Total Maximum Daily Loads of Carbonaceous Biochemical Oxygen Demand (CBOD) and Nitrogenous Biochemical Oxygen Demand (NBOD) for an Unnamed Tributary of La Trappe Creek

APPENDIX A

INPRG Model Description

INPRG is a steady state, mathematical model developed by Maryland Department of the Environment (MDE) for simulating free flowing streams for conventional pollutants. This program prepares input data and runs a free flowing stream model based upon the Streeter-Phelps equation. The program is written in FORTRAN IV. This program reads in raw data for tributary drainage area planimeter readings, station elevations, gaging station flow, velocity data, and stream temperature values. It computes a 90th percentile (design) stream temperature, plots regression between flow and stream velocity, and computes elevation differences between stations. The program can independently perform statistical analysis of data sets to obtain average values and predict levels of confidence. It also computes reaeration values for the stream reaches using Tsivoglou's formula. It adjusts all reaction rates in the model to the stream design temperature. The model is also capable of independently computing oxygen production, photosynthesis, and respiration values based upon chlorophyll *a* concentrations in the stream or estuary.

INPRG Input Data

As discussed above INPRG model prepares input data and runs a free-flowing stream model based upon the Streeter-Phelps equation. This program requires input data for tributary drainage area planimeter readings, station elevations, and segment lengths to calculate tributary flows, stream velocities and reaeration rates. The INPRG model input values for drainage areas, station elevations, and stream lengths for each INPRG model station were prepared.

STATION	SEGMENT	D.A. Mi^2	STATION ELEV. Ft.	STREAM LENGTH Ft.	STREAM LENGTH Meters
1	1-2	0.45	33	600	182
2	2-3	0.45	20	1600	488
3	3-4	0	10	3.1	1

Table A1: INPRG Model Input Data

INPRG calculates tributary stream flows for each station by multiplying the corresponding tributary drainage area by the inputted stream flow runoff rate. The stream flow runoff rate is determined by selecting a representative reference stream gaging station near the study stream; for the purposes of this effort, USGS gaging station 01492000 on Beaver Dam Branch at Matthews in Maryland was used.

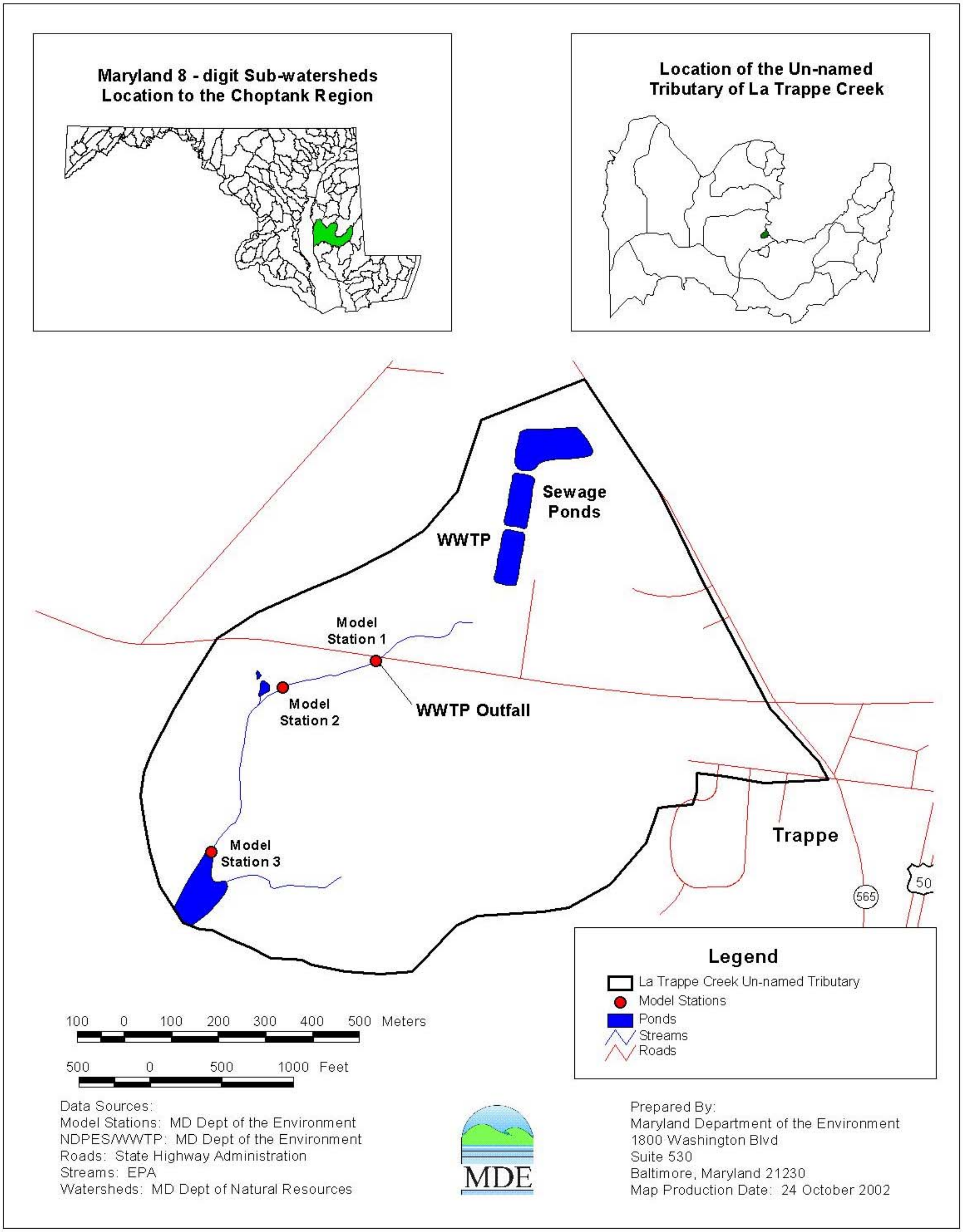


Figure A1: Model Segmentation for INPRG Model for Unnamed Tributary of La Trappe Creek

Water Quality Input Data

Input data from a total of three water quality sampling sites in the mainstem of the unnamed tributary of La Trappe Creek (UTLTC) were examined. MDE collected water chemistry data in support of TMDL development during August and September 1998. The location of the water quality stations where August and September water quality data measurements were taken are shown in Figure A2.

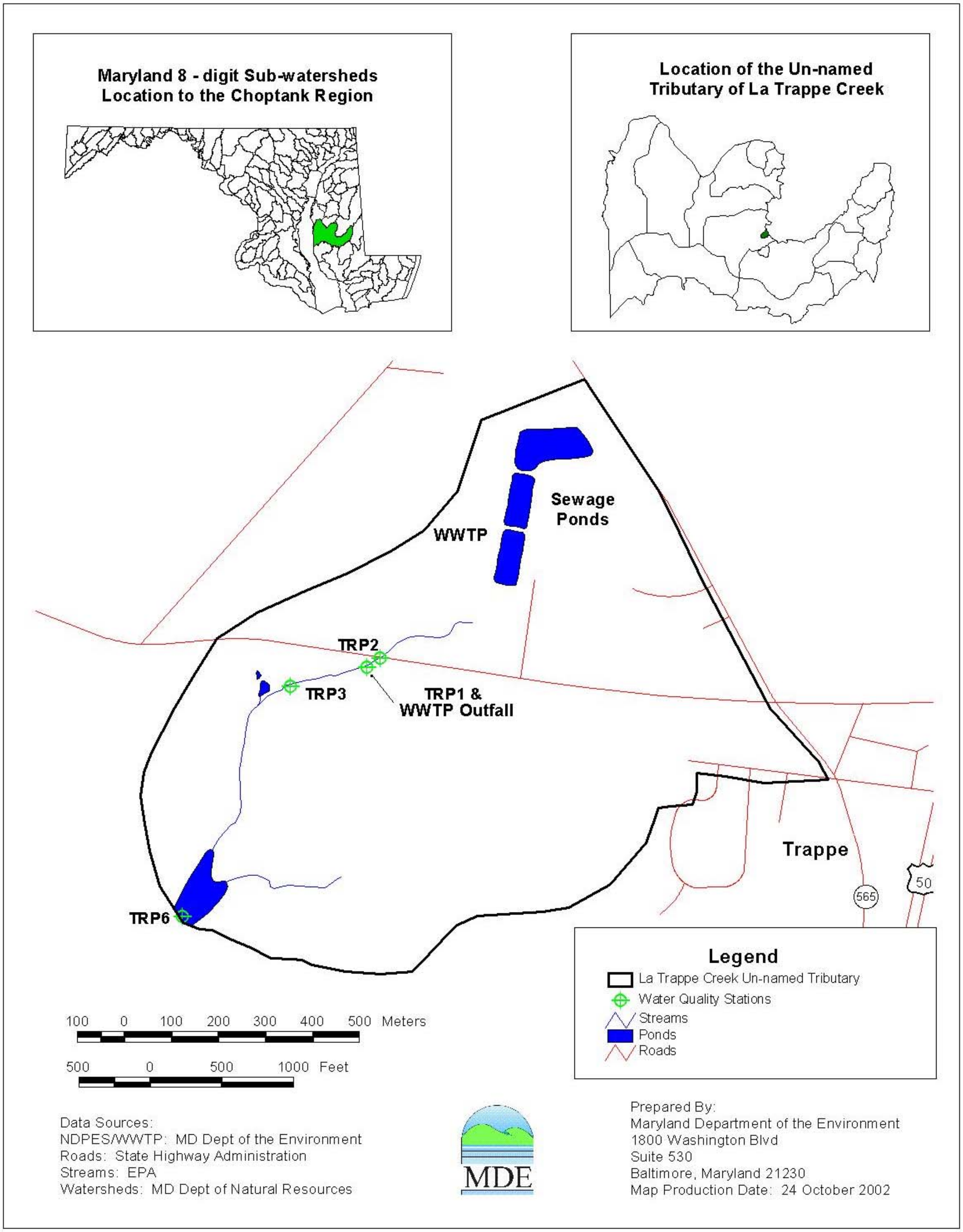


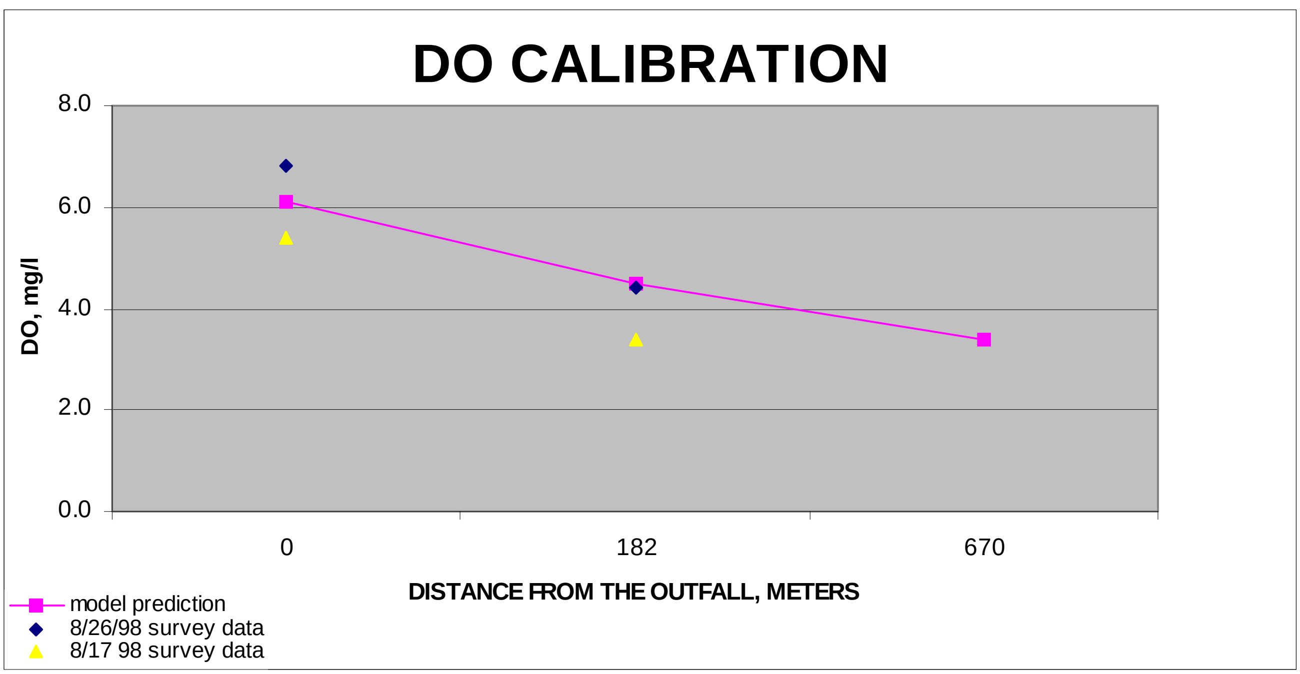
Figure A2: Unnamed Tributary of La Trappe Creek Watershed Water Quality Stations

INPRG CBOD, NBOD and Dissolved Oxygen Calibration

Once the INPRG model input data was analyzed and prepared, calibration runs were made for CBOD, NBOD and dissolved oxygen (DO). Calibration of the model for CBOD, NBOD and DO was achieved through the adjustment of the carbonaceous deoxygenating rate k_c and the nitrogenous deoxygenating rate k_n. The August 1998 water quality data was used for the calibration run. The observed water quality and model predictions for calibrated run for the UTLTC are shown in Table A2 and represented in Figures A3 through A5.

MODEL STATION	SEGMENT LENGTH	8/17/1998 CBOD mg/l	8/26/1998 CBOD mg/l	MODEL CBOD mg/l	8/17/1998 NBOD mg/l	8/26/1998 NBOD mg/l	MODEL NBOD mg/l	8/17/1998 DO mg/l	8/26/1998 DO mg/l	MODEL DO mg/l
1 (TRP 1)	182	15.6	12.3	13.95	26.3	30.1	28.2	5.4	6.8	6.1
2 (TRP 3)	488	7.1	9.2	12.35	23.1	23.8	27.4	3.5	4.4	4.6
3 (just upstream of Pond)	1			9.85			25.3			3.4

Table A2: CBOD, NBOD , DO observed data and Model Predictions



FigureA3: DO Calibration

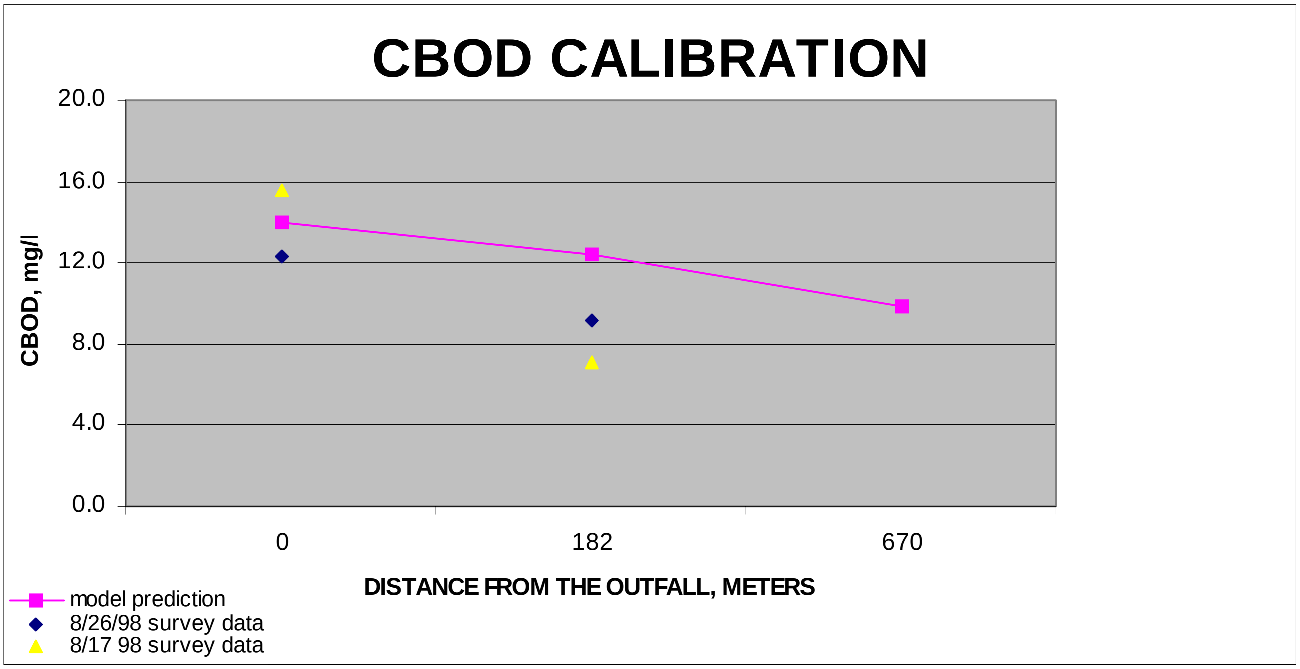


Figure A4: CBOD Calibration

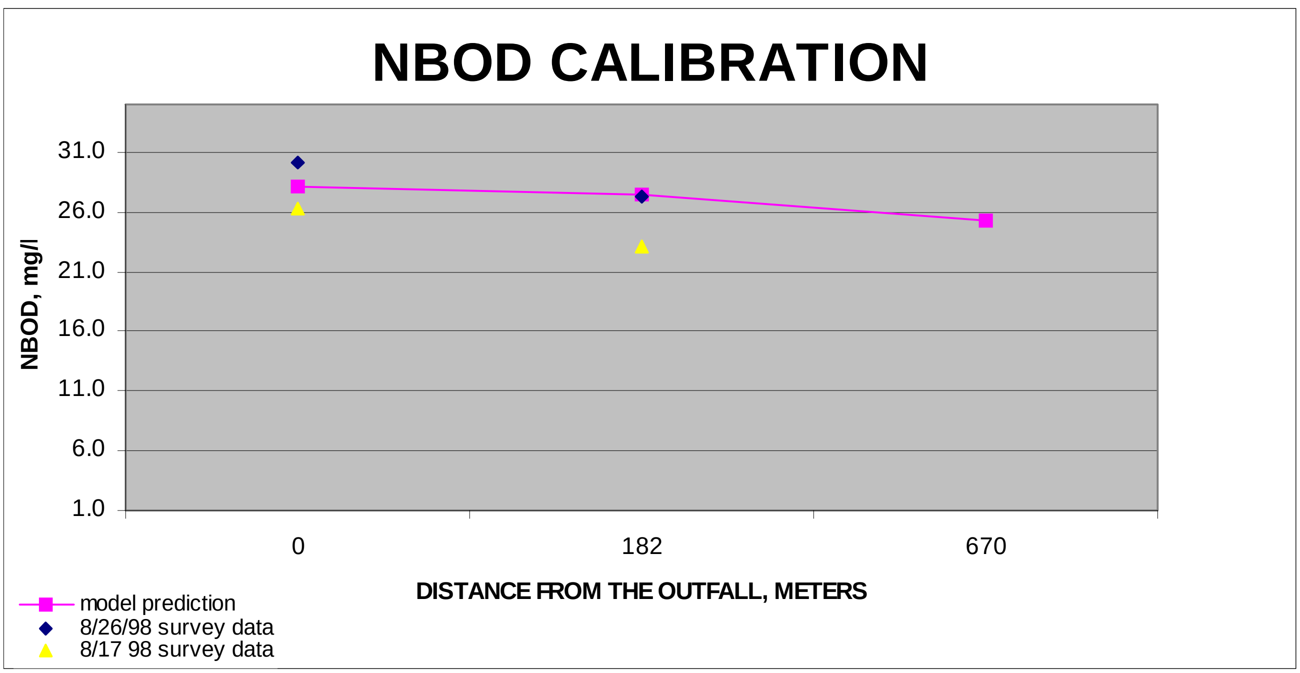


Figure A5: NBOD Calibration

INPRG CBOD, NBOD and DO Verification

Once the INPRG model was calibrated, input data was assembled to validate the model with the data collected on September 14,1998. The calibrated rate constants were used for verification run. The stream velocity was also estimated using the calibrated relationship between stream velocity and stream discharge. September 14,1998 water quality data was used for the verification run. The observed water quality and model predictions for verification run are shown in Table A3 and represented by Figures A6 through A8.

MODEL STATION	SEGMENT LENGTH	9/14 1998 CBOD mg/l	MODEL CBOD mg/l	9/14 1998 NBOD mg/l	MODEL NBOD mg/l	9/14 1998 DO mg/l	MODEL DO mg/l
1 (TRP 1)	182	13.6	13.6	27.1	27.1	6.7	6.7
2 (TRP 3)	488	10.8	12.1	22.5	26.6	4.9	5.35
3 (just upstream of Pond)	1		9.9		25.3		4.3

Table A3: CBOD, NBOD and DO observed data and Model Predictions for the UTLTC

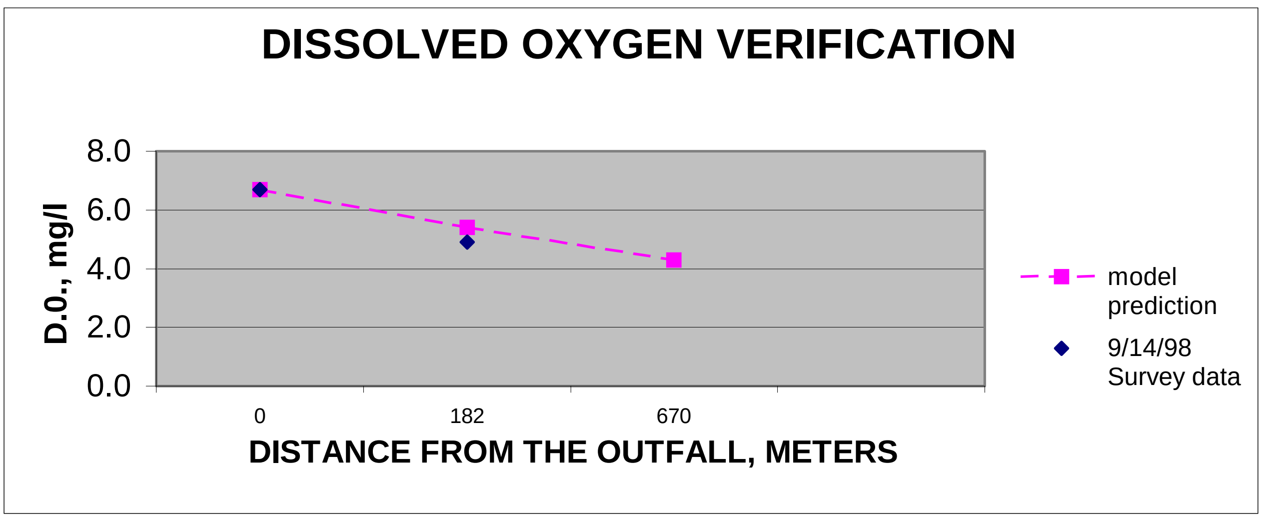


Figure A6: DO VERIFICATION

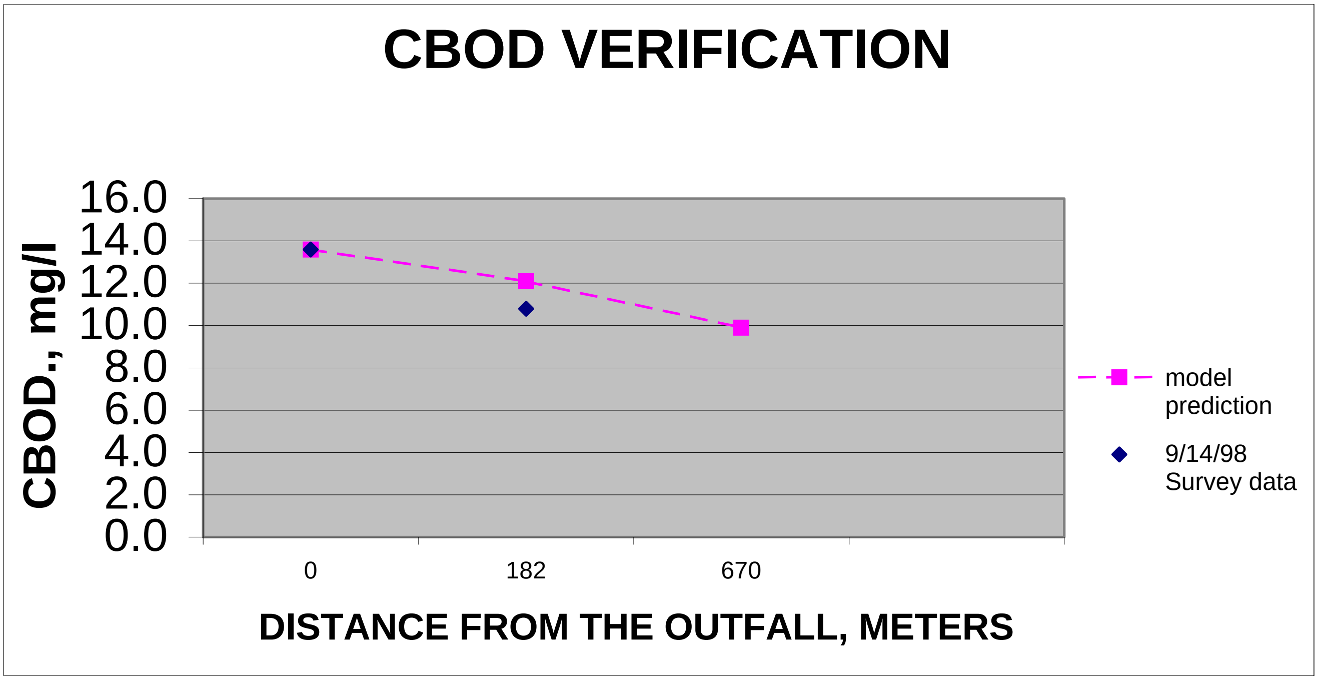


Figure A7: CBOD Verification

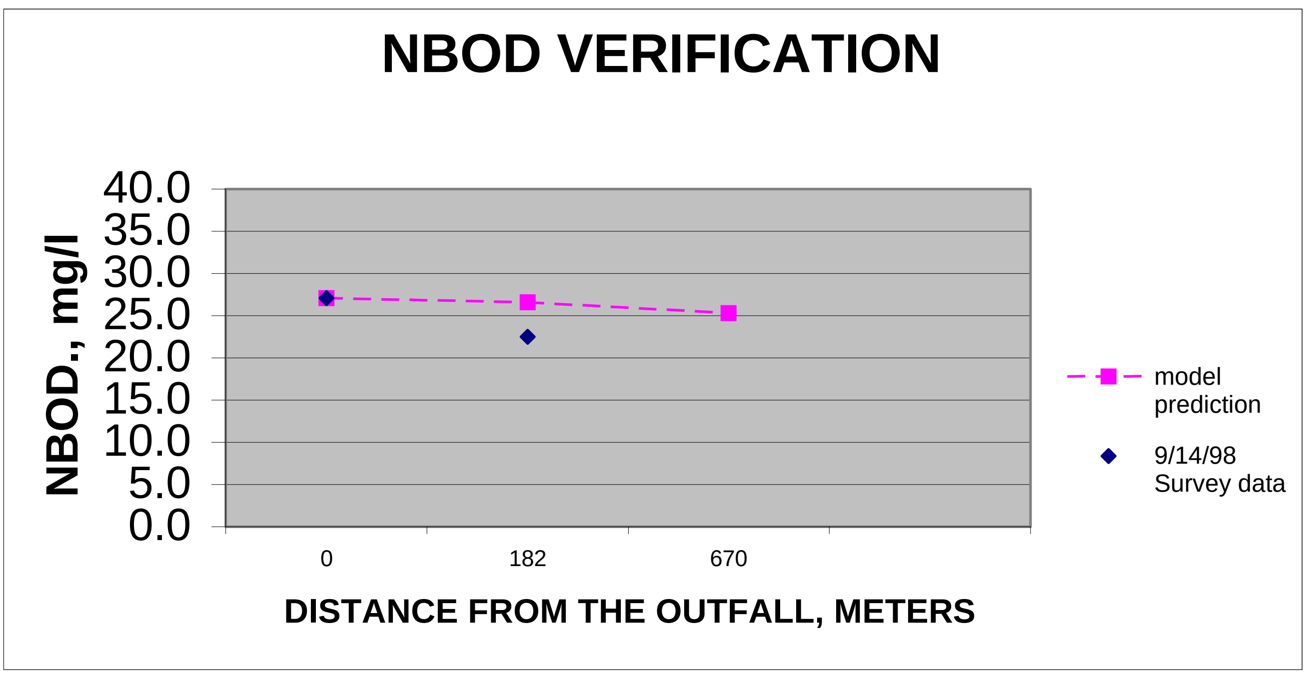


Figure A8: NBOD Verification

Application of INPRG Model

Once the INPRG model was calibrated, input data was assembled to simulate summer 7Q10 low flow and average stream flow conditions. The following sections discuss the development of the summer condition INPRG input data sets.

Estimation of Summer Stream Temperature

The INPRG program determines a 90th percentile stream temperature by developing a frequency distribution of the stream temperature input. No historical water quality station is located on UTLTC; therefore, water temperature data from the nearby water quality stations and USGS gaging station 01492000 were used to estimate the 90th percentile stream temperature. A 90th percentile stream temperature of 25.4 °C was determined from the temperature data shown in Table A4

STATION	YEAR	MONTH	DAY	WATER TEMP
MLE0020	70	7	15	24.0
MLE0020	70	9	01	23.2
MLE0020	70	10	05	18.3
MLE0020	71	06	08	26.0
MLE0020	71	07	21	20.5
MLE0020	71	10	05	21.0
MLE0020	71	08	18	25.8
MXS0005	76	08	18	26.2
01492000	78	09	06	21.0
01492000	78	10	23	15.5
01492000	79	06	11	18.0
01492000	79	07	11	19.5
01492000	79	08	27	23.5
01492000	79	10	11	10.5
01492000	77	09	19	23.0
01492000	78	07	11	22.0
01492000	78	09	06	21.0
01492000	78	10	23	15.5
01492000	76	08	05	19.5
01492000	76	10	06	17.0
01492000	77	06	21	19.5
01492000	77	08	17	23.0
01492000	77	09	19	23.0
01492000	75	09	18	15.0
01492000	75	10	20	15.5
01492000	76	06	22	21.5
01492000	76	08	05	19.5
01492000	76	10	06	17.0
01492000	75	06	23	19.5
01492000	75	08	14	23.0
01492000	75	09	18	15.0
01492000	75	10	20	15.5
01492000	74	07	18	21.0
01492000	74	08	21	20.5

01492000	74	10	11	12.0
01492000	73	06	05	20.0
01492000	73	07	19	22.0
01492000	73	09	04	23.5
01492000	73	10	11	16.0
01492000	72	06	08	16.0
01492000	72	07	25	24.0
01492000	72	08	10	20.0
01492000	72	09	09	18.5

Table A4: Stream Temperatures in Degrees Celsius

All of the model reaction rates (k_2, k_c and k_n) were adjusted by INPRG to the 90th percentile stream temperature of 25.4 °C.

<u>Estimation of Summer Stream Water Quality</u>

UTLTC background and tributary flow for summer condition were assumed zero, water quality observed during August and September surveys was used as UTLTC INPRG input data for model. Table A5 and A6 shows the water quality data used for the model station tributary flows.

STATION	TRIBUTARY/PLANT FLOW	Flow cfs	MODEL RUN FOR CURRENT CONDITIONS		
			CBOD mg/l	NBOD mg/l	DO mg/l
1	Plant Effluent	0.223 (0.144 MGD)	15	9.2	6
2	UTLTC	0	0	0	0
3	UTLTC	0	0	0	0

Table A5: INPRG Model Water Quality Input Data for Scenario 1

STATION	TRIBUTARY/PLANT FLOW	Flow cfs	MODEL RUN FOR FUTURE CONDITIONS		
			CBOD mg/l	NBOD mg/l	DO mg/l
1	Plant Effluent	0.309 (0.20 MGD)	15	9.2	6
2	UTLTC	0	0	0	0
3	UTLTC	0	0	0	0

Table A6: INPRG Model Water Quality Input Data for Scenario 2

Estimation of 7-Day, 10-Year Low Flow

The nearest USGS gaging station (i.e., gaging station 01492000 located on Beaver Dam Branch at Matthews, Maryland) was used to estimate the UTLTC 7Q10 low-flow. Listed below are USGS gaging station 01492000 statistics:

Station Name:	Beaver Dam Branch, Maryland
Station Number:	01492000
Latitude (dd.mm.ss)	39.29.38
Longitude (dd.mm.ss)	79.02.42
Drainage area (square miles)	5.85
7Q10 Flow (cfs)	0

7Q10 low-flow runoff rate = 0 cfs/sq. mile.

The above calculated 7Q10 low-flow runoff rate of 0 cfs/sq. mile was input into the INPRG program.

Estimation of 7-Day, 10-Year High Flow

The nearest USGS gaging station (i.e., gaging station 01492000 located on Beaver Dam Branch at Matthews, Maryland) was used to estimate the UTLTC average high stream flow conditions. Data from 1981, the last recorded year, was used to estimate the monthly high flow rate for spring/ winter months. Listed below are USGS gaging station 01492000 statistics:

Station Name:	Beaver Dam Branch, Maryland
Station Number:	01492000
Latitude (dd.mm.ss)	39.29.38
Longitude (dd.mm.ss)	79.02.42
Drainage area (square miles)	5.85
High-flow runoff rate	0 588cfs/sq. mile.

The above calculated average high-flow runoff rate of 0.588 cfs/sq. mile was input into the INPRG program, which computes the high flow for each modeling segment using the drainage area for the model segment.

Estimation of Stream Velocities

Stream velocity was estimated using the following statistical relationship, which was derived using the flow and corresponding velocity data of USGS01492000. The data is shown in Table A7.

$$\text{Log Velocity} = .353 \log(\text{discharge}) + (-.63201)$$

$$V = 0.2333\, Q^{0.353}$$

Using the above velocity Vs discharge relationship, the stream velocities are slope corrected using the following relationship:

V (segment) = { slope of segment / slope at gage }1/2 * V (gage)

STATION	FLOW CFS	VELOCITY FPS
01492000	1.0	0.18
01492000	17.1	0.56
01492000	10.8	0.44
01492000	5.58	0.38
01492000	1.15	0.46
01492000	7.70	0.32
01492000	3.18	0.34
01492000	15.1	0.50
01492000	3.79	0.40
01492000	5.94	0.38
01492000	2.72	0.25
01492000	2.43	0.26
01492000	1.06	0.18
01492000	1.33	0.15
01492000	2.53	0.38
01492000	0.51	0.22
01492000	1.89	0.26
01492000	3.03	0.34
01492000	8.97	0.40
01492000	8.39	0.35
01492000	6.49	0.38
01492000	5.62	0.28
01492000	1.97	0.43
01492000	1.46	0.26
01492000	7.51	0.40
01492000	9.04	0.60
01492000	4.30	0.47
01492000	6.08	0.44
01492000	11.9	0.61
01492000	6.69	0.54
01492000	12.3	0.81
01492000	17.1	0.69
01492000	5.84	0.55
01492000	10.2	0.94
01492000	4.67	0.39
01492000	5.90	0.63
01492000	5.22	0.67
01492000	5.46	0.64
01492000	19.4	0.56

Table A7: INPRG Model Flow and Velocity Data for V vs Q Relationship

INPRG Results for TMDL Scenarios

The following sections present the INPRG model results for the three TMDL scenarios presented in the main document.

Scenario One

Scenario one assumed 7Q10 flow-non-point source loads in addition to the facility effluent concentrations shown in Table A9 below. INPRG results are shown in Table A8.

Station	Distance From Headwaters meters	Upstream Just Before mixing			Downstream Just After Mixing		
		CBOD mg/l	NBOD mg/l	D.O. mg/l	CBOD mg/l	NBOD mg/l	D.O. mg/l
1	0	0	0	7.75	15	13.8	6
2	182	13.79	13.51	5.24	13.79	13.51	5.24
3	670	11.90	12.84	5.53	11.90	12.84	5.53

Table A8: INPRG Model Results for Scenario One

FACILITY	FACILITY FLOW gpd	BOD_5 mg/l	TKN Mg/l	DO mg/l
Trappe WWTP	144,000	10	3	6.0

Table A9: Assumed Facility Effluent Concentrations for Scenario one

Scenario Two

Scenario two assumed average flow non-point source loads in addition to the facility effluent concentrations shown in Table A11 below. Background CBOD, NBOD, and DO values were estimated using water quality data from nearby free-flowing streams. INPRG results are shown in Table A10. This scenario includes future flows of 56,000 gpd.

Station	Distance From Headwaters meters	Upstream Just Before mixing			Downstream Just After Mixing		
		CBOD mg/l	NBOD mg/l	D.O. mg/l	CBOD mg/l	NBOD mg/l	D.O. mg/l
1	0	6.90	4.10	7.30	10.45	8.35	6.73
2	182	10.40	8.26	7.41	10.40	8.26	7.41
3	670	10.18	7.85	7.34	10.18	7.85	7.34

Table A10: INPRG Model Results for Scenario Two

FACILITY	FACILITY FLOW gpd	BOD_5 mg/l	TKN Mg/l	DO mg/l
Trappe WWTP	200,000	10.0	3.0	6.0

Table A11: Assumed Facility Effluent Concentrations for Scenario Two

Scenario Three

Scenario three assumed 7Q10 low-flow non-point source loads in addition to the facility effluent concentrations shown in Table A11 below. . INPRG results are shown in Table A12. This scenario includes future flow of 56,000 gpd. This scenario also includes future loads for margin of safety (MOS) loads.

Station	Distance From Headwaters meters	Upstream Just Before mixing			Downstream Just After Mixing		
		CBOD mg/l	NBOD mg/l	D.O. mg/l	CBOD mg/l	NBOD mg/l	D.O. mg/l
1	0	0	0	7.75	16.4	15.5	6
2	182	15.22	15.21	5.28	15.22	15.21	5.28
3	670	13.34	14.54	5.55	13.34	14.54	5.55

Table A12: INPRG Model Results for Scenario Three

FACILITY	FACILITY FLOW gpd	BOD_5 mg/l	TKN Mg/l	DO mg/l
Trappe WWTP	200,000	10.9	3.37	6.0

Table A13: Assumed Facility Effluent Concentrations for Scenario Three

List of Equations for INPRG Model

The following equations are used in the INPRG Mathematical Model for Freshwater Streams:

1. Equations for Conversion of BOD to CBOD and TKN to NBOD

   As per guidelines of the Surface Discharge Permits Division, the following equations are used to convert BOD and TKN to CBOD and NBOD, respectively:

   CBOD = 1.5 ∗ BOD

   NBOD = 4.6 ∗ TKN

2. Equations To Estimate Decay of CBOD and NBOD Matter

   The following equations are used in the INPRG to characterize decay of the CBOD and NBOD matter with first order kinetics:

   k_c at temperature (T) = $k_{c20} * \{1.047^{(T-20)}\}$

   k_n at temperature (T) = $k_{n20} * \{1.08^{(T-20)}\}$

   $L_{ct} = L_{co} * e^{-(k_c * t)}$ and $L_{nt} = L_{no} * e^{-(k_n * t)}$

Where: T is 90th Percentile Stream Temperature for Summer period, ° C
k_{c20} is Standard CBOD Decay rate at 20° C, per day
k_{n20} is Standard NBOD Decay rate at 20° C, per day
k_c temperature corrected CBOD Decay Rate, per day
k_n temperature corrected NBOD Decay Rate, per day
t is time of travel, days
L_{co} is initial ultimate CBOD concentration, mg/l
L_{ct} is ultimate CBOD concentration at downstream after time of travel (t), mg/l
L_{no} is initial NBOD concentration, mg/l
L_{nt} is NBOD concentration at downstream after time of travel (t), mg/l

3. Reaeration Rates

The reaeration rates (k_a) are estimated using Tsivoglou's Formula. Refer to U.S. EPA Publication "Rates, Constants and Kinetics Formulations in Surface Water Quality Modeling, 2nd Edition, EPA/600/3-85/040, June 1985" for this formula.

$$k_a = \{0.054 * (\in H \div t)\} * \{1.022^{(T - 25)}\}$$

Where: k_a is reaeration rate at temperature (T), per day
$\in H$ is difference of elevations at two modeling points of a segment, ft.

4. Equation for Dissolved Oxygen Sag Prediction

The following equation for dissolved oxygen deficit is based on the Streeter- Phelps equation:

$$D = [\{kc * (Lct - Lco) \div (k\mathbf{a} - kc)\} * \{e -(kc * t) - e -(k\mathbf{a} * t)\}] + [\{kn * (Lnt - Lno) \div (k\mathbf{a} - kn)\} * \{e -(kn * t) - e -(k\mathbf{a} * t)\}] - [\{P - R - (S \div d)\} * t]$$

Where: D is dissolved oxygen deficit, mg/l
P is algal photosynthetic oxygen production rate, mg/l- day
R is algal respiration (dissolved oxygen consumption) rate, mg/l- day
S is sediment oxygen demand rate, gm/m^2- day
d is stream depth, meters

5. Equation for Saturation Dissolved Oxygen

The INPRG program estimates the dissolved oxygen saturation (C_S) in mg/l at each modeling point using the following formula:

$$C_S = \{(14.62 - 0.3893*T) + (0.006969*T^2) - (5.897*10^{-5}*T^3)\} * \{1 - (6.97*10^{-6}*\in H)\}$$

6. Equation for Dissolved Oxygen

The INPRG program uses the following formula to estimate dissolved oxygen at each modeling point:

$$C = C_S - D$$

Where: C is dissolved oxygen after time of travel (t), mg/l

Water Quality Data

DATE	FLOWS (CFS	CH_AA (UG/L)	CBOD (MG/L)	DO (MG/L)	TN (MG/L)	TP (MG/L)	TSS (MG/L)	TEMP (0C)
08/17/1998	0.067	0.3	15.6	5.4	5.91	2.760	37	21.3
08/26/1998	0.097	1.5	12.3	6.8	6.56	2.8	40	22
09/14/1998	0.085	1.0	13.6	6.7	6.10	3.180	26	20.8
AVERAGE	0.083	0.93	13.8	6.3	6.19	2.913	34	21

Table A14: Trappe WWTP Effluent Water Quality Data at the outfall 001

DATE	FLOWS (CFS	CH_AA (UG/L)	CBOD (MG/L)	DO (MG/L)	TN (MG/L)	TP (MG/L)	TSS (MG/L)	TEMP (0C)
08/17/1998	0.067	2.6	15.6	7.4	5.91	2.760	37	21.3
08/26/1998	0.097	5.0	12.3	7.9	6.56	2.8	40	22
09/14/1998	0.085	5.400	13.6	8.7	6.10	3.180	26	20.8
AVERAGE	0.08	4.33	13.8	8.0	6.19	2.913	34	21

Table A15: Water Quality Data at TRP2 in the UTLTC at Island Crossing Road

DATE	FLOWS (CFS	CH_AA (UG/L)	CBOD (MG/L)	DO (MG/L)	TN (MG/L)	TP (MG/L)	TSS (MG/L)	TEMP (0C)
08/17/1998		12	7.1	3.5	5.51	2.39	32	24.1
08/26/1998		3.9	9.2	4.4	5.53	2.62	23	25.1
09/14/1998		2.3	10.8	4.9	5.4	3.16	15	23.6
AVERAGE		6.1	9.03	4.26	5.48	2.72	23.3	24.3

Table A16: Water Quality Data at TRP3 in the UTLTC 200 yards downstream from the Island Crossing Road