APPENDIX B

Meduxnekeag River TMDL, May 1996 (Revised Draft)

Revised Draft

Meduxnekeag River TMDL

May 1996

Prepared by David Miller, P.E.
Division of Environmental Assessment
Bureau of Land and Water Quality

Executive Summary

A 13.3 mile long segment of the Meduxnekeag River from above the confluence of the South Branch to the Maine/Canada border was studied by Maine DEP staff to evaluate current water quality and to assess the impact of existing and proposed licensed discharges. The water quality model QUAL2E, version 3.22, was used in the evaluation. Three data sets obtained during August 1990, July 1993 and July 1995 were used to calibrate and verify the model. The following were concluded:

(1) The survey data as well as model runs indicate that the Meduxnekeag River is not attaining standards for dissolved oxygen concentration below the Houlton outfall. The major factor in this non-attainment is the diurnal effect of attached plant growth.

(2) DO deficit component analyses as well as treatment plant performance data indicate that point source BOD is a minor factor in the instream DO concentrations below the Houlton outfall.

(3) A method of total phosphorous allocation is presented which results in a very low allocation for Houlton which would require tertiary treatment.

(4) It is recommended that a pilot study be made at the Houlton treatment plant to investigate the reduction of phosphorous concentrations in the effluent to the extent possible under limited capital expenditures. Reference is made to work done at the Oakland treatment plant. Any study should include adequate data collection.

(5) Current license limits and conditions for A.E. Staley (Maine permit) are not a major factor in the low flow (7Q10) nutrient allocation, but if recommended studies are unsuccessful in attaining standards, more strict discharge limits may be required.

(6) The extent of upstream regulation or water withdrawals should be investigated.

(7) Should pilot studies at the Houlton treatment plant along with any non point source reductions be insufficient in achieving water quality standards, other options must be investigated.

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Introduction

The Meduxnekeag River is located in northeastern Maine and is a tributary of the Saint John River. The total drainage area at the point of confluence with the Saint John River in Canada is 516 mi.^{2}. The total drainage area at Houlton and at the Maine/Canada border are 231 mi.^{2} and 289 mi.^{2}, respectively. This study focuses on the 13.3 mile segment from approximately one mile above the confluence of the South Branch Meduxnekeag River at Carys Mills to the Canadian border (see Figure 1). The Meduxnekeag River is classified B by the state of Maine, which requires:

A. Class B waters shall be of such quality that they are suitable for the designated uses of drinking water supply after treatment; fishing; recreation in and on the water; industrial process and cooling water supply; hydroelectric power generation, except as prohibited under Title 12, section 403; and navigation; and as habitat for fish and other aquatic life. The habitat shall be characterized as unimpaired.

B. The dissolved oxygen content of Class B waters shall be not less than 7 parts per million or 75% of saturation, whichever is higher, except that for the period from October 1st to May 14th, in order to ensure spawning and egg incubation of indigenous fish species, the 7-day mean dissolved oxygen concentration shall not be less than 9.5 parts per million and the 1-day minimum dissolved oxygen concentration shall not be less than 8.0 parts per million in identified fish spawning areas. Between May 15th and September 30th, the number of Escherichia coli bacteria of human origin in these waters may not exceed a geometric mean of 64 per 100 milliliters or an instantaneous level of 427 per 100 milliliters.

C. Discharges to Class B waters shall not cause adverse impact to aquatic life in that the receiving waters shall be of sufficient quality to support all aquatic species indigenous to the receiving water without detrimental changes in the resident biological community.

The major licensed discharges within this segment include the city of Houlton and A.E. Staley Manufacturing Co. Currently, Staley is authorized by USEPA to discharge only during the period October 1 through May 31. This study was originally initiated by a request from Staley to permit a year round discharge to the Meduxnekeag River.

It was decided to perform a study of the Meduxnekeag River involving the collection of water quality/quantity data and the development of a water quality model to be used in assessing the assimilative capacity of the river at conditions of low flow and high temperature and in evaluating alternatives.

A previous draft of this report was issued during April 1994. It was concluded that additional information was required to fully address assimilative capacity issues. Based upon the information available at the time, Maine issued a year round discharge license to Staley which includes conditions regarding minimum river flow, dissolved oxygen monitoring, and a phosphorous limit. EPA is in the process of issuing a similar permit.

An additional series of data was collected during the summer of 1995. This revised draft report includes the 1995 data as well as additional modeling, analyses and recommendations.

Field Studies

During July 2, 3 and 5, 1990 personnel from the MDEP Presque Isle office established cross section locations within the river segment under study. At each station channel bottom profiles and water depth measurements were made and referenced to established points. River flow was measured at the bridge above the confluence of the South Branch at Carys Mills.

An attempt was made to collect an additional round of hydraulic data during July 23, 1990 but heavy rain cut this effort short.

During August 6-8, 1990 the MDEP Presque Isle personnel performed an intensive survey of the river segment. Each day dissolved oxygen and temperature readings were taken at each station during early morning and again during mid afternoon. In addition, water samples were collected at selected stations during the morning run. These samples were analyzed by MDEP for ammonia nitrogen (NH3), nitrate plus nitrite nitrogen (NO2+NO3), total phosphorous (TP), dissolved phosphorous (PO4), chlorophyll (chl-a) and 60 day BOD. Samples of effluent from Staley and Houlton treatment plants were taken and analyzed for the above constituents (except chl-a) as well as BOD5. River flow was also measured at Carys Mills.

During the next two years attempts made to perform a second intensive survey under low flow/high temperature conditions were unsuccessful due to high river flows. Additional hydraulic data (river profiles, water surface elevations and river flows) were collected during June 11-12, 1991 and a few water samples (major tributaries and Houlton effluent) were collected and flows measured during August and September 1992.

During July 27-29, 1993 a second intensive survey was conducted by Augusta MDEP personnel aided by a CREST program intern, representatives of the Houlton Band of Maliseet Indians and the Presque Isle office. River flows were higher than desired.

Finally, during July 1995 a third intensive survey was made under conditions of relatively low flow. This survey was conducted by Augusta and Presque Isle MDEP personnel with some assistance by the Houlton Band of Maliseet Indians.

Data Results

The water quality data collected during the above surveys are included in the Appendix. Figure 2 shows all of the dissolved oxygen (DO) data from the three surveys. Figure 3 shows the morning DO data only. Based upon these data, the Meduxnekeag River did not attain its classification standard for DO under the sampling conditions of 1990 and 1995 but did marginally meet standards under the 1993 survey conditions. Two measurements made during early morning during the 1990 survey indicated DO concentrations below the 7 ppm standard while several measurements made during the 1995 survey were significantly below this standard.

Model Development

Methodology

The modeling framework chosen for this study was the QUAL2E model. The modeling was performed with version 3.22 (August 1995). This model is supported by the USEPA Center for Exposure Assessment Modeling in Athens, Georgia. QUAL2E provides a framework for simulating up to 15 water quality constituents under steady state hydraulic and loading conditions. The model can also be used to evaluate the average daily effect due to diurnal variations in phytoplankton growth/respiration and meteorological conditions.

Figure 2
Meduxnekeag River
1990, 1993 and 1995 Data

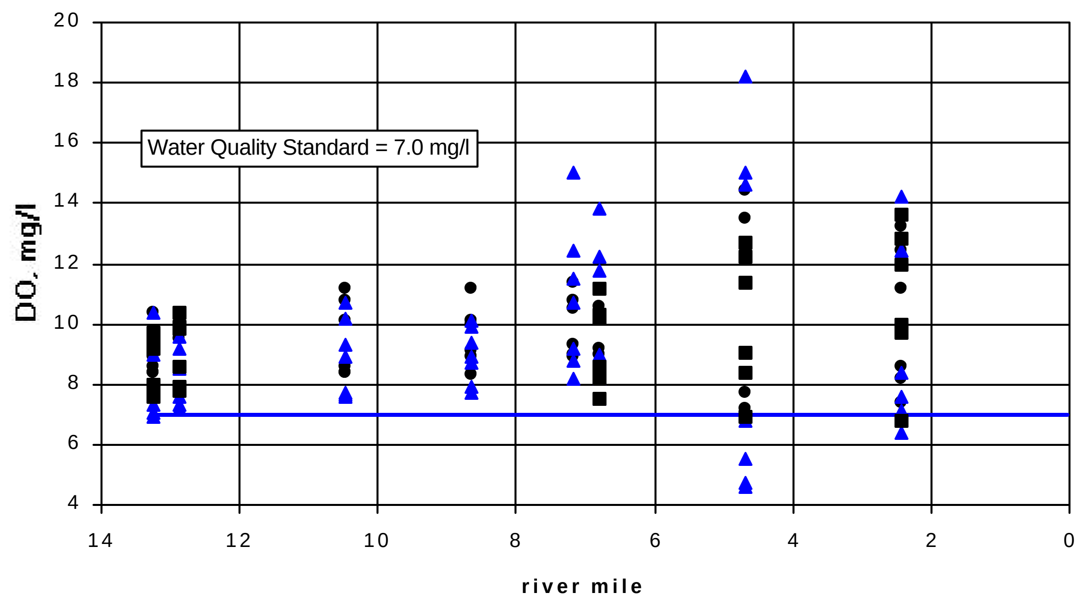
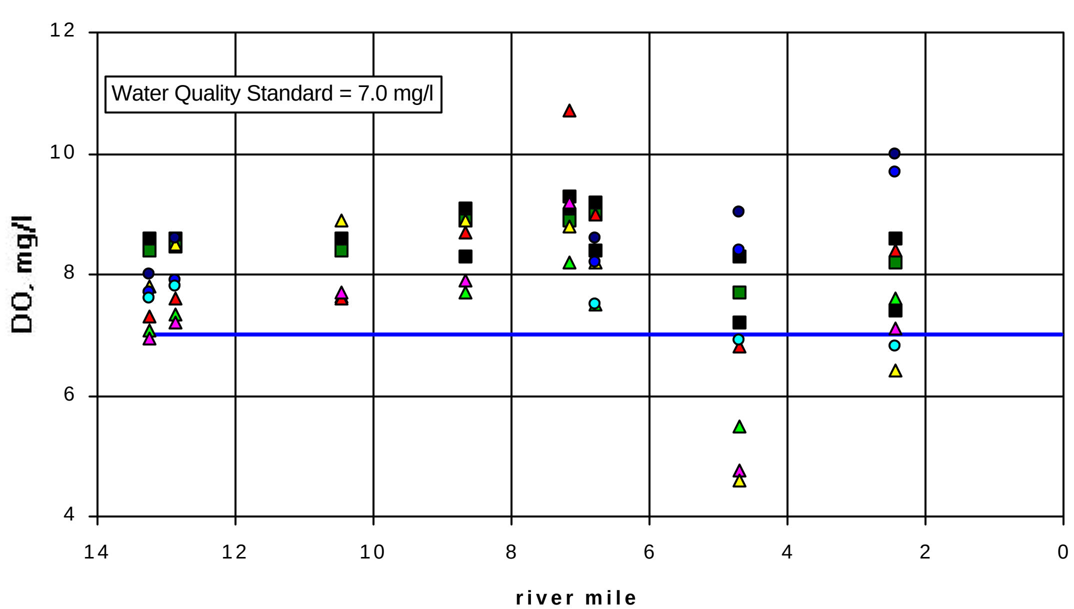


Figure 3
Meduxnekeag River
1990, 1993 and 1995 Morning Data



Hydraulic representation

For modeling purposes the river segment under investigation was divided into reaches of similar hydraulic characteristics. Each reach is then subdivided into elements, every element being equal in length. The setup for the Meduxnekeag River study is shown in Figure 4. Flow proceeds downstream from element to element and within each element complete and instantaneous mixing is assumed to occur. The hydraulics, which affect the velocity and depth of each element, can be represented in one of two ways: calculated from Manning's Equation or from an exponential function of flow. In this study the latter method was chosen.

The velocity and depth were represented as:

$$V = aQ^b$$
$$D = cQ^d$$

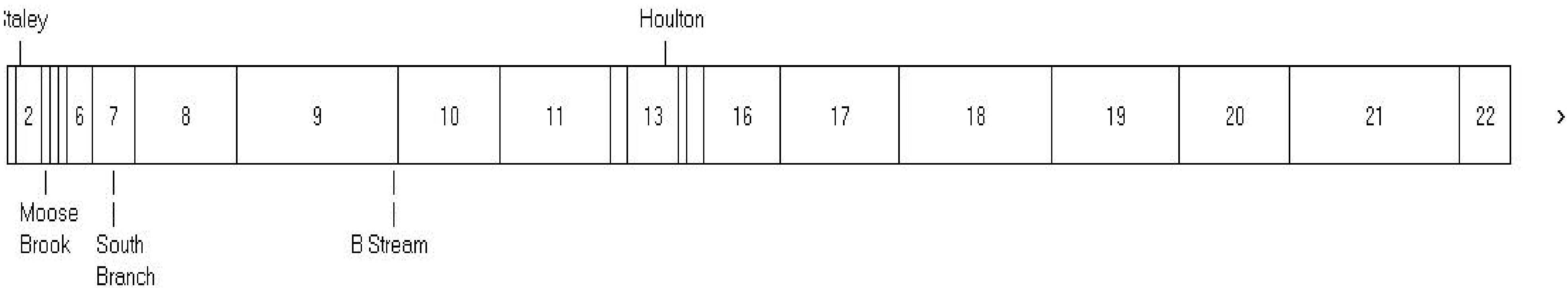
where:
V = velocity, ft/sec
Q = river flow, cfs
D = average depth, ft
a,b,c,d = constants

Using the cross sectional areas, flows and depths measured during 1990 and 1991, the above equations were solved for the constants a,b,c and d (Table 1).

model segment	V = aQ^b			D = cQ^d		
	a	B	r2	c	d	r2
1	0.015	0.747	1.00	0.834	0.214	0.98
2	0.081	0.492	0.93	0.166	0.44	0.92
3	0.128	0.448	0.97	0.175	0.481	0.98
4	0.094	0.563	1*	0.246	0.296	1*
5	0.227	0.323	1*	0.053	0.665	1*
6	0.028	0.704	0.97	0.349	0.279	0.86
7	0.041	0.689	1.00	0.641	0.257	1.00
8	0.044	0.638	1.00	0.208	0.352	1.00
9	0.043	0.559	1.00	0.24	0.391	1.00
10	0.368	0.242	0.84	0.031	0.706	0.99
11	0.166	0.351	1.00	0.088	0.55	1.00
12	0.019	0.747	est.	0.752	0.214	est.
13	0.013	0.74	1.00	0.686	0.253	1.00
14	0.174	0.351	est.	0.08	0.55	est.
15	0.016	0.74	est.	5.41	0.253	est.
16	0.051	0.535	0.94	0.15	0.428	0.90
17	0.31	0.257	1*	0.096	0.463	1*
18	0.033	0.604	0.99	0.196	0.389	0.97
19	0.063	0.631	1.00	0.448	0.174	0.98
20	0.065	0.559	0.99	0.258	0.329	0.99
21,22	0.331	0.222	0.90	0.074	0.59	1.00

* regression based on two data points only

Table 1
Hydraulic Coefficients


taley
Houlton
2
6
7
8
9
10
11
13
16
17
18
19
20
21
22
Moose Brook
South Branch
B Stream

Parameter representation

$CBOD_u$

The oxidation of organic matter is represented in the model by the ultimate carbonaceous biochemical oxidation demand (CBODu) decay rate, Kd as follows:

$dC/dt = -Kd\ (qd)^{T-20}\ (CBOD_u)$

$d(CBOD_u)/dt = -Kd\ (qd)^{T-20}\ (CBOD_u)$

where:

- C = oxygen concentration, mg/l
- t = time, days
- Kd = $CBOD_u$ decay rate at 20^o C, /day
- qd = $CBOD_u$ temperature coefficient
- T = element temperature, ^{o}C
- $CBOD_u$ = ultimate carbonaceous biochemical oxygen demand, mg/l (usually represented by a 60 day test)

$NBOD_u$

A part of the nitrogen cycle involves the oxidation of ammonia. This oxygen uptake can be represented by actually modeling the nitrogen cycle or by measuring and modeling ultimate nitrogenous biochemical oxygen demand ($NBOD_u$). In this study the latter method was used with the oxidation of $NBOD_u$ being represented by the $NBOD_u$ decay rate, Kn as follows:

$dC/dt = -Kn\ (qn)^{T-20}\ (NBOD_u)$

$d(NBOD_u)/dt = -Kn\ (qn)^{T-20}\ (NBOD_u)$

where:

- C = oxygen concentration, mg/l
- t = time, days
- Kn = $NBOD_u$ decay rate at 20^o C, /day
- qn = $NBOD_u$ temperature coefficient
- T = element temperature, ^{o}C
- $NBOD_u$ = ultimate nitrogenous biochemical oxygen demand, mg/l (usually represented by a 60 day test)

Reaeration

Oxygen exchange between the water surface and the atmosphere is represented by the reaeration rate, Ka as follows:

$dC/dt = Ka\ (qa)^{T-20}\ (DOsat-DO)$

where:

- C = oxygen concentration, mg/l
- t = time, days
- Ka = reaeration rate at 20^o C, /day
- qa = reaeration temperature coefficient
- T = element temperature, ^{o}C
- DOsat = dissolved oxygen saturation concentration, mg/l
- DO = element dissolved oxygen concentration, mg/l

QUAL2E provides eight options for the specification of Ka. In general, Ka is specified as a function of water velocity and depth. A number of investigators have developed relationships among Ka, velocity and depth. A popular method is that of Covar, who combined the work of O'Connor/Dobbins, Churchill and Owen into a single chart (see Figure 5). Covar's method was used for this study except that a maximum for Ka was established at 24 /day (this maximum is specified in the WASP model framework). Note that when instream DO concentration is greater than saturation, reaeration tends to result in transfer of DO from the water to the atmosphere.

Figure 5
Reaeration Rates - Covar Method

Diurnal effects

Aquatic plants, including macrophyton (large plants), phytoplankton (floating algae) and phytoperiphyton (attached algae) produce oxygen through photosynthesis using solar radiation. They also consume oxygen at all times through respiration. As a result, plant activity provides a net excess of oxygen during daylight hours and a net depletion during night hours. In waterbodies with significant plant populations, this activity results in diurnal variations in oxygen concentration with minimum concentration occurring at dawn and maximum concentration occurring in the afternoon. In fact, this effect can result in afternoon oxygen concentrations well above saturation levels.

The data obtained during all three surveys showed large diurnal swings in oxygen concentration with changes in DO concentration of up to 11.4 mg/l during a single day. The data also showed relatively low concentrations of chl-a (averages of 2.12, 2.29 and 2.02 ug/l with maximums of 2.8, 4.12 and 7.48 ug/l for the 1990, 1993 and 1995 surveys, respectively) which indicate low concentrations of floating algae. Large masses of attached algae were seen during the surveys, especially below the Houlton outfall at the bridge sites. Based on these data it is assumed that the large diurnal effects are due to plants rooted in or attached to the river substrate.

The QUAL2E model does not provide for the modeling of attached plants. In any case it would be difficult to quantify the plant mass. As a result the following approach was used in the modeling effort:

(1) The model was set up to model average daily DO concentration. In other words the model was calibrated to the average of the morning and afternoon field DO measurements.

(2) To account for the net daily gain in DO concentration due to plant growth, negative SOD (sediment oxygen demand) was specified in the model during the calibration process. Normally SOD represents an oxygen demand exerted by the sediments in terms of mass of oxygen per unit bottom area.

(3) For making assessments of minimum DO criteria, the average daily DO from the model is bracketed by the measured maximum diurnal DO variation at each sample station. The diurnal swing between sample stations was interpolated. This bracketing was accomplished by subtracting half of the diurnal variation from (and adding half to) the average daily concentration.

Temperature

Temperature is not modeled, but input as a daily average.

Model Calibration/Verification

Due to the normally high degree of uncertainty for the values of many parameters, models are calibrated and verified. This process gives much more credibility to the predictive capability of the model. Normally, a model is calibrated to the best data set (lowest flows, best quality data, etc.) and the same parameters used under the conditions of one or more additional data sets. The additional data set(s) should be collected under conditions which vary sufficiently from those of the first data set to provide confidence in the extrapolation of the model to design conditions. The model is verified when this process results in an acceptable match to each data set.

In this case the model was set up and calibrated to the 1990 data set prior to the 1993 survey. Using the flows, boundary conditions and treatment plant loads measured during the actual survey, the model was first calibrated for Kd and Kn rates by varying these rates within known ranges until adequate matches to the $CBOD_u$ and $NBOD_u$ concentration data were achieved. Next the model was calibrated to the DO data by adjusting the SOD inputs for each reach. As previously discussed, negative values for SOD were used to account for the net daily DO input from plant activity. The magnitude of the diurnal DO swing increased in the downstream direction, therefore the magnitude of the SOD input was lower for the downstream reaches (the SOD inputs for the final calibrated/verified model are shown in Table 2).

Model Segment	SOD Input gm/ft2/day O_2
1 thru 9	0.05
10	0.000
11	-0.100
12	-0.200
13, 14	-0.300
15 - 22	-0.500

Table 2
SOD Inputs for Calibrated/Verified Model

After the 1993 data set was collected, the model was run under the flow and boundary conditions measured during the 1993 survey. Additional adjustments were made to the parameters to achieve a reasonable fit to both 1990 and 1993 data sets. At this point the model provided good agreement to the two data sets, but these data sets were collected under less than ideal conditions. Specifically, river flows were higher than desired (5.2-6.7 times 7Q10 flow) and were similar in magnitude during the two surveys. This raised the question of the ability of the model to make reasonable predictions under low flow design conditions.

Subsequently, a third dataset was collected during 1995 under significantly lower river flows. The model was run under the 1995 conditions and the results compared to the 1995 data. Some adjustments were made to the model SOD inputs so that the model provided reasonable predictions for each of the three sets of data. The model results for each of the surveys are shown in Figures 6 through 14. The DO plots include the measured diurnal brackets as previously described under the diurnal effects section.

Sensitivity analyses

Sensitivity analyses were run on the calibrated/verified Meduxnekeag River model using the conditions of the 1995 survey. A sensitivity analysis again addresses the uncertainty surrounding parameter values by looking at the variation of the modeled variable (in this case DO, $CBOD_u$ and $NBOD_u$) that results when one of the model parameters is varied within a specified range.

For this study the model parameters Kd, Kn, SOD rate and Ka were varied within a range of +50% to -50% of the calibration values. The results are shown in Table 3 and Figures 15 and 16.

		DO		CBOD		NBOD	
Parameter	variation	change*	location**	change*	location**	change*	location**
CBOD	+50%	-0.05	13,6	-0.41	22,6	-	-
decay rate	-50%	0.05	13,5	0.48	22,6	-	-
NBOD	+50%	-0.01	various	-	-	-0.08	22,6
decay rate	-50%	0.01	various	-	-	0.09	22,6
SOD rate	+50%	-0.83	18,2	-	-	-	-
	-50%	0.84	18,2	-	-	-	-
reaeration	+50%	-0.53	18,4	-	-	-	-
rate	-50%	1.49	18,12	-	-	-	-

*maximum in mg/l

**model reach,element

Table 3
Sensitivity Analyses

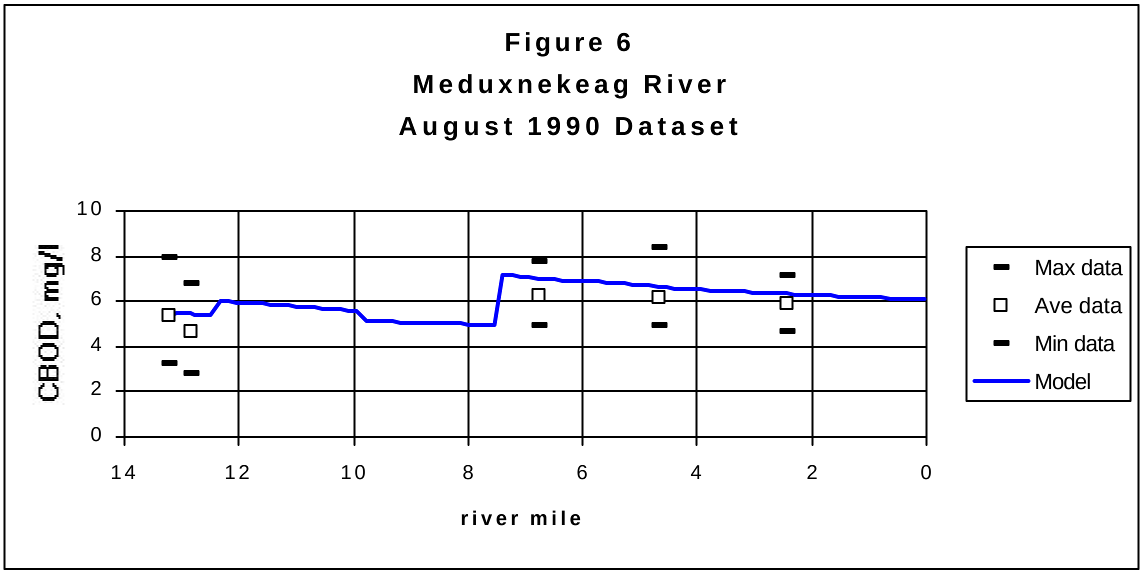


Figure 6
Meduxnekeag River
August 1990 Dataset
CBOD, mg/l
river mile
Max data
Ave data
Min data
Model

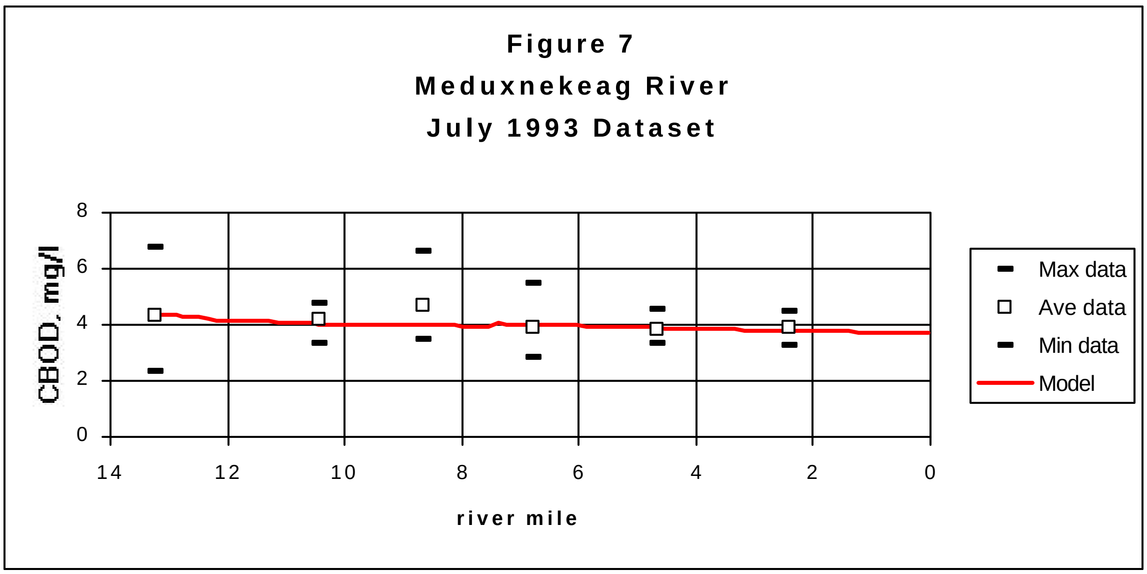


Figure 7
Meduxnekeag River
July 1993 Dataset
CBOD, mg/l
river mile
Max data
Ave data
Min data
Model

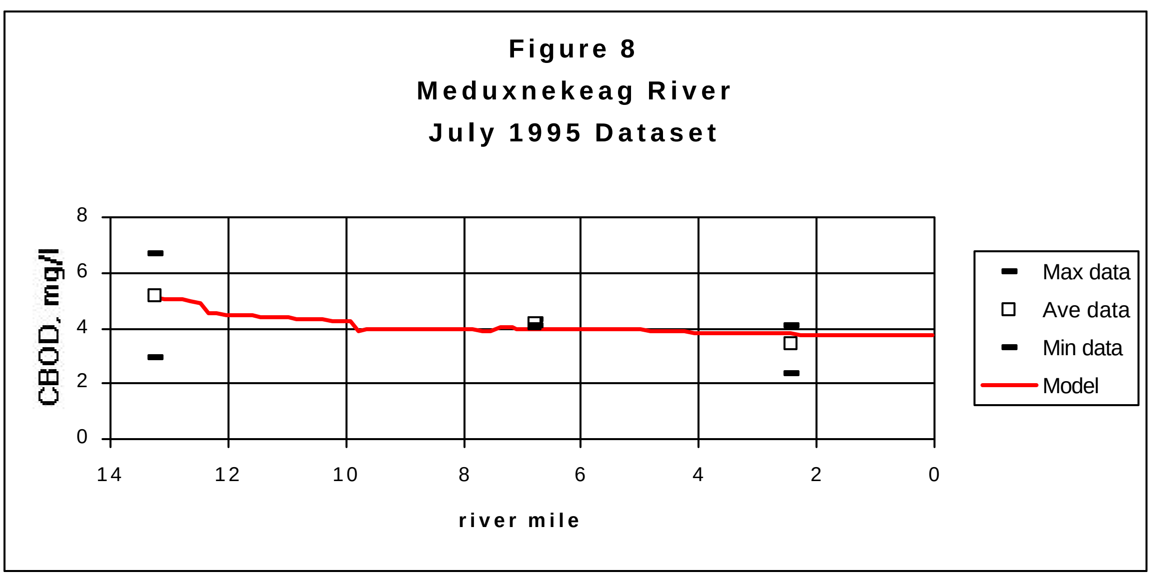


Figure 8
Meduxnekeag River
July 1995 Dataset
CBOD, mg/l
river mile
Max data
Ave data
Min data
Model

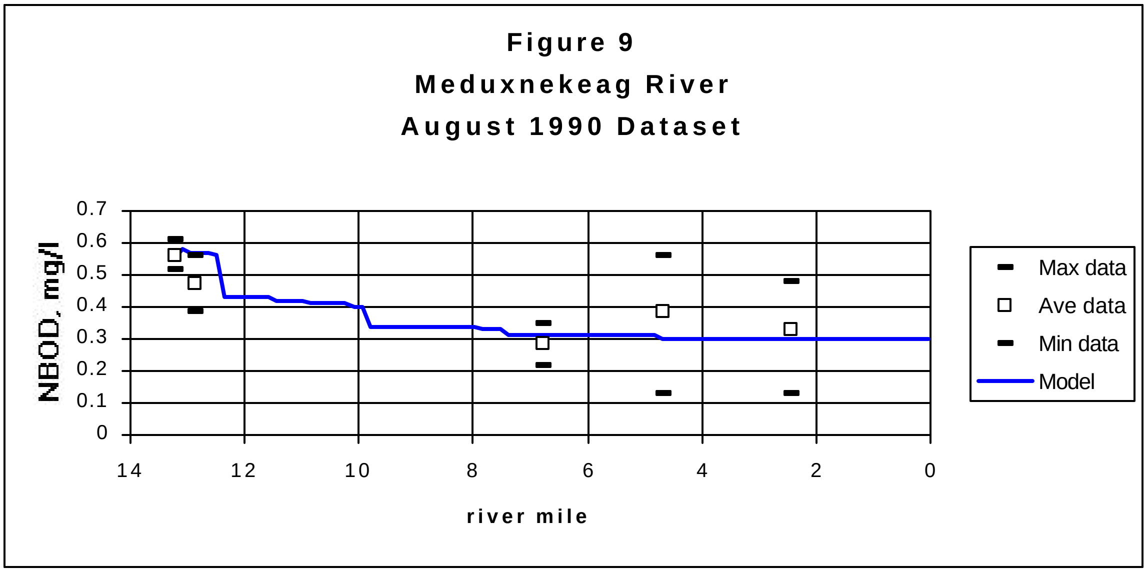


Figure 9
Meduxnekeag River
August 1990 Dataset
NBOD, mg/l
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
14
12
10
8
6
4
2
0
river mile
Max data
Ave data
Min data
Model

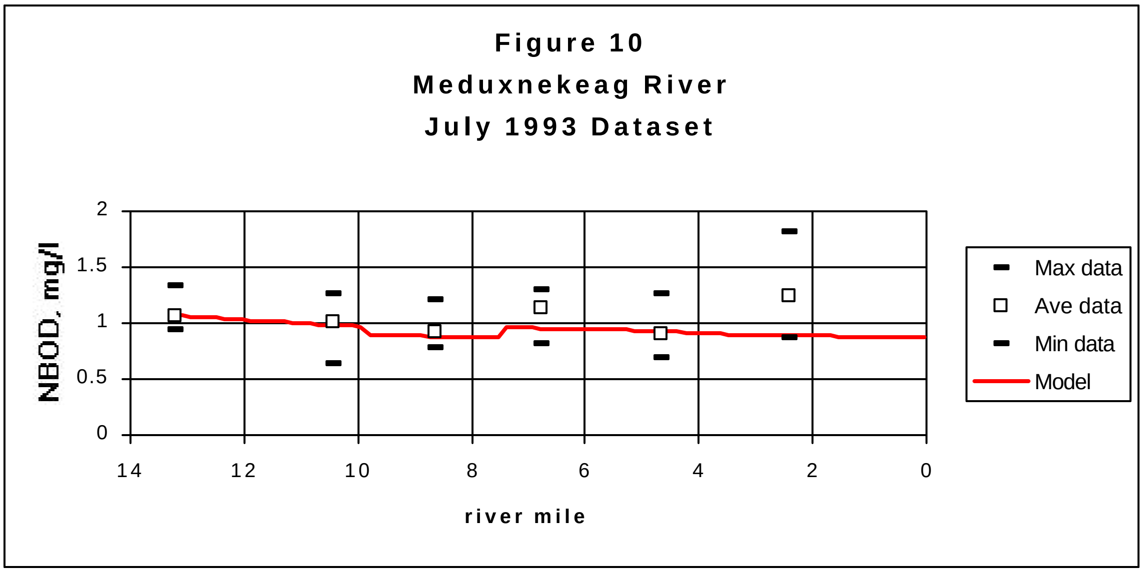


Figure 10
Meduxnekeag River
July 1993 Dataset
NBOD, mg/l
2
1.5
1
0.5
0
14
12
10
8
6
4
2
0
river mile
Max data
Ave data
Min data
Model

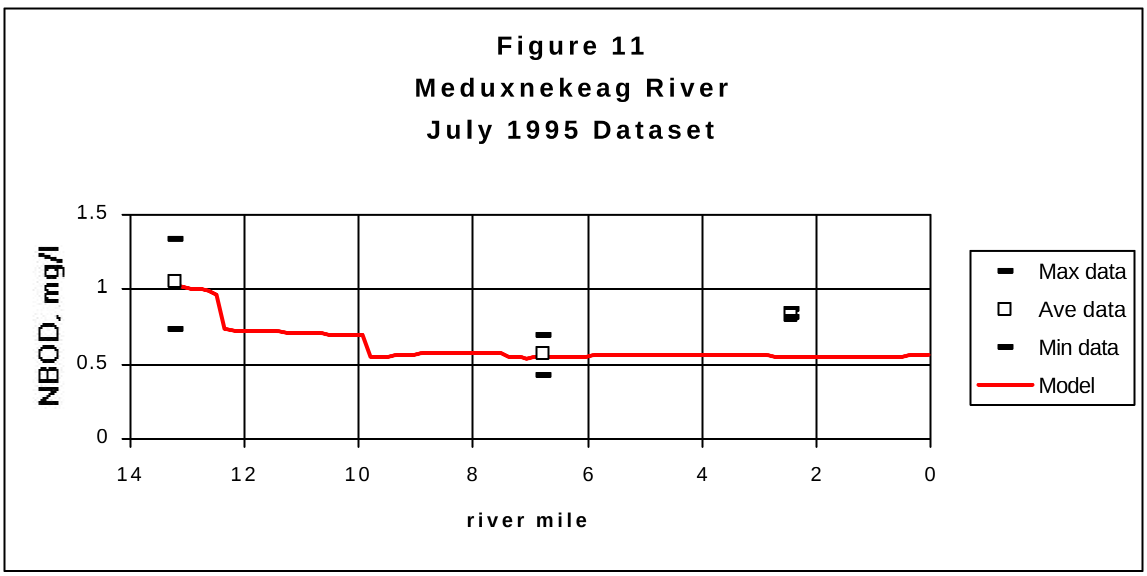


Figure 11
Meduxnekeag River
July 1995 Dataset
NBOD, mg/l
1.5
1
0.5
0
14
12
10
8
6
4
2
0
river mile
Max data
Ave data
Min data
Model

Figure 12
Meduxnekeag River
August 1990 Dataset

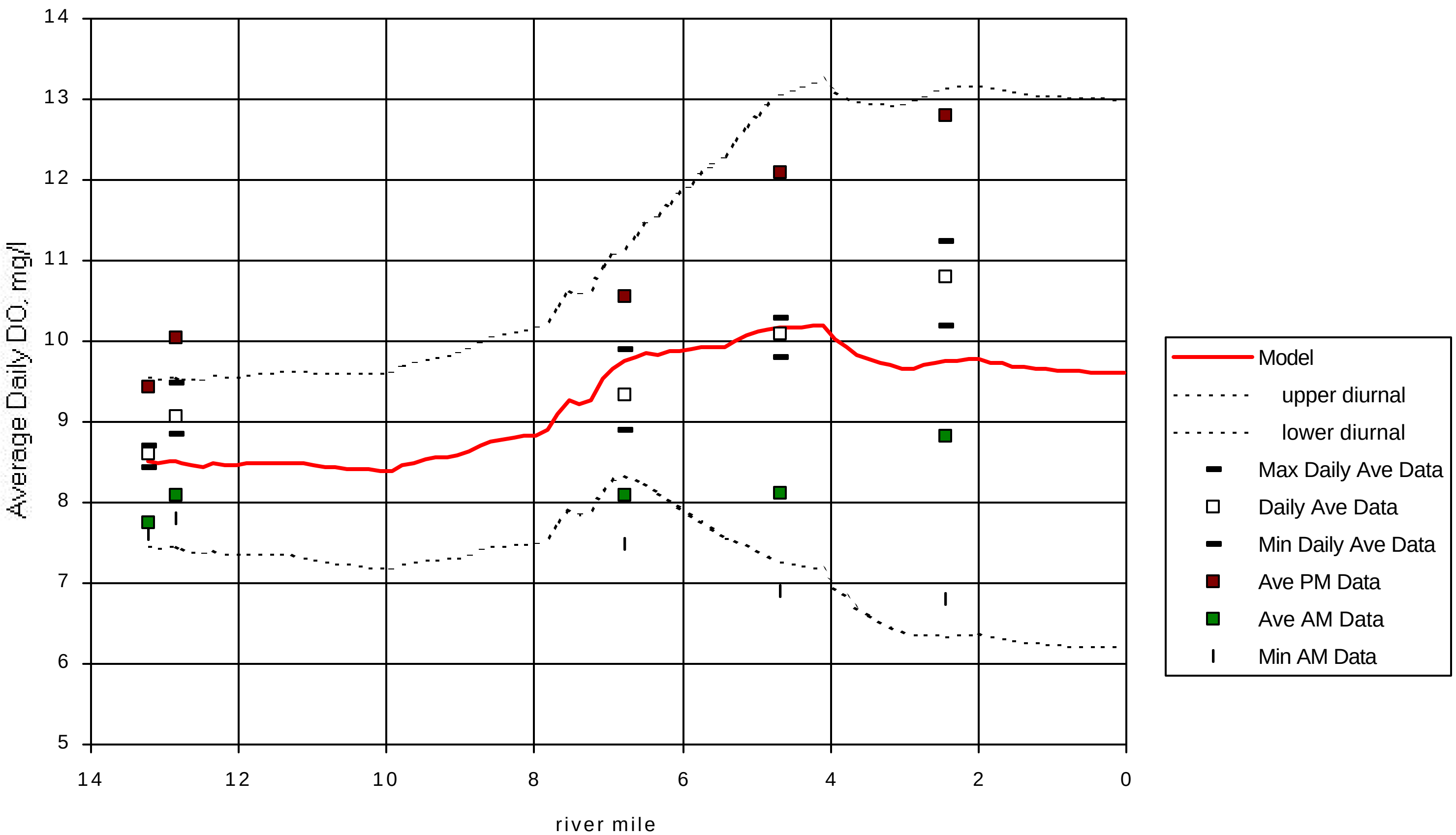


Figure 13
Meduxnekeag River
July 1993 Dataset

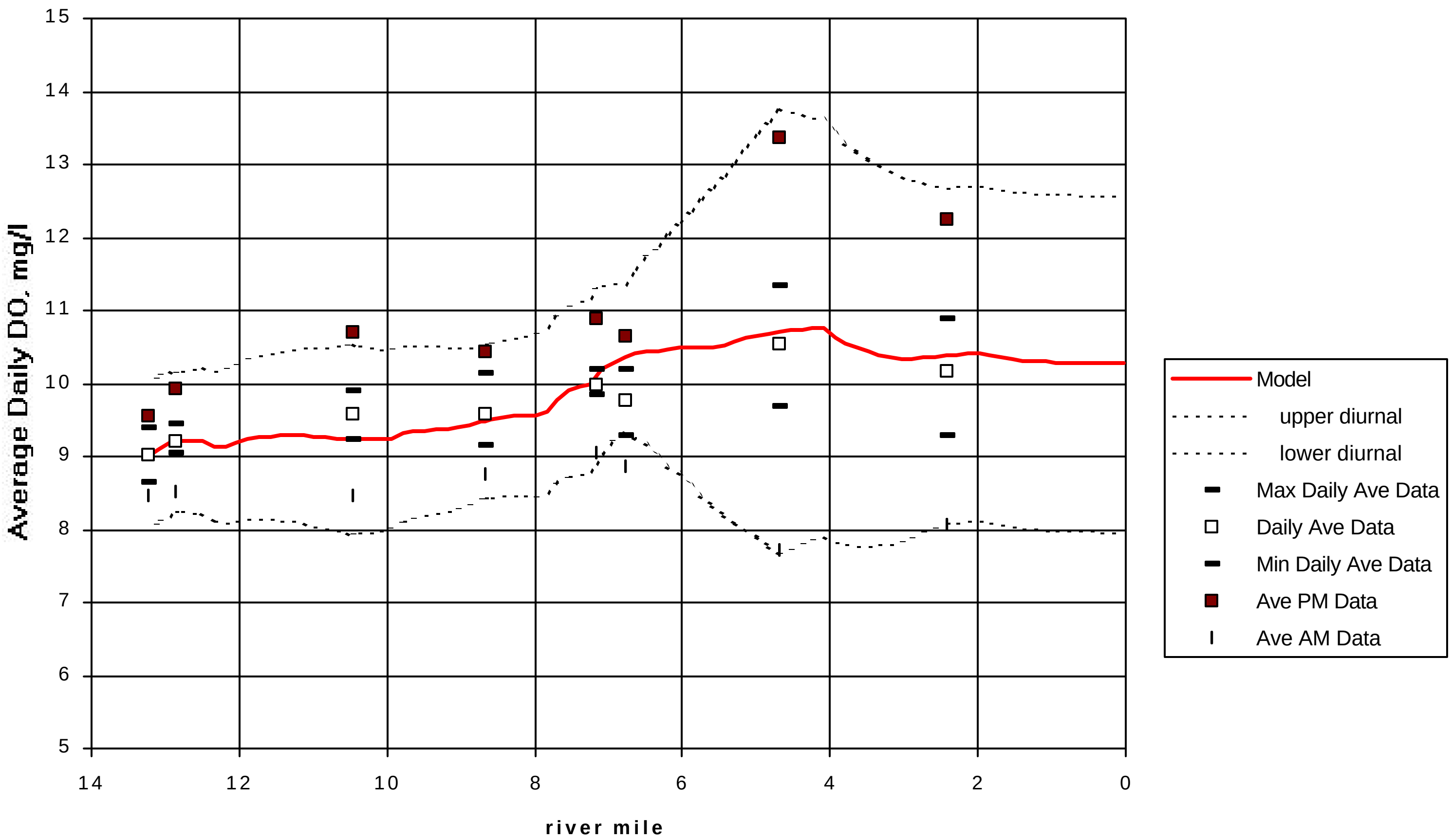


Figure 14
Meduxnekeag River
July 1995 Dataset

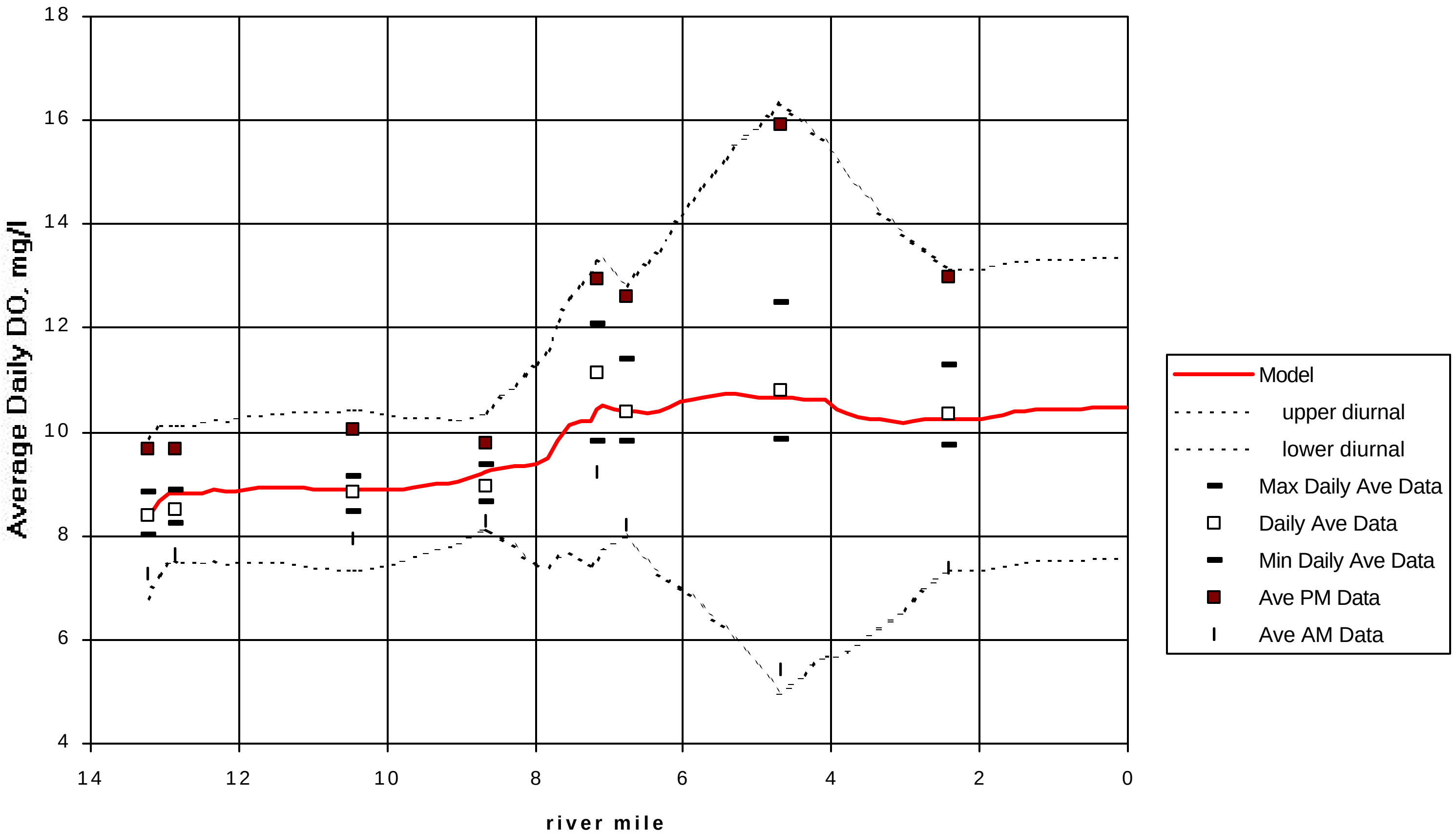


Figure 15
Meduxnekeag River
Ka Sensitivity

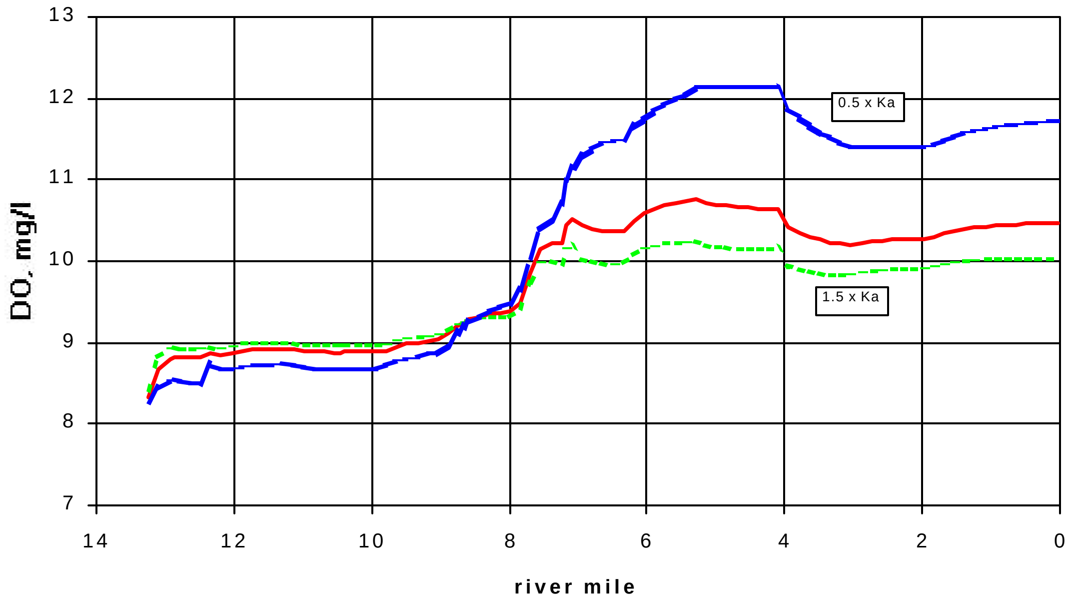
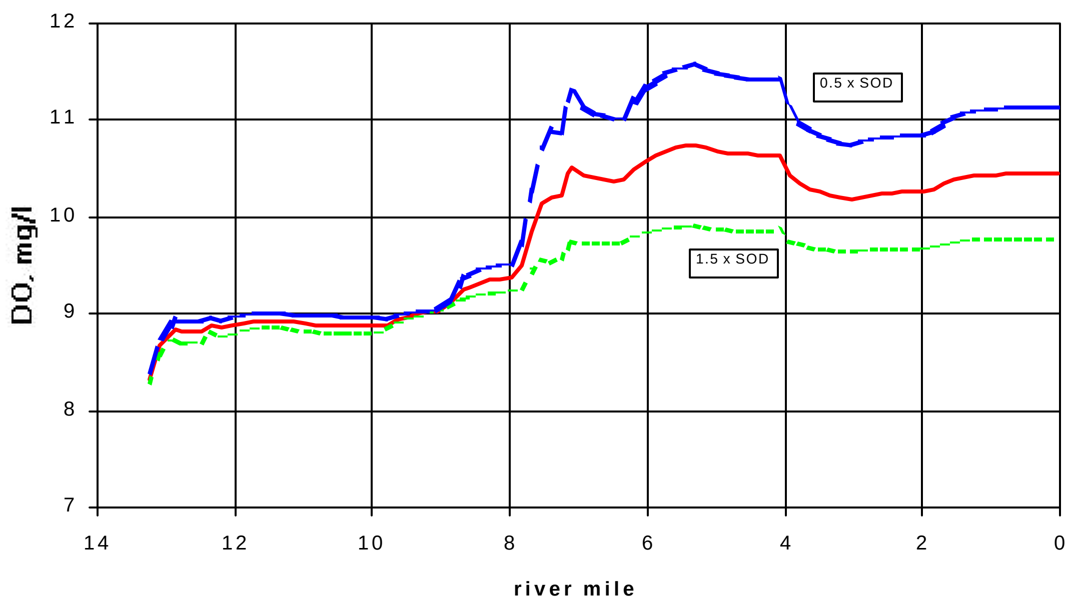


Figure 16
Meduxnekeag River
SOD Sensitivity



In general, the model is not sensitive to variation in Kd and Kn in predicting both BOD concentrations and DO concentration. The model in moderately sensitive to variation in Ka and SOD in predicting DO from the upper boundary down to the Houlton outfall with variation in DO less than +/- 0.5 ppm. Below the Houlton outfall this sensitivity to both Ka and SOD increases toward the lower boundary. This increased sensitivity corresponds with the increase in diurnal DO variation.

A decrease in Ka had a larger effect on DO than a corresponding increase in Ka (change of 1.3 ppm verses a change of 0.4 ppm at the downstream boundary). The reason for this is unclear, but it should be noted that oxygen transfer is generally from the water to the air due to the supersaturated DO concentrations.

These results indicate that the choice of SOD and reaeration inputs are critical and the choice of the decay rates less critical. To reiterate, SOD values were determined through calibration to DO data and represent diurnal plant effects. Reaeration rates were specified using established methods based on depth and velocity.

Assessment of Minimum Dissolved Oxygen Criteria

Introduction

The assessment of minimum water quality criteria is made assuming environmental conditions which are the worst case conditions that can be reasonably expected to occur at any one time. These conditions generally include 7Q10 low flow (representing the minimum seven day average flow that occurs statistical once every 10 years), high temperature and maximum licensed discharge loads.

Only one major point load, Houlton treatment plant, is licensed to discharge at low river flows. Staley is licensed to discharge at flows greater than 30 cfs as measured at their outfall. Therefore a second model was set up to assess the impact of both Staley and Houlton based on a river flow of 30 cfs at Staley.

Existing Licensed Conditions

Licensed Discharges

The current EPA license limits for BOD5 and flow for the two licensed discharges to the segment of the Meduxnekeag River under study are as follows:

	BOD5			Temp	Flow
Licensee	Monthly Ave. lb/day (mg/l)	Weekly Ave. lb/day (mg/l)	Daily Max. lb/day (mg/l)	Daily Max. ^oF	MGD
Houlton	375 (30)	563 (45)	625 (50)	-	1.5
Staley (001)	75*	-	133*	-	0.04*
Staley (002)	-	-	-	75	0.05

*October 1 - May 31

Table 4
Permit Conditions

Prior to evaluation of the 1995 survey data Maine issued a revised waste discharge license to Staley which allows for discharge during the summer period under specific conditions:

Licensee	BOD5 Monthly Ave. lb/day (mg/l)	BOD5 Weekly Ave. lb/day (mg/l)	BOD5 Daily Max. lb/day (mg/l)	Total Phos. Mon. Ave. lb/day	Temp Daily Max. ^oF	Flow MGD
Staley (001)	54*	-	67*	1.14	-	0.04*
Staley (002)	-	-	-	-	75	0.05

*(1) June 1 - September 15
(2) Minimum river flow of 30 cfs
(3) Monitor DO below Houlton outfall
(4) Instream DO not less than 7.0

Table 5
Maine "Summer" Permit Conditions for Staley

Before being input into the model, the discharge license loads must be converted from 5 day BOD (BOD5) to $CBOD_u$. In addition, the model input for $NBOD_u$ must be estimated from the BOD5 concentration. The relationships in Table 6 were derived from the results of the analyses made on the effluent samples taken during the surveys.

Licensee	CBODu/BOD5	NBODu/BOD5
Houlton	6.0	0.0
Staley	3.5*	0.15

*no data, assumed

Table 6
BOD Conversion Factors

Treatment Plant Performance

The following Table summarizes the "summer" performance (May-Sept) of Houlton and the annual performance for Staley on the Meduxnekeag River based upon 4 years of monitoring data (1990-1993):

	4 Year Performance				License Limit
Licensee	Ave. BOD5 lb/day	Ave. BOD5 mg/l	Monthly Ave. Flow MGD	Temp Daily Max. ^oF	Ave. BOD5 lb/day (mg/l)
Houlton	25.2* (weekly)	2.6* (weekly)	1.21*	-	563 (45)
Staley (001)	38.0** (monthly)	-	0.034**	-	75**, 54^
Staley (002)	-	-	0.03*	67.5*	[75^{o}F max]

*May - September
**October 1 - May 31
^June 1 - September 30

Table 7
Treatment Plant Performance

The following Table summarizes the actual average BOD5 loading during the three intensive field surveys:

			Survey		License Limit
Licensee	Survey	Ave. Flow MGD	Conc. BOD5 mg/l	Mass BOD5 lb/day	Monthly Ave. BOD5 lb/day
Houlton	Aug-90	1.63	5.8	78.9	375
	Jul-93	0.5	4.6	19.2	
	Jul-95	0.55	0.7	3.2	
Staley (001)	Aug-90	0.03	26.9	6.7	75
	Jul 93	0	0	0	Oct 1-May 31
	Jul-95	0	0	0	

Table 8
Survey Loading Conditions

River Flow

By law, the 7 day, 10 year low flow is required for computing the assimilative capacity of receiving waters. USGS maintains the following river flow gages in the Meduxnekeag River basin:

#01018000 Meduxnekeag River near Houlton, ME

Period of record: Dec. 1941 - Sept. 1982
Drainage Area: 175 $mi.^2$
Average Daily Discharge: 300.7 cfs
7 Day 10 Year Low Flow: 5.5 cfs

The flow duration curve for the Meduxnekeag River is shown in Figure 17.

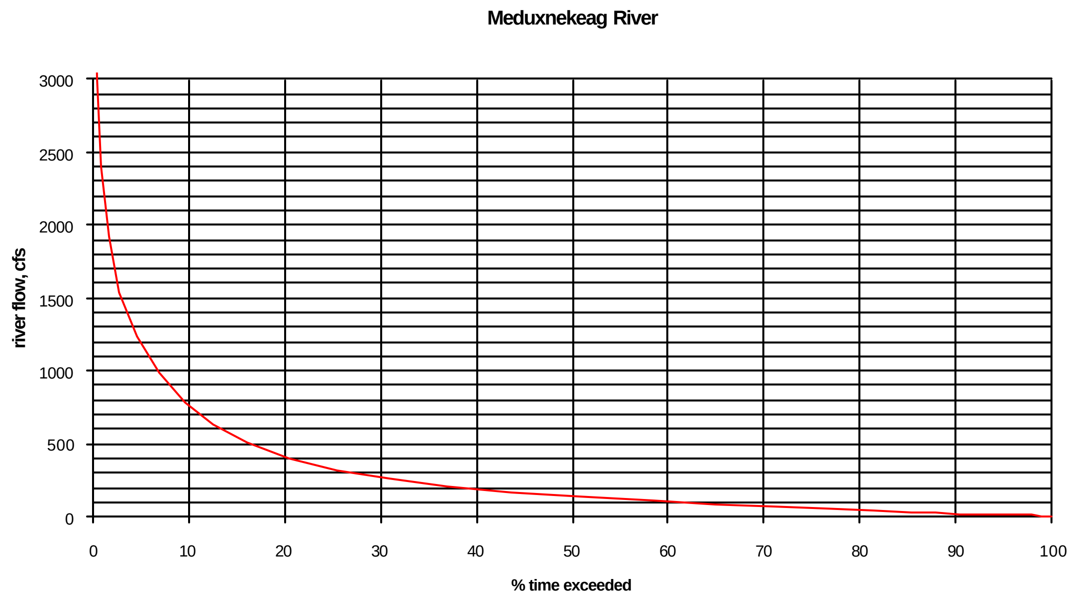


Figure 17
Meduxnekeag River Flow Duration Curve

Design Conditions

The low flow model runs were made using a 7Q10 low flow model and a 30 cfs model which were set up incorporating the following adjustments:

(1) Boundary river flows were specified as 7Q10 flows and 30 cfs at Staley, respectively.

(2) The effluent BOD5 mass loading from Houlton was input as the average weekly license limit. No load from Staley was input for the 7Q10 model. Maximum daily BOD5 permit loading was used for Staley in the 30 cfs model.

(3) Boundary conditions for $CBOD_u$, $NBOD_u$ and DO were specified as equal to the 1995 survey data for the 7Q10 model and equal to the 1990 survey data for the 30 cfs model.

(4) Temperature was specified as 22.4^oC.
.
(5) The diurnal DO range was taken as being equal to the 1995 data for the 7Q10 model. These data were measured at flows closest to 7Q10. The maximum diurnal range from the 1990 and 1993 surveys was used for the 30 cfs model. The values for points between stations were interpolated. Half of this diurnal variation was added to the modeled DO results (which represent average daily concentrations) and half was subtracted to provide estimates of the maximum and minimum daily DO concentrations.

(6) The negative SOD inputs, representing net daily DO increase due to plant activity, were not changed.

Model Results

The results of the existing license, 7Q10 model run is shown on the plot in Figure 18. Also included are the estimates of daily minimum and daily maximum diurnal DO concentrations for the existing license run. Shown in Figure 18A are runs representing: (1) performance loading from Houlton; (2) no discharge (BOD); and (3) no plant effects (i.e. no negative SOD). All of the model results represent average daily DO except (3) which represents daily minimum DO. The results indicate that DO limits would not be attained below the Houlton outfall at existing license conditions. Minimum DO concentration below Houlton is predicted as being 4.4 ppm at mile 4.7. The results also show that the impact at the sag point of BOD is small compared to the diurnal range. Assuming no plant activity, minimum DO for existing license loading of BOD from Houlton would be 6.9 ppm directly below the outfall (mile 7.4).

The results of the existing license, 30 cfs model run is shown on the plot in Figure 19. Also shown are runs representing: (1) performance loading from Houlton and Staley; (2) no discharge (BOD); and (3) no plant effects (i.e. no negative SOD). All of the model results represent average daily DO except (3) which represents daily minimum DO. Also included are the estimates of daily minimum and daily maximum diurnal DO concentrations for the existing license run. The results indicate that DO limits would not be attained below the Houlton outfall at existing license conditions. Minimum DO concentration below Houlton is predicted as being 5.9 ppm at mile 0.9 (this scenario does not account for Staley's requirement of no discharge when instream DO is less than 7.0 ppm). The results also show that the impact at the sag point of BOD is negligible compared to the diurnal range. Assuming no plant activity, minimum DO for existing license loading of BOD from Houlton and Staley would be 8.4 ppm between the Staley and Houlton outfalls (mile 9.9).

Component analysis

Further analyses were made to assess the relative contribution to the DO deficit (difference between DO saturation concentration and the instream DO concentration) of several factors. The model was run isolating each factor, with the results indicating the effect upon instream DO due to that factor alone. Figures 20-22 show the results for three locations, mile 10.5 between the Staley and Houlton outfalls, at mile 7.4 directly below the Houlton outflow and at mile 4.7 at the sag point below Houlton, for existing license conditions at 7Q10 river flow assuming no discharge from Staley.

A component analysis was also made using performance loading from Houlton at 7Q10 conditions. These results are shown in Figures 23-24.

Discussion

It is obvious from the low flow model runs that the major component in the DO deficit is plant activity, much more significant than BOD discharges. Low chl-a concentrations suggest that the plants are attached growth (phytoperiphyton and macrophytes) and not floating algae (phytoplankton). Thick growths of filamentous attached algae were noted below the Houlton outfall at the bridge sites during the surveys. Despite the apparent net daily gain in DO produced by the plants, overnight respiration results in depressed morning DO concentrations which are below classification limits at locations below the Houlton outfall.

Directly below the Houlton outfall the DO concentration of the effluent plays a major role in instream DO. This effect is rapidly reduced to the point where effluent DO is not a factor at the sag point. The model assumes an effluent DO of 5.0 mg/l, but a higher concentration is possible. Should the focus on attainment of DO standards shift to a point directly below the outfall, additional attention must be directed to the issue of effluent DO concentration.

Figure 18
Meduxnekeag River
7Q10 Model Run, Existing License

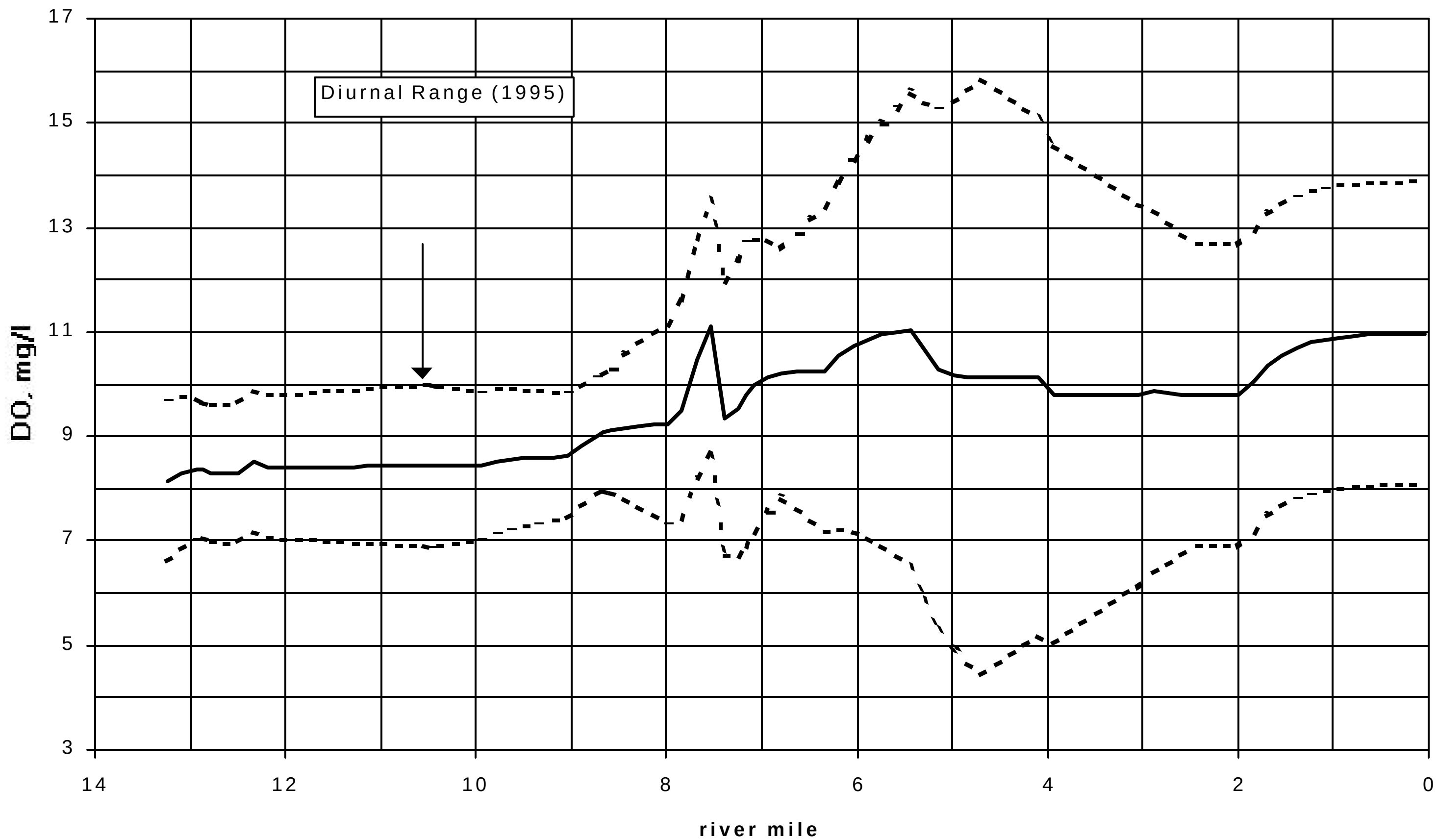


Figure 18A
Meduxnekeag River
7Q10 Model Runs

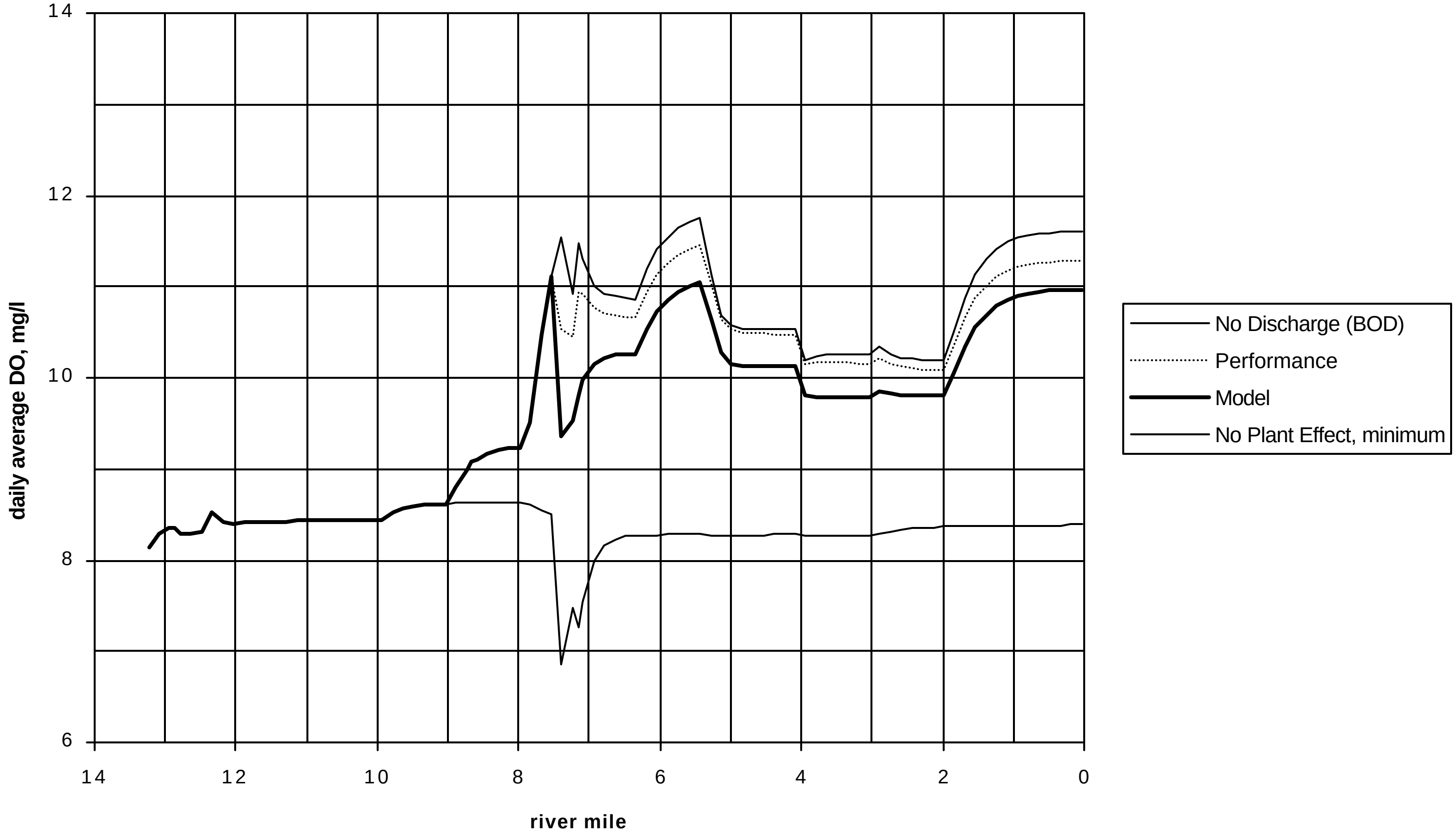


Figure 19
Meduxnekeag River
"30 cfs" Model Runs

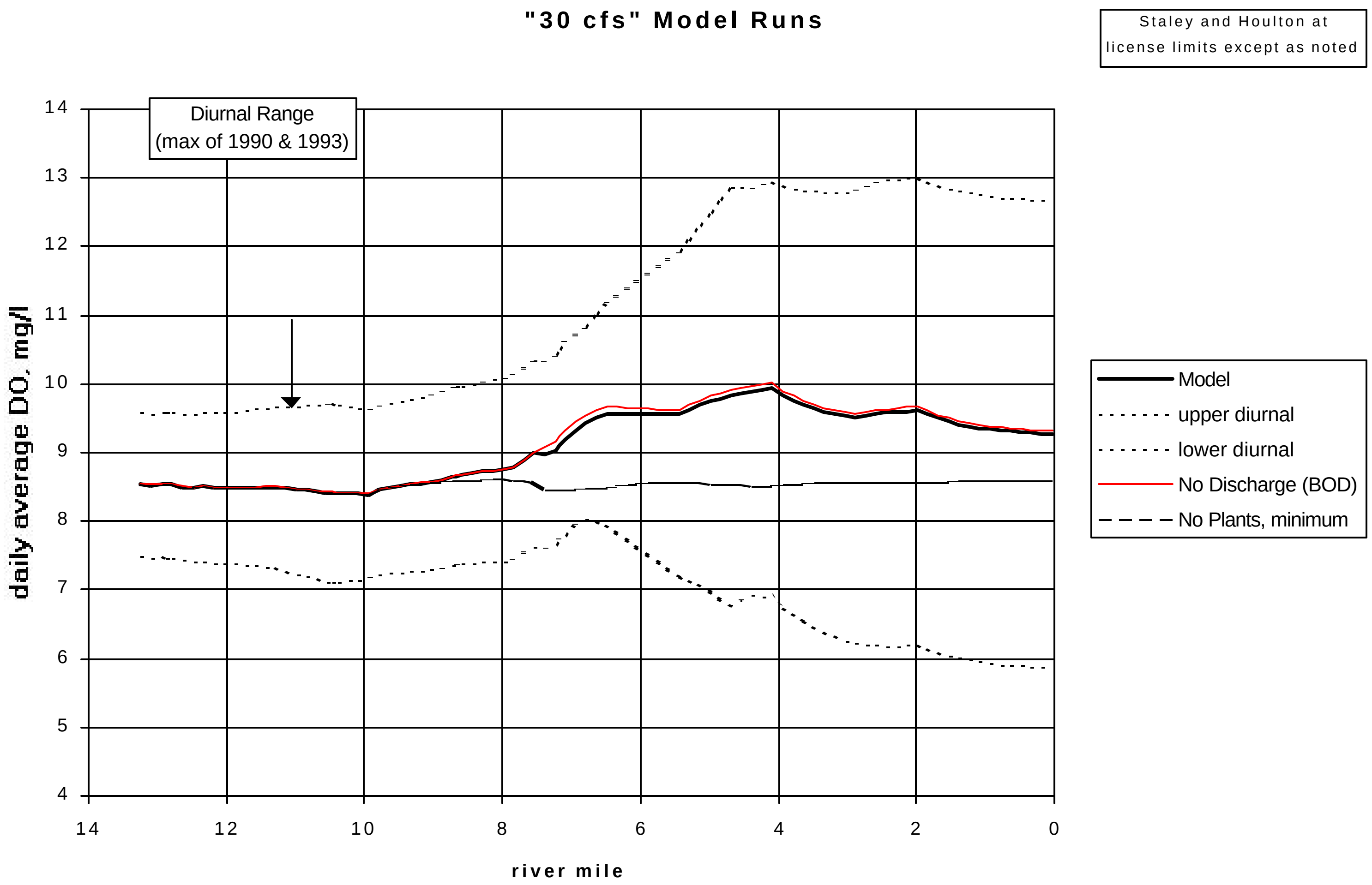


Figure 20
Meduxnekeag River
DO Deficit Component Analysis

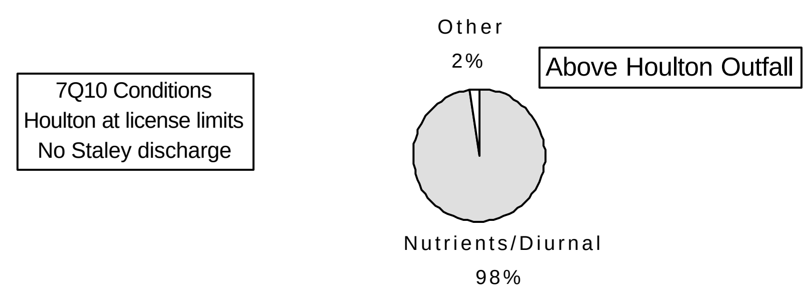


Figure 21
Meduxnekeag River
DO Deficit Component Analysis

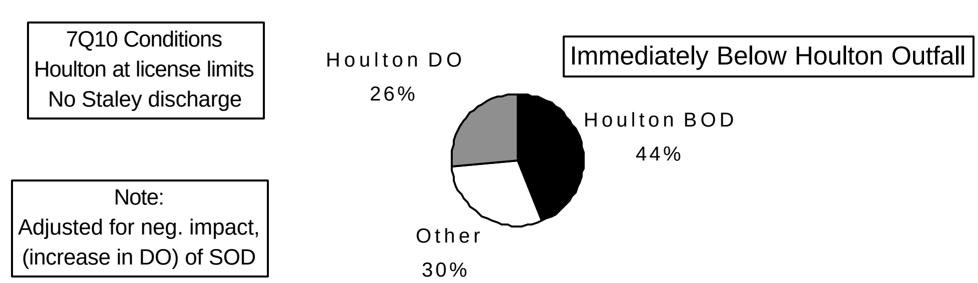
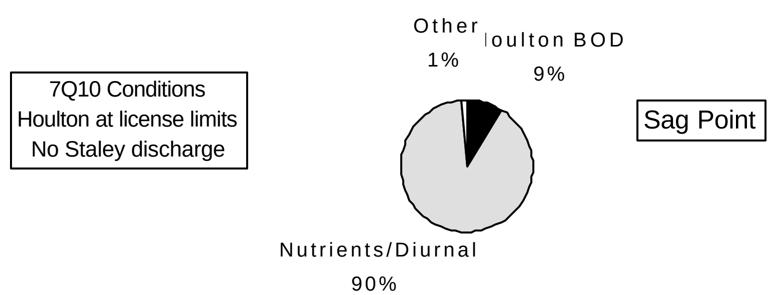


Figure 22
Meduxnekeag River
DO Deficit Component Analysis



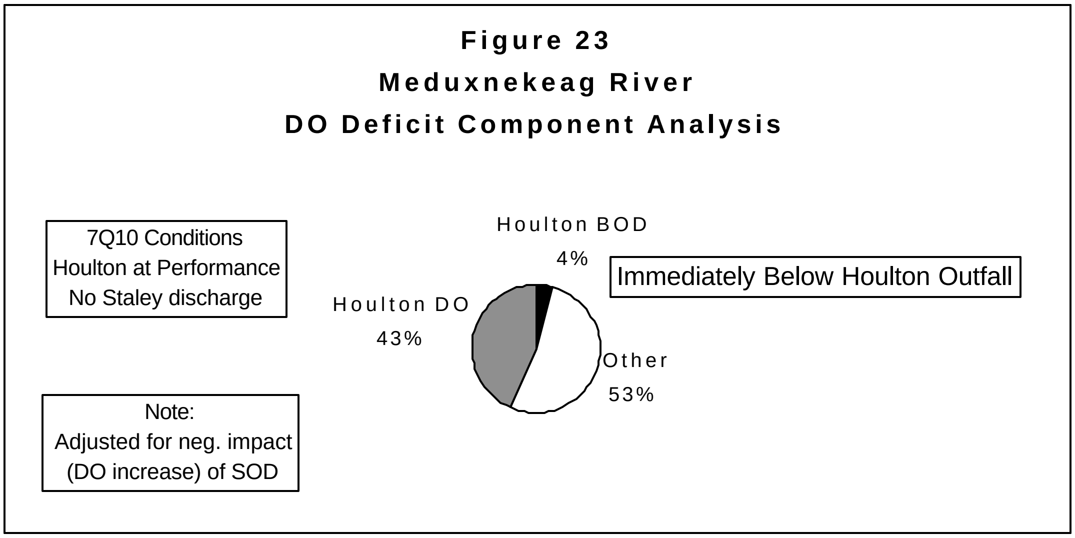


Figure 23
Meduxnekeag River
DO Deficit Component Analysis
7Q10 Conditions
Houlton at Performance
No Staley discharge
Note:
Adjusted for neg. impact
(DO increase) of SOD
Houlton BOD
4%
Houlton DO
43%
Other
53%
Immediately Below Houlton Outfall

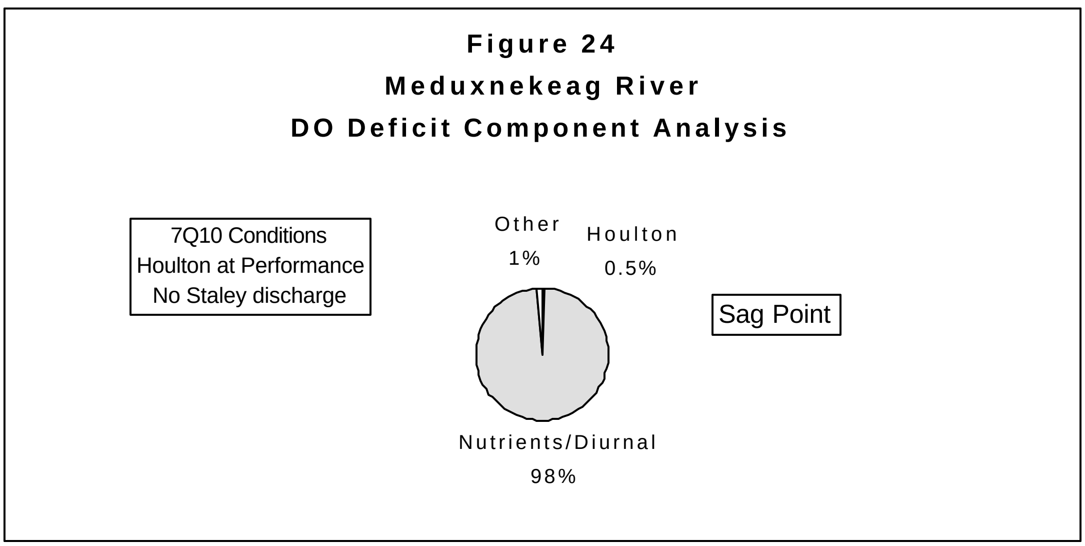


Figure 24
Meduxnekeag River
DO Deficit Component Analysis
7Q10 Conditions
Houlton at Performance
No Staley discharge
Other
1%
Houlton
0.5%
Sag Point
Nutrients/Diurnal
98%

Plant growth is affected by intensity of solar radiation, nutrient (nitrogen and phosphorous) availability and temperature. In general, the segment of the Meduxnekeag River under study is sufficiently shallow such that sunlight can penetrate to the river bed with little attenuation. Additionally, the river is wide enough (especially in the lower reaches) such that it is not completely shaded by tree branches. Given light availability, the nutrient concentrations are controlling the rate of plant growth.

In general, plant growth rate is controlled by nutrient concentration as follows:

u = u(L,T) (FN)

FN = minimum(N,P)

N = DIN/(KN + DIN)

P = DIP/(KP + DIP)

where:

u = net growth rate
u(L,T) = growth rate adjusted for light and temperature
FN = nutrient adjustment factor
DIN = dissolved inorganic nitrogen concentration
DIP = dissolved inorganic phosphorous concentration
KN,KP = half saturation constants for nitrogen and phosphorous, respectively

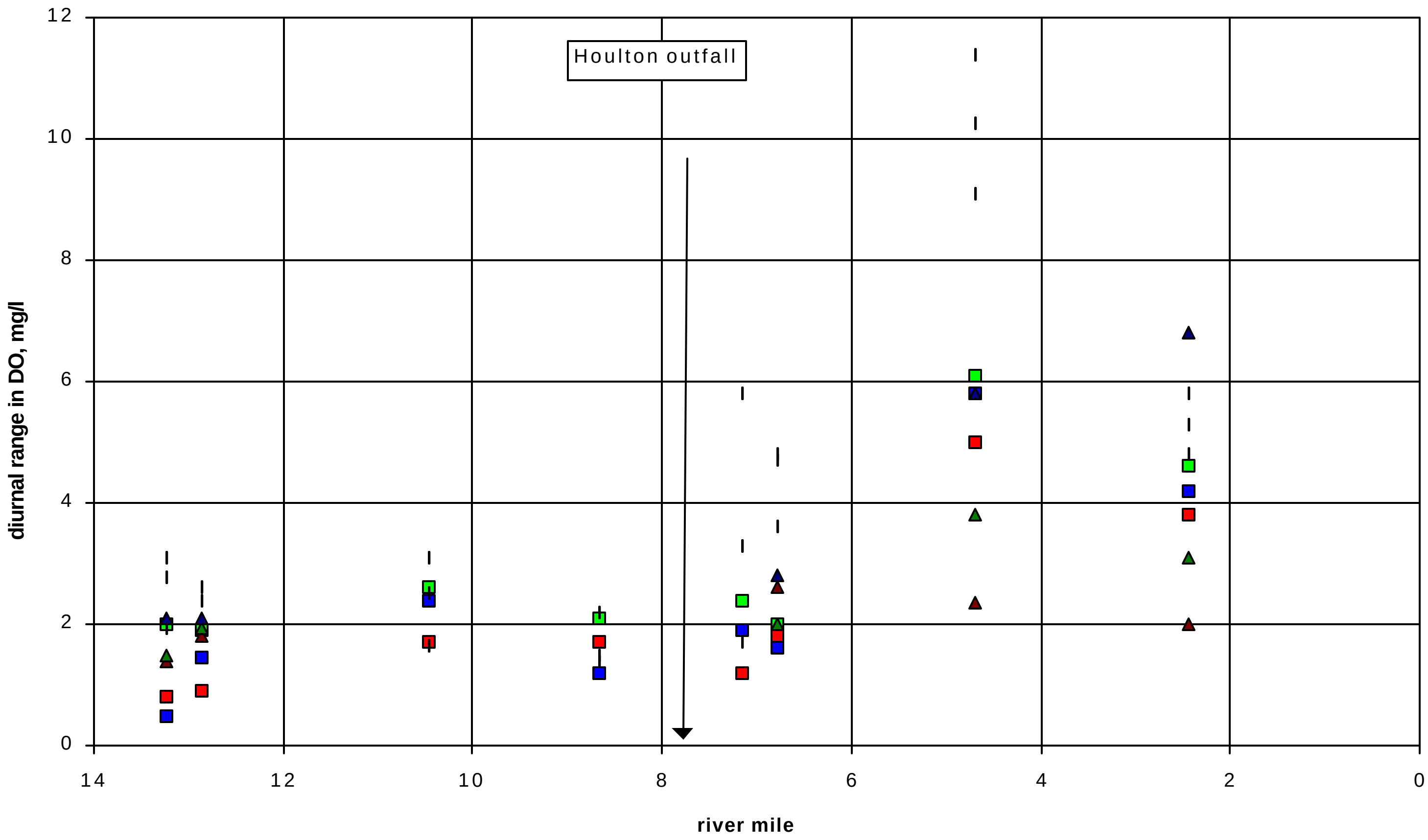
Generally accepted values for KN and KP are 0.025 mg/l and 0.001 mg/l respectively. This suggests that for ratios of dissolved inorganic nitrogen to dissolved inorganic phosphorous (DIN/DIP) greater than 25, phosphorous is the limiting nutrient. Looking at the background survey data (data at the sites above the discharges), results indicate DIN/DIP ratios of much greater than 25. Consequently it can be concluded that prior to the discharges phosphorous is the limiting nutrient.

The data indicate that the principle contribution to increased phosphorous concentrations is the Houlton discharge. Non point sources may contribute to phosphorous loading during periods when runoff occurs. The 1995 data set, which was collected during a very dry summer during which little runoff occurred, showed the greatest diurnal ranges and the lowest measured DO of the three data sets. Figure 25 shows the diurnal ranges from the three data sets. Significant increases in the magnitude of the diurnal DO variations occur below the Houlton outfall. Figure 26 through 28 show the TP data along with a plot of modeled TP concentration assuming it to be conservative (no decay, settling or uptake). These plots give an indication of the impact of the phosphorous loading from Houlton as well as the phosphorous uptake that is occurring below the outfall.

Staley is not permitted to discharge below a river flow of 30 cfs. Staley is now permitted a total phosphorous discharge of 1.14 lb/day. At 30 cfs this represents an increase in instream TP of from 1 ppb to 8 ppb. Although this loading contributes to increased plant growth, Staley is further restricted to discharging only when DO standards are met at critical sites below the Houlton discharge.

Projects are planned to investigate and reduce non point nutrient and suspended solids sources. Although this work should improve water quality especially during storm events, point source nutrient controls are required for attainment of class B DO standards.

Figure 25
Meduxnekeag River
1990, 1993 and 1995 data



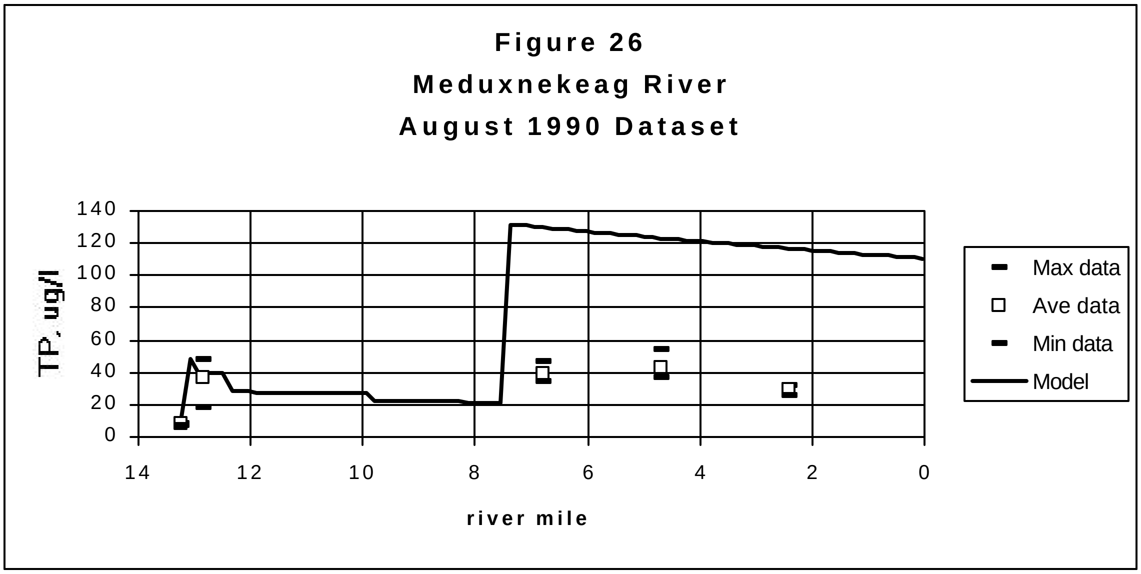


Figure 26
Meduxnekeag River
August 1990 Dataset
140
120
100
80
60
40
20
0
TP, ug/l
14
12
10
8
6
4
2
0
river mile
Max data
Ave data
Min data
Model

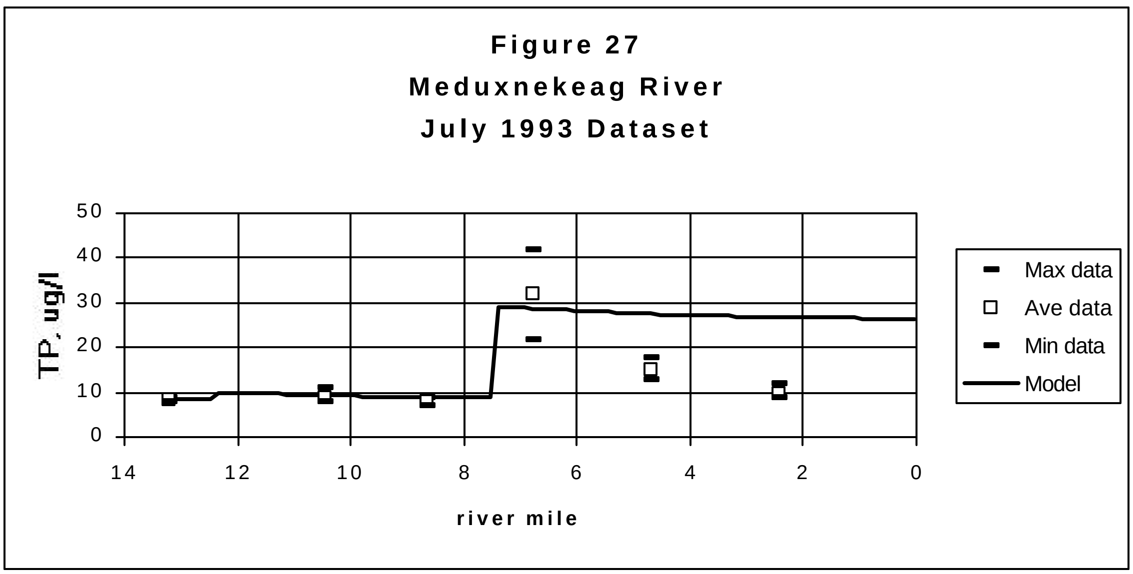


Figure 27
Meduxnekeag River
July 1993 Dataset
50
40
30
20
10
0
TP, ug/l
14
12
10
8
6
4
2
0
river mile
Max data
Ave data
Min data
Model

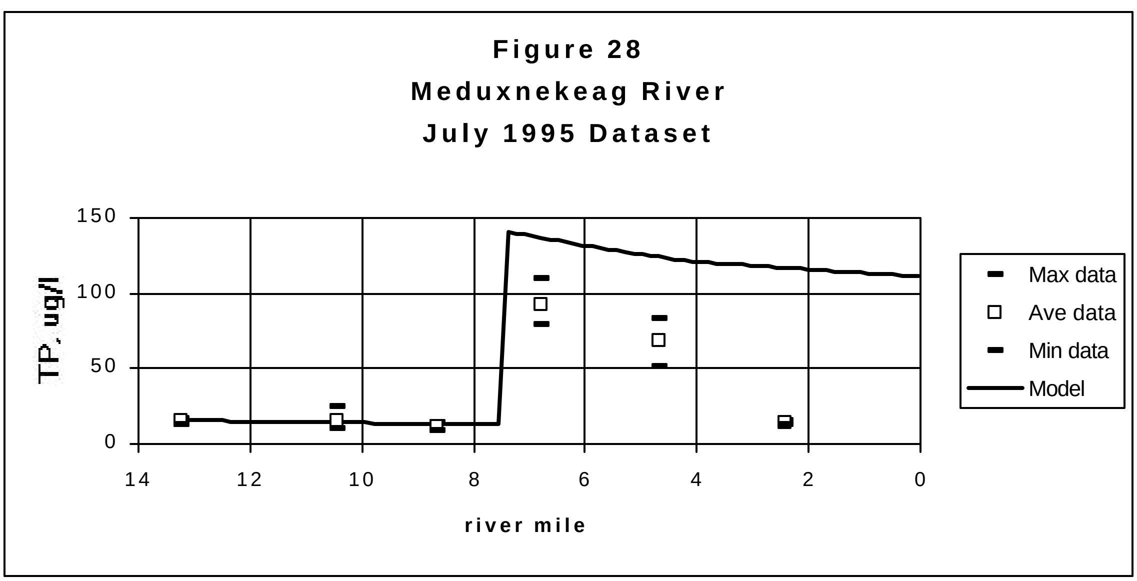


Figure 28
Meduxnekeag River
July 1995 Dataset
150
100
50
0
TP, ug/l
14
12
10
8
6
4
2
0
river mile
Max data
Ave data
Min data
Model

Nutrient Analyses/Load Allocation

The model was used to investigate the case of 7Q10 river flow, performance loading from Houlton, SOD specification representative of background conditions and diurnal range representative of background conditions to determine whether even strict nutrient controls would result in attainment of standards. The results are shown in figure 29. All but one data point are above 7.0 mg/l. The limiting DO occurs directly below the Houlton discharge and the reduction is due mainly to effluent DO concentration. Reduction of nutrient effects to background levels eliminates the major sag segment and transfers the DO issue to one involving the DO of the effluent.

In order to reduce the diurnal plant effects, phosphorous inputs must be reduced. A nutrient allocation was designed based upon the relationship between TP loading and diurnal DO range. The study area was divided into two segments: above the Houlton outfall and below the Houlton outfall. The 1993 and 1995 data sets were used to calculate the total TP mass load to each segment. These loads were converted to average concentration values using total inflow to each segment. These concentrations were plotted against average diurnal DO range for each segment and data set and a curve was fitted (see figures 30 and 31).

TP allocation charts were then developed for 7Q10 conditions by accounting for TP boundary loading as shown on figures 31 and 32 for loading in terms of mass and concentration, respectively. Finally, allocation charts were developed for "30 cfs" conditions to account for a discharge from Staley and are shown in figures 34 and 35.

Allocation Method

Referring to figure 18, a 45% reduction in diurnal DO range is required to meet DO standard of 7.0 mg/l at about mile 4.7. The average diurnal range below Houlton under 7Q10 conditions is 5.88 mg/l. The required average diurnal range is therefore 0.55 x 5.88 = 3.23 mg/l. Referring to figures 32 and 33, the required minimum TP loading from Houlton is therefore 1.25 lb/day or 0.1 mg/l at 1.5 MGD effluent flow. Staley's load is 0 due to river flow conditions.

Similarly for the 30 cfs river flow condition and referring to figure 19, a 32% reduction in diurnal range is required. The average range is 5.6 mg/l and the required average range is .68 x 5.6 = 3.8 mg/l. Referring to figure 34 the required maximum TP load from both Staley and Houlton is about 22 lbs/day. Given Staley's limit of 1.14 lbs/day TP, Houlton would be limited to about 21 lbs/day or 1.7 mg/l for TP under river flow conditions of 30 cfs at Staley.

Limitations

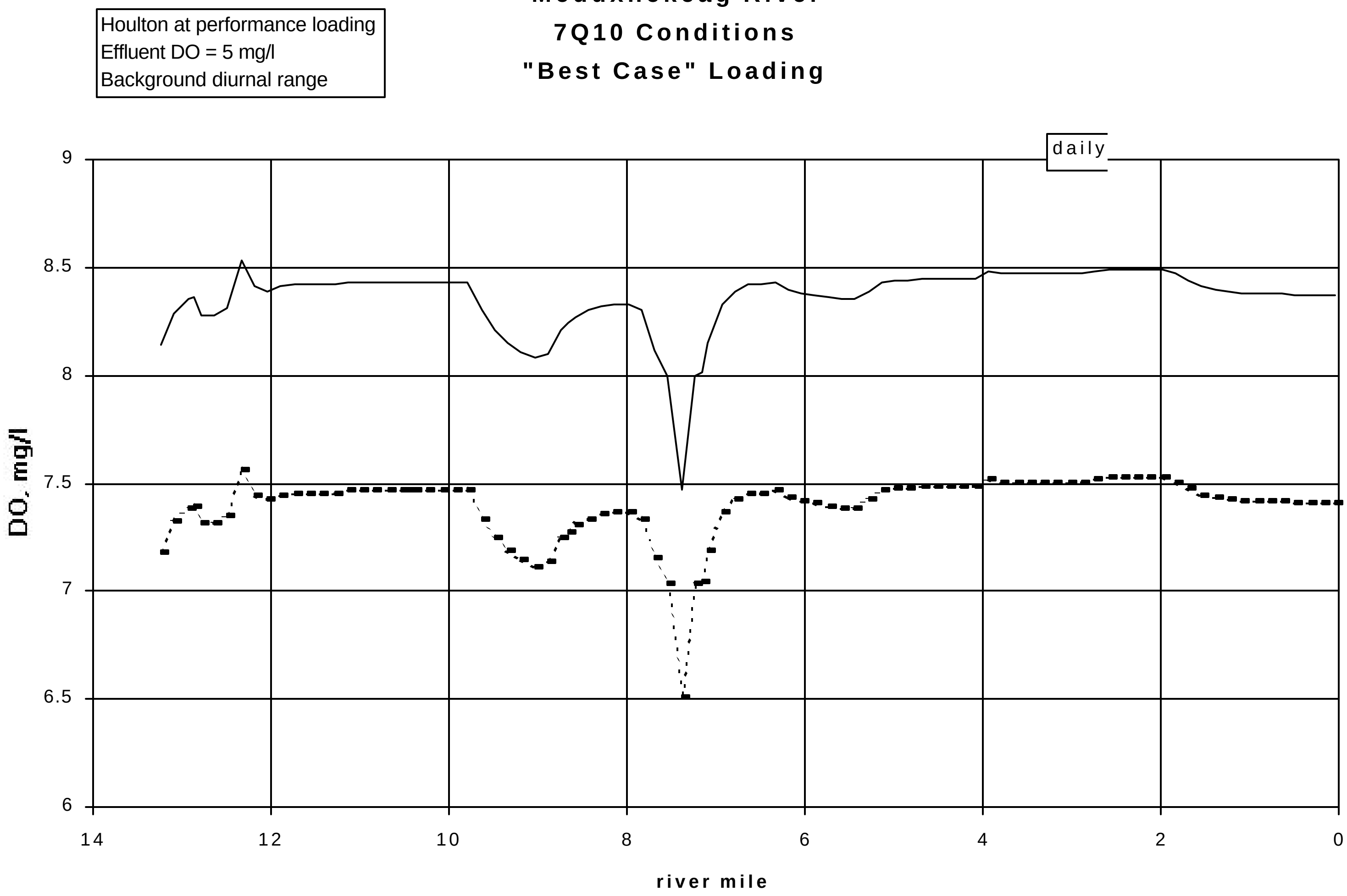
The above empirical method is subject to the following assumptions/limitations:

(1) Phosphorous limited conditions are assumed. This may not be the case below the Houlton outfall.

(2) The 7Q10 model diurnal range is assumed to be equal to that of the 1995 dataset. 1995 was a dry summer with flows in northern Maine approaching 7Q10 levels. Also there is a limit to the increase in diurnal range as well as its relationship to phosphorous concentration. For example, phosphorous loading may be increased to the point where phosphorous concentration is no longer the limiting factor in plant growth.

(3) The relationship between diurnal DO range and TP concentration is based upon averaging of a limited database.

Figure 29
Meduxnekeag River
7Q10 Conditions
"Best Case" Loading



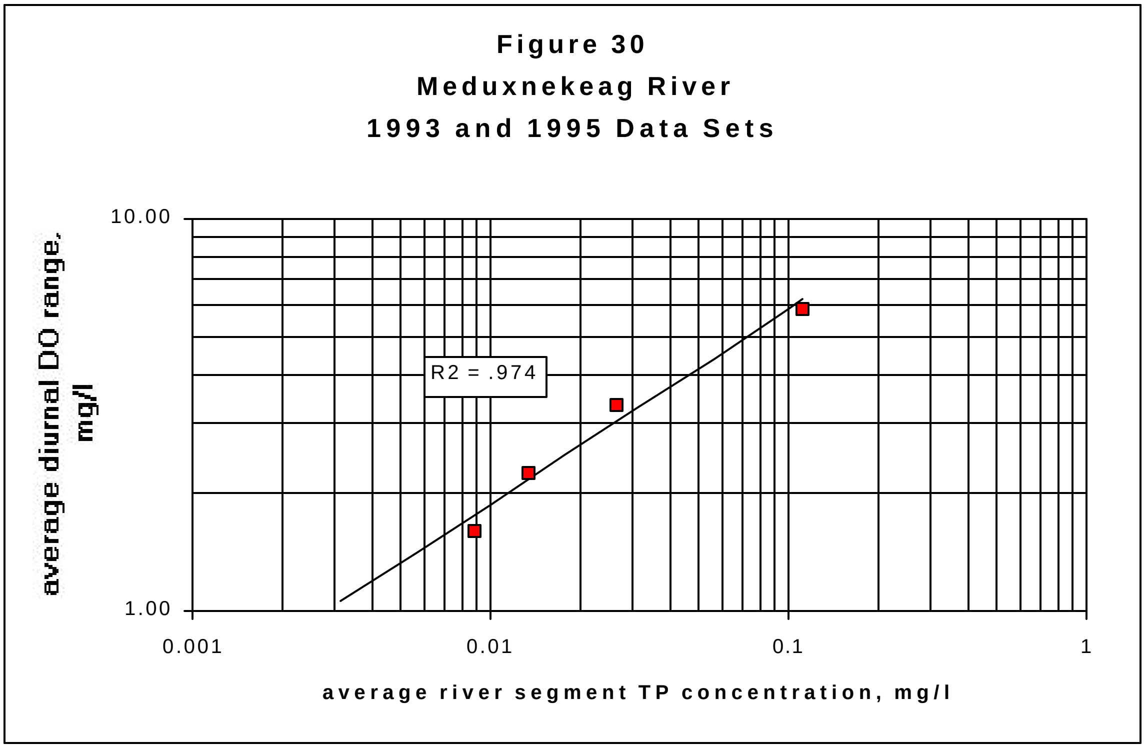


Figure 30
Meduxnekeag River
1993 and 1995 Data Sets
10.00
1.00
R2 = .974
0.001
0.01
0.1
1
average diurnal DO range, mg/l
average river segment TP concentration, mg/l

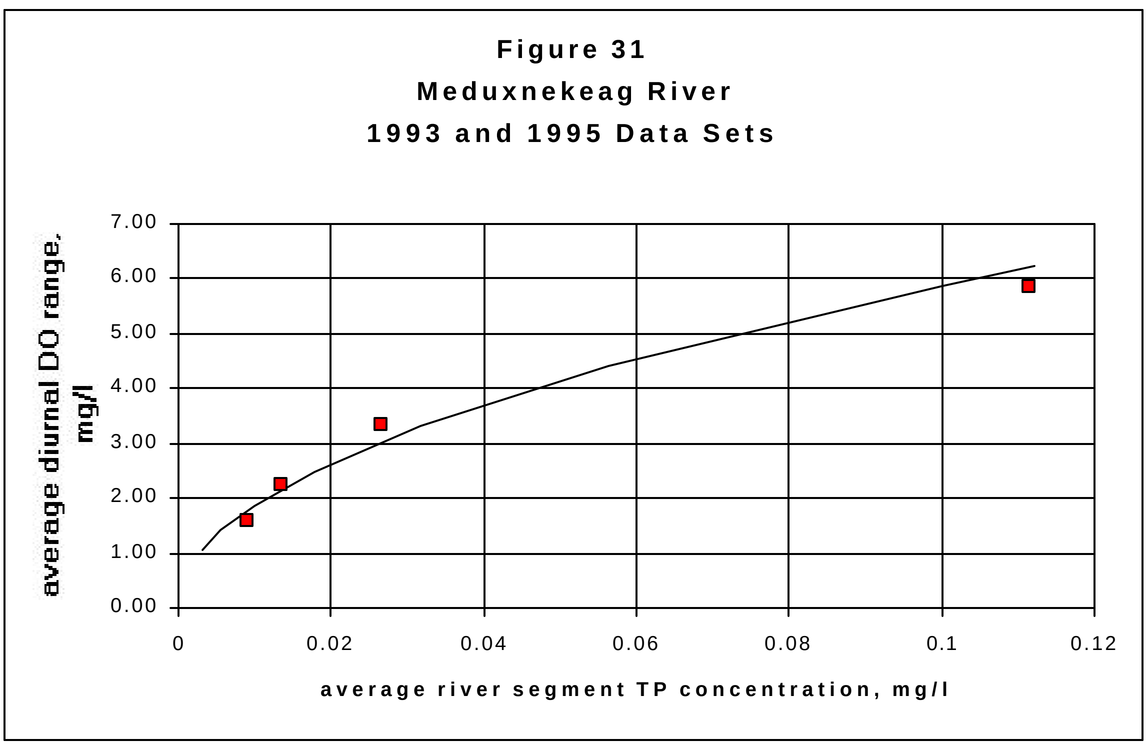


Figure 31
Meduxnekeag River
1993 and 1995 Data Sets
7.00
6.00
5.00
4.00
3.00
2.00
1.00
0.00
0
0.02
0.04
0.06
0.08
0.1
0.12
average diurnal DO range, mg/l
average river segment TP concentration, mg/l

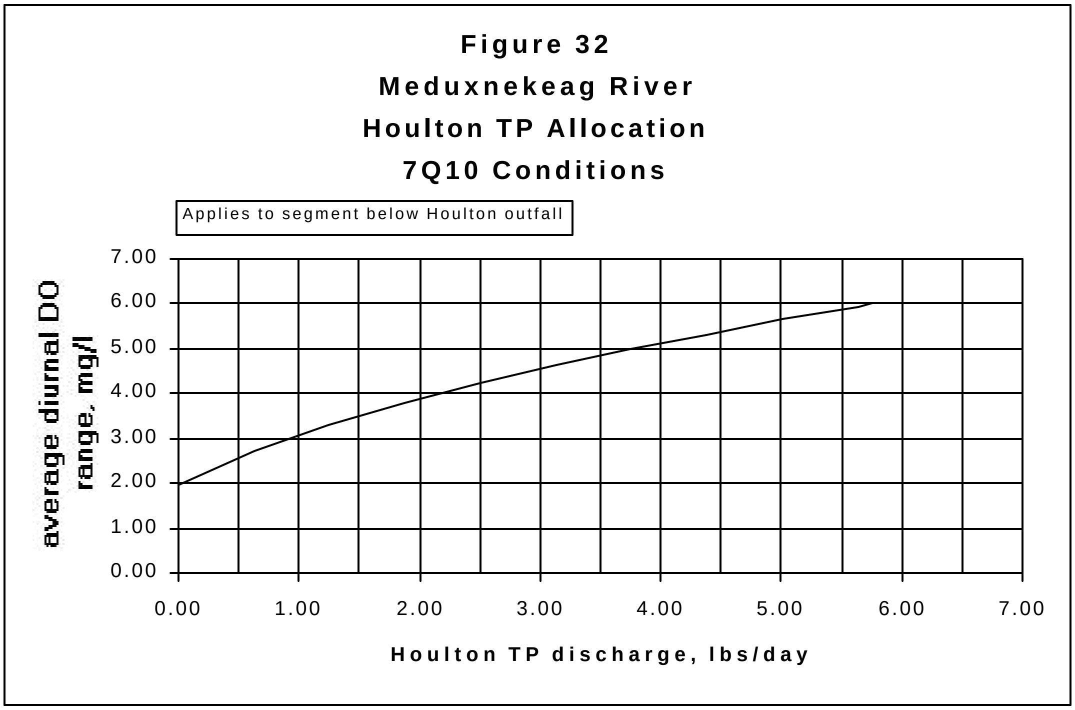


Figure 32
Meduxnekeag River
Houlton TP Allocation
7Q10 Conditions
Applies to segment below Houlton outfall
average diurnal DO range, mg/l
0.00
1.00
2.00
3.00
4.00
5.00
6.00
7.00
0.00 1.00 2.00 3.00 4.00 5.00 6.00 7.00
Houlton TP discharge, lbs/day

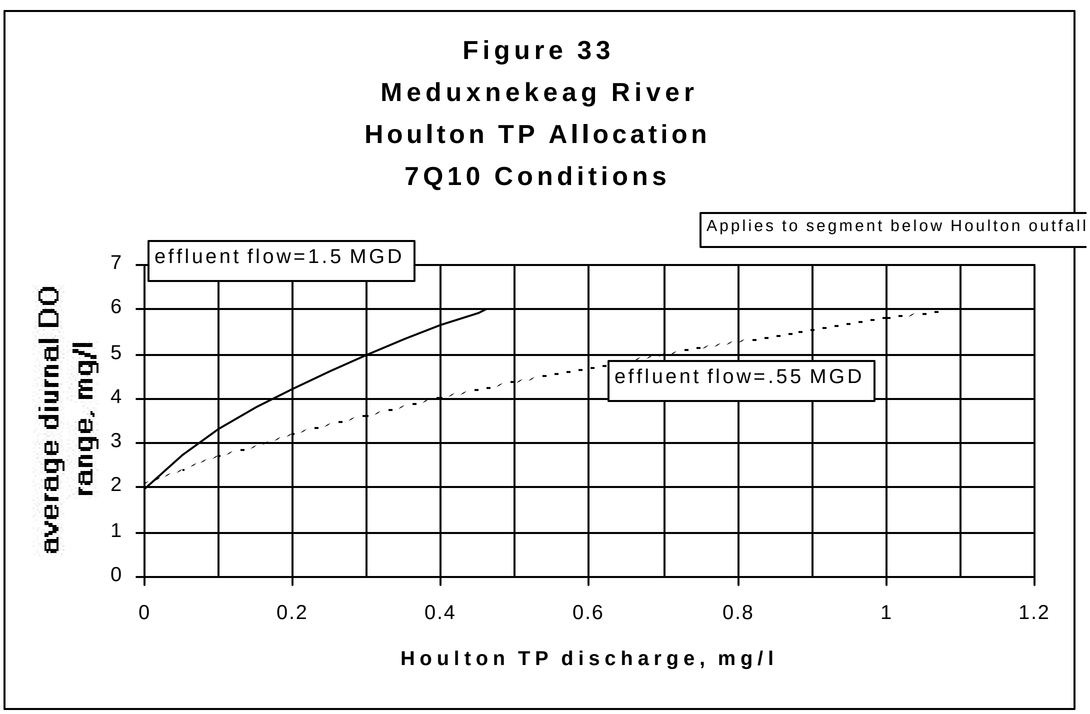


Figure 33
Meduxnekeag River
Houlton TP Allocation
7Q10 Conditions
Applies to segment below Houlton outfall
effluent flow=1.5 MGD
effluent flow=.55 MGD
average diurnal DO range, mg/l
0
1
2
3
4
5
6
7
0 0.2 0.4 0.6 0.8 1 1.2
Houlton TP discharge, mg/l

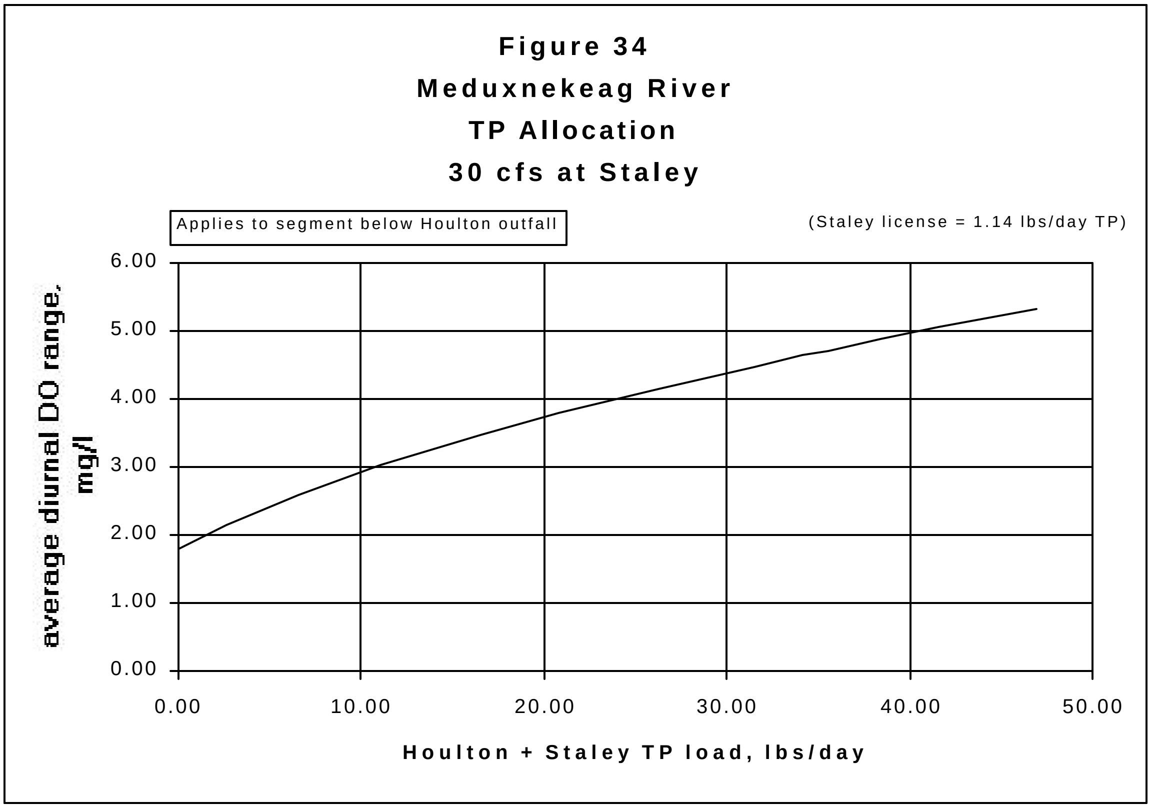


Figure 34
Meduxnekeag River
TP Allocation
30 cfs at Staley
Applies to segment below Houlton outfall
(Staley license = 1.14 lbs/day TP)
average diurnal DO range, mg/l
6.00
5.00
4.00
3.00
2.00
1.00
0.00
0.00
10.00
20.00
30.00
40.00
50.00
Houlton + Staley TP load, lbs/day

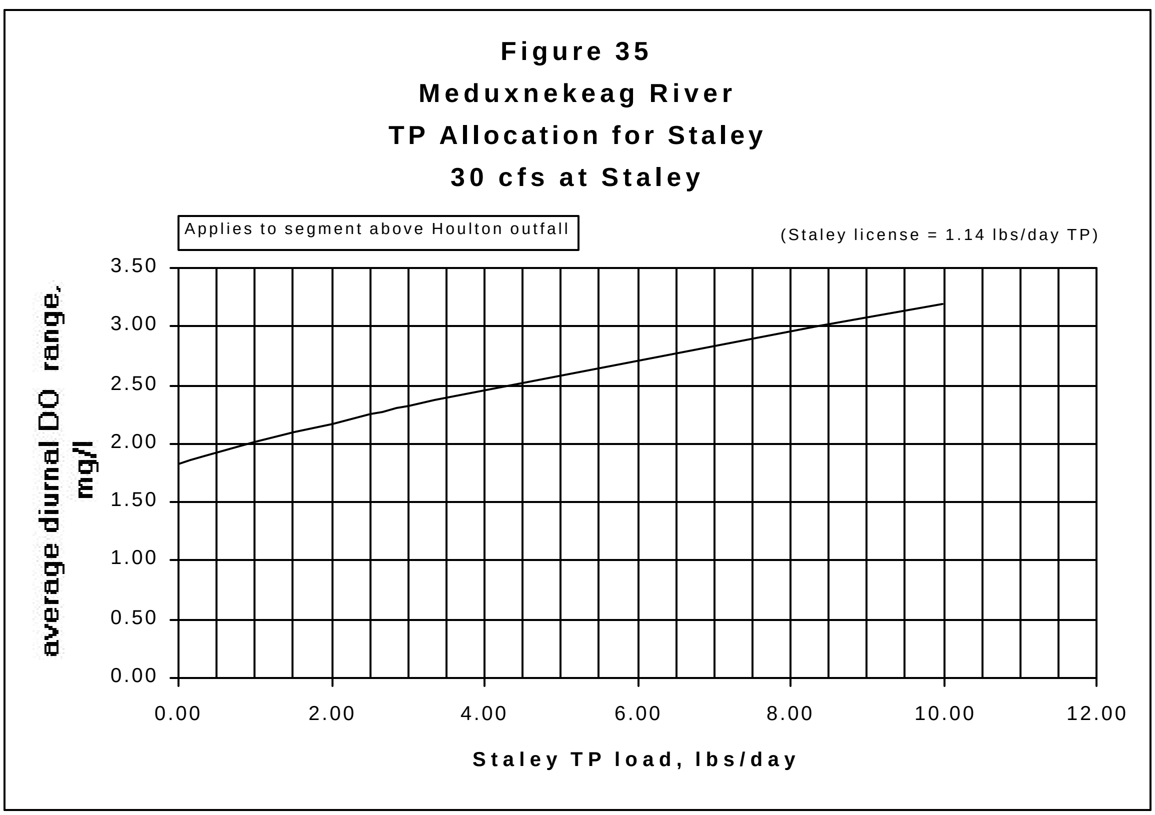


Figure 35
Meduxnekeag River
TP Allocation for Staley
30 cfs at Staley
Applies to segment above Houlton outfall
(Staley license = 1.14 lbs/day TP)
average diurnal DO range, mg/l
3.50
3.00
2.50
2.00
1.50
1.00
0.50
0.00
0.00
2.00
4.00
6.00
8.00
10.00
12.00
Staley TP load, lbs/day

Discussion and Recommendations

Data collected during the intensive surveys made for this study indicate that even under loading conditions much lower than license limits and river flows higher than 7Q10 flow, dissolved oxygen standards are not being met below the Houlton outfall during early morning hours. DO deficit component analyses as well as treatment plant performance data indicate that point source BOD is a minor factor in the low instream DO concentrations at the sag point. It is obvious that the major factor in the non attainment of class B DO standards is plant growth due to nutrient enrichment. Eliminating plant effects would shift the sag point to a very short segment directly below the Houlton outfall that is mainly influenced by effluent DO concentration.

Based on the allocation method presented, a TP limit of 1.25 lbs/day would be required for the Houlton discharge. This is equivalent to 0.10 mg/l at the licensed flow of 1.5 MGD or 0.12 mg/l at performance flow of 1.21 MGD. This level of treatment is generally not achievable in a secondary treatment plant. Staley's current limit of 1.14 lbs/day subject to conditions on river flow and instream DO, is not a major factor in the allocation.

It is recommended that nutrient reduction in the Houlton effluent be investigated. It is recommended that a pilot study be made at the Houlton treatment plant to investigate the reduction of phosphorous concentrations in the effluent to the extent possible under limited capital expenditures. Recent studies at the town of Oakland treatment plant indicated good results using chemical additives to precipitate phosphorous. TP concentrations were reduced to the range of 0.2-0.4 mg/l using additions of ferric chloride. Any study should include instream measurements of phosphorous concentrations and diurnal DO swings as well as qualitative observations of plant growth.

A study is planned to investigate nutrient and suspended solids loading from non point sources within the Meduxnekeag watershed. It may be possible that reduction in non point nutrient sources in combination with a reasonable reduction in TP from the Houlton discharge may result in significant improvements with regard to plant growth and minimum DO concentrations.

During the 1993 study, it was noted that river flows fluctuated within the three day study period. The extent of upstream regulation or water withdrawals should be investigated.

Should the above studies prove to be inadequate in achieving current water quality standards, additional options would be required to be investigated including:

(1) Strict TP limits on Houlton and Staley (tertiary treatment)
(2) Summer period removal of point source discharges.
(3) Flow based limits.
(4) Use Attainability Analysis and downgrading of the Meduxnekeag..

Appendix

Meduxnekeag River

Date	Flow, cfs Sta. 7	Flow, cfs S. Branch	Flow, cfs Moose Bk.	Flow, cfs Store*	Flow, cfs B-Strm	Flow, cfs Sta. 15	Discharge, cfs Houlton	Discharge, cfs Staley
7/3/90	66.6	-	-	-	-	-	1.55	0.04***
7/5/90	57.2	-	-	-	-	-	1.55	"
7/23/90	21.6**	-	-	-	-	-	1.70	"
8/6/90	17.7	-	-	-	-	-	2.63	0.034***
6/11/91	21	-	-	-	-	-	-	0
6/12/91	-	-	-	-	-	61.6	1.08	0
8/24/92	26.5	-	-	50.7	-	-	-	0
8/25/92	-	-	-	-	12.4	66.1	-	0
7/26/93	-	-	-	41.6	-	-	0.77	0
7/27/93	24.6	-	-	-	10.5	59.7	0.77	0
7/28/93	18.7	12.2	-	32	-	-	0.77	0
7/29/93	-	-	-	-	-	57.4	0.77	0
7/17/95	-	-	-	6.4	-	-	0.77	0
7/18/95	-	4.9**	-	9.5**	4.8**	-	0.93	0
7/19/95	-	-	0.2	11.9	-	26.2	1.08	0
7/20/95	-	-	-	14.3	-	-	0.62	0

* below confluence w/ S. Branch
**rain at time of measurement
***monthly average

MEDUXNEKEG RIVER

Sample Station	Date	Time	NH3-N (ppm)	NOx-N (ppm)	TP (ppb)	PO4-P (ppb)	CHL a (ppb)	TBOD (ppm)	NBOD (ppm)	CBOD (ppm)	BOD5 (ppm)	NOx-final
xsec 1	8/6/90	8:12	<.01	0.12	9	<1	1.61	5.4	0.56	4.84	-	0.25
Rch 1	8/7/90	7:30	<.01	0.14	8	<1	x	3.83	0.52	3.31	-	0.26
	8/8/90	7:00	<.01	0.13	8	x	x	8.58	0.61	7.97	-	0.27
xsec 4	8/6/90	8:33	<.01	0.15	18	28	1.29	4.84	0.56	4.28	-	0.28
Rch 4	8/7/90	7:51	<.01	0.23	46	33	x	3.26	0.39	2.87	-	0.32
	8/8/90	6:40	<.01	0.28	48	x	x	7.3	0.48	6.82	-	0.39
xsec 13	8/6/90	9:05	<.01	0.35	47	23	2.51	6.57	0.35	6.22	-	0.43
Rch 16	8/7/90	8:30	<.01	0.46	36	25	x	5.27	0.30	4.97	-	0.53
	8/8/90	6:15	<.01	0.47	35	x	x	8	0.22	7.78	-	0.52
xsec 15	8/6/90	9:27	<.01	0.32	54	23	2.8	5.54	0.56	4.98	-	0.45
Rch 18	8/7/90	8:45	<.01	0.5	37	23	x	5.21	0.13	5.08	-	0.53
	8/8/90	5:57	<.01	0.49	40	x	x	8.88	0.48	8.40	-	0.6
xsec 17	8/6/90	9:41	<.01	0.3	32	14	2.39	6.38	0.48	5.90	-	0.41
Rch 20	8/7/90	8:58	<.01	0.42	30	13	x	4.86	0.13	4.73	-	0.45
	8/8/90	5:37	<.01	0.47	26	x	x	7.57	0.39	7.18	-	0.56
	8/6/90	comp	1.75	0.05	x	16000	x	x	12.0	x	35	2.81
STALELY	8/7/90	comp	0.53	0.11	x	15000	x	x	16.9	x	19.5	4.01
	8/8/90	comp	<.05	0.05	x	x	x	x	13.7	x	26.1	3.21
	8/6/90	comp	0.54	1.7	x	2300	x	56	0	56	4	0.28
HOULTON	8/7/90	comp	<.04	4.5	x	1900	x	39	0	39	3.7	-
	8/8/90	comp	<.01	6.9	x	x	x	55	0	55	6.1	0.38

Meduxnekeag River

8/6/90 overcast

Sample Station	Time	Temp C	DO mg/l	DO % Sat
xsec 1	8:12	22.5	8	92.4
Rch 1	13:54	24	9.4	111.7
xsec 4	8:33	21.4	8.6	97.2
Rch 4	14:05	23	10.4	121.2
xsec 13	9:05	21.3	8.6	97
Rch 16	15:15	22.8	11.2	130.1
xsec 15	9:27	21	9.03	101.3
Rch 18	15:30	22.8	11.4	132.4
xsec 17	9:41	20.8	10	111.7
Rch 20	16:00	22.1	12	137.5

8/7/90 overcast

Sample Station	Time	Temp C	DO mg/l	DO % Sat
xsec 1	7:30	21.5	7.7	87.2
Rch 1	13:47	23.8	9.2	108.9
xsec 4	7:51	21	7.9	88.6
Rch 4	14:00	23.5	9.85	115.9
xsec 13	8:30	20	8.2	90.2
Rch 16	14:24	22.5	10.2	94.7
xsec 15	8:45	20	8.4	92.4
Rch 18	8:09	22.6	12.2	141.1
xsec 17	8:58	20	9.7	106.7
Rch 20	14:45	22.5	12.8	147.8

8/8/90 overcast

Sample Station	Time	Temp C	DO mg/l	DO % Sat
xsec 1	7:00	22	7.6	86.9
Rch 1	15:15	26.4	9.7	120.4
xsec 4	6:40	21.5	7.8	88.3
Rch 4	15:00	26	9.9	122
xsec 13	6:15	21	7.5	84.1
Rch 16	14:33	24.8	10.3	124.2
xsec 15	5:57	21	6.9	77.4
Rch 18	14:20	25	12.7	153.7
xsec 17	5:37	21	6.8	76.3
Rch 20	14:05	24.5	13.6	163.1

Meduxnekeag River

sample site	date	TKN ppm	NH3-N ppm	NOx ppm	PO4-P ppb	TP ppb	NOx final ppm	TBOD ppm	NBOD ppm	CBOD ppm	BOD5 ppm
xsec 1	8/25/92	0.3	<0.01	0.07	1	7	0.25	2.90	0.78	2.12	-
South Branch	8/25/92	0.5	<0.01	0.09	1	14	0.18	3.10	0.39	2.71	-
B Stream	8/25/92	0.3	0.02	0.39	<1	7	0.43	1.60	0.17	1.43	-
Houlton	8/25/92	1.3	0.27	9	2700	2600	11	9.70	8.66	1.04	2.12
	8/26/92	1.2	0.06	10	2300	2200	12	6.90	[6.9]	[0]	2.10
	8/27/92	1.2	0.8	12	2400	2500	14.5	7.61	[7.61]	[0]	1.66
	9/16/92	0.6	0.01	14	2200	2200	13	4.62	[0]	4.62	1.34
	9/17/92	0.8	0.01	15	2500	2500	14	5.15	[0]	5.15	2.58
	9/18/92	0.7	0.05	16	2600	2600	14	5.51	[0]	5.51	1.53

Meduxnekeag River

Sample Station	Date	Time	TKN (ppm)	NH3-N (ppm)	NOx-N (ppm)	TP (ppb)	PO4-P (ppb)	CHL a (ppb)	TBOD (ppm)	NBOD (ppm)	CBOD (ppm)	BOD5 (ppm)	NOx-final
xsec 1	7/27/93	8:05	0.2	<.01	0.05	9	<1	1.48	8.14	1.34	6.80	-	0.36
Rch 1	7/28/93	6:51	0.4	<.01	0.06	9	11?	-	4.95	0.95	4.00	-	0.28
	7/29/93	6:55	0.2	<.01	0.06	8	<.001?	1.44	3.28	0.95	2.33	-	0.28
xsec 9	7/27/93	7:38	0.3	0.01	0.15	11	1	1.86	5.94	1.13	4.81	-	0.41
Rch 9	7/28/93	7:27	0.3	<.01	0.21	8	1	-	5.74	1.26	4.48	-	0.5
	7/29/93	7:40	0.2	<.01	0.27	8	<1	2.06	3.99	0.65	3.34	-	0.42
xsec 11	7/27/93	7:20	0.3	<.01	0.22	9	1	1.54	7.85	1.21	6.64	-	0.5
Rch 11	7/28/93	7:50	0.2	<.01	0.27	8	1	-	4.68	0.78	3.90	-	0.45
	7/29/93	7:25	0.3	0.01	0.28	7	2	1.22	4.32	0.82	3.50	-	0.47
xsec 13	7/27/93	7:00	0.2	<.01	0.19	22	16	1.9	6.8	1.30	5.50	-	0.49
Rch 16	7/28/93	7:25	0.2	<.01	0.24	-	7	-	4.31	0.82	3.49	-	0.43
	7/29/93	7:05	0.3	0.02	0.25	42	16	1.88	4.13	1.30	2.83	-	0.55
xsec 15	7/27/93	6:42	0.3	<.01	0.1	13	3	4.12	5.8	1.26	4.54	-	0.39
Rch 18	7/28/93	7:05	0.3	0.01	0.24	15	6	-	4.03	0.69	3.34	-	0.4
	7/29/93	6:50	0.4	0.02	0.22	18	7	4.06	4.41	[0.78]	3.63	-	[0.4]
xsec 17	7/27/93	6:30	0.3	<.01	0.11	9	1	2.93	6.31	1.82	4.49	-	0.53
Rch 20	7/28/93	6:45	0.2	<.01	0.3	9	1	-	4.15	0.87	3.28	-	0.5
	7/29/93	6:35	0.3	0.01	0.27	12	3	2.97	5.14	1.04	4.10	-	0.51
	7/27/93	8:21	0.2	<.01	0.48	7	<1	0.66	4.94	0.65	4.29	-	0.63
B Strm	7/28/93	6:20	0.1	0.02	0.59	6	1	-	4.62	0.56	4.06	-	0.72
	7/29/93	6:25	0.1	0.02	0.21	6	1	4.82	2.67	1.86	0.81?	-	0.64
	7/27/93	7:45	0.4	<.01	0.16	13	2	2.11	5.83	1.39	4.44	-	0.48
S. Branch	7/28/93	7:16	0.3	<.01	0.22	11	3	-	5.29	1.08	4.21	-	0.47
	7/29/93	7:25	0.3	<.01	0.32	10	3	1.43	4.02	0.56	3.46	-	0.45
	7/27/93	comp.	1.5	0.49	0.93	1100	990	-	19.06	5.28	13.78	4.64	2.15
HOULTON	7/28/93	comp.	1.8	0.81	0.49	1300	1200	-	24.06	6.75	17.31	[9.04]	2.05
	7/29/93	comp.	2.9	1.7	0.18	1800	1600	-	21.94	11.69	10.25	-	2.88

Meduxnekeag River

7/27/93 cloudy, cool

Sample Station	Time	Temp C	DO mg/l	DO % Sat
xsec 1	8:05	19	8.6	92.7
Rch 1	15:50	19.4	9.4	102.2
xsec 4	7:55	18.5	8.6	91.8
Rch 4	15:40	19	9.5	102.4
xsec 9	7:38	17.9	8.4	88.5
Rch 9	15:15	18.3	10.1	107.3
xsec 11	7:20	17.8	8.3	87.3
Rch 11	15:00	17.3	10	104.1
xsec 12B	8:45	17.8	9.3	97.8
Rch 15	15:56	17.3	10.5	109.3
xsec 13	7:00	17.9	8.4	88.5
Rch 16	14:40	17.4	10.2	106.4
xsec 15	6:42	17.9	7.2	75.9
Rch 18	14:20	17.6	12.2	127.8
xsec 17	6:30	17.9	7.4	78
Rch 20	14:07	17.4	11.2	116.9
S. Branch	7:45	19.9	8.1	88.9
	15:30	18.2	9.2	97.6
B Stream	8:21	16.2	9	91.6
	16:10	16.1	10	101.5

7/28/93 cloudy, humid

Sample Station	Time	Temp C	DO mg/l	DO % Sat
xsec 1	6:51	17.8	8.4	88.4
Rch 1	15:00	19.5	10.4	113.2
xsec 4	7:04	17.2	8.5	88.3
Rch 4	15:12	19.2	10.4	112.6
xsec 9	7:27	15.6	8.6	86.4
Rch 9	15:33	19	11.2	120.7
xsec 11	7:50	16.1	9.1	92.4
Rch 11	15:20	18.5	11.2	119.5
xsec 12B	8:00	16	9	91.2
Rch 15	14:06	17.6	11.4	119.4
xsec 13	7:25	15.1	9.2	91.4
Rch 16	14:48	18.1	11.2	118.5
xsec 15	7:05	16	8.3	84.1
Rch 18	14:31	18.3	14.4	153
xsec 17	6:45	15.9	8.6	86.9
Rch 20	14:20	18.4	13.2	140.6
S Branch	7:16	16.6	9.2	94.4
	15:20	17.5	9.3	97.2
B Stream	6:15	15	9.5	94.2
	14:30	16.3	10.1	103
Houlton	8:30	14	2.8*	27.2

7/29/93 cloudy

Sample Station	Time	Temp C	DO mg/l	DO % Sat
xsec 1	6:55	18.8	8.4	90.2
Rch 1	14:25	18.7	8.9	95.4
xsec 4	7:09	18.3	8.45	89.8
Rch 4	14:20	19.8	9.9	108.4
xsec 9	7:40	18.2	8.4	89.1
Rch 9	14:45	19.5	10.8	117.6
xsec 11	7:25	18	8.9	94
Rch 11	15:00	19.1	10.1	109.1
xsec 12B	7:55	18	8.9	94
Rch 15	14:00	18.7	10.8	115.7
xsec 13	7:05	18	9	95.1
Rch 16	15:16	19.2	10.6	114.7
xsec 15	6:50	18	7.7	81.3
Rch 18	15:26	19.6	13.5	147.3
xsec 17	6:35	18	8.2	86.6
Rch 20	15:30	19.3	12.4	134.5
S. Branch	7:25	18.3	9	95.7
	14:36	19	9.3	100.3
B Stream	6:25	16.8	9.4	96.9
	14:15	17.5	9.9	103.5

Meduxnekeag River

Sample Station	Date	Time	TKN (ppm)	NH3-N (ppm)	NOx-N (ppm)	TP (ppb)	PO4-P (ppb)	CHL a (ppb)	TBOD (ppm)	NBOD (ppm)	CBOD (ppm)	BOD5 (ppm)	NOx-final
xsec 1	7/18/95	6:00	0.3	0.02	0.12	16	1	0.67	3.7	0.74	2.96	-	0.29
Rch 1	7/19/95	6:45	0.3	0.02	0.12	13	2	1.36	7	1.08	5.92	-	0.37
	7/20/95	6:05	0.4	0.02	0.08	17	1	1.06	8.03	1.34	6.69	-	0.39
xsec 9	7/18/95	6:50	0.3	0.02	0.44	25	1	0.96	-	-	-	-	-
Rch 9	7/19/95	7:10	0.4	<.01	0.48	10	1	1.09	-	-	-	-	-
	7/20/95	6:40	0.3	0.01	0.38	12	1	0.51	-	-	-	-	-
xsec 11	7/18/95	7:30	0.4	<.01	0.54	15	5	0.96	-	-	-	-	-
Rch 11	7/19/95	8:15	0.3	0.01	0.52	10	2	0.82	-	-	-	-	-
	7/20/95	7:15	0.3	0.01	0.45	9	2	<.5	-	-	-	-	-
xsec 13	7/18/95	6:45	0.3	<.01	0.72	110	92	1.23	4.95	0.61	4.34	-	0.86
Rch 16	7/19/95	7:20	0.3	<.01	0.67	88	74	2.35	4.56	0.43	4.13	-	0.77
	7/20/95	6:45	0.2	<.01	0.51	79	64	1.33	4.79	0.69	4.10	-	0.67
xsec 15	7/18/95	6:25	0.3	<.01	0.32	52	32	4.85	-	-	-	-	-
Rch 18	7/19/95	6:20	0.4	<.01	0.58	84	61	5.86	-	-	-	-	-
	7/20/95	6:00	0.4	<.01	0.32	73	51	7.48	-	-	-	-	-
xsec 17	7/18/95	6:00	0.3	<.01	0.02	13	1	0.96	3.26	0.87	2.39	-	0.22
Rch 20	7/19/95	6:45	0.3	<.01	0.1	14	3	2.37	4.96	0.82	4.14	-	0.29
	7/20/95	6:20	0.3	<.01	0.02	16	2	2.04	4.63	0.82	3.81	-	0.21
	7/18/95	7:40	0.2	0.02	0.9	8	2	<.5	1.79	0.00	1.79	-	0.89
B Strm	7/19/95	7:45	0.1	0.02	0.81	7	1	0.71	4.3	0.13	4.17	-	0.84
	7/20/95	6:50+/-	0.1	0.03	0.73	8	1	<.5	3.48	0.22	3.26	-	0.78
	7/18/95	6:40	0.5	<.01	0.47	15	2	1.34	2.78	0.39	2.39	-	0.56
S. Branch	7/19/95	7:20	0.3	<.01	0.38	14	2	1.07	6.08	0.56	5.52	-	0.51
	7/20/95	6:30	0.5	<.01	0.3	14	2	0.54	5.22	0.43	4.79	-	0.4
	7/18/95	comp.	0.7	<.01	10	3200	3200	-	5.1	0.00	5.10	0.80	<10
HOULTON	7/19/95	comp.	1	0.05	9.8	3400	3200	-	9.7	0.00	9.70	0.40	9.4
	7/20/95	comp.	0.9	0.04	9.4	3400	3300	-	11.7	0.00	11.70	0.90	8.9

Meduxnekeag River

7/18/95 cloudy, rain

Sample Station	Time	Temp C	DO mg/l	DO % sat
xsec 1	6:00	18	7.07	74.7
Rch 1	13:05	18	9	95.1
xsec 4	6:25	17.7	7.34	77.1
Rch 4	13:15+/-	17.8	9.2	96.8
xsec 9	6:50	17.1	7.65	79.3
Rch 9	14:00+/-	16.2	9.3	94.6
xsec 11	7:30	17.3	7.7	80.2
Rch 11	15:10	17.4	9.9	103.3
xsec 12B	8:15	17.1	8.2	85
Rch 15	15:40	17.2	11.5	119.5
xsec 13	6:45	17.4	7.5	78.2
Rch 16	16:15	17.5	12.2	127.5
xsec 15	6:00	17.7	5.5	57.7
Rch 18	16:30	17.6	14.6	153
xsec 17	6:00	17.2	7.6	79
Rch 20	16:45	17.7	12.4	130.2
S. Branch	6:40	17.8	8.97	94.4
	13:45+/-	18	9.6	101.4
B Stream	7:40	16	8.2	83.1
	14:10+/-	16.2	9.4	95.6

7/19/95 cloudy, clearing

Sample Station	Time	Temp C	DO mg/l	DO % sat
xsec 1	6:45	17.5	7.3	76.3
Rch 1	15:30	26	10.4	128.2
xsec 4	7:00	18	7.6	80.3
Rch 4	15:20	25.5	10.2	124.6
xsec 9	7:10	17	7.6	78.6
Rch 9	14:55	23	10.7	124.7
xsec 11	8:15	16.9	8.7	89.8
Rch 11	14:40	23	10.1	117.7
xsec 12B	8:45	17	10.7	110.7
Rch 15	16:30	23.9	12.4	147
xsec 13	7:20	16.8	9	92.7
Rch 16	14:25	23	13.8	160.9
xsec 15	6:20	16.7	6.8	69.9
Rch 18	13:50	23	18.2	212.2
xsec 17	6:45	16.6	8.4	86.2
Rch 20	14:00	24	14.2	168.7
S Branch	7:20	18	8.4	88.7
	15:15	21.2	9.4	105.9
B Stream	7:45	16	8.2	83.1
	15:50	22	9.3	106.4
Houlton	16:11	23.5	8	94.1

Meduxnekeag River

7/20/95 sunny, warm;rain in PM

Sample Station	Time	Temp C	DO mg/l	DO % sat
xsec 1	6:05	19.3	6.94	75.3
Rch 1	13:46	23.9	9.7	115
xsec 4	6:20	18.9	7.2	77.5
Rch 4	14:04	23	9.6	111.9
xsec 9	6:40	18	7.69	81.2
Rch 9	14:39	23.2	10.2	119.4
xsec 11	7:15	19	7.9	85.2
Rch 11	15:57	24.2	9.4	112.1
xsec 12B	7:40	18.7	9.2	98.6
Rch 15	15:26	24.2	15+	179+
xsec 13	6:45	18.6	8.2	87.7
Rch 16	16:38	24.3	11.8	141
xsec 15	6:00	19	4.75	51.2
Rch 18	16:52	25	15+	182+
xsec 17	6:20	18.7	7.1	76.1
Rch 20	17:02	24.8	12.4	149.5
S. Branch	6:30	17.7	8.97	94.2
	14:15	23.7	8.9	105.1
B Stream	6:50+/-	18	7.57	80
	15:00	22.2	9.5	109.1
Houlton	10:20	16.1	8	81.2
above outfall	15:40	24.9	10.6	128

7/21/95 overcast, warm

Sample Station	Time	Temp C	DO mg/l	DO % sat
xsec 1	8:19	20.9	7.8	87.3
Rch 1				
xsec 4	8:33	21	8.5	95.3
Rch 4				
xsec 9	8:51	20.1	8.9	98.1
Rch 9				
xsec 11	7:03	20.9	8.9	99.6
Rch 11				
xsec 12B	7:48	20.1	8.8	97
Rch 15				
xsec 13	6:47	20.1	8.2	90.4
Rch 16				
xsec 15	6:17	20.5	4.6	51.1
Rch 18				
xsec 17	6:27	20.1	6.4	70.5
Rch 20				
S. Branch	8:39	20.2	8.9	98.3
B Stream	7:12	19.5	7.8	84.9