phosphorus calibration
ON hydrolysis	.02 - .4	0.075	0.001	1 / day	Turned off, insignificant in Aroostook
Chl-a to Algae Ratio	10 - 100	50	80	ug-chl-a / mgA	Chl-a calibration
Non-Algal light extinction coef.	Variable		0.2	1 / ft	
Fraction of bottom area available for periphy. growth	0 - 1	Variable	0.7	unitless	Dissolved Oxygen / Phosphorus Calibration
Carbonaceous BOD Decay	.01 - 5.6	≥ Bottle rate	0.05	1 / day	Laboratory bottle decay rates used
Ammonia Decay	.1 - 1.0	Variable	0.2	1 / day	NH3-N calibration

Table 5 Environmental Parameter Rates Used in Aroostook River Model Variable by Model Reach

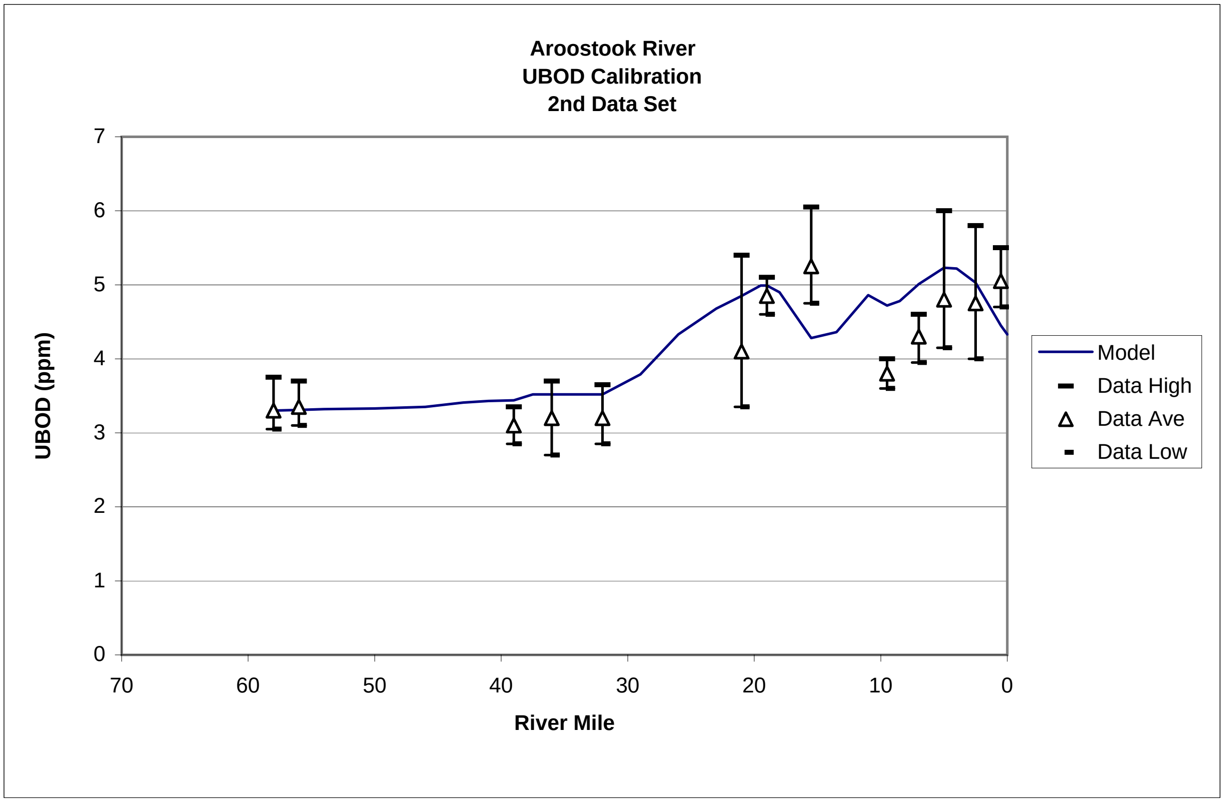
Model Reach #	Reach Description	River Miles	Benthal BOD Source mg / ft^2-day		Sediment Oxygen Demand mg/ft^2-day	Reaeration Rate Option	Reaeration Rate at 20^o C (/day)	ON Settling (/day)	OP Settling (/day)		PO4-P Uptake Rate (mg/ft^2-day)		OP Decay (/day)	*Algae Loss Coef. (/day)	
	Data Set		8/14-16	8/28-30	Both	Both	Both	Both	8/14-16	8/28-30	8/14-16	8/28-30	Both	8/14-16	8/28-30
1	Ashland	58.5 - 50.0					5.29								
2	Pudding Rock	50.0 - 43.5					6.61								
3	Donelly Island	43.5 - 40.0			150		9.07		0.1		0.01				
4	Washburn	40.0 - 37.5					4.47								
5	Crouseville	37.5 - 34.5	10				4.08	0.1					0.05		
6	Presqus Isle above P I Str	34.5 - 29.5				O-D	3.75								
7	Presque Isle Stream #1	1.5 - 1.0					5.69								
8	Presque Isle Stream #2	1 - 0.5					5.47		5		1.5			0.2	0.1
9	Presque Isle Stream #3	0.5 - 0.0					5.09								
10	Presque Isle below P I Str	29.5 - 27					10.92			0.1	0.01		0.25		
11	Maysville	27.0 - 20.0			50		6.98			2	1.5	2.2			
12	Caribou Dam Impoundment Upper	20.0 - 19.0	80	40			0.41								
13	Caribou Dam Imp. McGraw	19.0 - 18.0					0.51	0.5					0.05		
14	Caribou Dam Imp. Middle	18.0 - 17.0				ID	0.36		0.1						
15	Caribou Dam	17.0 - 15.5					0.25			0.1	0.01				
16	Caribou Dam to L Madawaska R	15.5 - 11.0	40				9.05						0.25	1.0	
17	Little Madawaska R #1	5.0 - 4.0					12.95								
18	Little Madawaska R #2	4.0 - 3.0					12.81								
19	Little Madawaska R #3	3.0 - 2.0	10		10		20.38	0.01	10	20	2	2.8			0.1
20	Little Madawaska R #4	2.0 - 1.0				O-D	13.28		0.1		0.01			0.2	
21	Little Madawaska R #5	1.0 - 0.0					17.65								
22	Below L Madawaska R	11.0 - 8.5					4.20		0.5	3	2	3	0.05		
23	Goodwin	8.5 - 6.5					4.13								
24	Stevensville	6.5 - 5.0	40		85		1.83	0.5	0.1		1				0.2
25	Tinker Dam Imp Upper	5.0 - 3.5					0.26							1.5	
26	USA / Canada Border	3.5 - 0.0				ID	0.30		0.01		1	1.5			

O-D = Oconnor Dobbins

ID = Impoundment Default

* In Qual 2e, Algae losses from settling, death, and predation are all assigned in the settling rate.

Figure 5a - Ultimate BOD Calibration - Aug 28 - 30 2001 Data Set



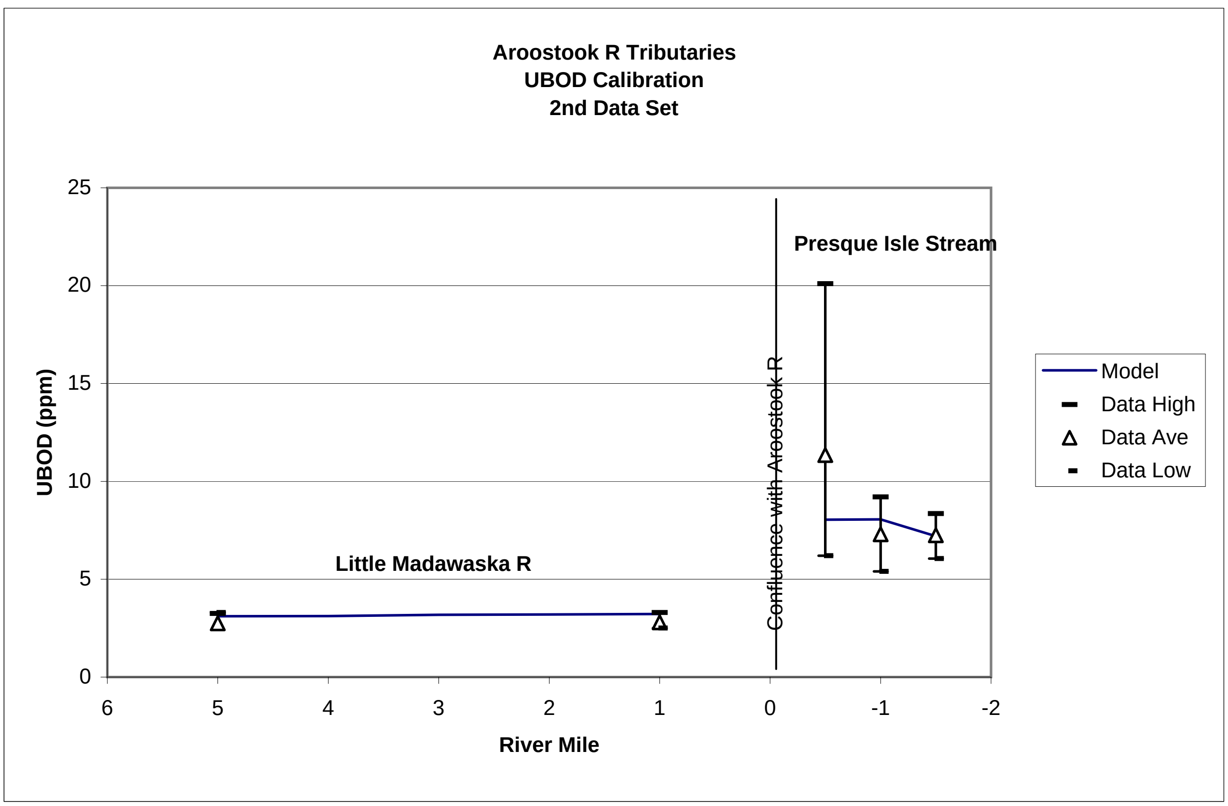
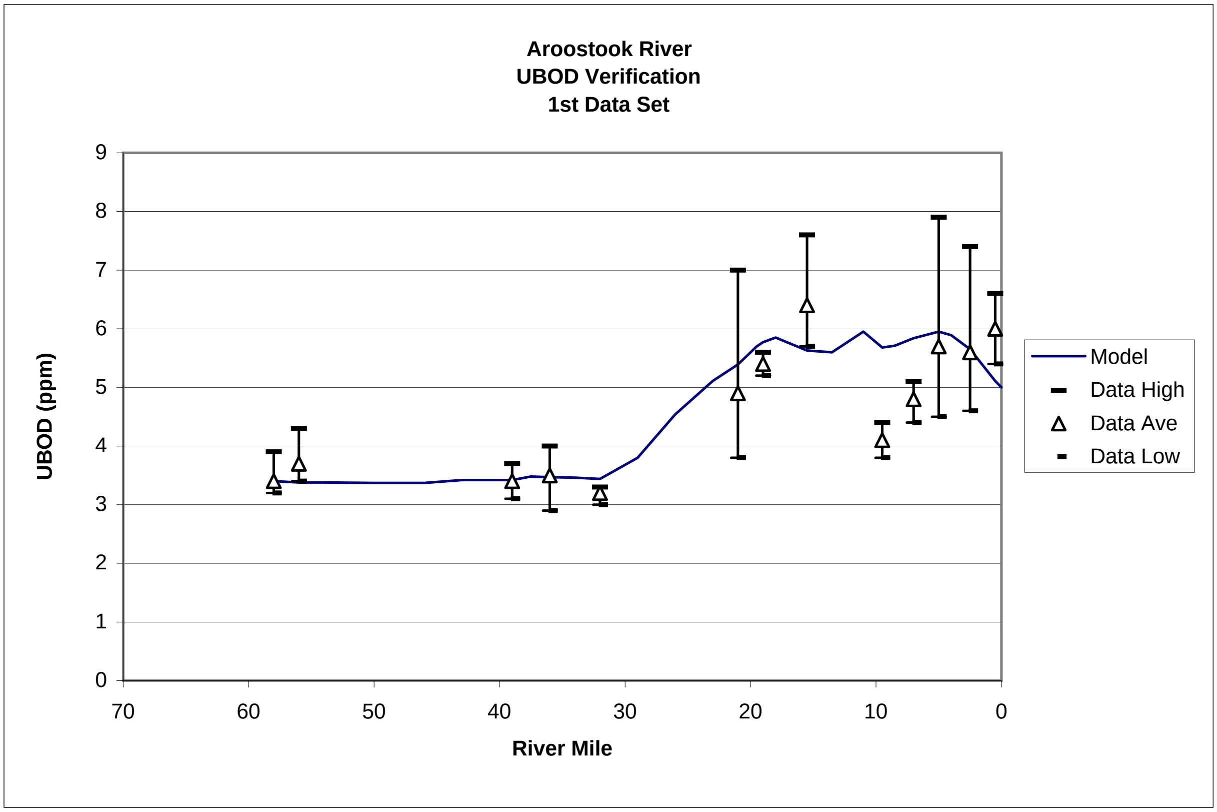


Figure 5b - Ultimate BOD Verification - Aug 14 - 16 2001 Data Set



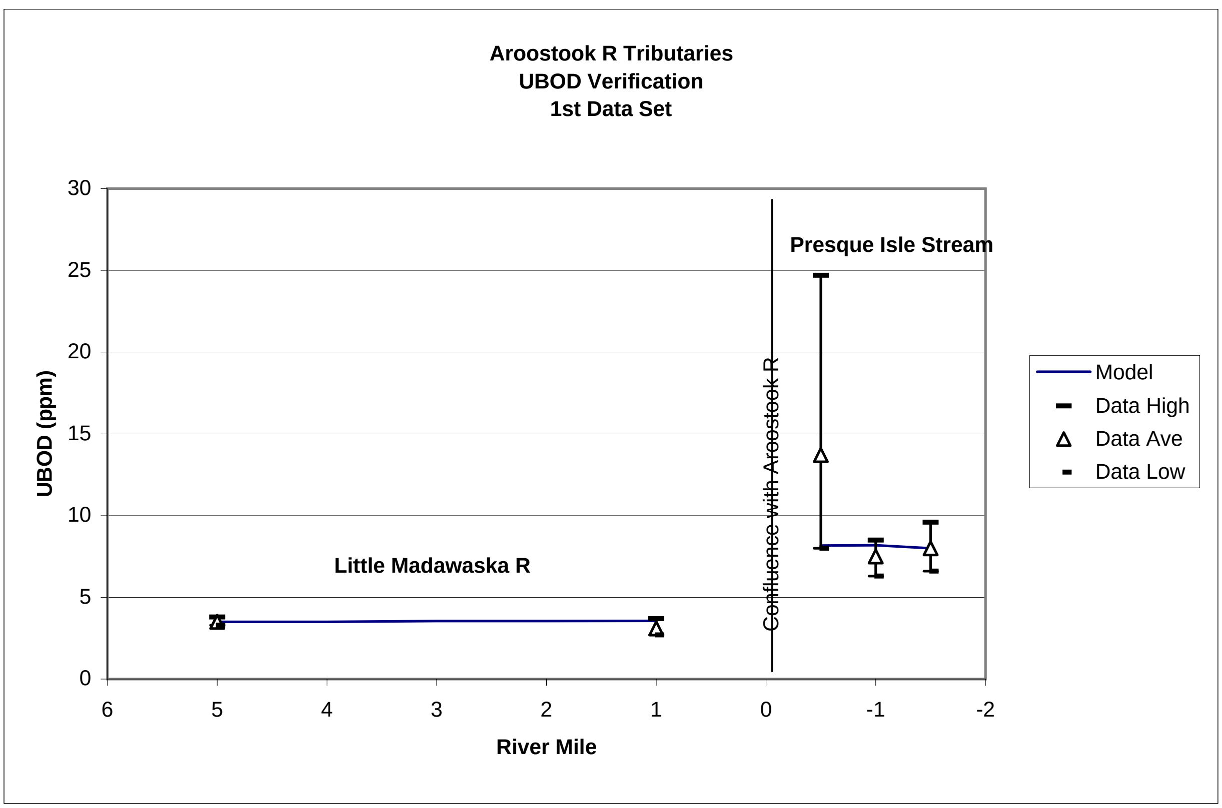
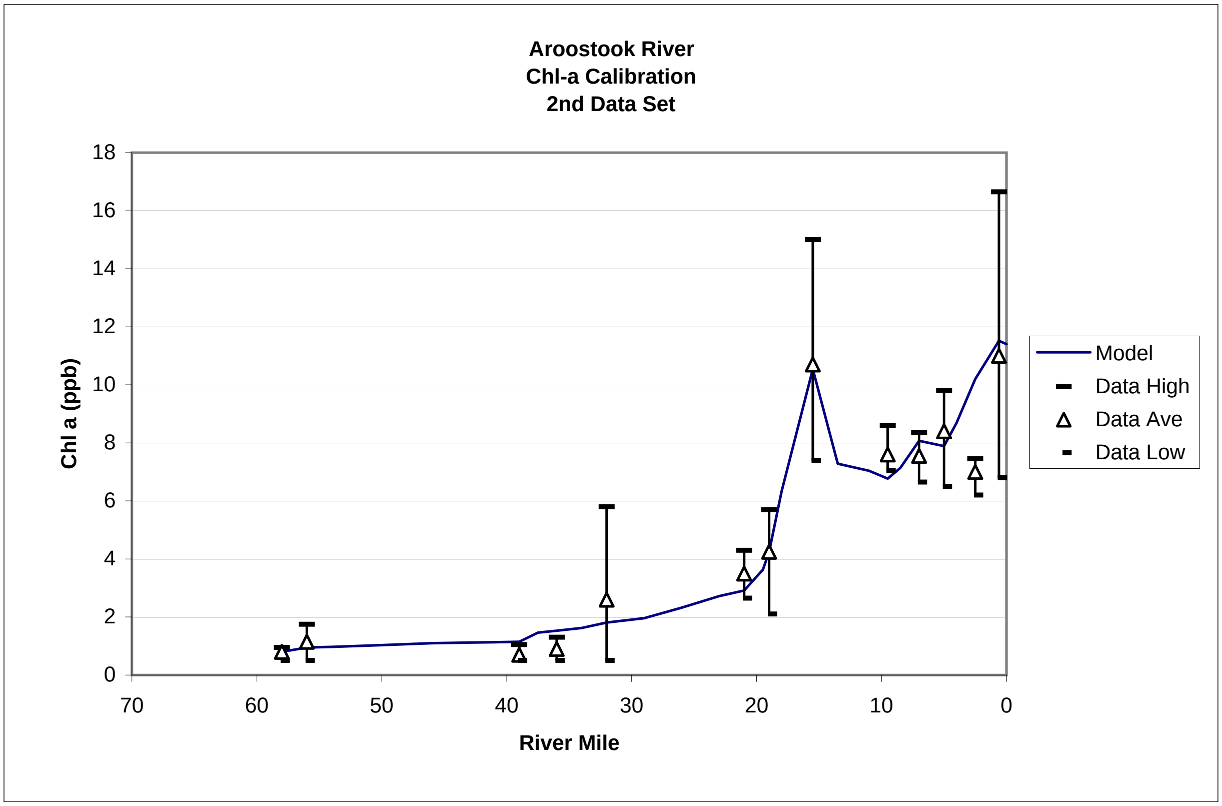


Figure 6a - Chlorophyll-a Calibration - Aug 28 - 30 2001 Data Set



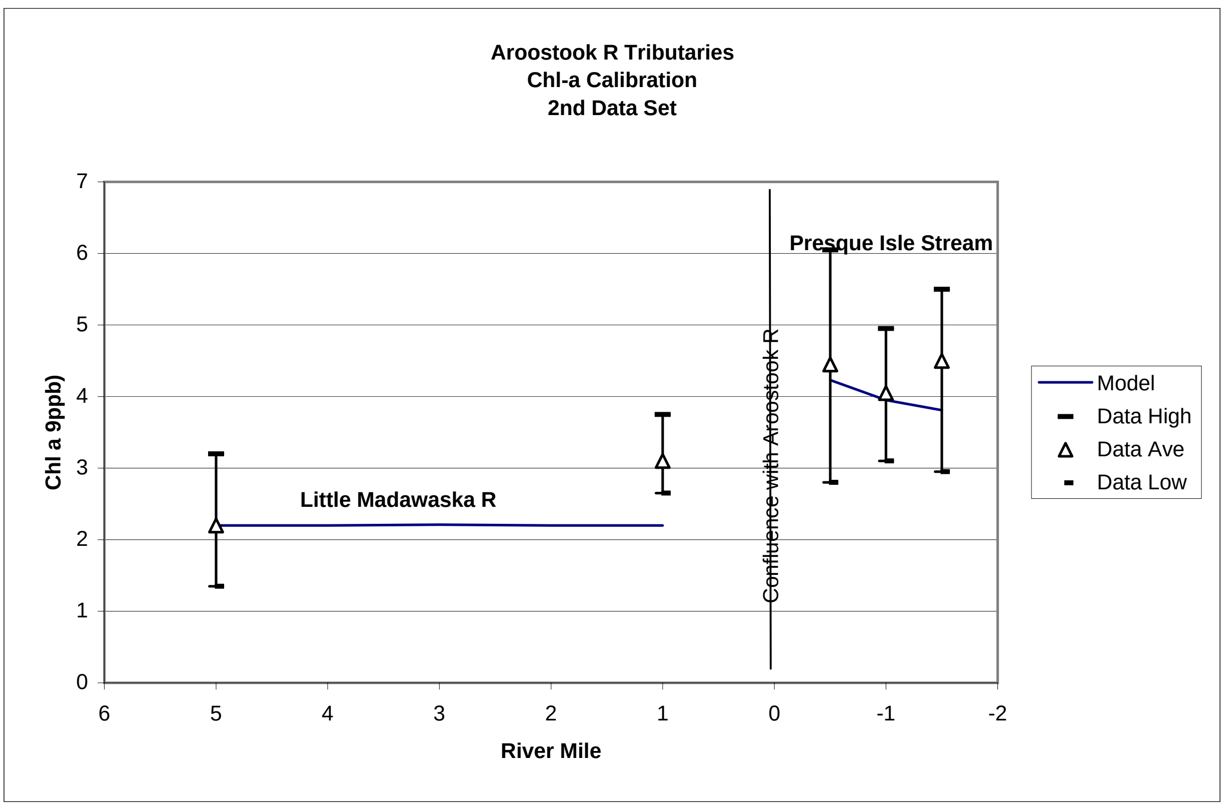
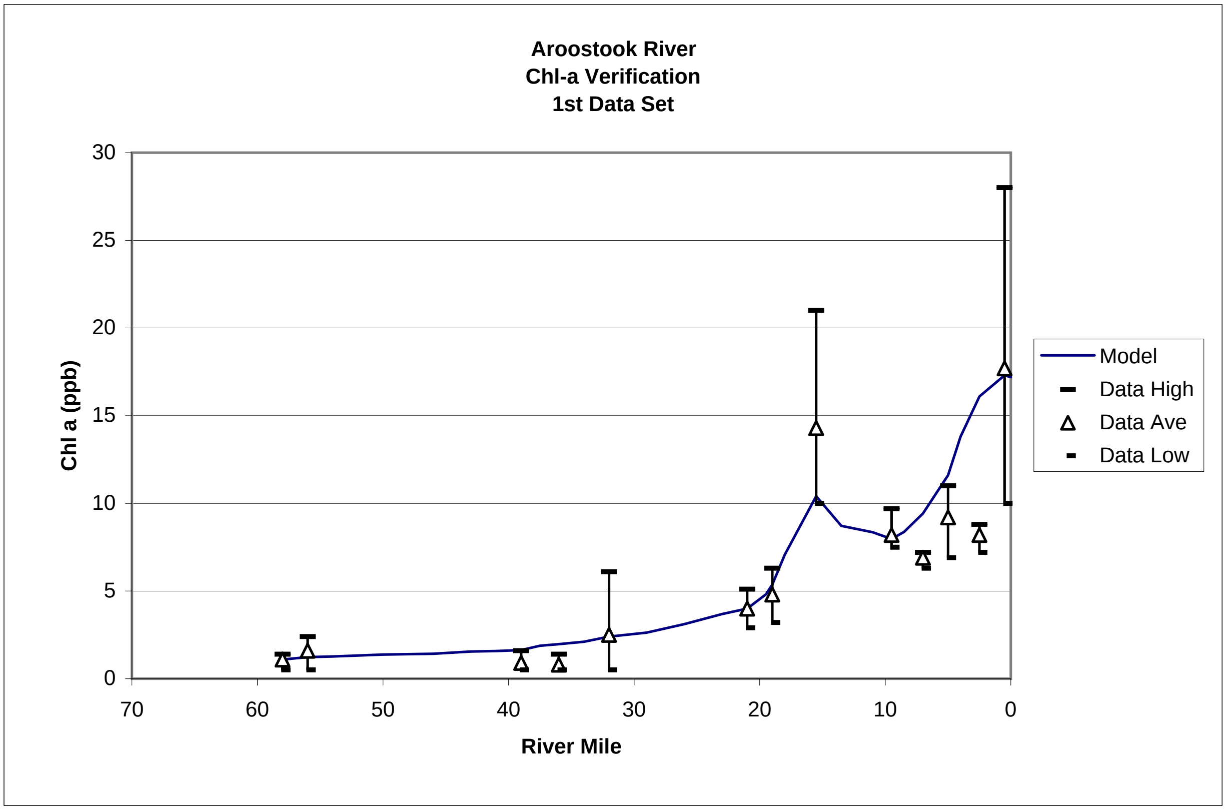


Figure 6b - Chlorophyll-a Verification - Aug 14 - 16 2001 Data Set



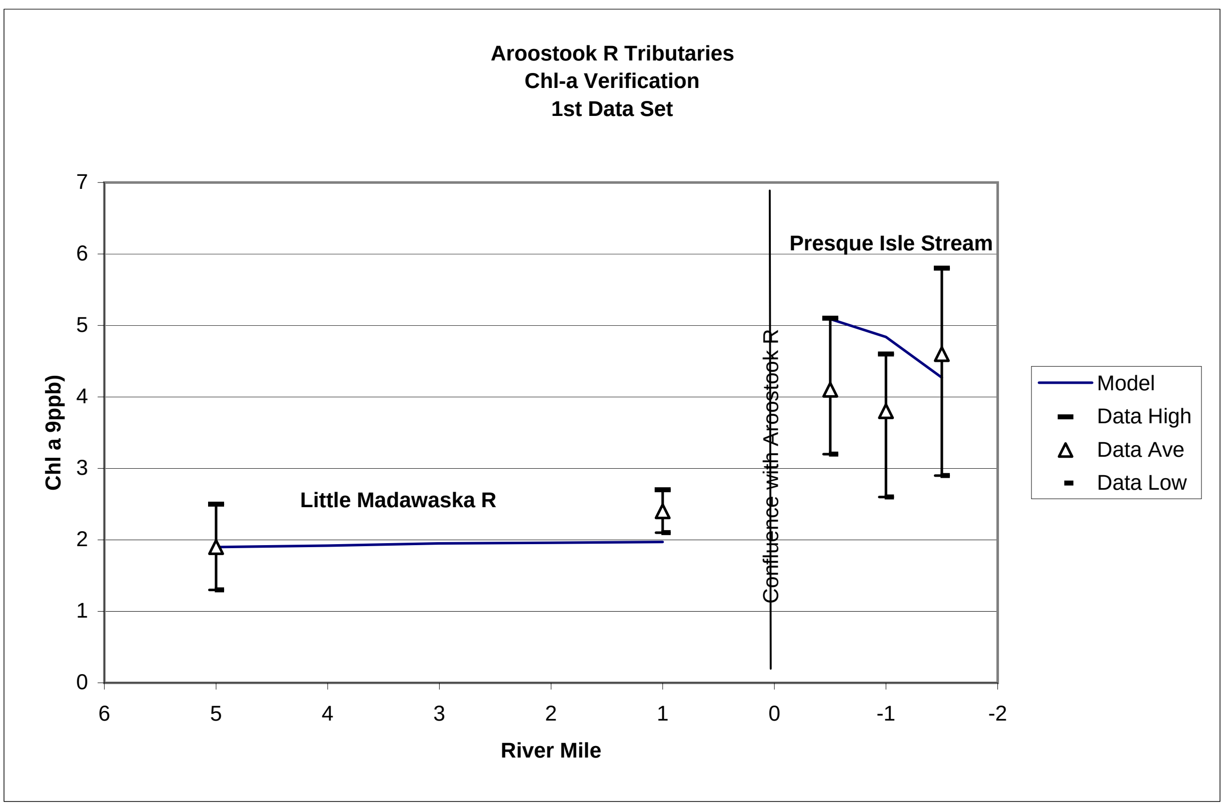
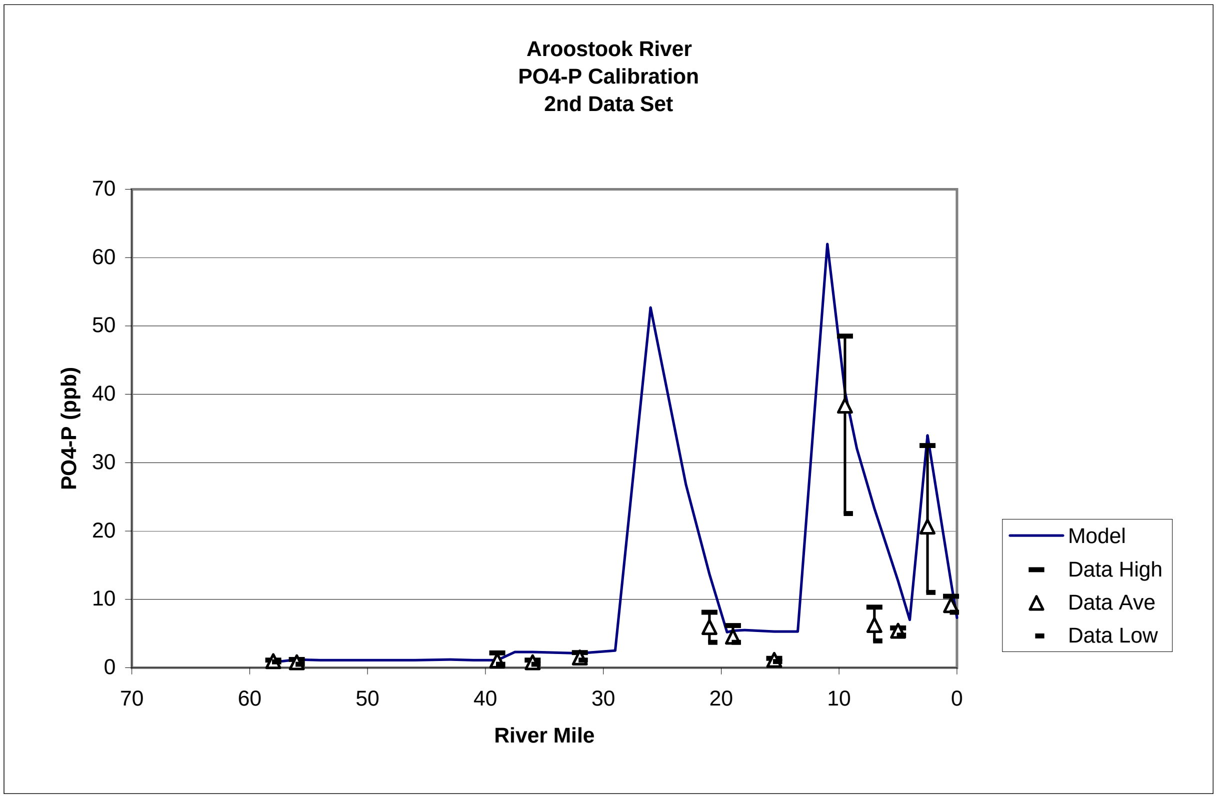


Figure 7a - Orthophosphorus Calibration - Aug 28 - 30 2001 Data Set



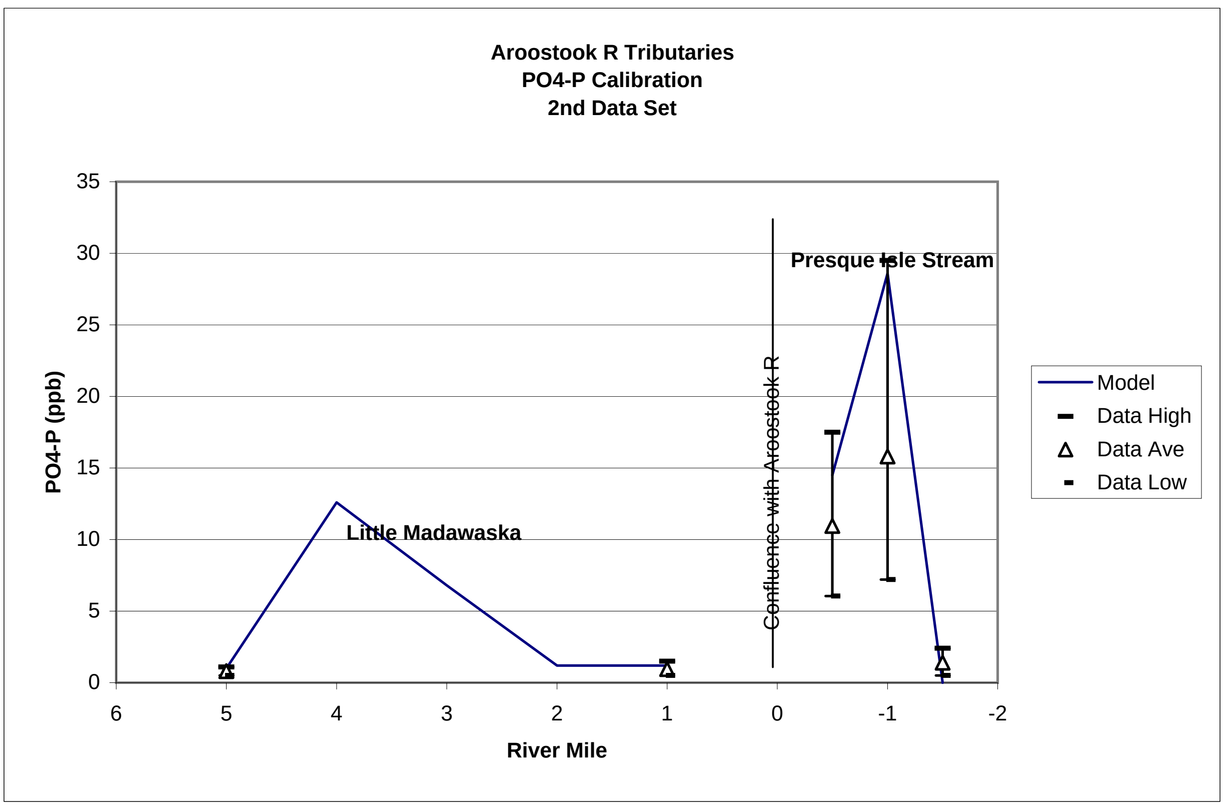
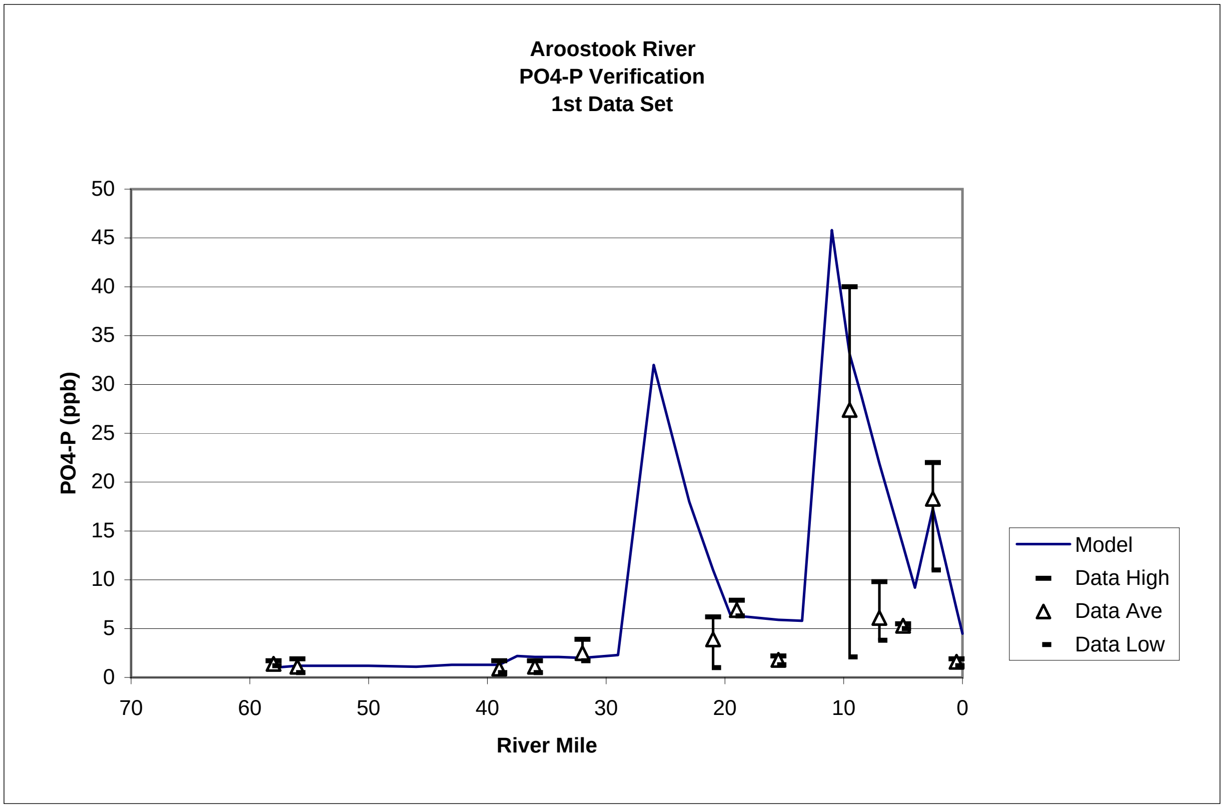


Figure 7b - Orthophosphorus Verification - Aug 14 - 16 2001 Data Set



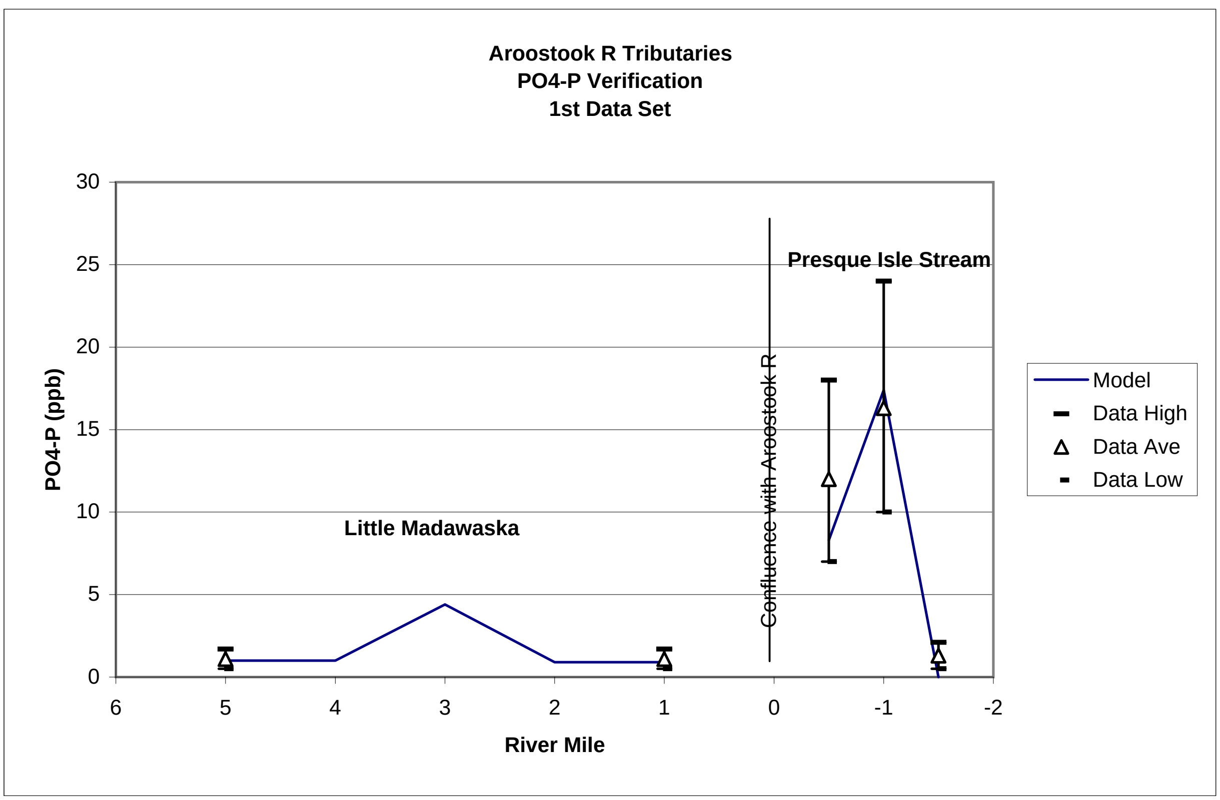
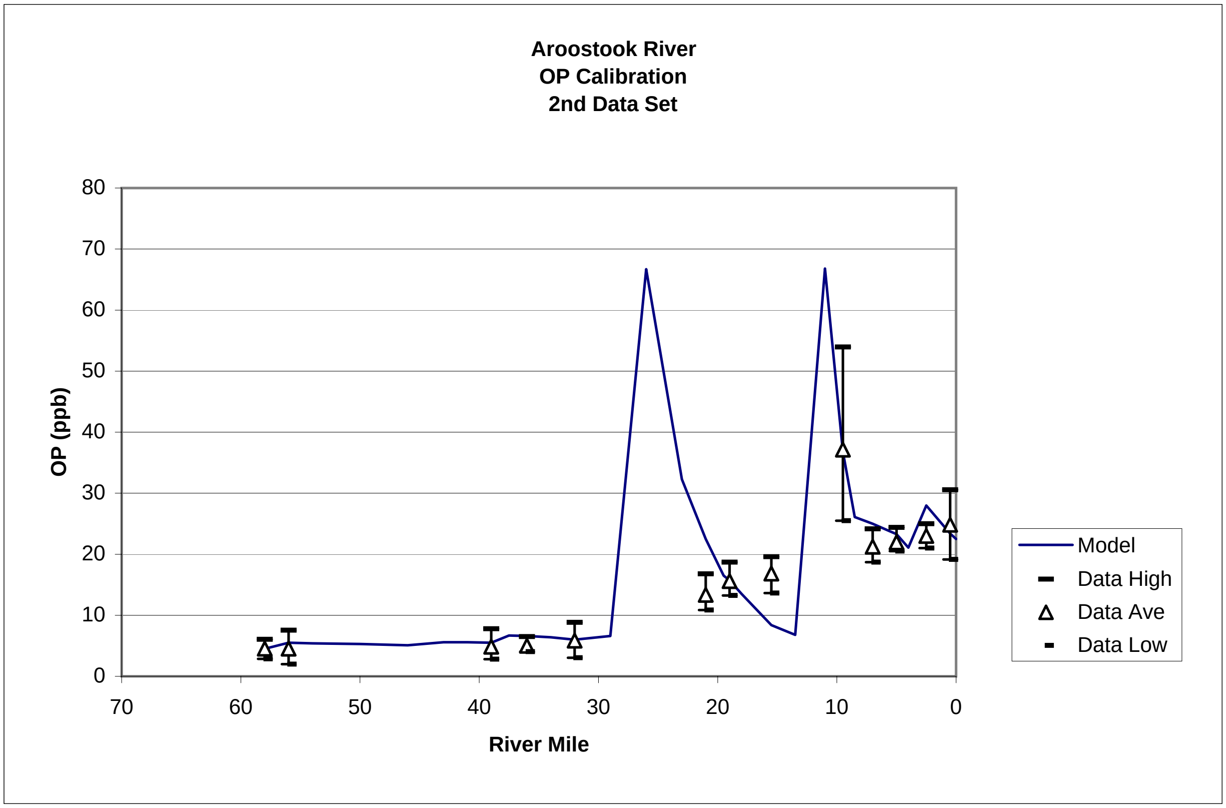


Figure 8a - Organic Phosphorus Calibration - Aug 28 - 30 2001 Data Set



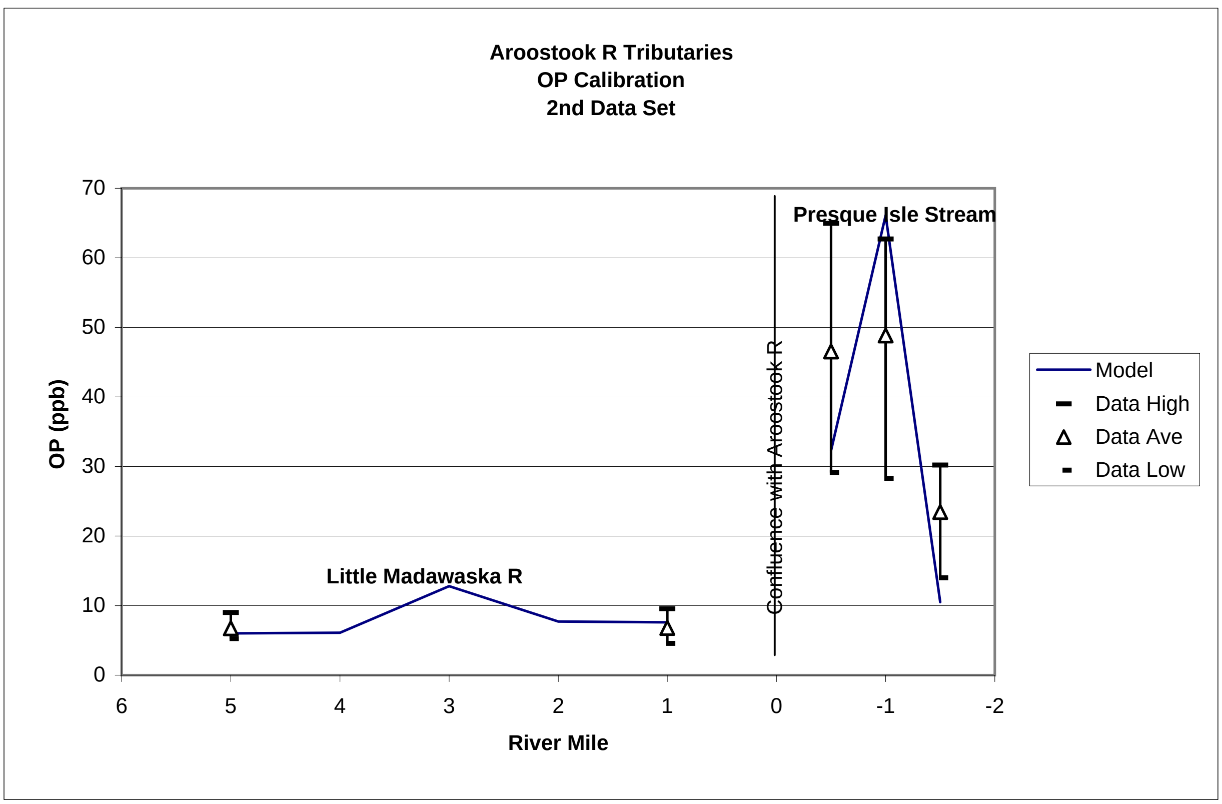
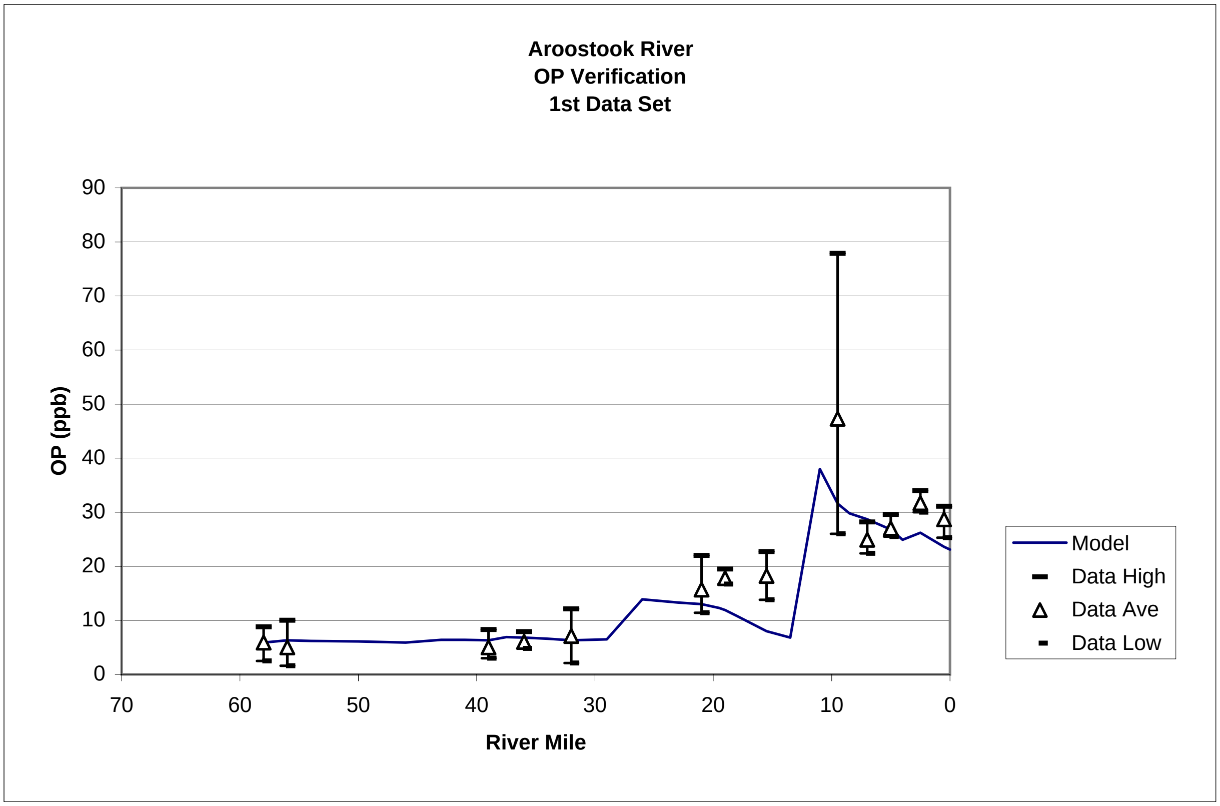


Figure 8b - Organic Phosphorus Verification - Aug 14 - 16 2001 Data Set



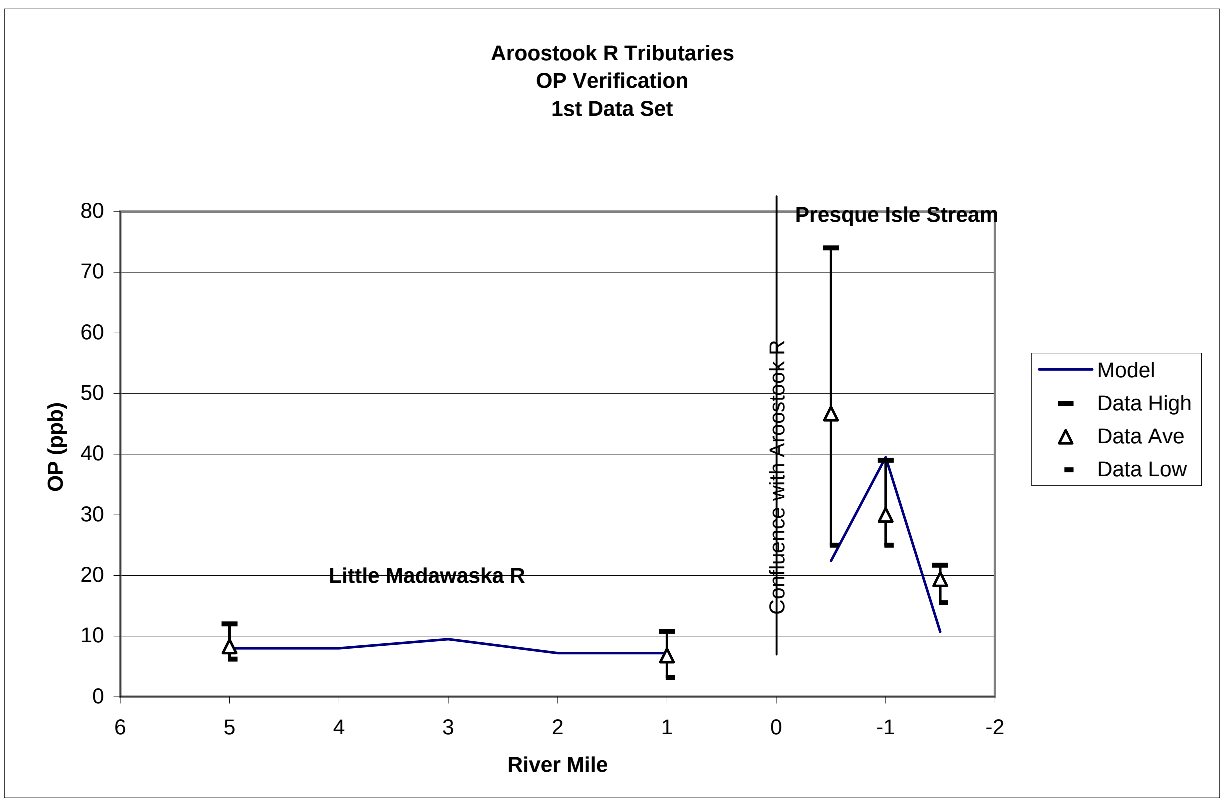
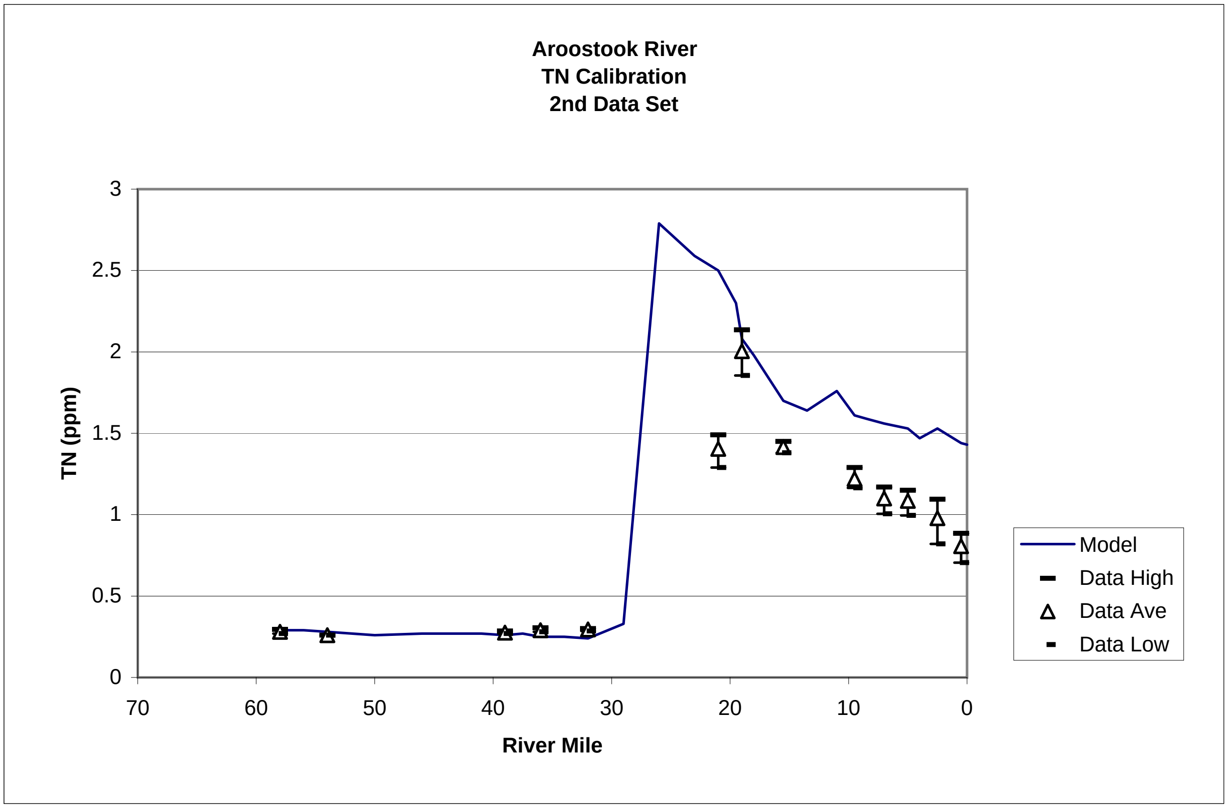


Figure 9a - Total Nitrogen Calibration - Aug 28 - 30 2001 Data Set



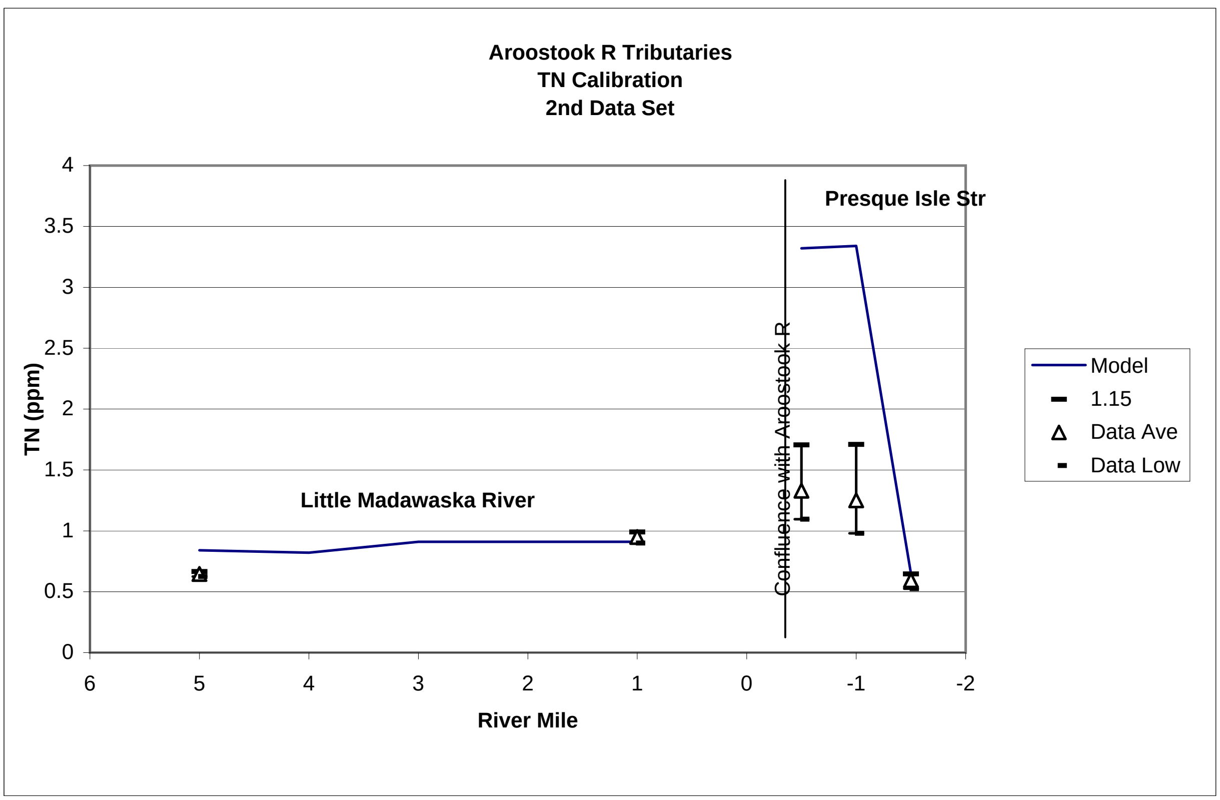
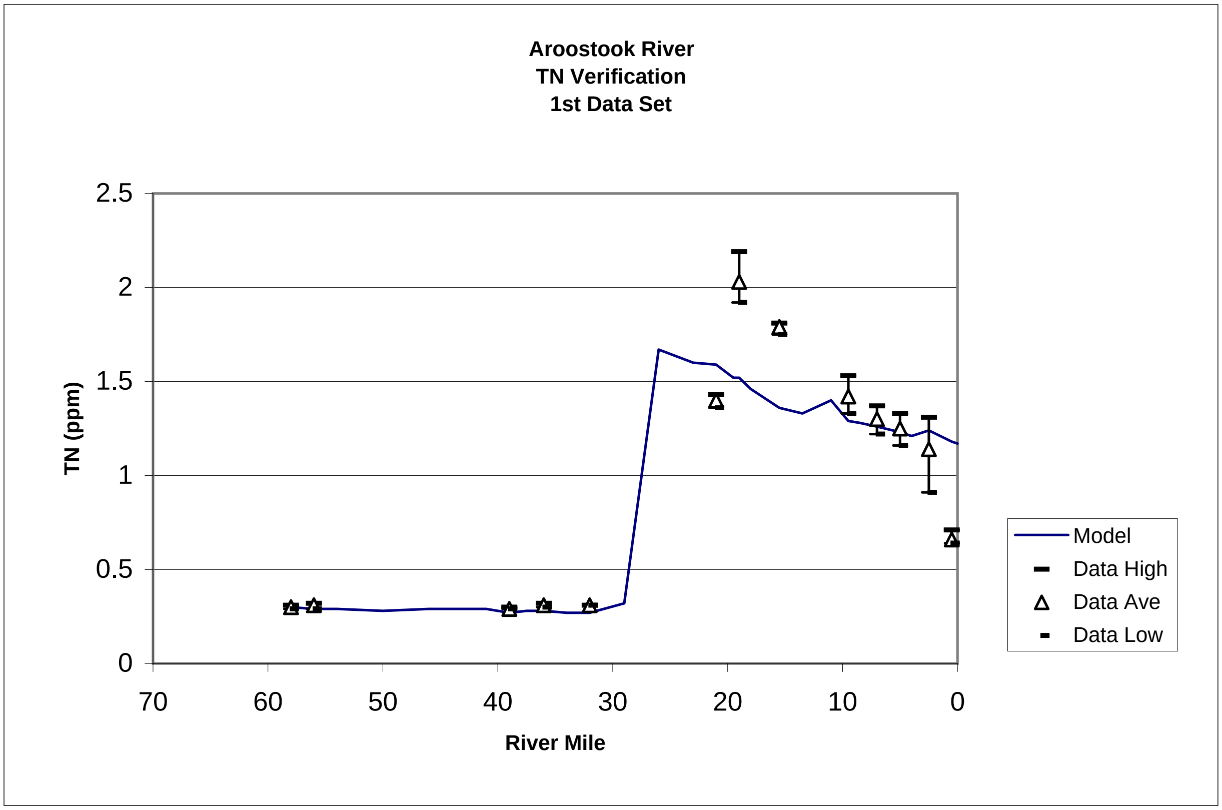


Figure 9b - Total Nitrogen Verification - Aug 14 - 16 2001 Data Set



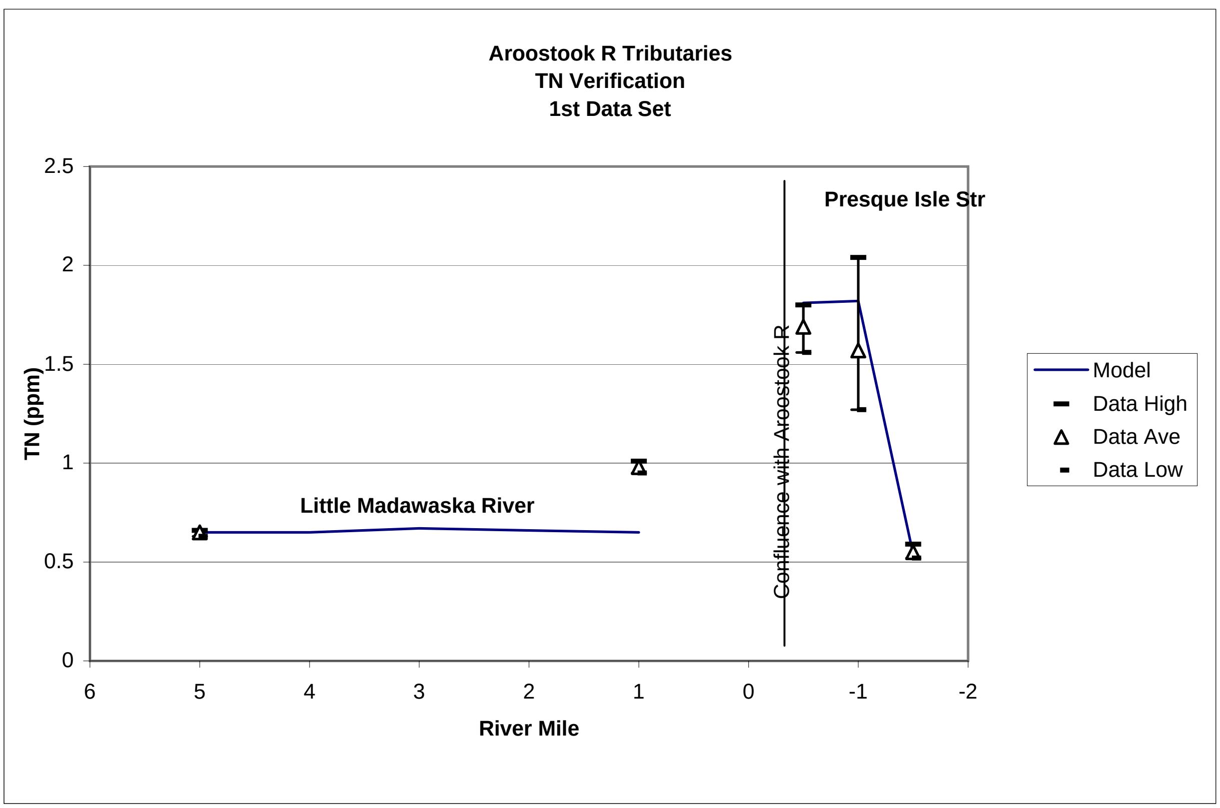
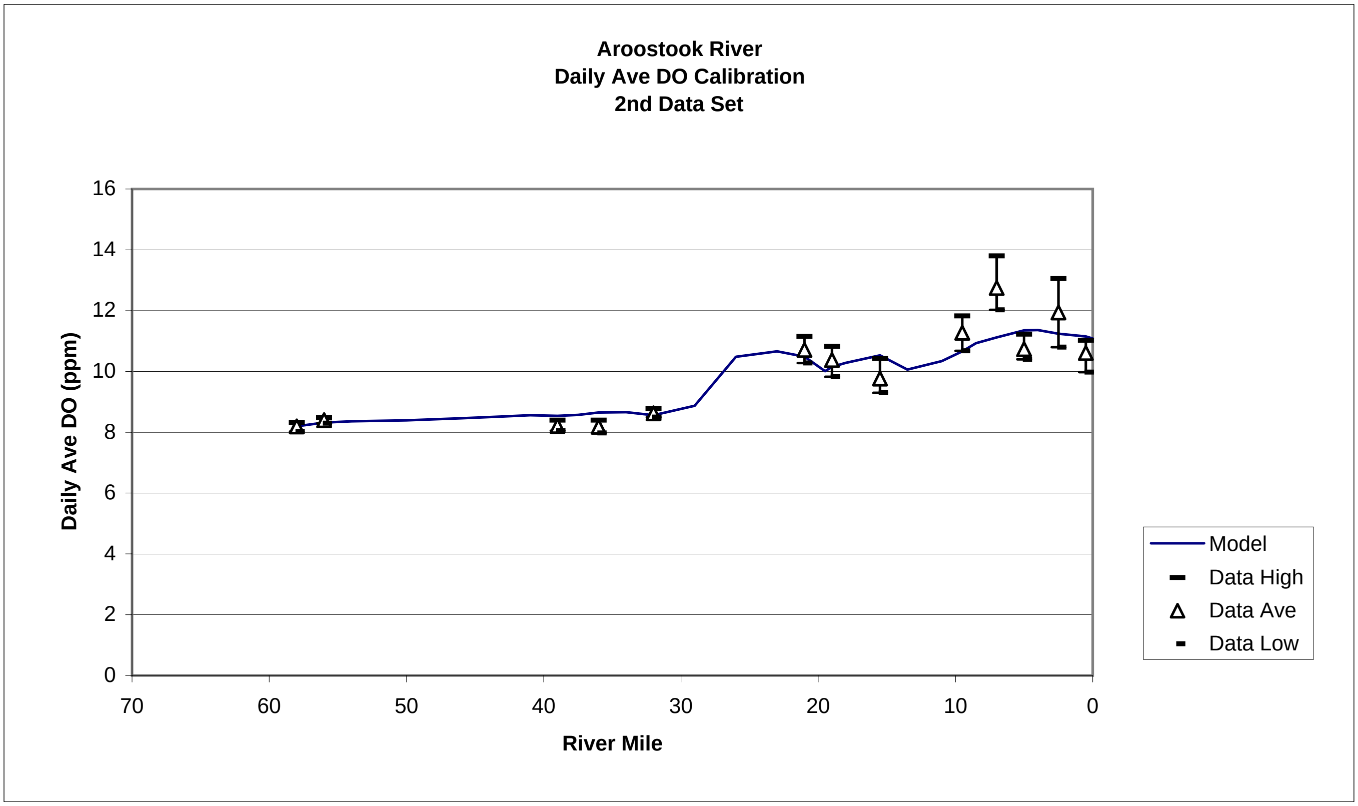


Figure 10a - Average Dissolved Oxygen Calibration - Aug 28 - 30 2001 Data Set



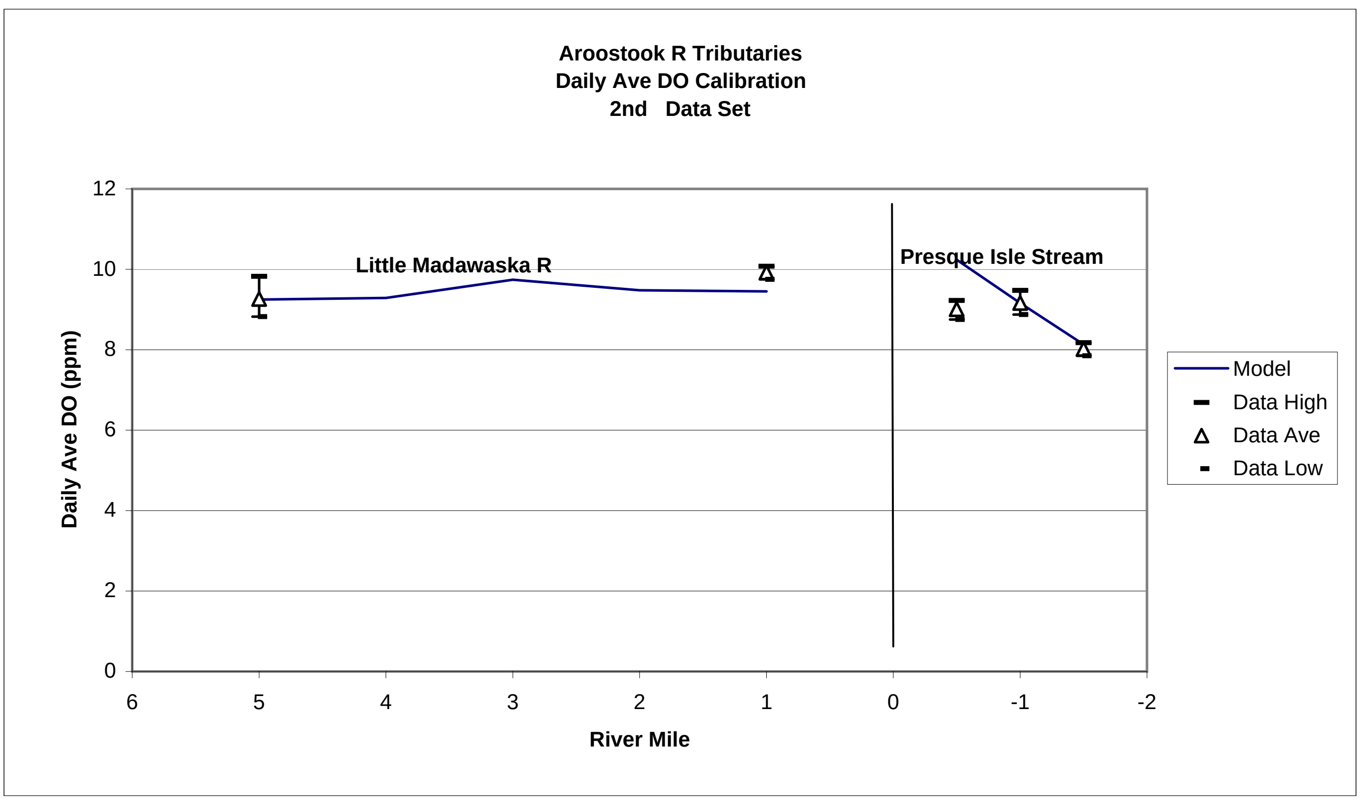
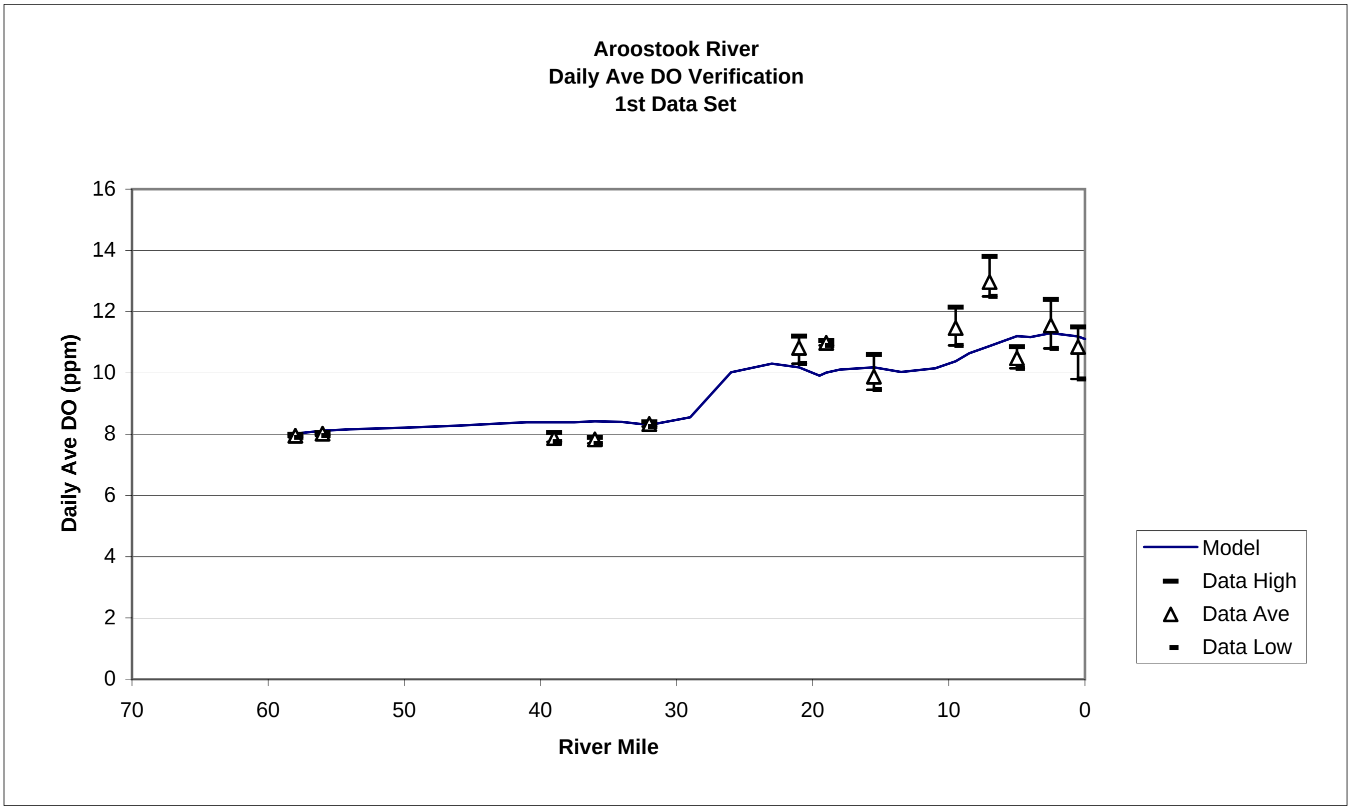


Figure 10b - Average Dissolved Oxygen Verification - Aug 14 - 16 2001 Data Set



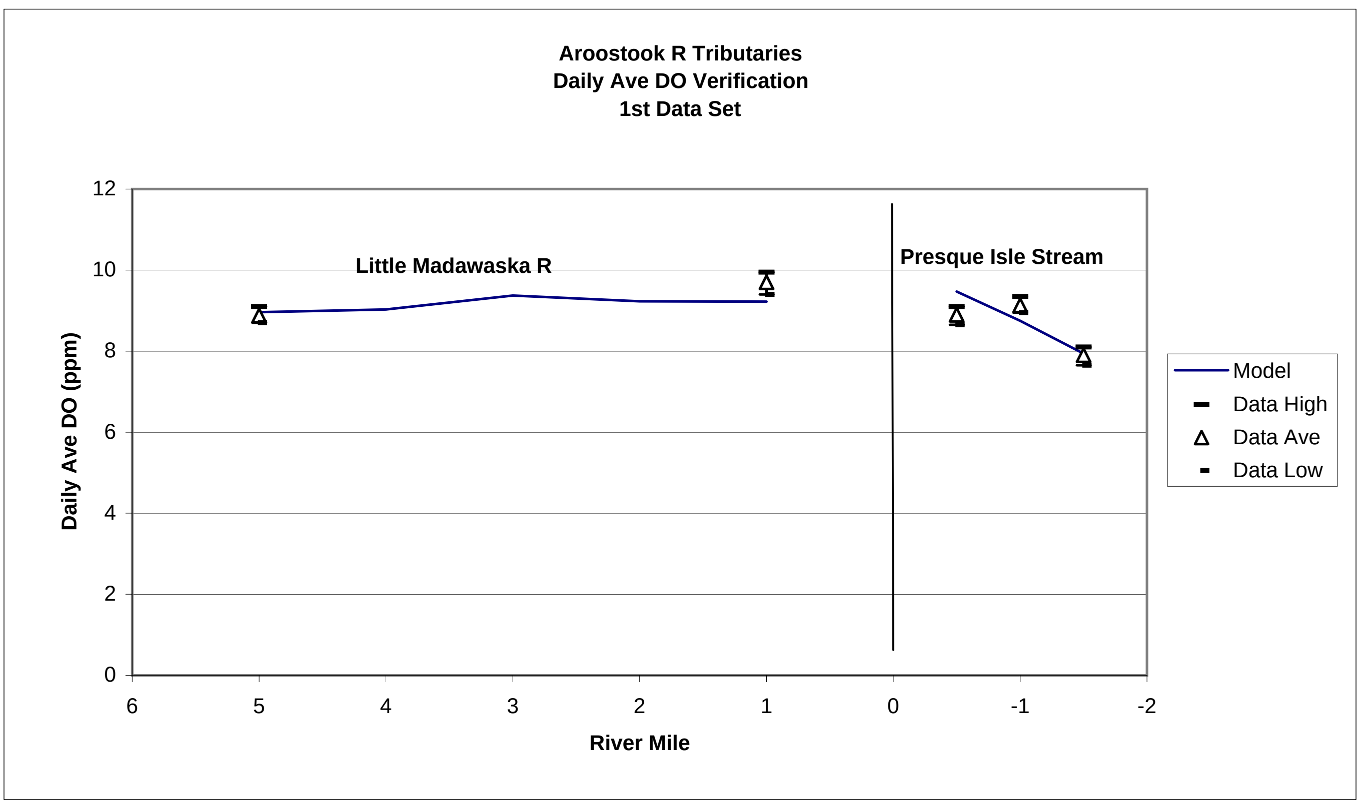
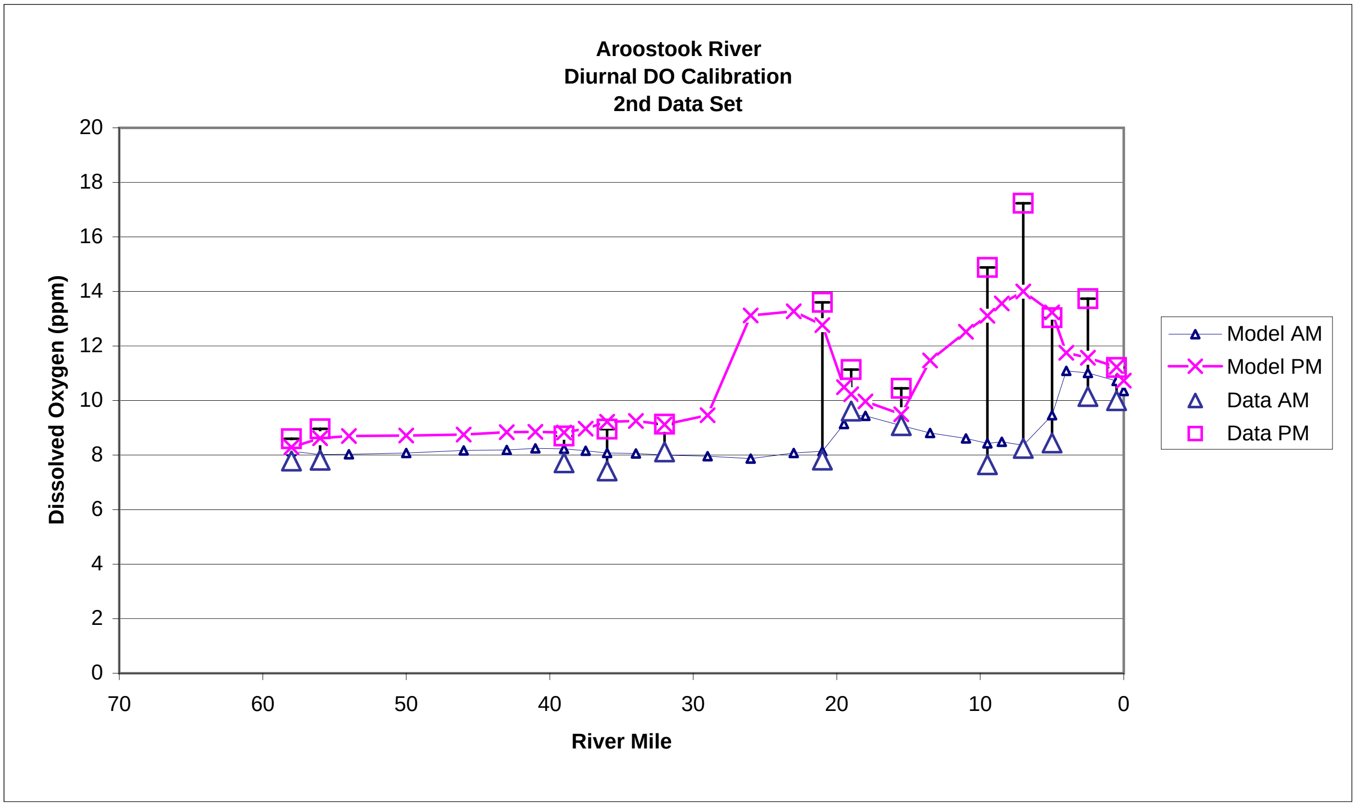


Figure 11a - Diurnal Dissolved Oxygen Calibration - Aug 28 - 30 2001 Data Set



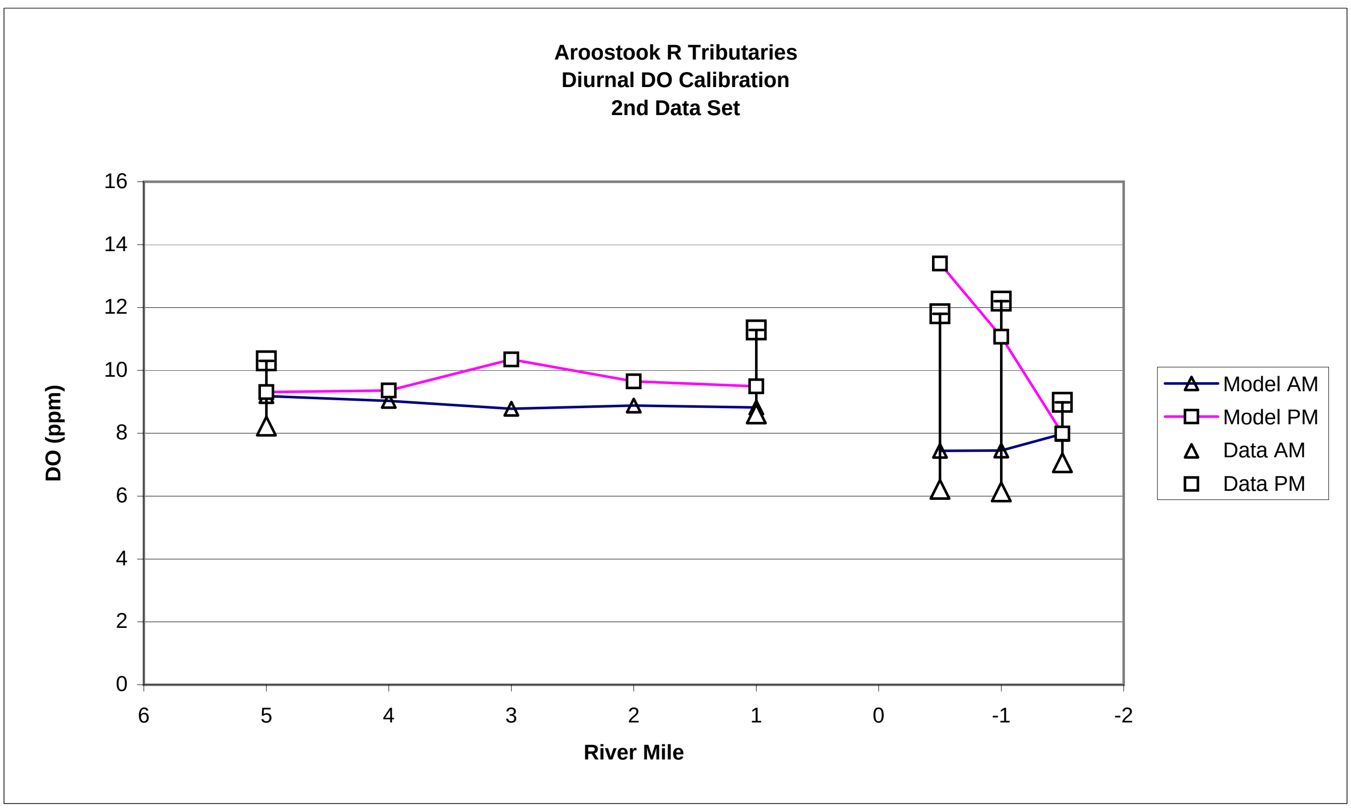
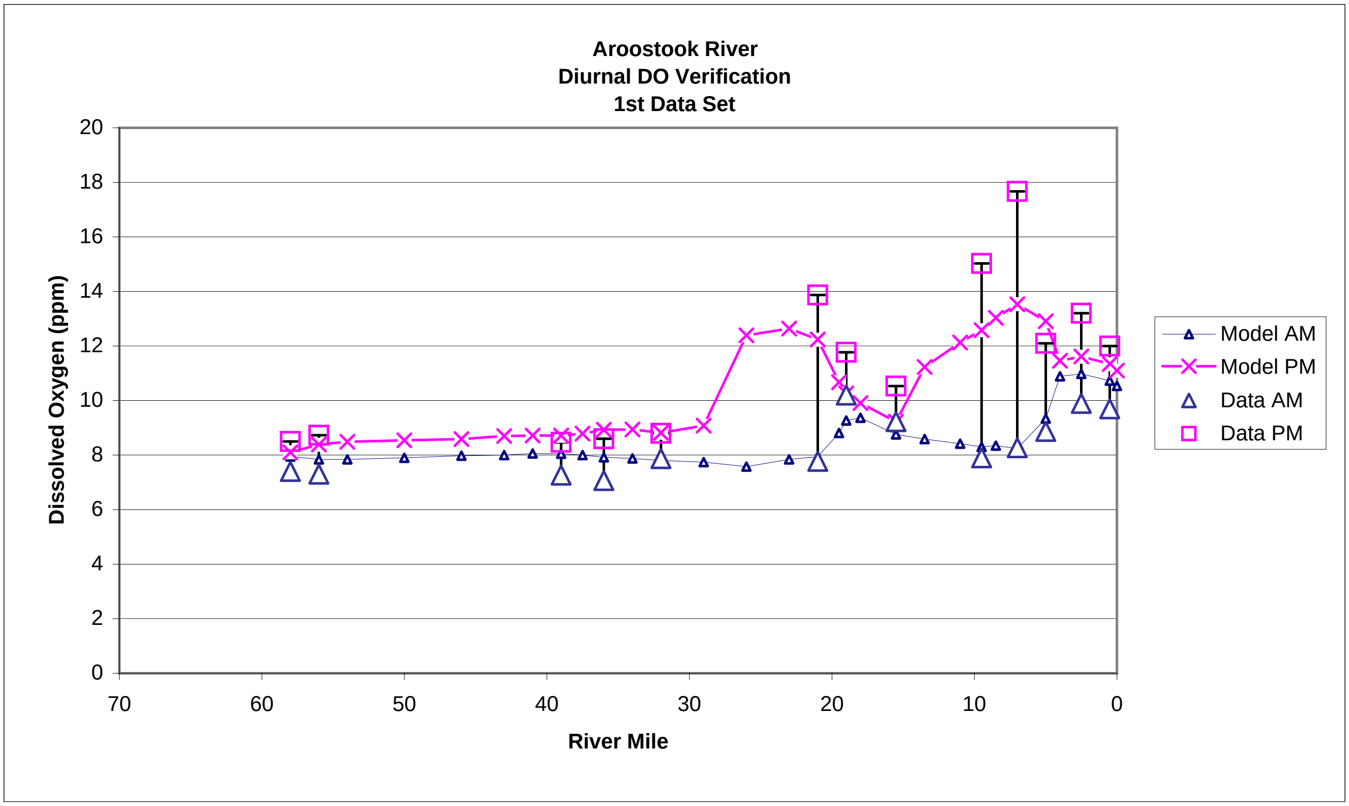
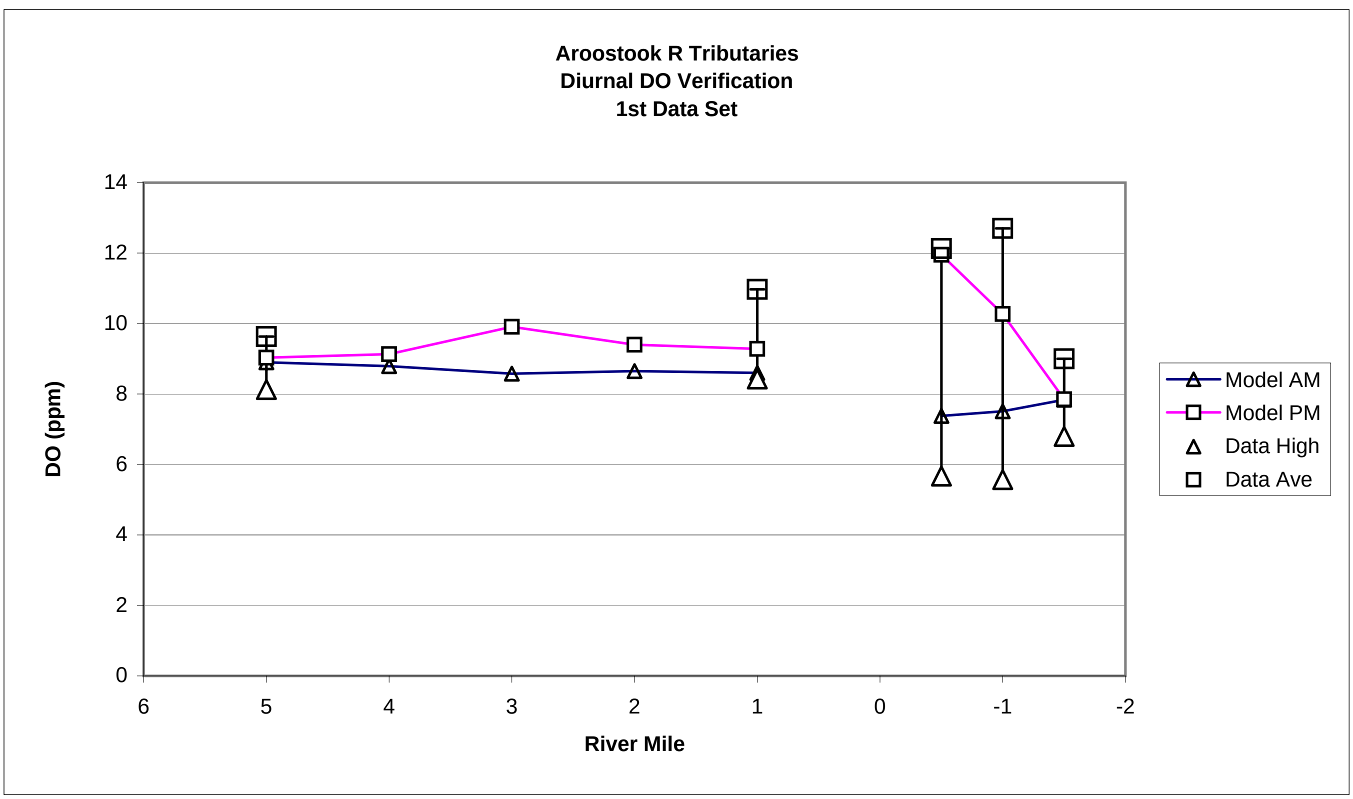


Figure 11b - Diurnal Dissolved Oxygen Verification - Aug 14 - 16 2001 Data Set





sampling dates; Aug 28 -30 and Aug 14-16 to describe the data even though data outside this time period was also used in the modeling analysis.

The calibration and verification of the model was problematic, due to the unstable and highly dynamic nature of a river that is dominated by algal interactions. As mentioned earlier, the difference between the early morning and late afternoon dissolved oxygen readings (diurnal DO range) was often 6 ppm and as much as 10 ppm. This system is very complex and is marginally within the limits of application of water quality models for predictions.

In addition, there is a large loss of nitrogen and phosphorus (orthophosphorus in particular and organic phosphorus, nitrogen, and nitrate nitrogen to a lesser extent) below some of the point source discharges that are assimilated quickly in a relatively short distance (1 to 2 miles). For example, 80% to 90% of the orthophosphosphorus is assimilated below the Presque Isle and Caribou discharges in one to two miles of river length. The model had difficulty simulating this phenomena. It is deduced that large quantities of orthophosphorus are being uptaken by bottom attached plants. To compensate for this phenomena, a orthophosphorus uptake rate was included in the modeling effort. This is not directly included in the model, but can be simulated by assignment of negative flux rate into sediments (which is actually uptake by the benthic algae).

In a large river with impoundments where currents are not significant, the UBOD decay rates derived in the laboratory test often give satisfactory results for an estimation of the actual ambient rates. The Aroostook River falls into this category river type. The laboratory rates are derived from a least square regression line fit of many UBOD values measured over the 60 day time period. The following equation is used in this analysis.

$\mathbf{BOD_t = UBOD\ (1\text{-}e\text{-}^{kt})}$ Where BOD_t = BOD in ppm at any given time
UBOD = The final ultimate BOD in ppm
K = The BOD decay rate (/day)
T = Time in days.

A CBOD decay rate of 0.05 per day was used for both the calibration and verification data sets. This resulted in a satisfactory match of modeled to measured ultimate CBOD (Figures 5a, 5b).

Nitrogenous BOD decay is not an issue on the Aroostook River. At almost all river locations, the measured value of ammonia nitrogen was under the detection limit of 0.04 ppm.

A benthic CBOD source rate was assigned to all model reaches. This value varied from 10 to 80 mg / ft^2-day. Some user judgement is necessary when assigning this rate. The rates assigned to the model resulted in an improved BOD calibration when using the measured laboratory rates in the BOD calibration. Given that the rate of CBOD decay is well established through many laboratory tests, curve fitting to the data is a reliable way to estimate CBOD benthic sources, so long as the rates are consistent with expected trends from pollutant inputs. This is definitely the case for the Aroostook River model.

A low rate of 10 mg / ft^2-day was assigned to reaches with low impact from point source discharges, which includes the river reaches from Ashland to the confluence of Presque Isle Stream and the Little Madawaska River. A rate of 40 mg / ft^2-day was used in areas impacted by point sources, except 80 mg / ft^2-day was used in the Caribou dam impoundment on the first data set. The higher benthic BOD assigned in impoundments may actually be due to algae that settles in the impoundments. The algae measured in the first data set above the Caribou dam was about 50% higher than the second data set and this could explain the higher sediment CBOD source rate assigned to the first data set.

The chlorophyll-a was calibrated and verified as follows. There are many different parameter rates that can be adjusted when calibrating chlorophyll a. Most of these were set to default values. For the algae growth rate, MDEP's experience in modeling phytoplankton has almost always resulted in an algae growth rate of 1.8 to 2.0 per day. For the Aroostook, a value of 1.8 per day was used. This initially resulted in modeled chlorophyll-a being lower than measured. The algal loss coefficient was next adjusted lower in some reaches until a satisfactory match of modeled to measured chlorophyll a occurred (Figures 6a, 6b).

Although referred to in the Qual2e users manual as algal settling, the settling term actually represents algal losses due to settling, death, and zooplankton grazing (the latter two of these are not separately included in the input coefficients for Qual2e). Hence in the Aroostook Modeling Report, it is referred to as an algal loss coefficient. In most modeled reaches, a algal loss coefficient of 0.2 ft/per day and 0.1 ft/per day, respectively for the first and second data sets gave the best results.

In the reach below the Caribou dam, the data indicate that large losses of algae are occurring. This is most likely due to the change of algae type from a phytoplankton dominated system to that of benthic dominated algae as the river changes from impounded to free flowing. A rate of 1.0 ft/day gave the best result in both data sets for this reach.

In the Tinker dam impoundment, there appeared to be a larger loss of algae in the first data set when compared to the second data set. The exact reason for this is unknown. An algal loss coefficient of 1.5 ft/day was assigned to reaches here in the first data set.

As mentioned earlier, there appears to be a large loss of dissolved phosphorus below point source discharges. The exact reasons for this are uncertain, but two possible reasons are discussed. One theory could be that a microhabitat of lush bottom plant growth may be occurring directly below outfall pipes as the river's response for alleviating abnormally high phosphorus levels here. This could result in a rapid uptake of nutrients. To a lesser extent, the settling of orthophosphorus could be occurring. Although dissolved solids do not ordinarily settle, other studies have shown that orthophosphorus can attach onto particulate solids through adsorption. The phosphorus uptake rate assigned as a negative flux to the sediments was used to simulate both phenomena. This was used as the main mechanism to calibrate orthophosphorus. To a lesser extent, this loss phenomena also occurs for organic phosphorus and organic nitrogen. Adjustments to the settling rate were used to calibrate these parameters.

Woodard and Curran mentions another possible explanation for rapid phosphorus loss in the Aroostook River in their comments to the draft modeling report. They believe it is a physical – chemical process in which calcium in the Aroostook River under a high pH environment is precipitating the PO4-P out of the water column. Although this is possible to some extent, MDEP has observed the rapid uptake of phosphorus in other river studies, even in a much lower pH environment, and still suspects that most of the uptake is occurring by the benthic algae. W&C's theory is mentioned in this final report as a phenomena to investigate in future river sampling. In any event, the algae is causing the high pH, and would still be indirectly responsible for the rapid uptake of phosphorus, assuming that this theory is valid.

The phosphorus loss inputs were generally adjusted to very high rates below point source discharges and lower rates in less impacted areas. When these and some other adjustments were made to the model, a good calibration of chlorophyll-a and nutrients results (figures 7a, 7b, 8a, 8b, 9a, 9b).

The dissolved oxygen calibration involves both a daily average calibration and a daily minimum calibration. The former involves running the model in the steady state mode and comparing the model output to the daily average dissolved oxygen observed in both data sets. The latter involves running the model in the dynamic mode and comparing the model output to the AM and PM dissolved oxygen observed in both data sets.

The calibration of dissolved oxygen involves the initial steps of calibrating BOD, chlorophyll a, and nutrient and subsequent steps of estimating the reaeration rate (K_a) and sediment oxygen demand rate (SOD) for each modeled reach of river[5]. Then the periphyton component of the model must be adjusted so that both diurnal and daily average dissolved oxygen outputted by the model match the data. K_a and SOD are typically very variable over the length of a river and the rates assigned can be quite different reach by reach.

There are a number of formulas to estimate reaeration based upon research by experts. Up to eight different formulations can be specified by the user in QUAL2. The O-Connor Dobbins reaeration formula which calculates reaeration as a function of velocity and depth was used in most reaches.

$$\mathbf{k_a = 12.85\ V^{.5}/D^{1.5}}$$ where v = velocity in fps, and D = depth in ft

In the deeper and lower velocity reaches, k_a was calculated by an impoundment reaeration formula which is considered a lower bound for k_a whenever the O Connor-Dobbins formula results in a lower estimate.

[5] The reaeration rate, K_a, is the rate at which oxygen from the atmosphere enters the water column at the surface. K_a is typically high in stretches of rapids or shallow water, and low in impounded or sluggish water. Sediment oxygen demand is the oxygen demand exerted by bottom sediments to the water column.

$k_a = 3/D$

This option is not directly available in QUAL2EU, but can be calculated outside the model and input as a user specified rate. The reaeration rates calculated by the model were quite variable ranging from a low of 0.25 per day directly above the Caribou dam to a high of 20.38 per day on the Little Madawaska River (Table 5).

SOD analyses at two river impoundment locations were undertaken in the autumn of 2001 by USEPA. The measured values of 50 and 85 mg / ft^2-day were used for the Caribou dam and Tinker dam impoundments, respectively. A lower value of 10 mg / ft^2-day was used for the free flowing river sections from the Caribou dam to the head of the Tinker dam impoundment and the Little Madawaska River segments.

A higher SOD rate of 150 mg / ft^2-day was used in the upper reaches of the Aroostook (Ashland to Prsque Isle). The model predicts higher dissolved oxygen than measured here, when an input SOD rate equivalent to the Caribou dam impoundment was used. The reason for this appears to be the unusually high algae and periphyton oxygen production rates used for the model. This rate cannot be assigned as a reach variable rate and may be inappropriate for this section of the river where algae levels are low compared to the river below the confluence of Presque Isle Stream. Adjustments to other parameters were considered without success (Table 6).

Table 6 Dissolved Oxygen Calibration Sensitivity Upper Aroostook

Dissolved Oxygen (ppm)							
Sample Location	Data Ave DO (ppm)	Aug 28-30 Calibration	Run 1	Run 2	Run 3	Run 4	Run 5
Rte 11 Ash.	8.19	8.19	8.19	8.19	8.19	8.19	8.19
Ashland Below	8.39	8.32	8.67	8.67	8.72	8.3	8.47
Washburn	8.21	8.54	8.94	8.93	8.81	8.68	8.72
Crouseville	8.18	8.65	9.15	9.14	9.15	9.08	8.6
Above Rte 1 Presque Isle	8.62	8.56	9.15	9.13	9.01	9.66	8.4
Model Inputs							
SOD (mg/ft^2-day)		150	50	50	50	50	50
Velocity (ft/sec)		.4 - .72	Same	Same	x .5	Same	Same
Reaeration (/day)		3.75 - 9.07	Same	Same	Lower*	1	1
Benthic CBOD (mg/ft2-day)		10	Same	40	Same	Same	Same
O2 Production Algae/Peri		20 / 6	Same	Same	Same	Same	1.6 / 1.6

*Lower reaeration due to less velocity.

The SOD rate of 150 mg/ft^2-day is being used to assure that the boundary DO above Presque Isle predicted by the model is accurate. The model may eventually be discontinued above Presque Isle, due to the low probability of water quality issues there.

The diurnal range of dissolved oxygen (minimum AM and maximum PM DO) were used to calibrate the periphyton component of the model. No direct measurements of periphyton were made. Periphyton, filamentous algae such as Cladaphora, and vascular plants (macrophytes) could all contribute to the diurnal dissolved oxygen swing. In a river that is so abundant with algae, this would be difficult to measure accurately. The dissolved oxygen range measures the response of bottom attached plants. This is analogous to the BOD test in which organic matter is not measured directly, but the response of organic matter or dissolved oxygen depletion is used as a measure of oxygen demanding substances.

The parameter rates used for each model reach are summarized in tables 4 and 5. To calibrate dissolved oxygen, values of oxygen production by algae and periphyton (20 and 6, respectively) are much higher than literature values. There are no adjustments that can be made to the model within literature values that will result in a good calibration. Much of the dissolved oxygen data is supersaturated (> 100% saturation) and it is unclear if the model can perform as well under these conditions. The calibration of dissolved oxygen with these parameter rates results in a good fit of the model output to the daily average (Figures 10a and 10b) and daily minimum of the measured data (Figures 11a and 11b). The data appear to indicate that compliance of dissolved oxygen should not be an issue on this river, and hence the unusual oxygen production rates assigned to the model are likely not an issue.

Sensitivity Analysis

In a sensitivity analysis, some of the parameter rates can be tested to determine which are more important in the development of the model. The model calibration run (Aug 28-30) was used as a basis for the sensitivity analysis runs. Fifteen different parameter inputs are tested (Table 8a,b) for responses to dissolved oxygen, carbonaceous BOD, chlorophyll a, periphyton, and orthophosphorus. Each parameter was varied by ± 50% and the model output for the five water quality constituents was then compared at three strategic locations. The three locations chosen are above the Caribou dam, Goodwin, and at the international border in the Tinker dam impoundment. The two impoundment sites had the highest phytoplankton levels, and the Goodwin site, the highest diurnal DO swings and hence the highest levels of bottom attached plants.

The results of the sensitivity analysis are first tabulated in units as ± (Table 8a) and then as average percentages (Table 8b). It should be apparent that the algae rates were most sensitive in the impoundment locations (Caribou dam, international border) and the periphyton rates in the flowing section (Goodwin).

From this analysis, it can be observed that the most important parameters in calibrating dissolved oxygen are the reaeration rate, algae or periphyton growth rates, orthophosphorus uptake rate, and the algae or periphyton oxygen production rates. For the BOD calibration both the BOD decay rate and the CBOD benthic source rate are important. For the chlorophyll a calibration, the algae growth rate, the orthophosphorus uptake rate, and the algae loss coefficients are the most important parameters. The periphyton growth rate and orthophosphorus uptake rate are the most important parameters for the model's prediction of periphyton. The orthophosphorus uptake rate is

Table 7a

Above Caribou Dam			Ave DO	BOD	Chl-a	Periphyton	PO4-P
			ppm	ppm	ppb	mg chl-a / ft^2	ppb
Aug 28-30 Model Run			10.53	4.28	10.54	0	5.3
SA1	SOD	+ 50% - 50%	± .3				
SA2	BOD Decay	+ 50% - 50%	- .19 + .28	- .76 + .97			
SA3	Benthic CBOD	+ 50% - 50%	± .17	± 1.14			
SA4	Reaeration*	+ 50% - 50%	-.53 + 1.52				
SA5	Algae Growth	+ 50% - 50%	+ 1.56 - 1.17		+ 8.32 - 10.24	0 + 11.2	- 3.6 + 2.6
SA6	Periphyton Growth	+ 50% - 50%	Model would not run due to nonconvergence of algae - .10		+ .72	0	+ 1.1
SA7	Algae Loss	+ 50% - 50%	± .11		- 1.05 + 1.14	0	± .3
SA8	PO4-P Uptake	+ 50% - 50%	- 3.07 + 1.09		- 10.18 +2.94	0	- 5.3 + 29.1
SA9	P Half - Saturation Algae	+ 50% - 50%	- .33 + .46		- 1.75 + 2.33	0	+.6 - .8
SA10	P Half - Saturation Periphyton	+ 50% - 50%	- .05 Model would not run due to nonconvergence of algae		+ .28	0	+ .3
SA11	P- Content Algae	+ 50% - 50%	- .18 + .15		- 1.64 + .52	0	- 1.4 + 1.6
SA12	P-Content Periphyton	+ 50% - 50%	Model would not run due to nonconvergence of algae + .17		+ .56	0	+ .9
SA13	Light Saturation Algae / Peri.	+ 50% - 50%	- .4 + .77		- 1.59 + 2.62	0	+ .6 - .8
SA14	Oxygen Production Algae	+ 50% - 50%	± 1.42				
SA15	Oxy. Production Periphyton	+ 50% - 50%	± .34				

Goodwin			Ave DO	BOD	Chl-a	Periphyton	PO4-P
			ppm	ppm	ppb	mg chl-a / ft^2	ppb
Aug 28-30 Model Run			11.12	5.01	8.07	40.1	23.3
SA1	SOD	+ 50% - 50%	± .19				
SA2	BOD Decay	+ 50% - 50%	- .01 + .03	- .69 + .90			
SA3	Benthic CBOD	+ 50% - 50%	-.01 + .02	± 1.38			
SA4	Reaeration	+ 50% - 50%	-.69 + 1.79				
SA5	Algae Growth	+ 50% - 50%	+ .58 - .19		+ 11.6 - 6.74	- 4.9 + 2.4	- 4.0 + 2.6
SA6	Periphyton Growth	+ 50% - 50%	Model would not run due to nonconvergence of algae - 1.27		+ .62	- 22.1	+ 1.5
SA7	Algae Loss	+ 50% - 50%	- .08 + .74		- 2.95 + 5.55	+ .8 - 1.7	+ .5 - .8
SA8	PO4-P Uptake	+ 50% - 50%	- 2.33 + .42		- 7.13 + 2.85	- 40.1 + 5.7	- 23.3 + 37.4
SA9	P Half - Saturation Algae	+ 50% - 50%	-.05 + .03		- 1.38 + 1.94	+ .5 - .8	+ .5 - .9
SA10	P Half - Saturation Periphyton	+ 50% - 50%	- .21 Model would not run due to nonconvergence of algae		+ .22	- 4.0	+ .3
SA11	P- Content Algae	+ 50% - 50%	- .06 + .03		- .52 + .50	± .4	- 1.3 + 1.5
SA12	P-Content Periphyton	+ 50% - 50%	Model would not run due to nonconvergence of algae + .03		+ .48	+ .4	+ 1.3
SA13	Light Saturation Algae / Peri.	+ 50% - 50%	- .16 + .28		- 1.15 + 1.79	- 1.6 + 1.8	+ .6 - .9
SA14	Oxygen Production Algae	+ 50% - 50%	± .18				
SA15	Oxy. Production Periphyton	+ 50% - 50%	± 1.76				

* The sensitivity analysis reaeration response to DO is the opposite of what normally occurs, due to supersaturation of DO.

Table 7a **Sensitivity Analysis - Deviation from Base Case for ± 50% Adjustment of Rates**							
USA / Canada Border			Ave DO	BOD	Chl-a	Periphyton	PO4-P
			ppm	ppm	ppb	mg chl-a / ft^2	ppb
Aug 28-30 Model Run			11.15	4.45	11.52	0	12.5
SA1	SOD	+ 50% - 50%	- .47 + .54				
SA2	BOD Decay	+ 50% - 50%	- .14 + .25	- 1.02 + 1.47			
SA3	Benthic CBOD	+ 50% - 50%	± .22	± 1.46			
SA4	Reaeration	+ 50% - 50%	- 0.80 + 1.90				
SA5	Algae Growth	+ 50% - 50%	+ 2.6 - .23		+ 9.07 - 10.84	0 + 24.7	- 7.6 + 6.1
SA6	Periphyton Growth	+ 50% - 50%	Model would not run due to nonconvergence of algae - .59		+ .31	0	+ 1.6
SA7	Algae Loss	+ 50% - 50%	- .55 + .50		- 3.52 + 4.92	0	+ 1.5 - 1.7
SA8	PO4-P Uptake	+ 50% - 50%	- 4.17 + .63		- 11.46 + 1.58	0	- 12.5 + 62.4
SA9	P Half - Saturation Algae	+ 50% - 50%	- .23 + .25		- 1.88 + 1.38	0	+ 1.0 - .7
SA10	P Half - Saturation Periphyton	+ 50% - 50%	- .05 Model would not run due to nonconvergence of algae		+ 0.10	0	+ .4
SA11	P- Content Algae	+ 50% - 50%	- .19 + .13		- .47 + .35	0	- 3.1 + 3.6
SA12	P-Content Periphyton	+ 50% - 50%	Model would not run due to nonconvergence of algae + .10		+ .26	0	+ 1.4
SA13	Light Saturation Algae / Peri.	+ 50% - 50%	- .7 + 1.16		- 2.17 + 3.55	0	+ 1.5 - 1.7
SA14	Oxygen Production Algae	+ 50% - 50%	± 1.94				
SA15	Oxy. Production Periphyton	+ 50% - 50%	± .24				

* The sensitivity analysis reaeration response to DO is the opposite of what normally occurs, due to supersaturation of DO.

Table 7b

Sensitivity Analysis -% Deviation from Base Case for 50% Adjustment of Rates

Above Caribou Dam		Ave DO	BOD	Chl-a	Periphyton	PO4-P
		ppm	ppm	ppb	mg chl-a / ft^2	ppb
Aug 28-30 Model Run		10.53	4.28	10.54	0	5.3
SA1	SOD	2.8%				
SA2	BOD Decay	2.2%	20.2%			
SA3	Benthic CBOD	1.6%	26.6%			
SA4	Reaeration*	9.7%				
SA5	Algae Growth	13.0%		88.0%		58.5%
SA6	Periphyton Growth	1.0%		6.8%		20.8%
SA7	Algae Loss	1.0%		10.4%		5.7%
SA8	PO4-P Uptake	19.8%		62.2%		324%
SA9	P Half - Saturation Algae	3.8%		19.4%		13.2%
SA10	P Half - Saturation Periphyton	0.5%		2.7%		5.7%
SA11	P- Content Algae	1.6%		10.2%		28.3%
SA12	P-Content Periphyton	1.6%		5.3%		17.0%
SA13	Light Saturation Algae / Peri.	5.6%		20.0%		13.2%
SA14	Oxygen Production Algae	13.5%				
SA15	Oxy. Production Periphyton	3.2%				

Goodwin		Ave DO	BOD	Chl-a	Periphyton	PO4-P
		ppm	ppm	ppb	mg chl-a / ft^2	ppb
Aug 28-30 Model Run		11.12	5.01	8.07	40.1	23.3
SA1	SOD	1.7%				
SA2	BOD Decay	0.2%	16.0%			
SA3	Benthic CBOD	0.1%	27.5%			
SA4	Reaeration	11.1%				
SA5	Algae Growth	3.5%		113.6%	9.1%	14.2%
SA6	Periphyton Growth	11.4%		7.7%	55.1%	6.4%
SA7	Algae Loss	3.7%		52.7%	3.1%	27.9%
SA8	PO4-P Uptake	12.4%		61.8%	57.1%	130.3%
SA9	P Half - Saturation Algae	0.4%		20.6%	16.2%	3.0%
SA10	P Half - Saturation Periphyton	1.9%		2.7%	10.0%	1.3%
SA11	P- Content Algae	0.4%		6.3%	1.0%	6.0%
SA12	P-Content Periphyton	0.3%		6.0%	1.0%	5.6%
SA13	Light Saturation Algae / Peri.	2.0%*		18.2%	4.2%	3.2%
SA14	Oxygen Production Algae	1.6%				
SA15	Oxy. Production Periphyton	15.8%				

Table 7b

Sensitivity Analysis - Deviation from Base Case for ± 50% Adjustment of Rates

USA / Canada Border		Ave DO	BOD	Chl-a	Periphyton	PO4-P
		ppm	ppm	ppb	mg chl-a / ft^2	ppb
Aug 28-30 Model Run		11.15	4.45	11.52	0	12.5
SA1	SOD	4.5%				
SA2	BOD Decay	1.8%	28.0%			
SA3	Benthic CBOD	2.0%	33.0%			
SA4	Reaeration	12.1%				
SA5	Algae Growth	12.7%		86.4%		54.8%
SA6	Periphyton Growth	5.3%		2.7%		12.8%
SA7	Algae Loss	4.7%		36.6%		12.8%
SA8	PO4-P Uptake	21.5%		56.6%		300.0%
SA9	P Half - Saturation Algae	2.2%		14.2%		6.8%
SA10	P Half - Saturation Periphyton	0.4%		0.9%		3.2%
SA11	P- Content Algae	1.4%		3.6%		26.8%
SA12	P-Content Periphyton	9.0%		2.3%		11.2%
SA13	Light Saturation Algae / Peri.	8.3%		24.8%		12.8%
SA14	Oxygen Production Algae	17.4%				
SA15	Oxy. Production Periphyton	2.2%				

* The sensitivity analysis reaeration response to DO is the opposite of what normally occurs, due to supersaturation of DO.

the main parameter responsible for the calibration of PO4-P and to a lesser extent, the algae growth rate is important.

It should be understood that one of the primary reasons for the orthophosphorus uptake rate sensitivity in these runs is that when this rate is increased by 50%, the river's orthophosphorus goes to zero, which result in the total depletion of any algae and the related oxygen production. Hence a threshold of phosphorus limitation is crossed. In the actual calibration / verification of the model, the necessary precautions would be taken by the modeler to assure that this threshold isn't crossed. The sensitivity analysis was undertaken and tabulated in a uniform way rather than arbitrarily conducting the analysis to avoid crossing this threshold.

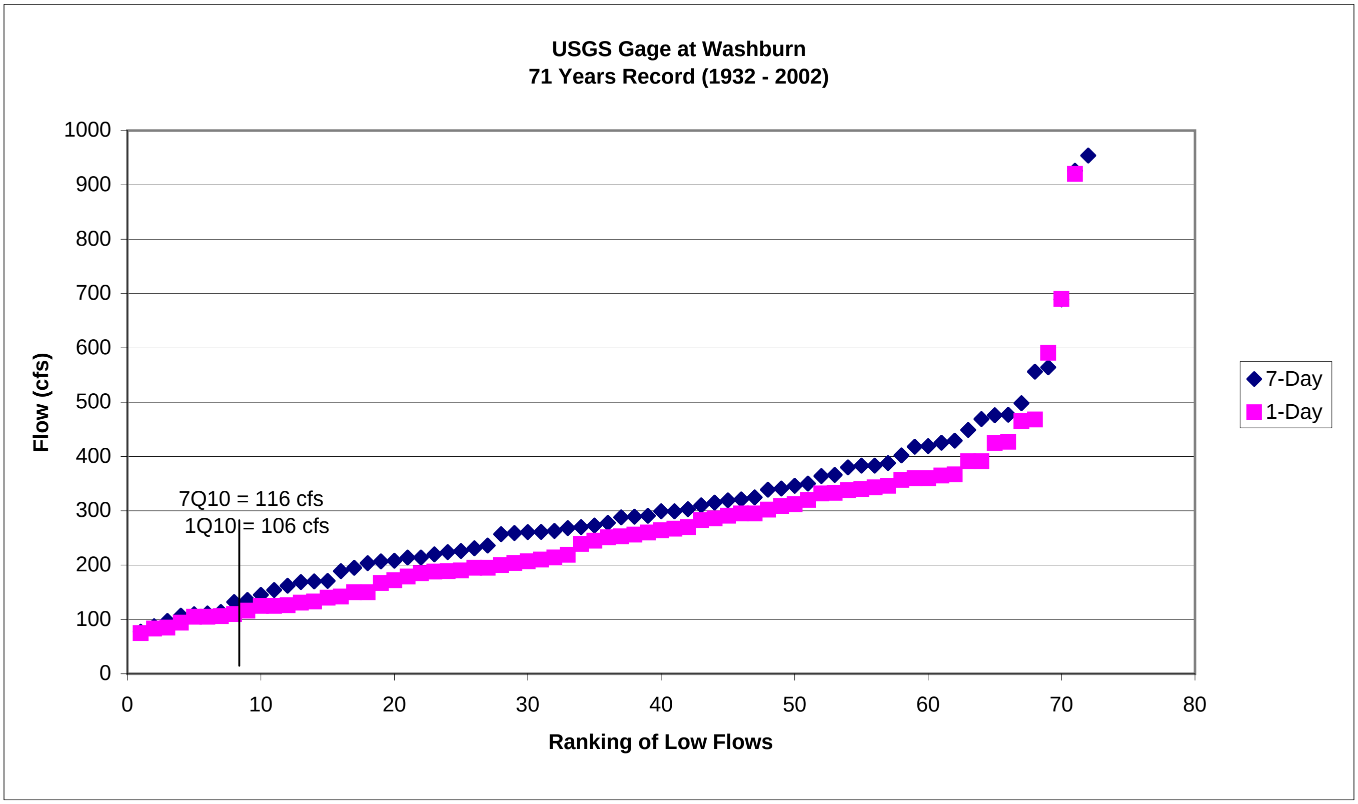
Model Predictions Runs of Current Conditions at 10-Year Low Flow

After a water quality model is calibrated to observed data, a prediction run is made at worst case conditions to assure water quality standards will be achieved at all locations. Worse case conditions are defined by low river flows, when dilution of wastewater is at a minimum; by high water temperatures, when the saturation of dissolved oxygen is lower and BOD decay and oxygen demand from the sediment are higher; and by point sources discharging at licensed limits. Non- point source loads are accounted for as tributary loads with pollution concentrations as measured in the August 2001 surveys, distributed load inputs in the model incremental flow, and as sediment oxygen demand (which results partially as sediment that has settled during runoff events prior to low flow).

The 7-day 10-year low flow (7Q10)[6] is used to assess compliance with dissolved oxygen criteria. Prior estimates of 7Q10 were based upon USGS gages utilizing the period of record up to 1991. This analysis was updated to also include the years from 1992 to 2002. The updates resulted in new 7Q10's of 116 cfs at the Washburn USGS gage and 67 cfs at Masardis USGS gage (Figure 12). The updated information for flow results in new 1Q10 flows of 106 cfs at Washburn and 60 cfs at Masardis. The previously derived flow balance (Table 3) was used to determine various 7Q10 flows and 1Q10 flows at different locations. Dilutions for the toxics program regulation for point source discharges (Chap. 530.5) will be changed based upon this updated information (Table 8).

[6] The 7-day 10-year low flow (7Q10) is the lowest 7-day average flow expected to occur at a frequency of once in ten years. The 1-day ten year low flow (1Q10) is the lowest single day flow expected to occur at a frequency of once in ten years.

Figure 12 - Determination of 10-Year Low Flows



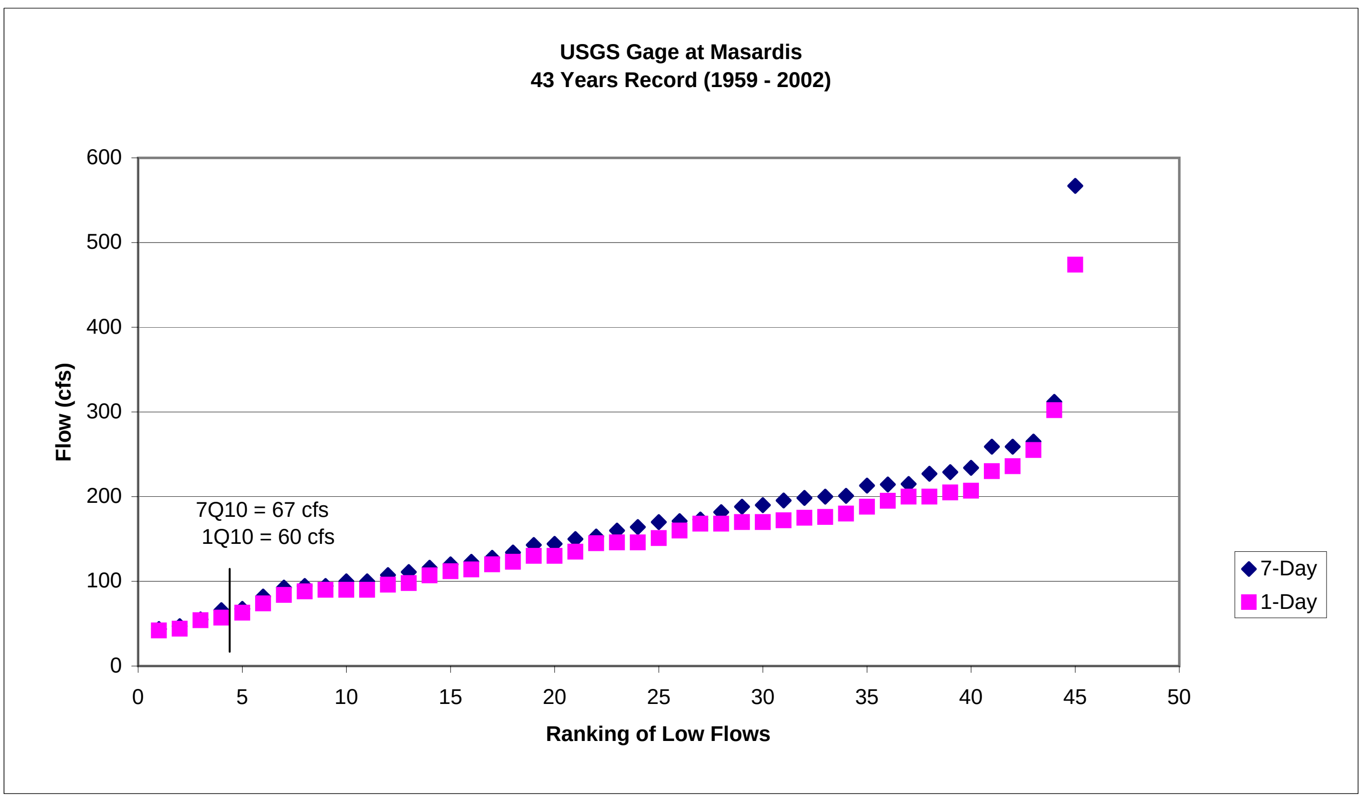


Table 8 Summary of Point Source Dilutions for Toxics Program

		New Flow Statistics		Old Flow Statistics	
	River	7Q10	1Q10	7Q10	1Q10
Masardis Gage	Aroostook	67	60	85	79
Washburn Gage	Aroostook	116	106	146	122
Presque Isle Stream above WWTP				8.3	7.1
Little Madawaska R above WWTP				10.7	9.1

		New Flow Statistics		WWTP Flow MGD	Old Dilution		New Dilution	
	River	7Q10	1Q10		Chronic	Acute	Chronic	Acute
Ashland	Aroostook	98	90	0.30	263	220	212	194
Washburn	Aroostook	116	106	0.28	335	141	268	245
Presque Isle	Aroostook	126	115	2.30			36	33
	Presque Isle Str	3.0	2.7	2.30	2.3	2.0	1.8	1.8
McCain Foods	Aroostook	126	115	2.50			34	31
Caribou	Aroostook	134	122	1.41	80	68	62	57
Loring	Little Madawaska	28	26	2.50	3.8	3.3	8.2	7.6
Fort Fairfield	Aroostook	162	148	0.60	206	173	175	160

Note: Presque Isle Stream and Little Madawaska new statistics based upon flow measurements in the summer of 2001during a 7q10 event.

Two tests are run with the water quality model to check dissolved oxygen compliance with statutory criteria; one to test compliance of minimum dissolved oxygen criteria and a second to test compliance with the monthly average criteria of 6.5 ppm. In the first test assessing compliance with minimum dissolved oxygen criteria, river flows are inputted as 7Q10; river temperatures are inputted as a weekly average; and point sources are inputted at their weekly average licensed loads. In the second test assessing compliance with monthly average dissolved oxygen criteria, river flows are inputted as 30Q10; river temperatures are inputted as a monthly average; and point sources are inputted at their monthly average licensed loads.

The river temperature used for 7Q10 was based upon the first August data set in 2001, which contain higher temperatures than the second data set. The temperatures assigned to the model begin at 22 ^{o}C for the upper Aroostook in the free flowing regions and eventually increase to 24 ^{o}C in impounded river sections.

In both these runs, pollutants that are not included in the license such as nitrogen or phosphorus are ordinarily inputted as measured in the calibration data. The ultimate point source BOD must be derived from the product of a BODu/BOD5 ratio (which is derived from data) and the licensed BOD5 concentration. Point source inputs to the model is summarized in table 9. Model runs were made with the Presque Isle Sewer District’s outfall re-located to the Aroostook River as required in their current waste discharge license by 2007.

As mentioned earlier in the report, the parameter rates for benthic CBOD, organic phosphorus settling, orthophosphorus uptake, and the algal loss coefficient are different for some of the modeled reaches when comparing the calibration and verification model input. The average of the different rates is used in the prediction run as the most reliable prediction of water quality chemistry in the Aroostook River. The rates used in the calibration / verification data set inputs are also run in the model. This will give a range of prediction for dissolved oxygen and chlorophyll-a, for example, given the high variability in the unstable environment of the Aroostook River and the data limitations in attempting to describe this environment. In such an unstable environment, a range of prediction maybe more appropriate than assigning a single prediction result for given model inputs.

Table 9 Point Source Inputs at 10-Year Low Flow

7Q10	Licensed Parameters					Model Input						
	Flow	Monthly Ave.	BOD5 Weekly Ave	BOD Daily Max.	CBODu/ BOD5	CBODu Mo Ave Week Ave	ON	NH3-N	NO3-N	Chl-a	OP	PO4-P
	mgd	PPD	PPD	PPD		PPM	PPM	PPM	PPM	PPB	PPM	PPM
Ashland	0.3	75	113	125	2.91	87 131	1.99	0.24	0.03	80	0.88	0.46
Wasburn	0.28	70	105	117	10.34	310 465	9.42	1.8	1.33	608	2.33	3.03
Presque Isle*	2.3	575	863	959	3.54	106 159	1.7	0.1	6.02	4.8	0.2	1.7
McCain Foods Tier II Production	4.0	794.0	1869	2077	3.52	84 197	46.9	0.08	0.26	6.4	0.39	2.34
Caribou	1.41	880	1436	1595	2.26	169 276	10.1	0.39	13.6	71	0.3	1.4
Loring	2.5	626	938	1043	3.64	109 164	1.48	0.04	3.1	0.6	0.57	0.56
Fort Fairfield	0.6	556	970	1078	1.8	200 349	9.9	2.47	28.2	1.5	0.73	2.44

Note: McCain Foods, Caribou, and Fort Fairfield are not licensed as a weekly average. This was assigned in the model run by the product of 0.9 and the daily maximum licensed BOD5.

* Assumed inputs for Preque Isle with outfall re-located to the Aroostook River. BOD5 is BPT and no immediate phosphorus limit.

The classification of the Aroostook River is class B from Ashland to the confluence of Presque Isle Stream. Below the confluence of Presque Isle Stream it is class C to the USA / Canada border with the exception of a 3-mile segment above the Caribou water supply intake (which is near the Caribou dam). The water quality classifications are illustrated in figure 2.

The dissolved oxygen criteria is as follows:

Class B Daily minimum $\geq$ 7.0 ppm and 75% of saturation
Class C Daily minimum $\geq$ 5.0 ppm and 60% of sat.; monthly average $\geq$ 6.5 ppm

Currently the general provisions section of the water quality classification law states that discharges cannot cause the pH of waters to fall outside the range of 6.0 to 8.5.

In river systems with significant levels of algae, a daily minimum dissolved oxygen level typically occurs in the early morning hours. During the evening hours, the lack of light results in extended respiration of algae and the continuous consumption of oxygen in the river. During the daytime, oxygen that is produced through photosynthesis greatly exceeds the oxygen consumed through respiration resulting in a maximum river dissolved oxygen concentration in mid to late afternoon. The difference between the minimum and maximum daily dissolved oxygen in the river is referred to as the diurnal swing of dissolved oxygen. There is similarly a diurnal trend in pH in rivers that are eutrophic which results in a minimum pH at dawn and a maximum pH in the afternoon hours. Afternoon pH readings can often exceed 8.5 in a highly eutrophic river system. The time of day in which water quality criteria are most likely to be not met in eutrophic river systems is dawn for dissolved oxygen and the afternoon hours for pH.

The model must be run in the dynamic mode for predictions of the daily minimum dissolved oxygen. The model prediction run of point sources discharging licensed amounts indicates that minimum dissolved oxygen criteria should be met in all portions of the Aroostook River. Large diurnal dissolved oxygen swings are predicted that are similar to the measured swings in the calibration data sets (figure 13).

When the range of model predictions for daily minimum dissolved oxygen are explored, given the uncertainty of the mentioned four parameter rates, the predicted dissolved oxygen is not appreciably different (Figure 13a). Dissolved oxygen predictions are slightly lower using the 8/14-16 parameter rate inputs and slightly higher using the 8/28-30 parameter rate inputs, but both are always within 0.2 ppm of the model run utilizing average parameter rate inputs. In all cases predictions for dissolved oxygen greatly exceed minimum DO criteria required by state law.

Algae blooms (chlorophyll a > 8 to 12 ug/l) are projected for 13 to 23 miles of the river from Maysville to the international border with chlorophyll a levels as high as 17 ug/l predicted (Figure 14). High levels of periphyton are also predicted by the model in free-flowing river sections below point source discharges which is consistent which what has been visually observed in the field. The model predictions, laboratory data, and observations in the field all indicate that there is an eutrophication issue on the Aroostook River from Presque Isle to the international border.

When the range of model predictions for chlorophyll-a are explored, given the uncertainty of the mentioned four parameter rates, the predicted chlorophyll-a (Figure 13a) is not appreciably different in the Caribou dam impoundment (RM 20.0–15.5). The higher algae loss rates, and phosphorus loss terms assigned as PO4-P uptake and organic-P settling to the 8/28-30 data set results in lower model predictions for chlorophyll-a when compared to the 8/14-16 data set. In the Tinker dam impoundment at the international border (RM 5.0–0.0) the higher phosphorus loss terms result in a greater depletion of PO4-P in the 8/14-16 data set to the extent where it becomes limiting for algae growth. This ultimately results in a rapid drop-off of algae, since it has run out of the available phosphorus needed to sustain itself. If phosphorus does deplete this quickly, the Caribou dam impoundment would be the controlling location for eliminating algae blooms. From a regulatory perspective, it still would not make much difference which parameter rates are used, since the chlorophyll-a at the Caribou dam impoundment is not significantly different for all parameter rates investigated.

For the monthly average model run, river flows are input at the 30-day 10-year low flow (30Q10); point sources at the monthly average licensed limit, and river temperatures may be decreased from the levels assigned at 7Q10 flow. The 30Q10 flow on the Aroostook is higher than the 7Q10 flow at the Washburn USGS gage by about 35%. The flows on the Aroostook River 7Q10 input were increased by 35% for the monthly average run. There is no information available to determine how to assign monthly average temperatures. The same temperature was used in the 30Q10 run as the 7Q10 run. This should give slightly conservative results.

The monthly average model predictions are run in the steady state mode. The model prediction run at 30 Q10 flow to check compliance with monthly average dissolved oxygen criteria of 6.5 ppm indicates that criteria will be met everywhere (figure 15). In rivers with large amount of algae such as the Aroostook, monthly and daily average dissolved oxygen are not a compliance issue, since the amount of oxygen produced by the algae greatly exceeds the amount of oxygen consumed in the time period considered.

When the range of model predictions for the monthly average dissolved oxygen are explored, given the uncertainty of the mentioned four parameter rates, the predicted model dissolved oxygen is not appreciably different, except in the final two miles of the Tinker dam impoundment (RM 2.0-0.0). Here, the rapid drop-off in chlorophyll-a as algae due to phosphorus limitation in the 8/28-30 data set also result in a rapid drop-off of dissolved oxygen in the final two river miles, due to the oxygen production lost from the displaced algae. Predicted dissolved oxygen are still well within monthly average DO levels of 6.5 ppm needed to maintain designated uses of cold water fish species.

Currently QUAL2MDEP does not have the capability to model pH. The river pH issue is discussed in a later section of the report.

Component Analysis

A component analysis is ordinarily undertaken for a water quality model to help determine which factors are the major contributors to the dissolved oxygen deficit. Various inputs or factors may be subtracted from the model and the difference in dissolved oxygen predicted by the model from a base case is observed. It can then be

Figure 13
Model Prediction of Dissolved Oxygen at 7Q10 Flow

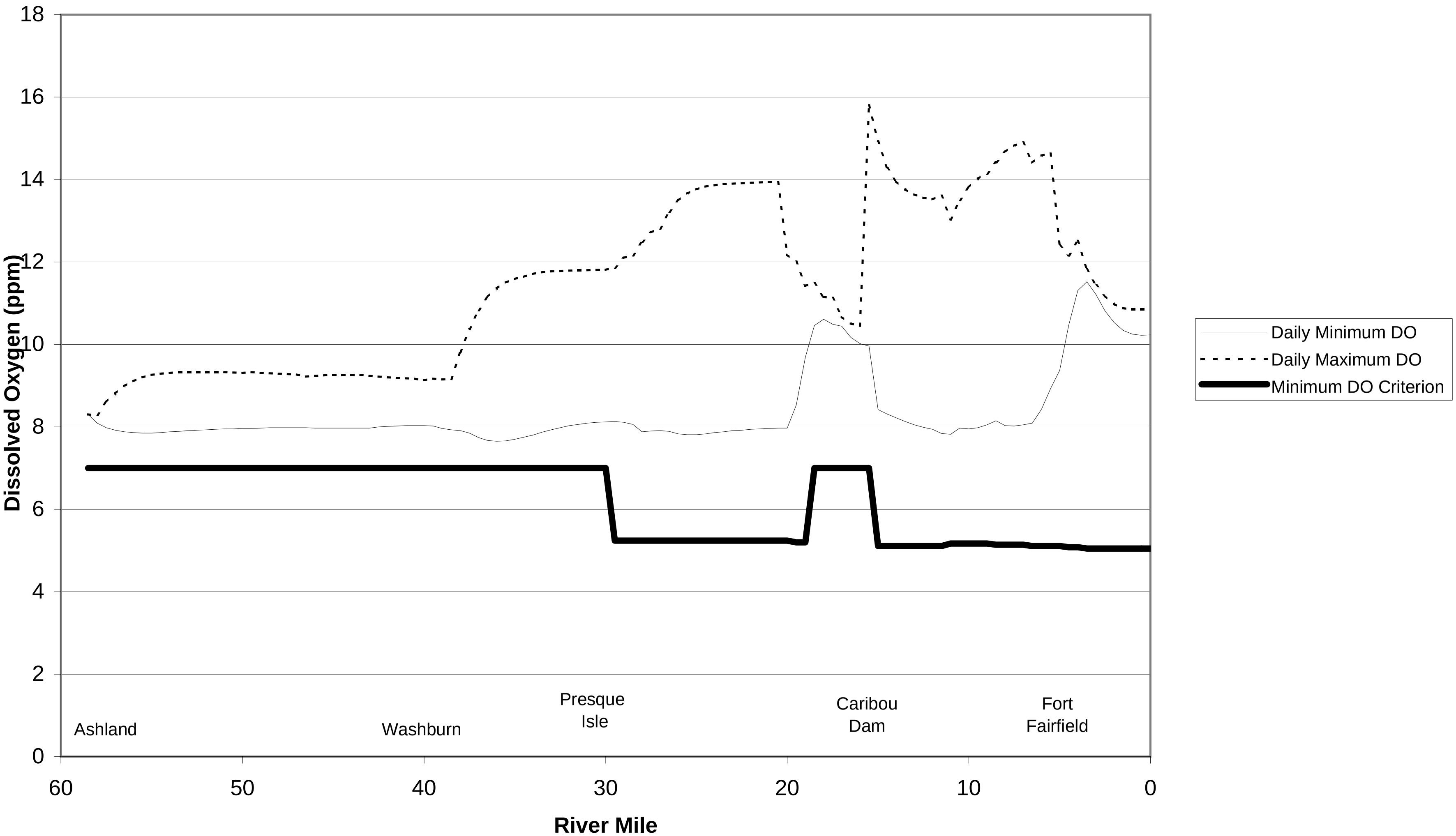


Figure 13a
Model Prediction of Minimum DO with Alternate Parameter Rates

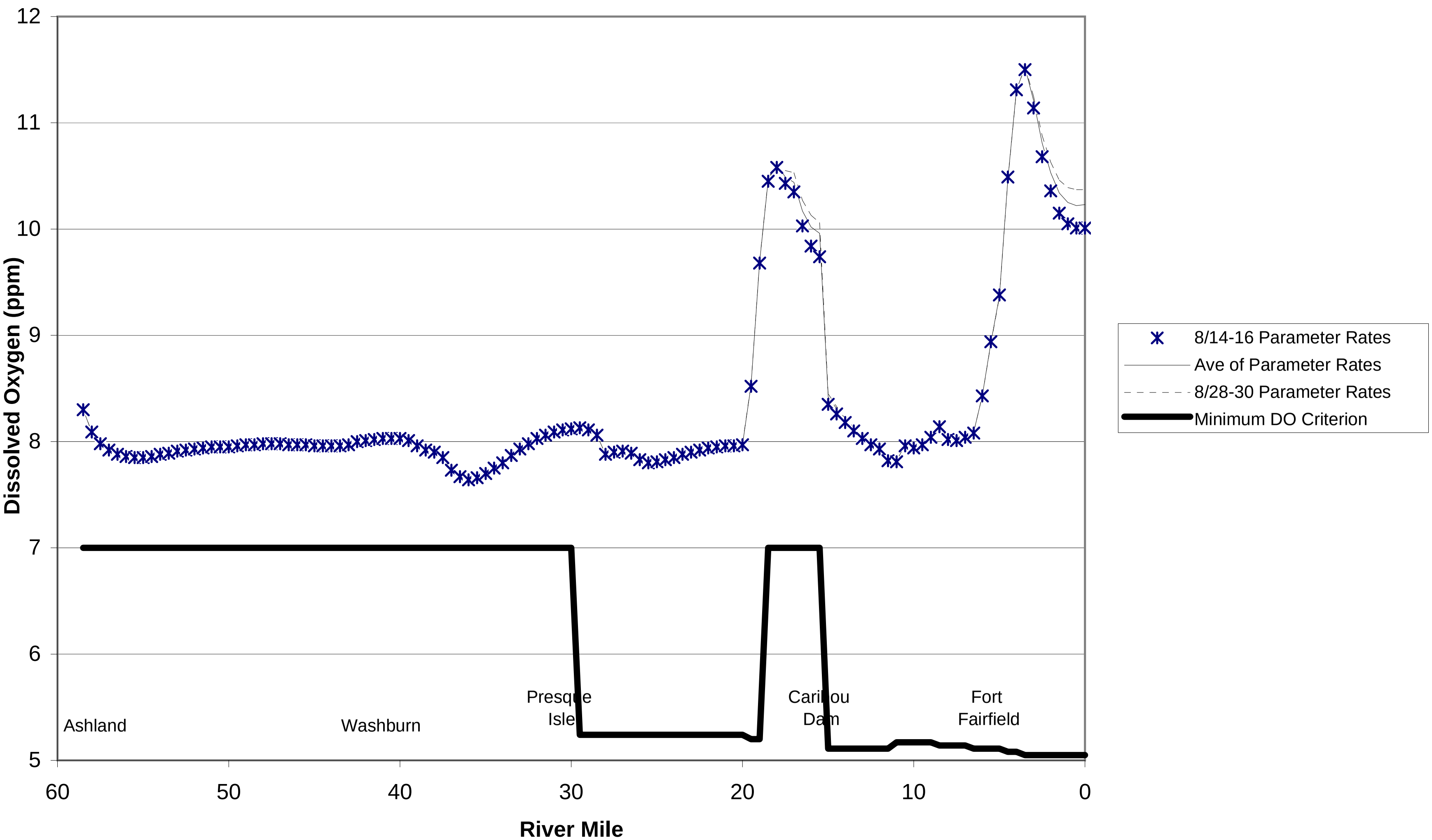


Figure 14
Model Prediction of Chlorophyll-a at 7Q10 Flow

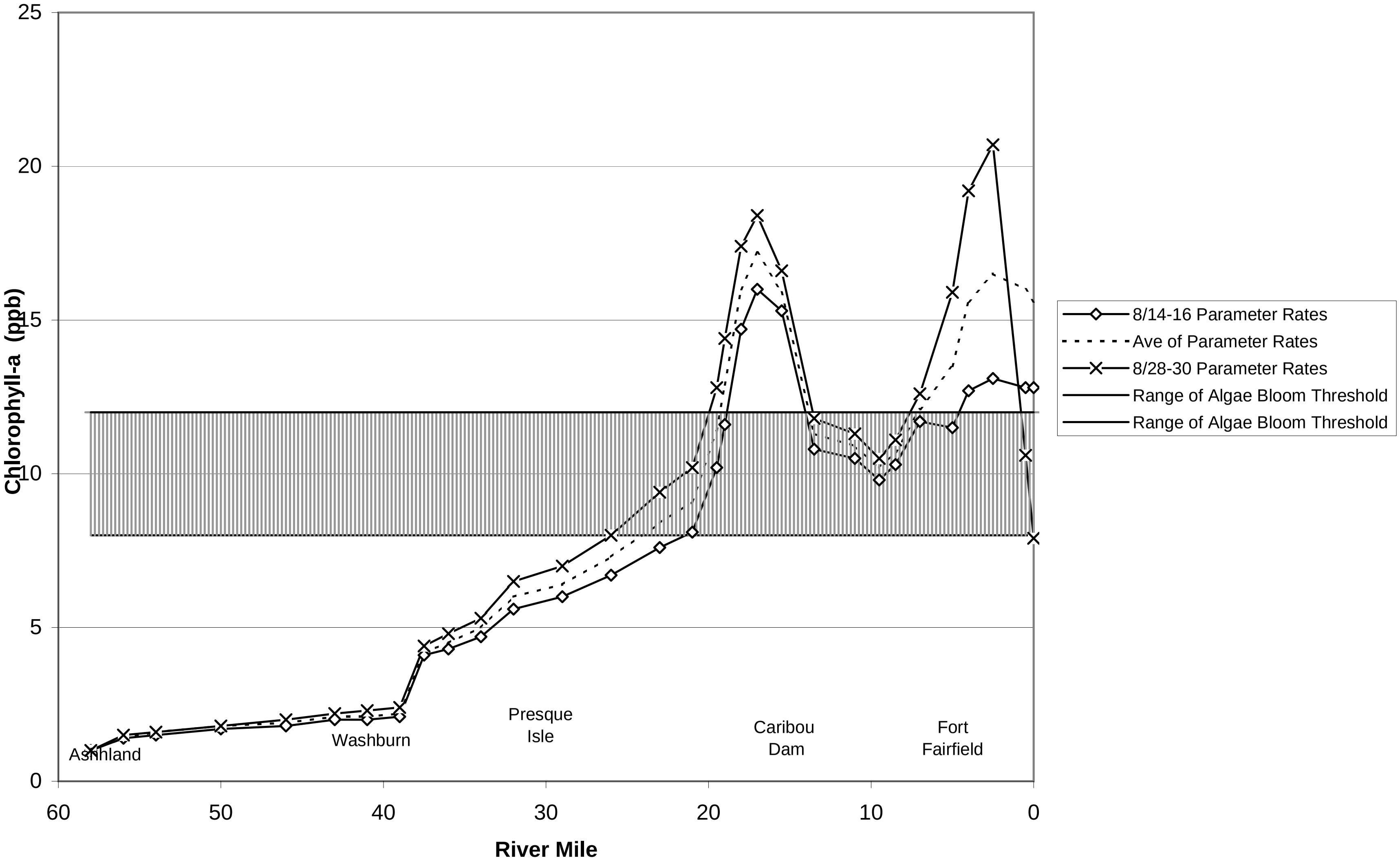
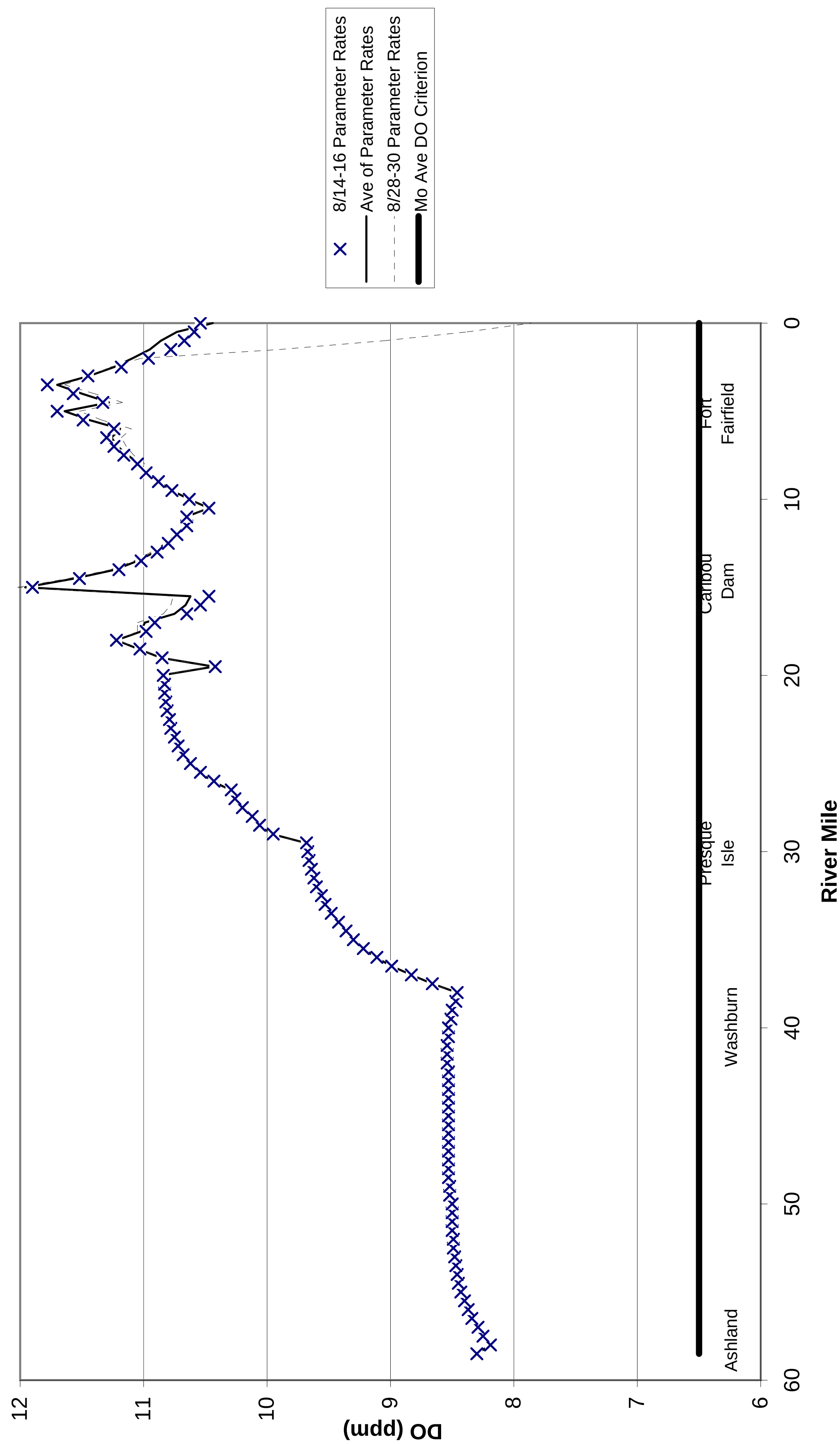


Figure 15
Model Prediction of Monthly Average Dissolved Oxygen at 30Q10 Flow



determined which inputs are significant and worth following up with remedial efforts in river cleanup situations. In the case of the Aroostook River, there does not appear to be an issue with compliance of dissolved oxygen criteria. However there is an issue with high algae levels in the river. Phosphorus is ordinarily the limiting nutrient in fresh water systems, which must be reduced in order to alleviate eutrophication.

A component analysis in the Aroostook is further complicated by the high amount of dissolved oxygen supersaturation that is predicted by the model. Some of the parameter rates assigned to the model for the algae and periphyton systems are quite variable, and cannot be expected to remain constant for significant load reductions. Which rates to use for significantly reduced point source inputs, for example, becomes problematic, since the model was not calibrated under these conditions.

For the cited reasons, the component analysis was undertaken by comparing input loads of point and non-point sources of ultimate BOD and total phosphorus. It can be observed (Figure 16) in this analysis that at 7Q10 river conditions, McCain Foods and Presque Isle are the major source of phosphorus in the river, assuming that both are discharging at licensed flows with contributions of 43% and 17% of the total river phosphorus load, respectively. Assuming that all discharges are discharging their licensed BOD5 loads at 7Q10 flow, McCain Foods, Loring, Caribou, and Presque Isle are all significant inputs with contributions of 29%, 15%, 15%, and 14%, respectively of the total ultimate BOD load (Figure 17). For both phosphorus and BOD, base flow non-point and background sources are not significant, accounting collectively for 4% and 13% of the total river load for phosphorus and BOD, respectively.

Model Predictions with Reduced Point Source Phosphorus

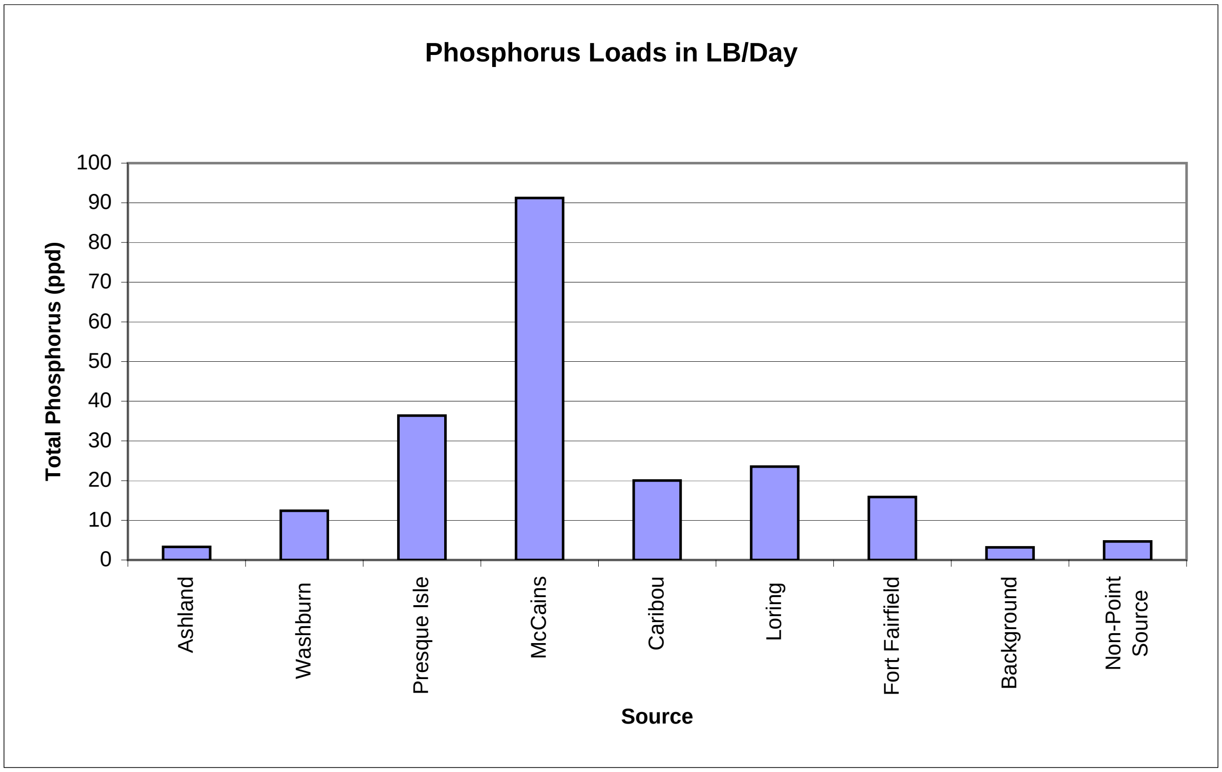
Different levels of point source reductions were investigated to determine the amount needed to alleviate eutrophication on the Aroostook River. There are currently no direct numerical criteria in Maine's water quality standards that define an acceptable trophic state for rivers. There are narrative criteria that allow for the regulation of nutrients.

The General Provision section of Maine's water quality classification standards 464(4A(4)) specifies that" the Department may not issue a waste discharge license for discharges to waters of the State that impart color, taste, turbidity, toxicity, and radioactivity or other properties that cause those waters to be unsuitable for the designated uses and characteristics ascribed to their class. The Aroostoook River is classified as class C and B in the area of eutrophication. Class C and B standards specify that the waters shall be suitable for the designated use of 'drinking water supply after treatment; fishing; recreation in and on the water (swimming) ; industrial process and cooling water supply; hydroelectric power generation, except as prohibited under Title 12, section 403; and navigation; and as a habitat for fish and other aquatic life'.

High concentrations of total phosphorus lead to excessive concentrations of phytoplankton or floating algae in low velocity areas commonly referred to as 'blooms' of algae. The floating algae are transported with river flow. Algae blooms impart color,

Figure 16 Phosphorus Loads to the Aroostook River at 7Q10 Flow

Note: McCains is limited by their waste discharge license to TP of 91 ppd as a monthly average. TP load for Presque Isle derived from 1995 data prior to phosphorus reducrtions from advanced treatment. Phosphorus loads for other point sources computed by the average concentrations and flows measured during the three-day surveys.



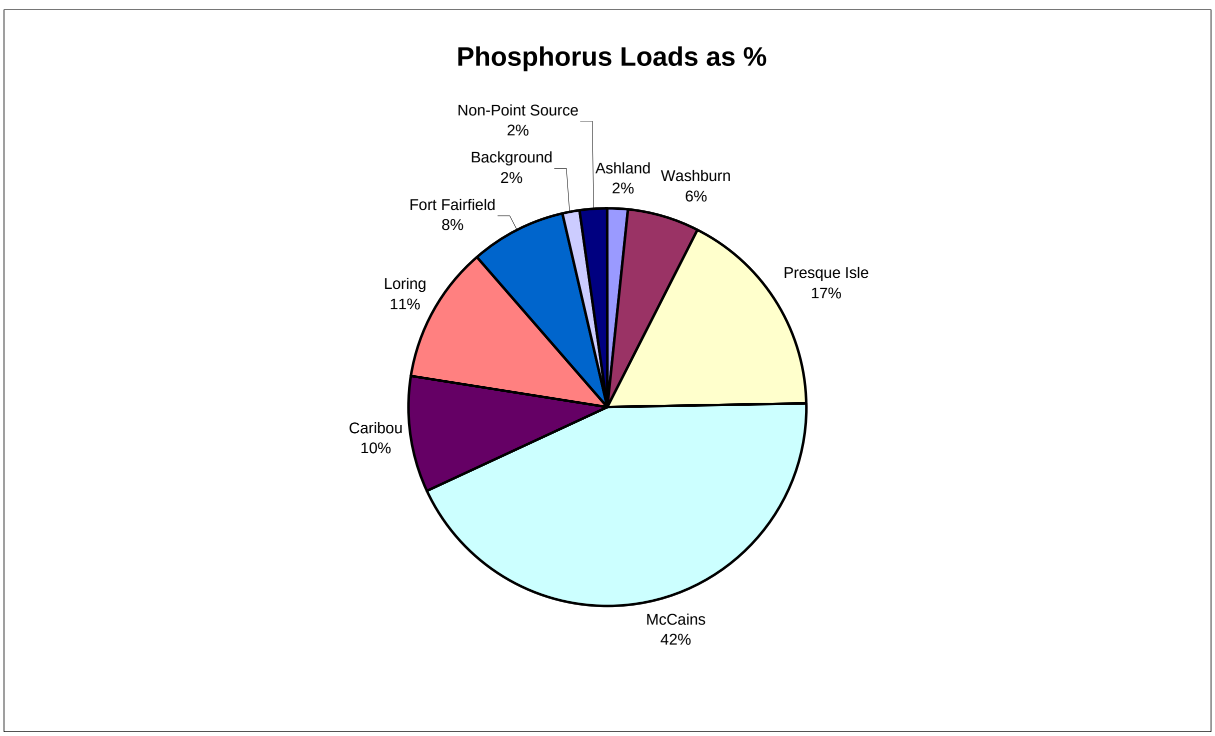
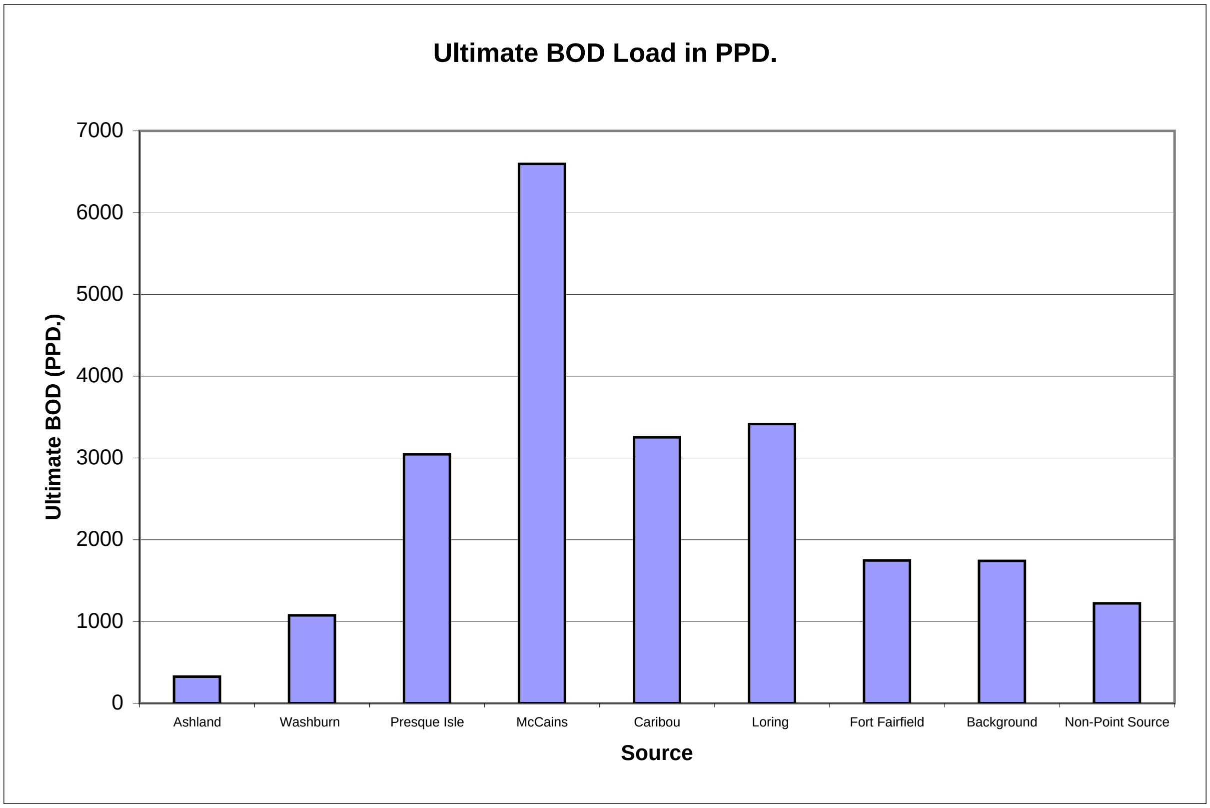
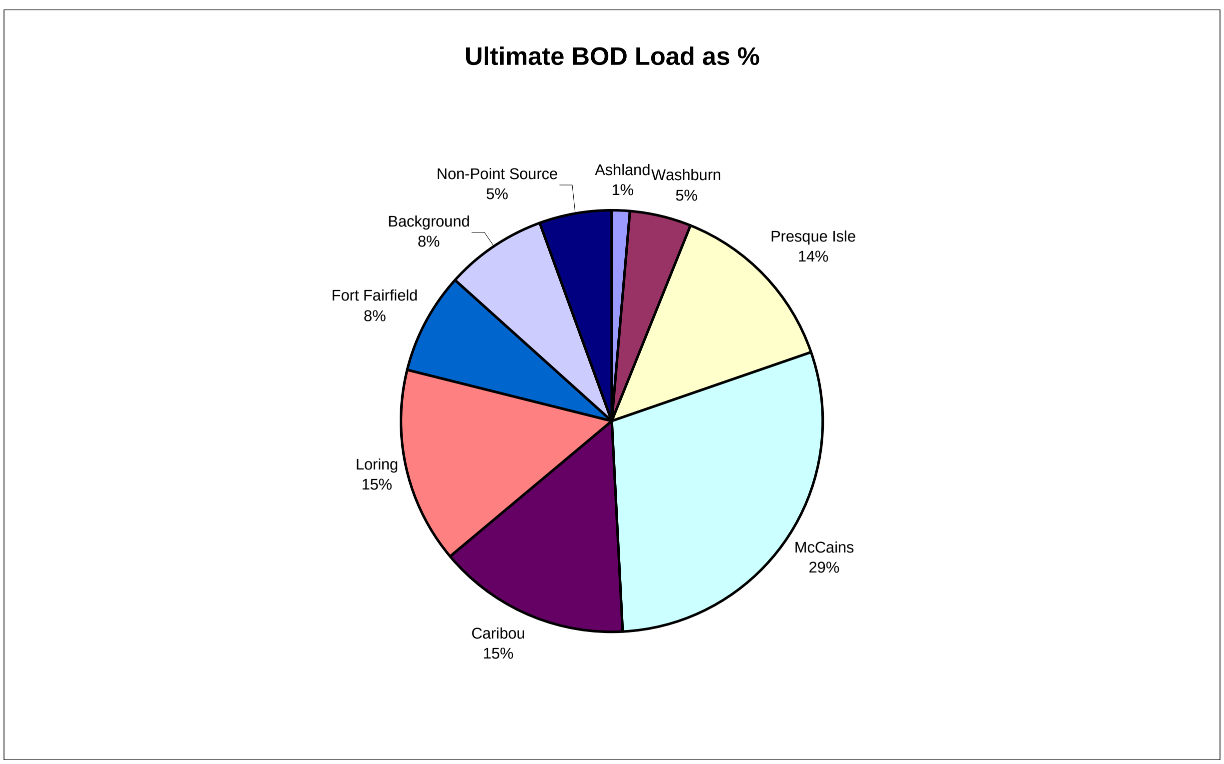


Figure 17 Ultimate BOD Loads to the Aroostook River at 7Q10 Flow





cause high turbidity, and result in overall conditions that cause waters to be unsuitable for swimming. In flowing river sections, the conditions are more favorable for stationary algae that are attached to the river bottom rather than floating algae. Bottom attached algae similarly result in designated uses of water contact recreation not being met.

Each state is being required by USEPA to derive numeric nutrient criteria by 2005. Maine has historically been using a chlorophyll-a level of 8 ppb to define the threshold level for algae blooms. A chlorophyll-a level of 8 ppb has been used in the lakes program as a threshold level for an algae bloom for more than two decades. In addition, the 8 ppb chlorophyll a level is listed in the available literature as a threshold to prevent nuisance algae blooms in EPA's Nutrient Criteria Technical Guidance Manual for Rivers and Streams.

Recently DEP has applied a range of 8 to 12 ppb to describe blooms in a river impoundment. It is uncertain at this time exactly what chlorophyll a value should be used to describe eutrophic blooms in flowing waters. In the interim, MDEP is using a range of 8 to 12 ppb to describe chlorophyll-a levels where designated uses become inhibited due to algae blooms. There is currently no precedent on threshold levels of benthic algae where designated uses become inhibited, but it is likely that this could also be an issue on the Aroostook River after the nutrient criteria are developed in the next year.

Model prediction runs were undertaken with reduced phosphorus inputs from McCain Foods and Presque Isle, who collectively in the component analysis section of the report have been identified as the two largest sources of phosphorus to the river. These runs can provide some guidance as to the necessary reductions at the two major sources of phosphorus. The results of the model prediction runs are summarized below (Table 10).

Table 10 Summary of Model Runs with Reduced Point Source Phosphorus

Model Run	Description	Maximum Chl.-a (ppb)	Maximum PO4-P (ppb)
ARO7qt	Point Sources at License	17	140
ARO7qtL	50% Reduction TP for PISD, McCains	17	70
ARO7qtL1	TP = 1 ppm PISD, McCains	15	56
ARO7qtL2	TP = 0.5 ppm PISD, McCains	9	33
ARO7qtL3	Non-point source & natural TP = 0	17	140
ARO7qtL4	TP Point Sources = 0	3	1

The conclusion from this exercise is that a 70% to 80% reduction in river orthophosphorus levels may be necessary to approach levels of algae at the threshold bloom levels of 8 to 12 ppb chlorophyll-a. Of course, the final limits could depend upon what the nutrient criteria will be approximately one year from now but these model runs suggest that a TP mass limit based upon licensed flow and a TP concentration of 0.5 ppm is possible for Presque Isle and McCain Foods.

Presque Isle is currently meeting a 0.2 ppm requirement on Presque Isle Stream for PO4-P or a mass limit of 3.8 ppd. Based upon a TP concentration of 0.5 ppm, the mass model input for Presque Isle is 9.6 ppd. McCain Foods is currently licensed for a summer monthly average TP limit of 91 ppd. Based upon a TP concentration of 0.5 ppm, the mass model input for McCains is 16.7 ppd.

The model runs show that with a 50% reduction of TP from McCain Foods and Presque Isle, virtually no reduction of algae will result, due to the large excess of phosphorus within the system. The river is no longer phosphorus limited at the high phosphorus input conditions and large reductions are needed before phosphorus limitation is reached. Also, with natural and non-point TP reduced to zero, there is also virtually no reduction in algae levels due to the large source of TP from point sources. With point sources reduced to zero, algae levels measured as chlorophyll-a are reduced to background concentrations of 3 ppb.

Summary of Results and Recommendations

Low early morning dissolved oxygen levels, that are under statutory criteria, do not appear to currently be an issue on the Aroostook, despite the high levels of floating and bottom attached algae observed and measured in impoundments and flowing river sections. Both the data collected and model predictions support this statement. Large reductions of point source phosphorus are needed to reduce algae to a non-eutrophic state. Non-point (runoff induced) phosphorus pollution, although not significant at base flow conditions, shouldn't be totally ignored.

The Aroostook River watershed is unique from most other modeling studies undertaken by MDEP on other rivers statewide. A large portion of the watershed in the Aroostook River is composed of agricultural and cleared land when compared to other watersheds. This results in a large potential for non-point source pollution.

As stated in the preceding sections, non-point pollution is currently not expected to be a significant contributor of water quality degradation during base flow conditions. During runoff events, the proportion of non-point source phosphorus and BOD loading to the river increases as compared to base flow conditions. However the river travel times are also decreased as river flow increases. As a result, a large portion of runoff loads during storm events may pass through without having a large impact on water quality.

It is presumed some proportion of the runoff loads will impact the river during base flow conditions. For example, particulate BOD and phosphorus could settle to the river bottom in impoundments or other areas with slow river velocities. Dissolved phosphorus may also be uptaken and stored in plant cells of bottom attached algae. The exact proportions are difficult to predict and is beyond the capability of the water quality model.

A plot in the data report comparing tributary wet weather and dry weather total phosphorus (Figure 18, Data Report) is repeated here for convenience (Figure 18,

Figure 18
Tributary Sampling TP

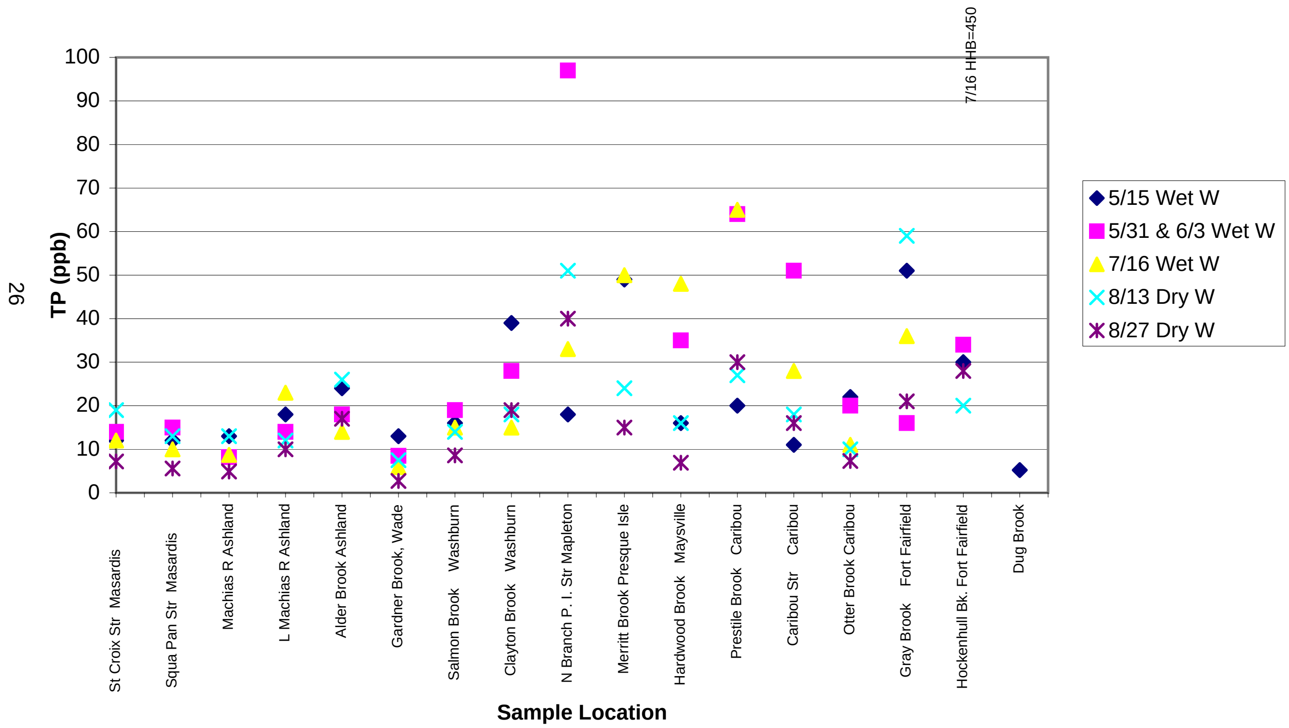


Table 11 – Non-Point Source Pollution Potential of Tributaries	
Tributary	NPS Pollution Potential
St Croix Stream, Masardis	Low
Squa Pan Stream	Low
Machias River, Ashland	Low
Little Machias River, Ashland	Low
Alder Brook, Ashland	Moderate
Gardner Brook, Wade	Low
Salmon Brook, Washburn	Low
Clayton Brook, Washburn	Moderate
North Branch Presque Isle Stream, Mapleton	High
Merritt Brook, Presque Isle	High
Hardwood Brook, Maysville	High
Prestile Brook, Caribou	High
Caribou Stream, Caribou	High
Otter Brook, Caribou	Low
Gray Brook Fort Fairfield	High
Hockenhull Brook, Fort Fairfield	High

Modeling Report). By observing the difference in dry weather and wet weather total phosphorus concentrations and the actual TP levels in all tributaries relative to one another, a ranking system was developed (high medium, low) for each tributary. A high ranking was assigned to tributaries with at least one TP concentration approaching 50 ppb and a noticeable elevated level in most of the wet weather TP samples when compared to the dry weather TP samples. A medium ranking was assigned when a majority of all TP samples were greater than 20 ppb; at least one TP concentration approaching 40 ppb; and a noticeable elevated level in most of the wet weather TP samples when compared to the dry weather TP samples. A low ranking was assigned when most of the TP concentrations of all samples was under 20 ppb and there was no noticeable difference in TP concentrations when comparing the wet and dry weather TP concentrations.

The prior section indicated that non-point source reductions are not effective in reducing eutrophication, due to the large phosphorus loads from point sources that are enough to generate large growths of phytoplankton and bottom attached algae even if non-point source loads could be entirely eliminated. It can be presumed as point source phosphorus is reduced, the non-point source runoff loads will become more important as pollution sources. Best management practices should be implemented first on tributary watersheds that are ranked as a high potential for pollution (Table 10).

The issue of high periphyton and bottom attached algae is more difficult to address without the criteria (to be developed in 2005) in place. As stated earlier in the report, high pH is often an issue in very productive river systems in the afternoon hours. The current modeling software of Qual2MDEP does not have the capability to model pH During the collection of stream transect data in 2002, one-half of the afternoon pH measurements from Presque Isle to Fort Fairfield exceeded the maximum allowable pH of 8.5 (Table 12). The range of pH in these exceedances was 8.5 to 9.

Table 12 – Summary of pH Readings 2002

Location	Date	Time	Temp. (^oC)	pH
Presque Isle Str. confluence	8/30/02	9:45	19.8	7.8
McCain Outfall		10:21	20	8.17
Maysville		11:40	20.3	**9.0**
Below Caribou Dam		13:10	20.8	8.16
Caribou Utilities		13:30	20.7	**8.65**
L. Madawaska R. confluence		14:33	19.8	8.38
Adjacent Parkhurst Rd, P. I.	9/3/02	14:20	21.6	**8.96**
Gray Brook confluence, Fort F		16:00	21.1	**8.98**

The best way of assuring that pH criteria are met and algae levels are not excessive in the Aroostook River is the collection of an additional data set at reduced point source inputs of TP. If possible, a data set should be collected with both McCain Foods and Presque Isle targeting a TP level of 1 ppm. Fort Fairfield has food processing manufacturing inputs to their treatment plant, which have the potential for high variability of TP as an uncontrolled source. If possible, Fort Fairfield should be practicing pollution prevention technologies to minimize phosphorus inputs during the collection of additional data. Total phosphorus license allocations for point sources should be re-evaluated by the model after the collection of the additional data set recommended and nutrient criteria development are final.

Responses to Comments

Woodard and Curran Comments (Representing McCain Foods)

Letter received from Paul Porada of W&C, Feb 12, 2004.

1. Comment: Both the introduction and Table 1 indicate that McCain Foods has a licensed flow average of 2.5 MGD. McCain has a two tier license and it may be beneficial to the readers to clarify this. Present facility production places the wastewater flows in the Tier #1 license, or 2.5 MGD. The Tier #2 license flow of 4.0 MGD would apply upon completion of an expansion in potato processing capacity. The expansion project by McCain has yet to occur.

Response: Agree. This will be clarified in table 1 and the Introduction section of the final report.

2. Comment: Page 7 of the report says that data collected on August 28-30 were used to calibrate the model, and data collected on August 14-16 are used to verify the model. Two points of refinement can be made. First, the data collection periods are 5-day events which commence with wastewater samples dates ahead of river water sample dates. For example the so called ‘first data set’ collection started August 12, and ended August 16. The second point of clarification is that the environmental parameter rates of Table 5 show the process resulted in two separate calibration sets and no verification set. As noted on page 12 a few parameter rates for the benthal BOD, phosphorous and algal loss are varied within each calibration model. It does appear that the predictive case 7Q10, and 30Q10 models splits the difference of these two calibration models. For a demonstration of the model’s response to the user judgment applied in assigning rates, it would be informative to know how well the August 12-16 model would verify the model’s prediction accuracy if the August 26-30 calibration environmental parameter rates were applied. Can this calibration\verification comparison be provided?

Response: The three day periods are when most of the data was collected and are hence being used to describe the data sets. Data three weeks previous to the second data set and two weeks previous to the first data set were actually used, when available, for the model input. These time periods represent the time of travel over the study reach. Both of these points will be clarified in the final report.

Your second point of contention for calibration Vs verification of the model greatly exaggerates the amount of variability in the assignment of parameter rate inputs for model calibration and verification. As stated in the draft report, different rates were only assigned in 4 of the 37 rates considered and in only some of the modeled reaches; or about 4% of the time when considering the number of rates and length of the river in which they were assigned. More importantly, can all of the rates be expected to be constant or easily defined in a environment that is so unstable? The answer to this is obviously no.

The point that needs to be addressed in the final report is how much of a difference would result in the prediction runs? The rates assigned for both input calibration and verification could be used to define a range of predictions and the average of these (as was done in the draft report) the expected prediction. This could be viewed as the limitations of the model, given the variability in the data and the amount of data collected to describe this variability. This approach is better than observing the range of the model calibration / verification output to observed data, since ultimately the modeler would have to accept marginal matches of the model to observed data in the prediction runs. Additional prediction runs with varied parameter rate inputs and text explaining it will be provided in the final report.

3. Comment: The PO4-P Uptake Rates are a negative flux, i.e. a loss rate within the model. It would be easier for the reader to understand this condition if the negative sign was placed in front of these PO4-P flux rates summarized on Table 5.

Response: Table 5 actually is defining an uptake rate of PO4-P, not a flux. A negative flux is more difficult for the reader to understand than just explaining it as uptake.

4. Comment: From statements on page 12 and discussion on page 30 the report deduces that large quantities of orthophosphorous (PO4-P) are being taken up by bottom attached plants. We disagree that the large loss of PO4-P is actually uptake by benthic algae. We believe it is a physical chemical process, not a biological removal process, and to support this theory we offer the following explanation.

Aroostook county water is relatively hard, having dissolved minerals, especially during summer when flows are low. The parent material for regional soils there is often limestone, and rock formations in the area contain calcium and magnesium, hence the hard water. The calcium in the water is precipitating the PO4-P as calcium phosphate (apatite). The reaction of dissolved calcium and phosphate occurs better if there are seed crystals such as sediment or rock present, certainly the case in a river. A higher pH solution, as apparently exists in the Aroostook River, would further enhance the reaction. Ferric and aluminum ions would have similar effect on removing PO4-P from solution. In support of this phosphorous precipitate phenomenon the Department should reference the letter from McCain Foods to Bill Sheehan of the DEP, dated September 17, 2002. In the letter a description of white particles found on the river bottom below the outfall are described. When tested, the white particles were found to be an inert solid containing phosphorous.

Response: This theory is a possible explanation for some of the losses of phosphorus in the Aroostook River and will be included in the final report as something to investigate in future data collection. Even if it does occur, the high levels of algae are indirectly causing this phenomena by causing a much higher pH in the river than what would ordinarily occur in a mesotrophic or oligotrophic system. DEP has observed the rapid uptake of large amounts of orthophosphorus in other river studies with high levels of bottom attached algae, and this is probably the major cause of phosphorus uptake.

5. Comment: The CBOD source rates were assigned by user judgment, yet no literature rates are given in Table 4. Are these CBOD source rates simply guesses that make the BOD calibrations fit? Does literature support that CBOD source rates are higher below point sources?

Response: The BOD decays rates for the Aroostook are well defined through many laboratory tests taken at many river locations in both data sets. It is therefore reliable to use curve fitting as a method of describing CBOD source rates, so long as their assignment makes logical sense, i.e. higher rates are assigned in reaches where there are pollutant inputs. There is little literature guidance for the assignment of these rates, other than it is variable and it makes logical sense that it would be higher below a point source or other significant pollutant input.

6. Comment: Table 4, page 13, indicates that the oxygen production rates for both algae and periphyton are far above literature ranges for these rates. These unusual rates were necessary to make the model fit the data. However, it is likely these unusually high rates are an indication that there is another factor of the dissolved oxygen balance that is not properly accounted for and that algal representation is awry.

Response: The unstable nature of dissolved oxygen makes this parameter difficult to define. A great deal of time was spent attempting to define this parameter and this is the best that could be done with the given data. Given that dissolved oxygen compliance is not an issue in either the data or model prediction runs, it is not worthwhile spending a lot more time on this issue. DEP is always willing to consider making adjustments to any model provided pro-active and constructive comments are made that are not ambiguous. These comments could be useful for improving the performance of the model. However if criticism of the model takes the place of helpful suggestions, no further improvements can be made to the model.

7. Comment: The model simulates McCain Foods effluent having dissolved oxygen of 2.0mg/L. In fact, effluent DO levels for McCain Foods are always much higher, typically greater than 8 mg/L. This particular effluent DO value may not be critical to river oxygen, but it would be appropriate for the model representation to be as accurate as possible.

Response: McCain Foods' dissolved oxygen effluent levels will be inputted as 8.0 ppm in the prediction runs for the final report.

8. Comment: Table 5 indicates that the PO4-P uptake rate in model Reach 10 is -0.01 mg/ft^2-day. We have observed that the 7Q10 model input utilizes -0.05 mg/ft^2-day for this reach. Is there a reason?

Response: This is an apparent input error that will be corrected in the model prediction runs for the final report.

9. Comment: The phosphorous loading for McCain Foods input into the 7Q10 predictive case model file is not correct. The flow value in Table 9 did not match the numeric model data set. It appears that the concentrations were calculated using the Tier #1 license flow of 2.5 MGD, and then the flow rate for the Tier #2 license value of 4.0 MGD was used in the numeric input. The error results in 60% more total phosphorous being simulated in the 7Q10 model than is allowed by the license.

Response: Agree. This will be corrected in the final report.

10. Comment: In the absence of dissolved oxygen non-attainment on the Aroostook River it appears that the Department had to find another reason to justify phosphorous reduction. Text of page 45 and 48 is implying that recreational use of the Aroostook River is not being met. Historically, bacteria, pathogens, and toxics have been considered the factors precluding water contact recreation. We are unaware that the Department has changed use interpretation such that algae can cause water to be unsuitable for swimming or recreation. The standard and its source should be referenced in the report.

Response: This interpretation has already been used in other TMDL's approved by EPA and is explained fully in the second paragraph of the section "Model Predictions with Reduced Point Source Phosphorus" (P 48). Woodard and Curran should be aware that water quality standards contain both narrative and numerical standards and both are equally important in defining the attainment / non-attainment status of water bodies.

11. Comment: The second paragraph of page 48 provides the basis for using an 8 ug/L chlorophyll-a level which in turn is used to derive nutrient loading limits for wastewater discharges. We do not agree with the approach of applying lake thresholds to riverine systems because there are significant differences in algal species and flushing dynamics present in the different water systems. In support of the 8 ug/L chl-a level as a threshold to prevent nuisance algal blooms the modeling report makes reference to the EPA's Nutrient Technical Guidance Manual for River and Streams [presumably EPA-882-B-00-002]. This threshold level is being presented in the modeling report out of context because the EPA document says the "8 ug/L chl-a level constitutes the dividing line between eutrophic and mesotrophic lakes."[EPA, page 102]. We also observe that EPA's document states "algal species composition should be used in the data analysis to validate stream classifications and enable development of indicators of nutrient conditions and the likelihood of nuisance algal blooms." [EPA, page 81]. The modeling report accurately states that it is uncertain what chlorophyll-a levels should be used to describe blooms in flowing waters. Until such time as the state develops science-based chlorophyll-a criterion for rivers, we believe it is inappropriate to be making licensing decisions based upon this acknowledged uncertainty.

Response: It is not only the levels of chlorophyll-a in the water column, but also the levels of bottom attached algae, which could ultimately define phosphorus limits for point source discharges. As stated in the draft report, the nutrient criteria to be developed next year will be the deciding factor on where limits may fall. It was not the intention in the report to immediately require P-limits. This will be clarified in the final report. The P-limits should proceed only after the collection of an additional data set under reduced phosphorus inputs and the establishment of the nutrient criteria.

DEP thought it was important to make all stakeholders aware of the nutrient issue on the Aroostook River and give some idea for ballpark estimates of phosphorus allocations, given the current science and knowledge of this issue. A level of 8 ug/l is listed in the EPA River Nutrient Criteria Technical Guidance Manual as a threshold level for eutrophy (p101) which is analogous to a bloom threshold. Given that algae blooms in rivers will almost always develop in impoundments with little current, there is little difference to the lake environment and there should also be little difference in describing a bloom threshold. A range of 8 to 12 ug/l for chlorophyll-a is being used as the likely threshold level for algae blooms in the final report.

Given the high levels of benthic and floating algae, and the large swings in DO and pH on the Aroostook, it is obvious that nutrients are an issue here and some reductions of phosphorus are likely in the near future. It is hoped that McCain's and other stakeholders take this issue seriously and at least consider what the targeted P-reductions investigated in the report will mean for them. It is also hoped that some of the stakeholders will agree to voluntary P-reductions in a future summer under which more data can be collected. Such a program of voluntary P-reduction and river data collection has occurred at the Houlton discharge and Meduxnekeag River for a number of years with great success.

12. Comment: On page 51, Table 12 summarizes pH readings. Conclusions are being made that the high afternoon pH is the result of algae, hence indirectly related to phosphorous discharges. The data set used in reaching the conclusion is only from daylight hours. To be validated this conclusion needs to be supported by night pH values. If pH is high both day and night it is likely caused by water chemistry rather than diurnal algal effects.

Response: AM pH data could be collected in the future, but it should be obvious to most readers with a science background that pH values of 8 to 9 are not a normally occurring phenomena without some unusual situation such as a highly eutrophic system. The high algae levels and large diurnal DO swings both suggest that the algae are the cause. DO and pH diurnal swings on these systems almost always occur together.

13. Comment: Other measures to protect the river are available, such as lowering flash boards on dams to cut detention time, or even full dam removal. Can these and similar options be evaluated as part of the solution?

Response: These measure could reduce the growth of phytoplankton, but would increase the growth of benthic algae. An interesting question could be are the impoundments actually helping dissolved oxygen in a environment of lush nutrients by inhibiting or interrupting the growths of continuous benthic plants?

14. Comment: Agriculture and other non-point source contribution, albeit a smaller effect during drought events, does contribute to the overall long term water quality. The report indicates the need for Best Management Practices for non-point source control and prioritizes watersheds, yet falls short of assigning responsibilities. Who might be the appropriate parties to assist with non-point source abatement?

Response: This is beyond the scope of the report, which investigates model inputs and expected water quality.

McCain Foods

Email message received from Bill Daniels Jan 12, 2004. Employee of McCain Foods.

Hello Paul,

In reviewing the Aroostook River Modeling Report Draft, I noticed on table 1, that you had used Tier II figures for McCain Foods BOD5 effluent limitations with Tier 1 flows of 2.5 mgd. Tier II flows are 4.0 mgd.

Would it be possible to insert the words "Permitted Limitations of Point Source Discharges to Aroostook River" ? As it stands, it is shedding poor light on the facilities listed leading the reader to think that those are actual discharge figures. Your clarification on the collective dischargers would be of better service listed under this table.

Thank You

Bill Daniels, Environmental Coordinator

McCain Foods USA, Inc, Easton

Response: The tier I and tier II production levels will be clarified in table 1 and the introduction section of the final report. It will also be clarified that the numbers in table 1 are license limitations, not actual discharge levels.

Steve Sutter

Abutting landowner to McCain Foods. Email message received Jan 27, 2004.

Paul

Appreciate your good work.

Minor edits (1) Figure 16 has an incomplete Note at the top, (2) page 48 last paragraph "Presque Isle is currently" and (3) a period to conclude the text (page 51).

Stakeholder comments from Steve Sutter, abutter to McCain Foods

1. Executive summary #10 non point BMP "should be implemented on all tributaries that meet with the main stem at and below Presque Isle." I reported to MDEP nuisance algae at the confluence of Merritt Brook with the river September 2003, for example. (Or at least advise the reader how MDEP selects priority tributaries.

2. In introduction, I suggest you at least footnote that there was still a (perhaps in your judgement relatively minor) point source (overboard discharge) between McCain Foods and Caribou in 2001 and 2002. It's Phoenix Enterprises, dba Town and Country Apartments (licensed 8500 gpd, BOD5 30 mg/l). It could be contributing to eutrophication at Maysville.

3. Page 41 Figure 14 shows chlorophyll-a topping 8 ug/l from a point below McCains to the international border. Suggest that you substitute that for the word “Maysville.”

Thank you for your consideration.

Steve Sutter

1720 S Maple Ave.

Fresno, CA 93702

Response: The minor edits are noted and will be corrected in the final report.

1. The ranking system was developed as follows. By observing the difference in dry weather and wet weather total phosphorus concentrations and the actual TP levels in all tributaries relative to one another, a ranking system was developed (high medium, low) for each tributary. A high ranking was assigned to tributaries with at least one TP concentration approaching 50 ppb and a noticeable elevated level in most of the wet weather TP samples when compared to the dry weather TP samples. A medium ranking was assigned when a majority of all TP samples were greater than 20 ppb; at least one TP concentration approaching 40 ppb; and a noticeable elevated level in most of the wet weather TP samples when compared to the dry weather TP samples. A low ranking was assigned when most of the TP concentrations of all samples was under 20 ppb and there was no noticeable difference in TP concentrations when comparing the wet and dry weather TP concentrations. This explanation will be added to the test in the final report. Merritt Brook was assigned a high ranking priority for non-point source BMP’s.

2. The footnote will be added in the introduction section of the report. This discharge is relatively minor compared to the others in the report, since it is diluted 986:1 at 7-day 10-year low flow conditions.

3. Figure 14 has major towns in the watershed inserted as text as a convenience to the reader who may not be familiar with the river mile locations.