Limno-Tech, Inc.
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Memorandum

DATE: **January 21st, 2003**
PROJECT: **ERC313**

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DC DOH

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Appendix A: The Development of the Rock Creek Metals Models

Introduction

Limno-Tech, Inc. (LTI) developed and applied models to be used by EPA and DC DOH for determination of Total Maximum Daily Loads (TMDLs) for metals in the District of Columbia portion of Rock Creek. This memorandum documents the development and application of the metals models including the technical approach, calibration of the total suspended solids (TSS) and copper models, the calculation of applicable water quality standards used for comparison with model results, and application of the models over a representative three-year period. It contains a description of the SWMM model applied in Rock Creek, the development of model inputs, and relevant assumptions about the data available for model development and application.

While the availability of data to support model development and application was not abundant, it was adequate and enabled the models to be developed and applied with reasonable confidence in their ability to predict instream concentrations of TSS and metals. A conservative approach was used so that application of the models would overestimate rather than underestimate pollutant concentrations. In addition, the model was used in TMDL determination in conjunction with a margin of safety.

This documentation is focused on the TSS and copper models, but information on the development and application of lead and zinc models is also provided.

Technical Approach

The technical approach to model development and application was centered on 1) developing a model that had appropriate complexity given the modeling issues to be addressed and the availability of data to support model development; and 2) utilizing other locally developed models to the fullest extent possible. Given this approach, the SWMM model was selected for the simulation of TSS and metals in Rock Creek. SWMM has process and transport capabilities that are consistent with the needs of a model to support development of TMDLs for metals in Rock Creek. In addition, SWMM has been successfully applied recently in Rock Creek for other studies, including a bacteria TMDL and the development of a long term control plan for CSOs in the District of Columbia.

Calibration of the TSS and Copper Models

Copper and TSS models of Rock Creek were calibrated using the data collected by LTI in 2003. During the summer and fall, LTI sampled five storm events. During each storm event, seven samples were collected at two locations along Rock Creek; Candy Cane City and Devils Chair Bridge. The location of these sampling stations and a USGS gage in the watershed are given in Figure 1. Each sample was analyzed for total copper, dissolved copper, and TSS.

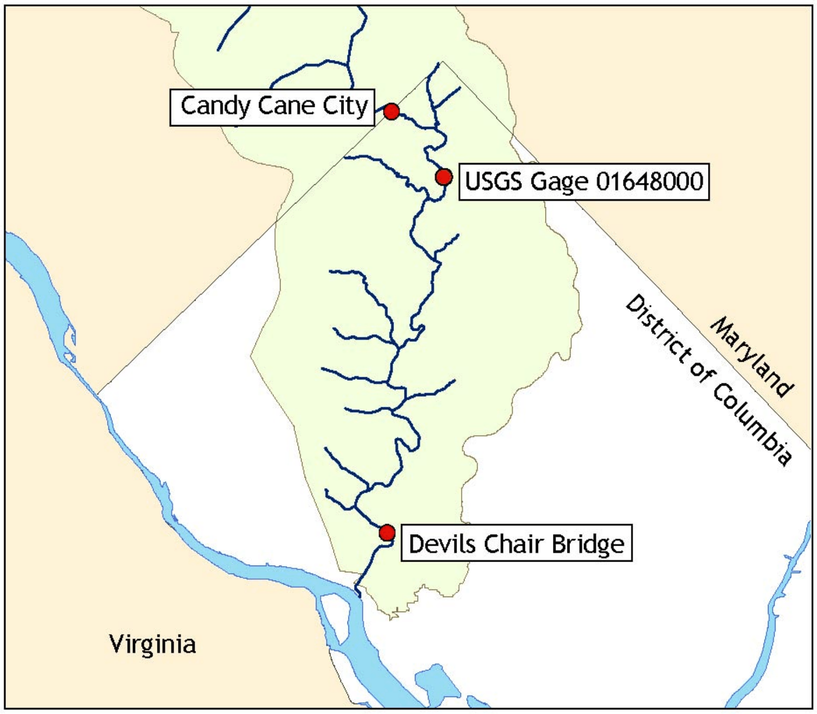

Figure 1: LTI Sampling Locations and USGS Gage Locations in Rock Creek

Input Data

The first input dataset needed for the models is a set of upstream data. This dataset includes all flows and loads from Maryland into the District of Columbia for Rock Creek. Flow for the upstream dataset was based on the USGS gage at Sherrill Drive (USGS 01648000). Hourly flow from Sherrill Drive was adjusted to represent flow at the boundary of Maryland and the District of Columbia using areal weighting based on watershed area. The data collected by LTI at Candy Cane City was used to determine the concentrations of total copper and TSS at the upstream boundary of the District of Columbia. The data collected by LTI was used in two ways. During the five storm events sampled, the data was used directly as input to the model. When copper and TSS concentration data were not available, relationships between flow and TSS, along with flow and copper were used to estimate the concentrations. These relationships were determined using the data collected by LTI and are represented using the following equations:

$$TSS(mg/L) = 0.436\ Flow\ (cfs) - 5.255$$

$$Total\ Copper\ (ug/L) = 0.052\ Flow\ (cfs) + 4.491$$

The data used to create these formulas along with a solid line showing the relationship are presented in Figure 2 for TSS and Figure 3 for Total Copper.

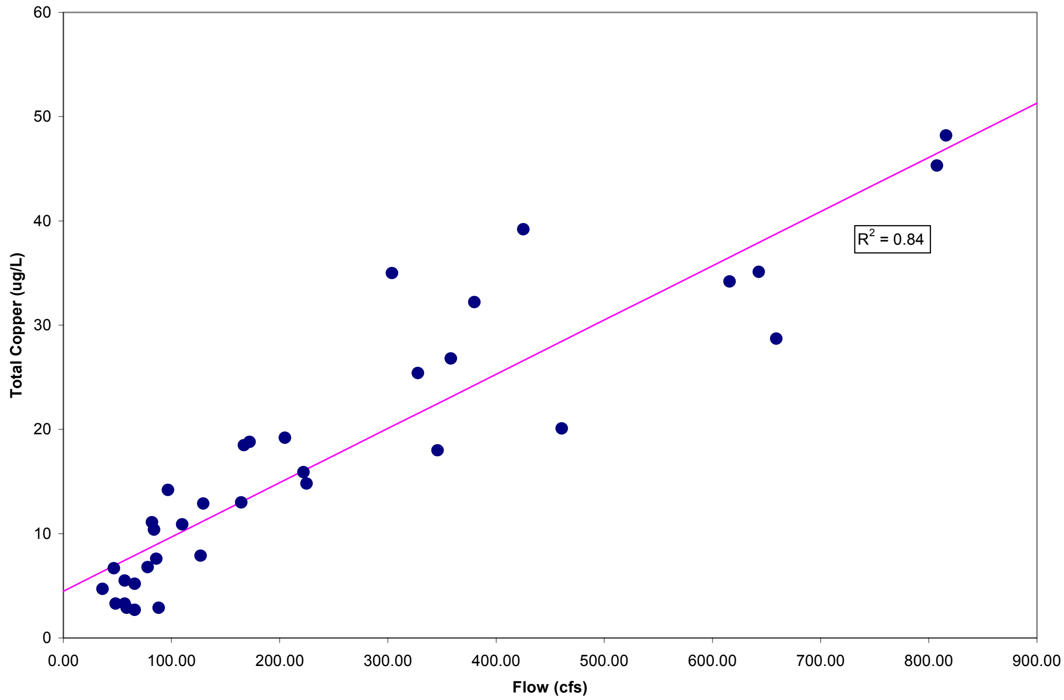

Figure 2: TSS versus Flow for the Five Storm Events Sampled

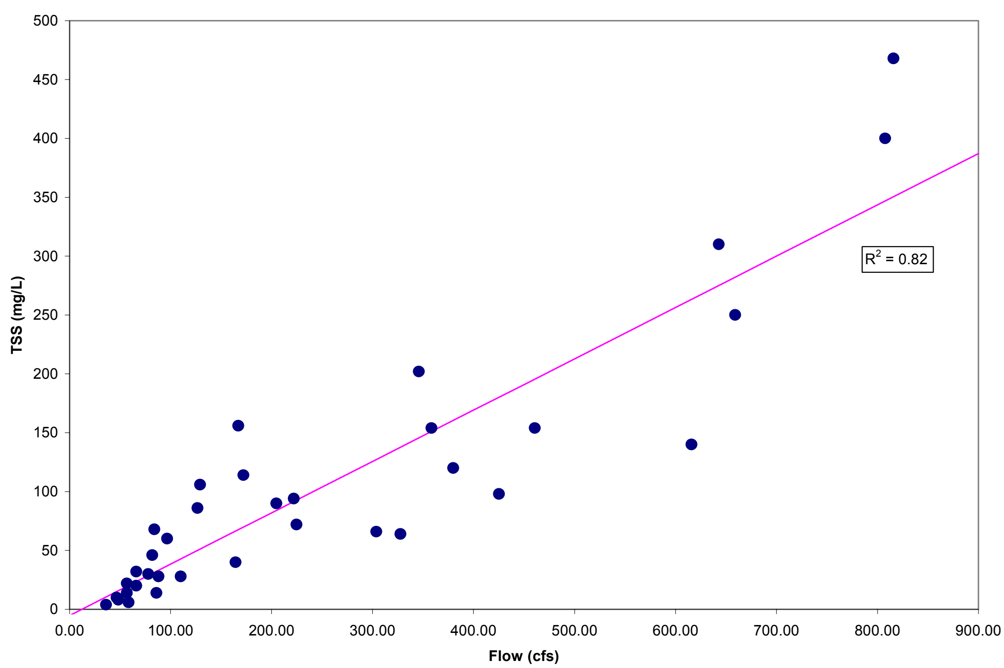

Figure 3: Total Copper versus Flow for the Five Storm Events Sampled

For CSO and storm water inputs to the models, the DC WASA July 2002 Long Term Control Plan (LTCP) models were used. Storm water and combined sewer flows for current conditions were determined by running these models. The output of these models was then used as input for the Rock Creek metals models. For TSS, the concentrations presented in the LTCP for CSOs and storm water were used. These values are given in Table 1. For total copper, the concentration for CSOs was calculated as the average of all the data collected at the Piney Branch outfall for the LTCP. The concentration of total copper in storm water was determined by averaging all of the storm water data collected in 1994, 1995, and 2003 (Figure 4). The results for TSS and copper are presented in Table 1.

Table 1: TSS and Total Copper Concentrations for Storm water and CSOs.

Constituent	**CSO Concentration**	**Storm water Concentration**
TSS (mg/L)	130	94
Total Copper (ug/L)	26	78

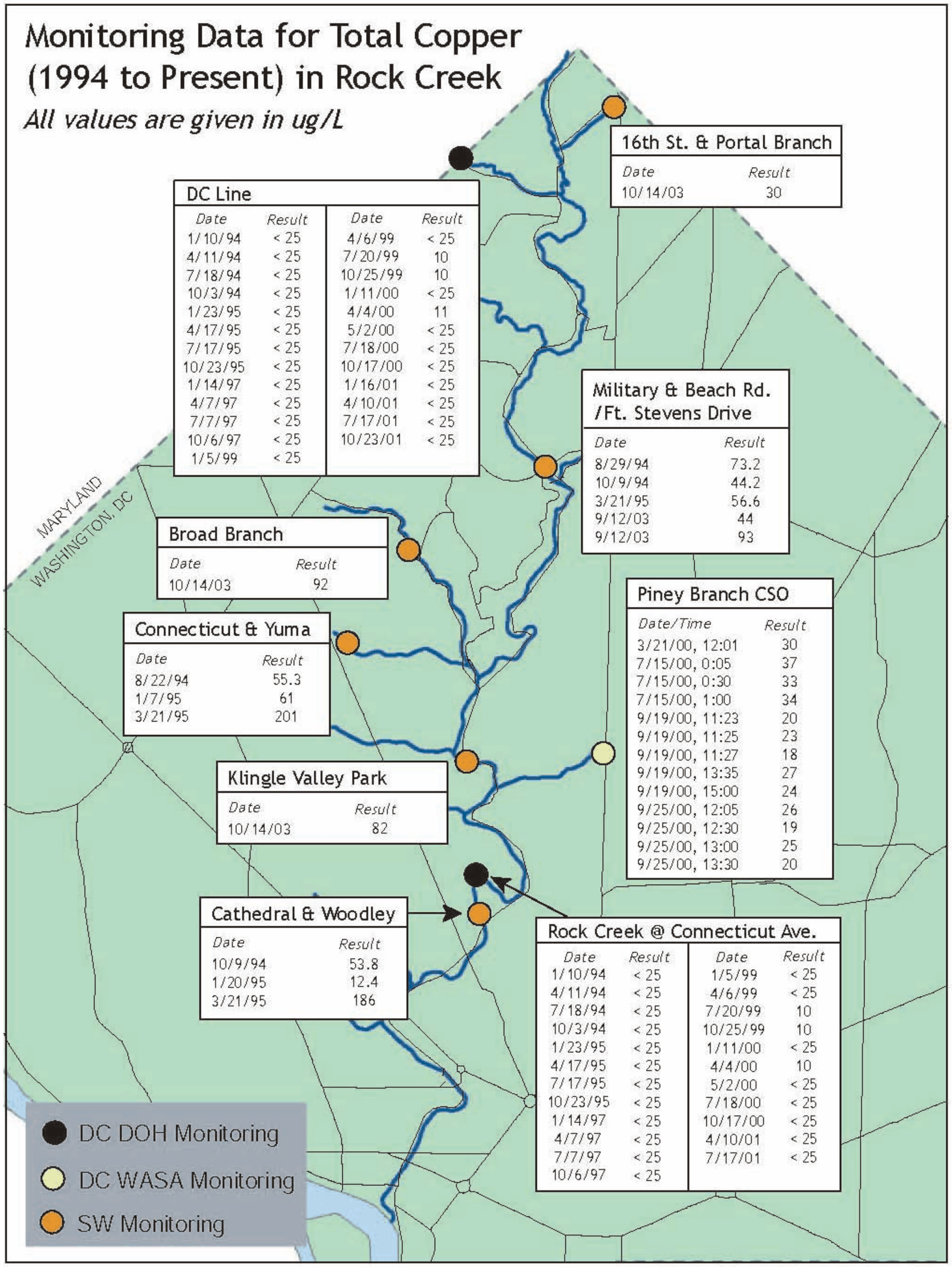

Figure 4: Total Copper Data

There are additional storm water sources within the Rock Creek watershed. These inputs do not flow through the storm water or CSO system of the District of Columbia. The majority of these flows come from parkland along Rock Creek its tributaries. To determine the flows from these areas, the simple method was used (MWCOG, 1987). A widely used flow estimation approach, application of the simple method used rainfall, drainage area, and runoff coefficients to estimate the flow. Then TSS and total copper concentrations for storm water (given in Table 1) were used to generate load inputs.

The TSS Model

A TSS model of Rock Creek was constructed, using the model framework of Rock Creek developed for the LTCP and the Bacteria TMDLs. Using a set of LTI developed pre-processors, the input data was manipulated to create a SWMM input file. This was then run through the existing SWMM model for the period from July 1st, 2003 to October 31st, 2003. Using this SWMM model, it is assumed that there is no resuspension or deposition in Rock Creek. The calibration results for all five storms are presented below as Figures 5 through 9. Modeled results are compared to the data collected at Devils Chair Bridge which is located approximately one mile upstream of the confluence of Rock Creek with the Potomac River. Note that the model was not cailbrated to the data collected at Candy Cane City as this data was used to construct the upstream boundary in the model.

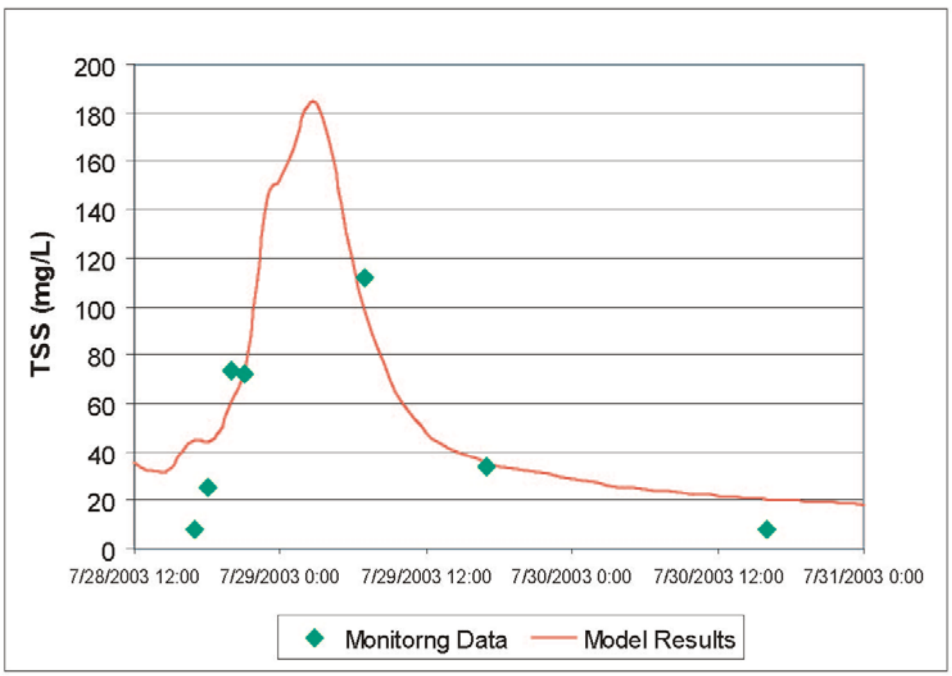

Figure 5: TSS Calibration of Storm Event 1 at Devils Chair Bridge

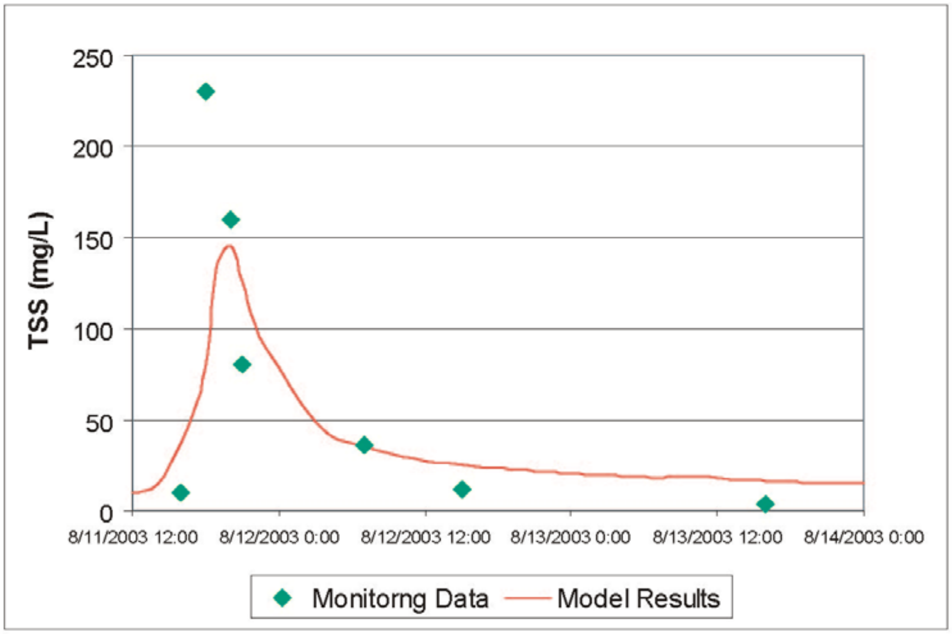

Figure 6: TSS Calibration of Storm Event 2 at Devils Chair Bridge

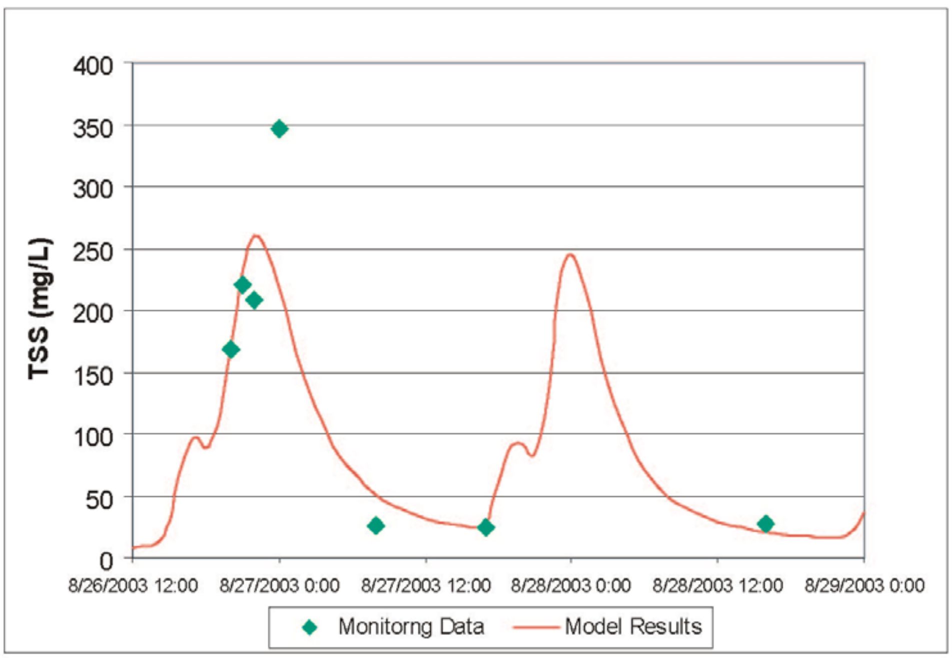

Figure 7: TSS Calibration of Storm Event 3 at Devils Chair Bridge

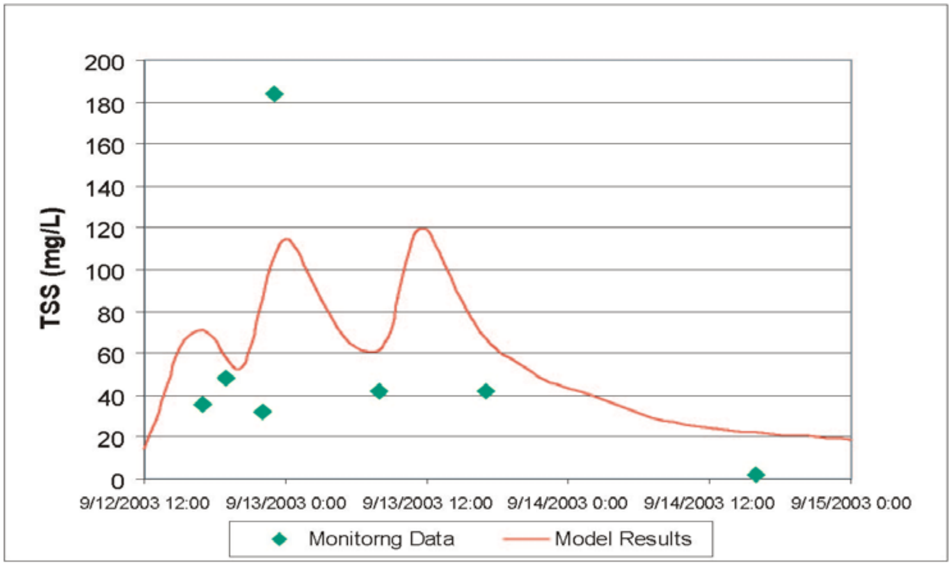

Figure 8: TSS Calibration of Storm Event 4 at Devils Chair Bridge

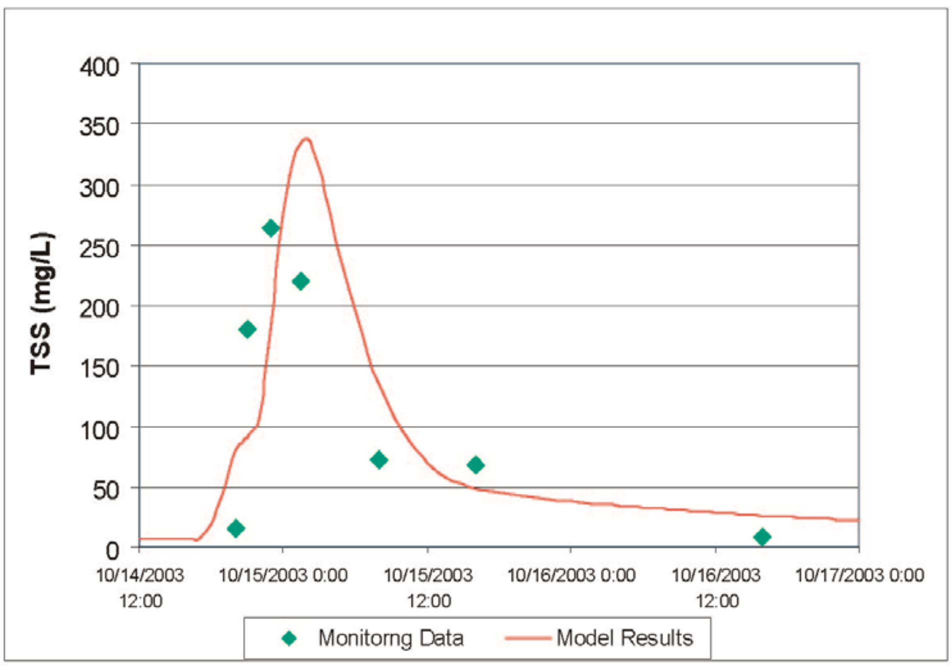

Figure 9: TSS Calibration of Storm Event 5 at Devils Chair Bridge

Reviewing the results of the calibration, it was determined that the model does an adequate job of estimating TSS in Rock Creek. The model does a very good job of estimating TSS in Storm Event #1, while underestimating the TSS concentration during some storms and overestimating the TSS in other storms. The TSS model of Rock Creek was run with an hourly time step using a single value for TSS concentrations of CSOs and storm water instead of the expected variations in the TSS concentrations of CSO and storm water. While this assumption may lead to less than perfect calibration results, the model is expected to provide reasonable results for the TMDLs. To check to make sure that the model is not biased, a 1:1 plot has been produced and it is provided as Figure 10.

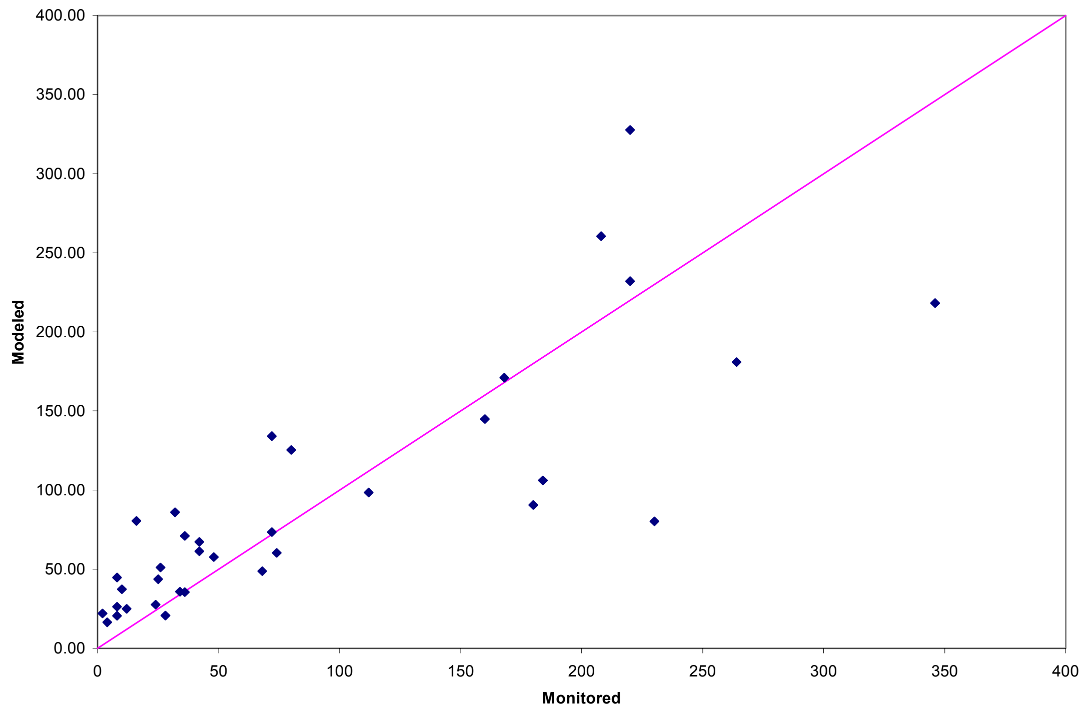

Figure 10: TSS Model Calibration - Modeled versus Monitored Results

As shown in the figure, no obvious signs of bias are present in the TSS model. The model does not consistently overestimate or underestimate the TSS concentrations in Rock Creek.

The Total Copper Model

Similar modeling techniques were used for the total copper model. Using the SWMM model, total copper concentrations were calculated for Rock Creek. The transformation of copper from the particulate to dissolved phases was not simulated in Rock Creek. This assumption is expected to be valid as water moves through Rock Creek very quickly (approximately three hour travel time from the MD/DC boundary to the Potomac) and it is anticipated that no transformations will occur during this time. The results of the calibration for total copper at Devils Chair Bridge are presented in Figures 11 through 15.

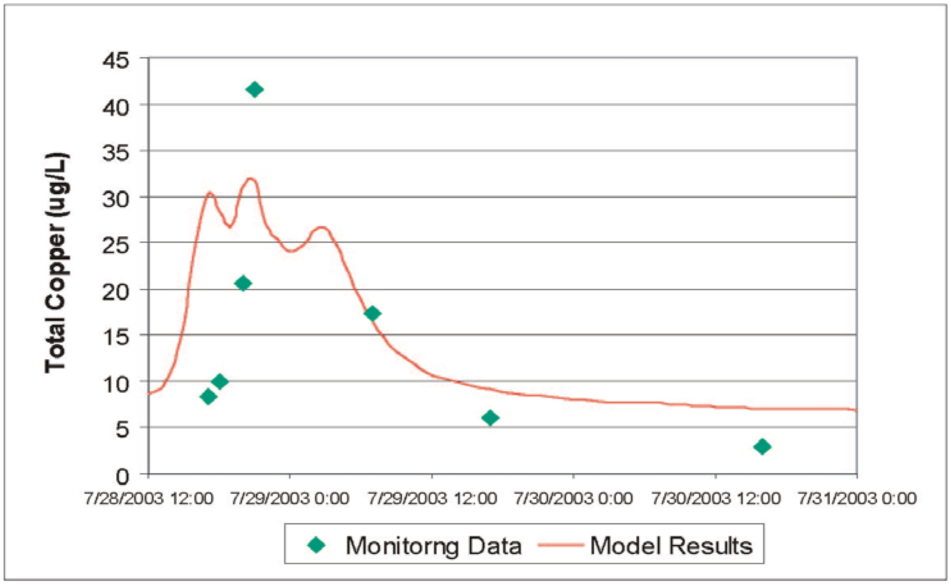

Figure 11: Total Copper Calibration of Storm Event 1 at Devils Chair Bridge

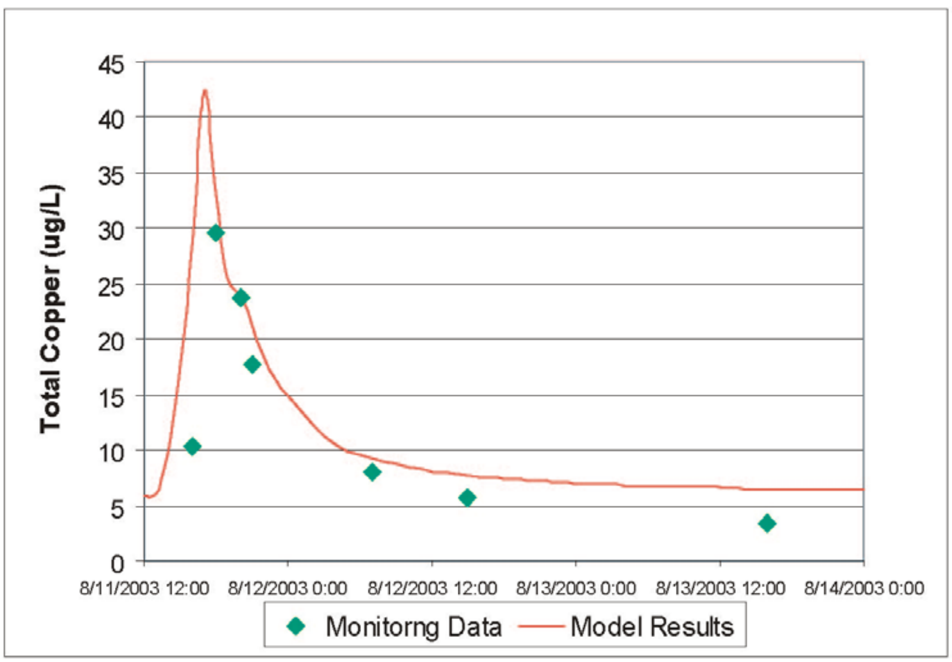

Figure 12: Total Copper Calibration of Storm Event 2 at Devils Chair Bridge

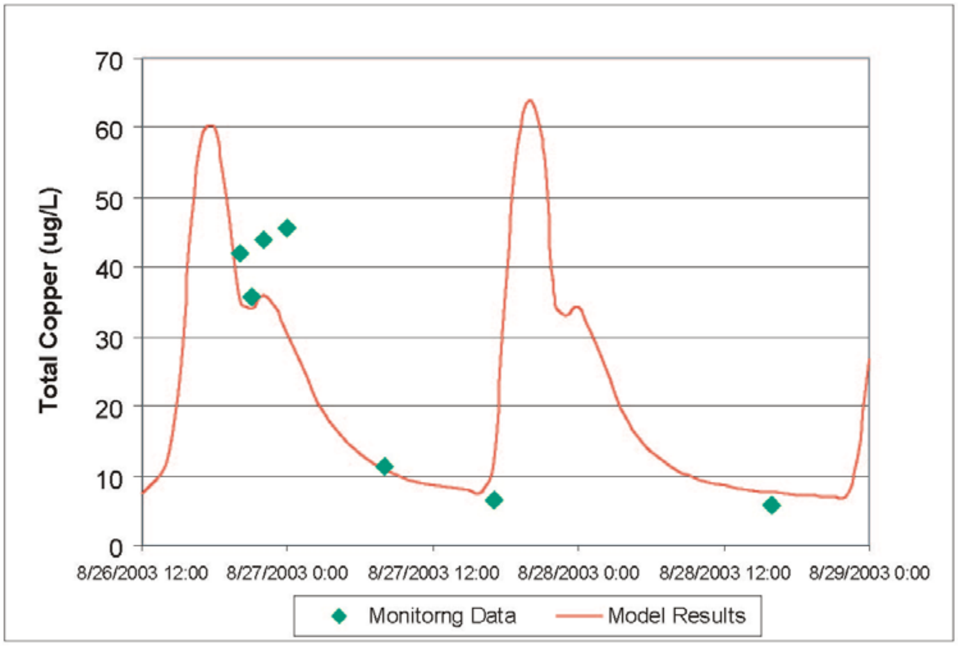

Figure 13: Total Copper Calibration of Storm Event 3 at Devils Chair Bridge

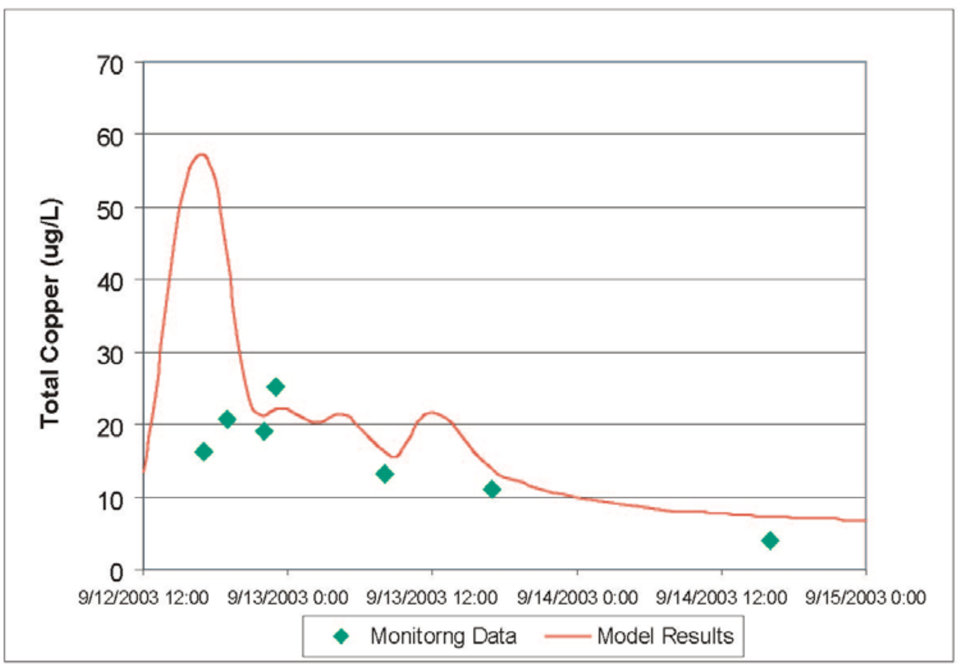

Figure 14: Total Copper Calibration of Storm Event 4 at Devils Chair Bridge

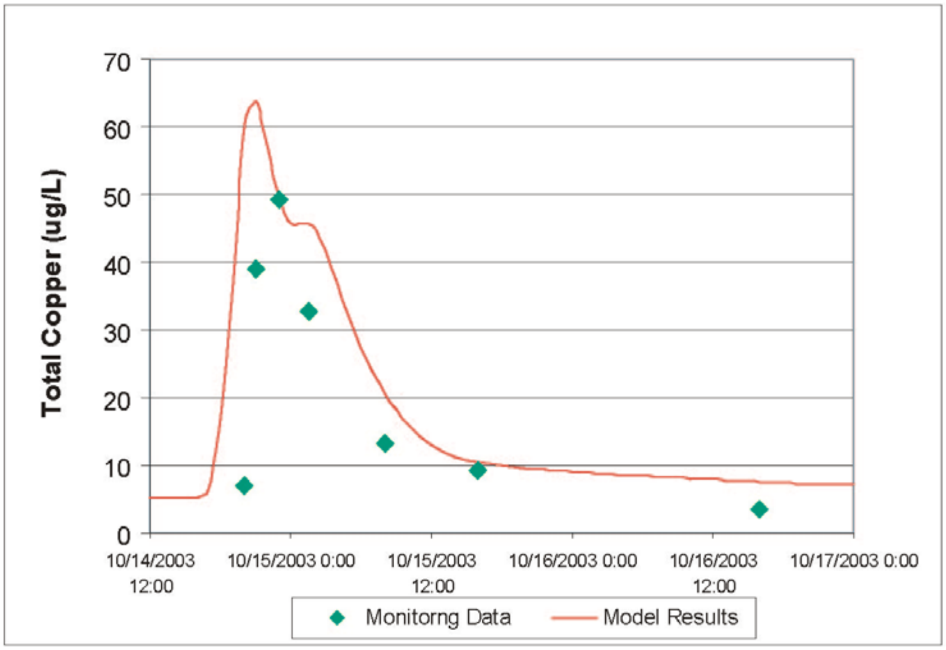

Figure 15: Total Copper Calibration of Storm Event 5 at Devils Chair Bridge

The calibration results are similar to those for TSS. Again, the model overestimates the total copper concentrations at some points, while underestimating the concentrations during other storm events. Looking at the 1:1 line (Figure 16), the model tends to slightly overestimate the concentration of total copper during the calibration. However, this provides a conservative estimate of copper in Rock Creek.

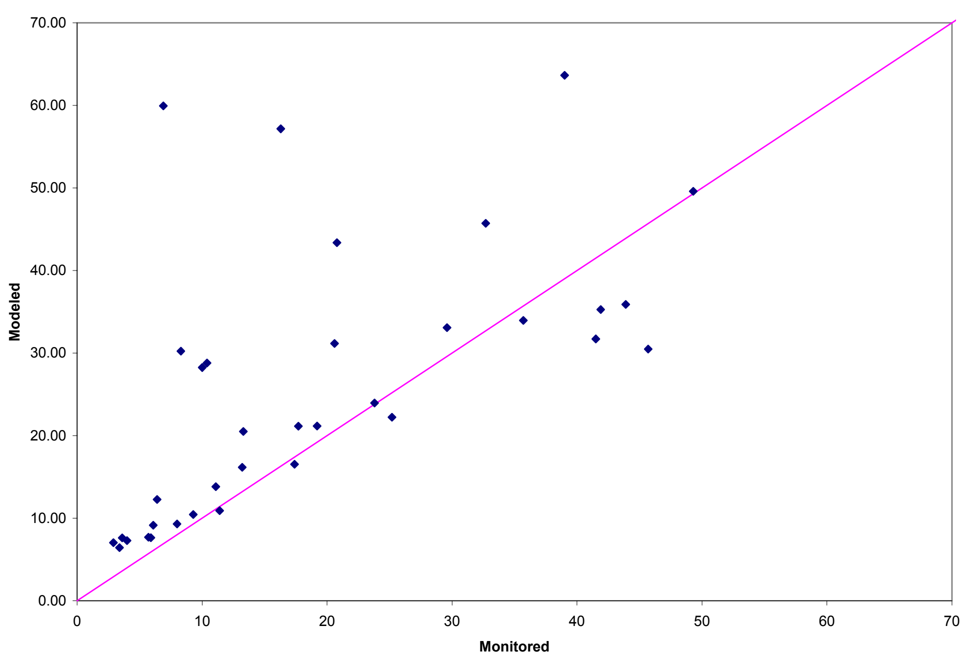

Figure 16: Total Copper Model Calibration - Modeled versus Monitored Results

Dissolved Copper

Developing a model of dissolved metals is a very complex process. Therefore, another approach was used to determine concentrations of dissolved copper in Rock Creek. A partition coefficient along with concentrations of TSS and total copper can be used to calculate dissolved copper concentrations. This relation is given as:

$$Dissolved\ Copper = Total\ Copper\left[\frac{1}{\left(\frac{k_d * TSS}{10^6} + 1\right)}\right]$$

where: Total and Dissolved Copper are given in ug/L
TSS is given in mg/L
k_d is the partition coefficient in l/kg (Thomann, 1987)

In the EPA Technical Guidance Manual for Performing Waste Load Allocations, Book II-Streams & Rivers (1984), partition coefficients for various metals, including copper and zinc, are provided. For copper, the following relationship is given:

$$k_d = 1.04x10^6 * TSS(mg / L)^{-0.7436}$$

Comparing this relationship to the data collected during the sampling program completed by LTI provided a good correlation as shown in Figure 17. Therefore, this relationship was used to determine dissolved copper concentrations in Rock Creek. Figures 18 to 22 provide the results of the calibration of dissolved copper for the five storm events at Devils Chair Bridge. In each figure, the water quality standards for acute and chronic conditions are also shown. The derivation of these standards is given later in this memorandum.

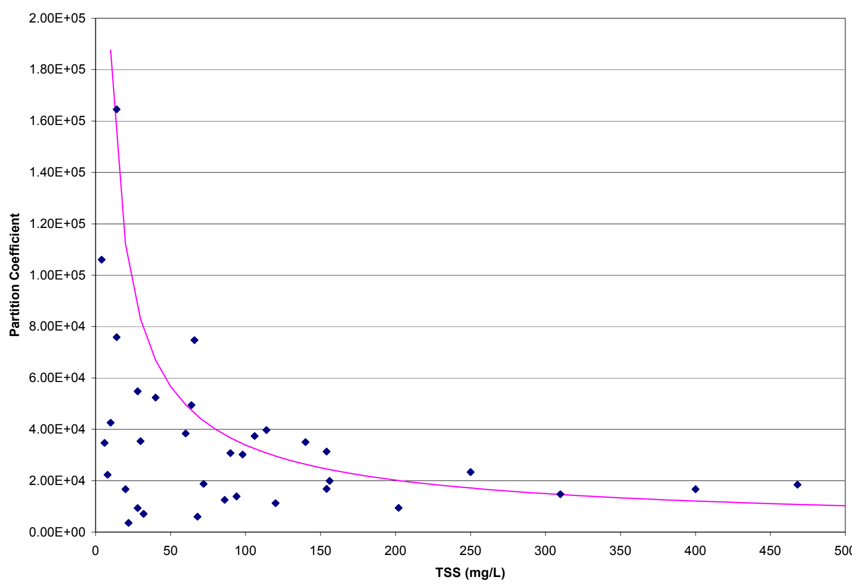

Figure 17: TSS versus the Partition Coefficient

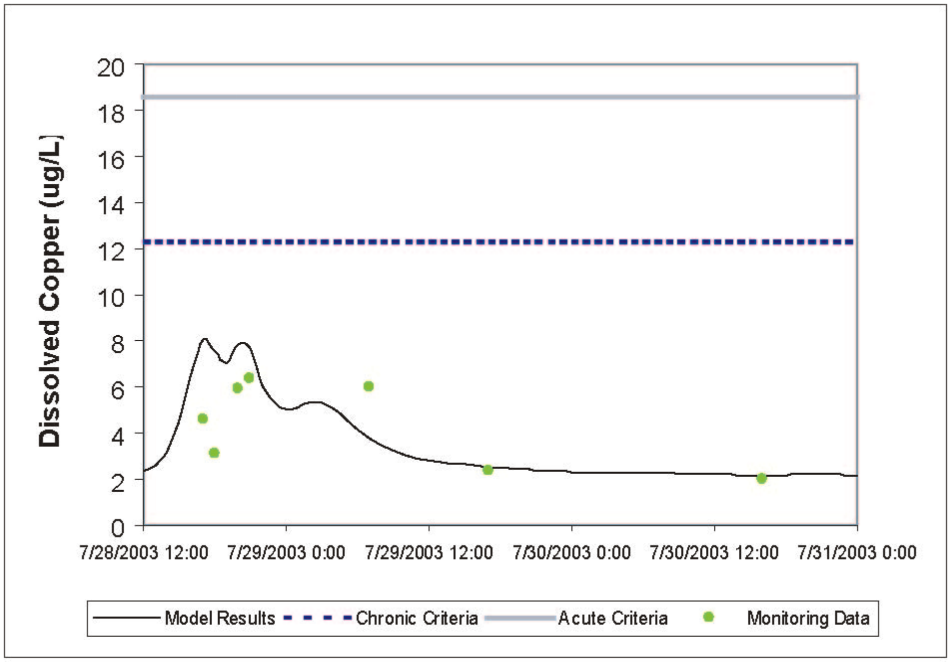

Figure 18: Dissolved Copper Calibration of Storm Event 1 at Devils Chair Bridge

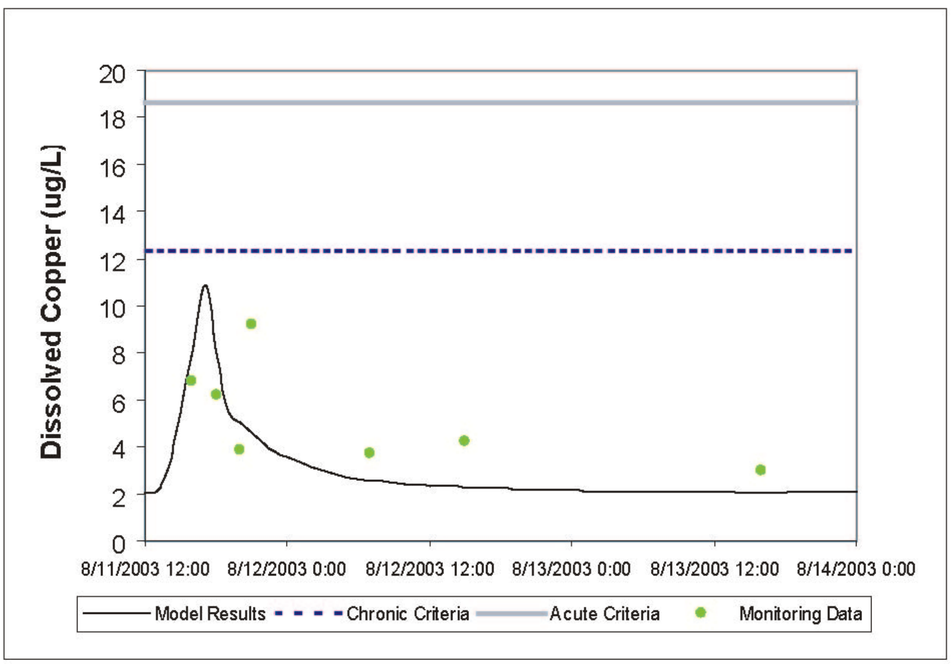

Figure 19: Dissolved Copper Calibration of Storm Event 2 at Devils Chair Bridge

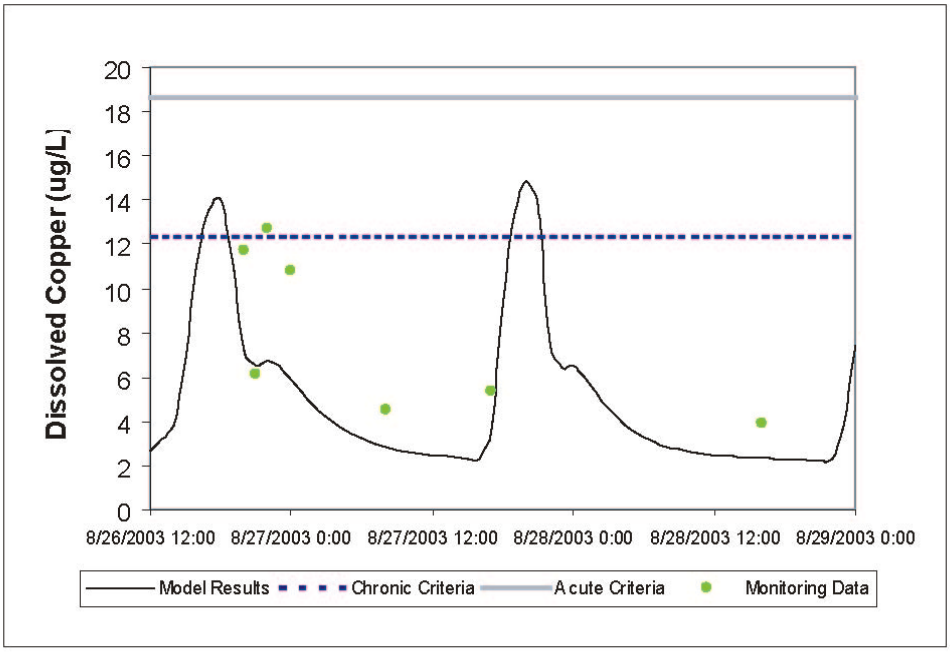

Figure 20: Dissolved Copper Calibration of Storm Event 3 at Devils Chair Bridge

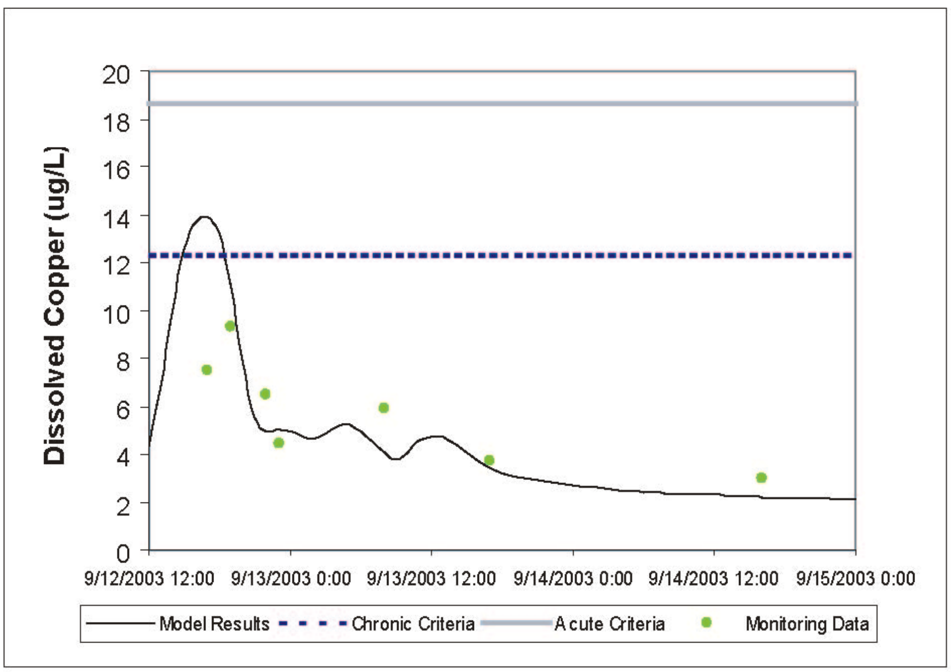

Figure 21: Dissolved Copper Calibration of Storm Event 4 at Devils Chair Bridge

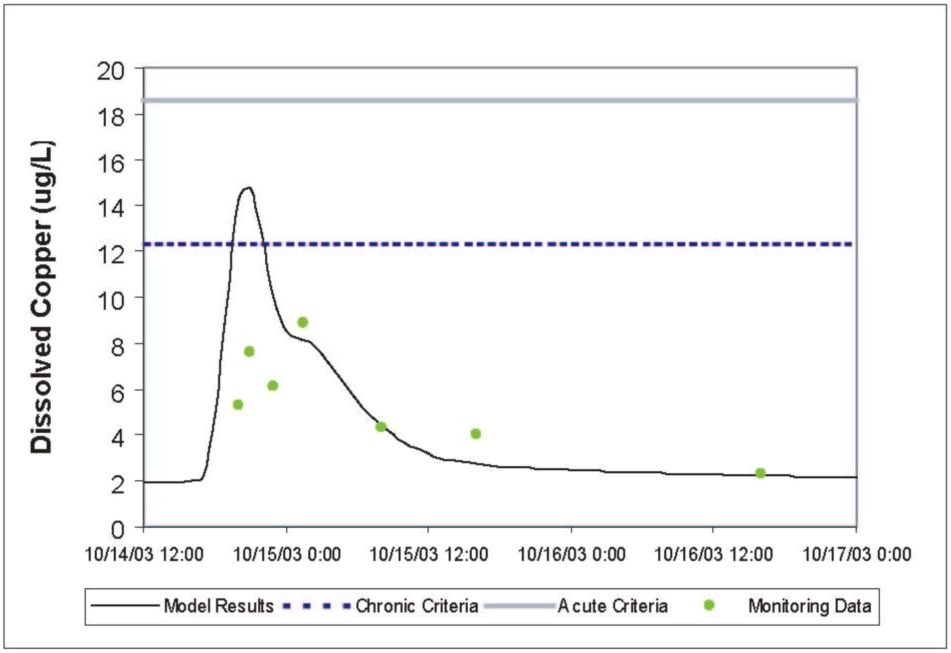

Figure 22: Dissolved Copper Calibration of Storm Event 5 at Devils Chair Bridge

With this calibration of dissolved copper, development of an approach for the metals TMDLs in Rock Creek was completed. At this point it is important to notice that even though the model results exceed the chronic criteria for dissolved copper during storm events 3,4, and 5, the time of exceedance is very small and the chronic criteria is a four-day average. If the data is averaged over four days, the chronic standard is not exceeded during any of the calibration storm events. The acute criteria for dissolved copper is never exceeded during any of the calibration storm events.

Calculating the Water Quality Standards in Rock Creek

Standards for dissolved metals in Rock Creek are based upon hardness. Therefore, the first step in calculating water quality standards is determining the hardness in Rock Creek. Using data for Rock Creek from 1984 through 2000, the 50th percentile hardness value was found to be 110 mg/L as $CaCO_3$. As shown in Figure 23, there is little correlation of hardness with flow in Rock Creek. Due to this fact, one constant value of hardness was used when calculating the standard.

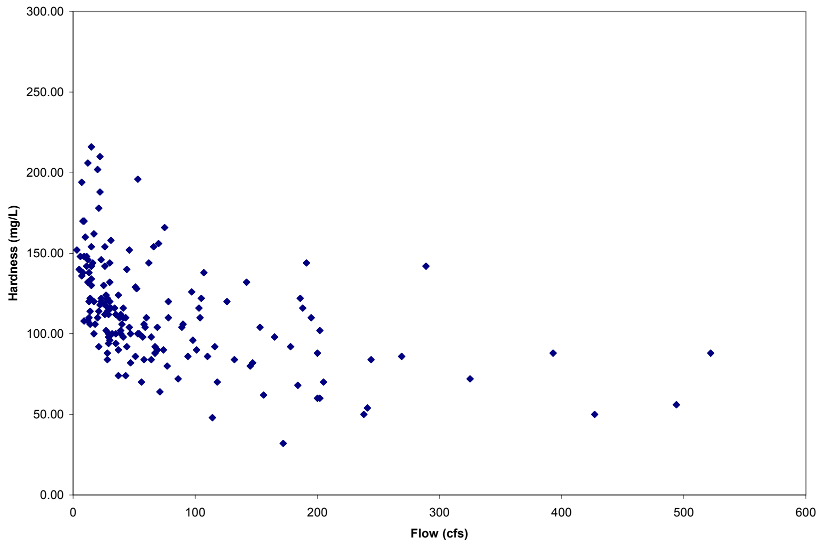

Figure 23: Hardness as a Function of Flow in Rock Creek

The chronic(CCC) and acute (CMC) water quality standards for dissolved copper are given by:

$$CCC = 0.96 * e^{(0.8545\ln(hardness)-1.465)}$$

$$CMC = 0.96 * e^{(0.9422\ln(hardness)-1.464)}$$

For a hardness of 110mg/L of $CaCO_3$, the CCC is 12.3 ug/L and the CMC is 18.6 ug/L for dissolved copper.

Dissolved lead water quality standards are calculated using:

$$CCC = 0.78 * e^{(1.2730\ln(hardness)-4.705)}$$

$$CMC = 0.78 * e^{(1.2730\ln(hardness)-1.460)}$$

For a hardness of 110mg/L of $CaCO_3$, the CCC is 2.79 ug/L and the CMC is 71.63 ug/L for dissolved lead.

The water quality standards for zinc are determined in a similar manner:

$$CCC = 0.986 * e^{(0.8473\ln(hardness)+0.7614)}$$

$$CMC = 0.978 * e^{(0.8473\ln(hardness)+0.8604)}$$

This leads to a CCC of 113.3 ug/L and a CMC of 124.1 ug/L for dissolved zinc.

TMDL Model Application

The representative three-year period from 1988 to 1990 used in developing the LTCP, the Anacostia River and tributary TMDLs, and other Rock Creek tributary TMDLs was used when applying the model for these TMDLs. This time period includes a wet year, a dry year and an average year.

Copper

The SWMM Model was run for TSS and Total Copper in Rock Creek using inputs developed in a manner similar to that described in the calibration section of this memorandum. The copper and TSS concentrations were kept at levels used in the calibration, while flows varied based upon the rainfall during the three-year period. Following completion of the three-year model simulation, the output was transformed to dissolved copper concentrations using the methods described previously. The results of the three-year run for dissolved copper at Segment 7 (Massachusetts Avenue Bridge) of the Rock Creek model are presented in Figure 24.

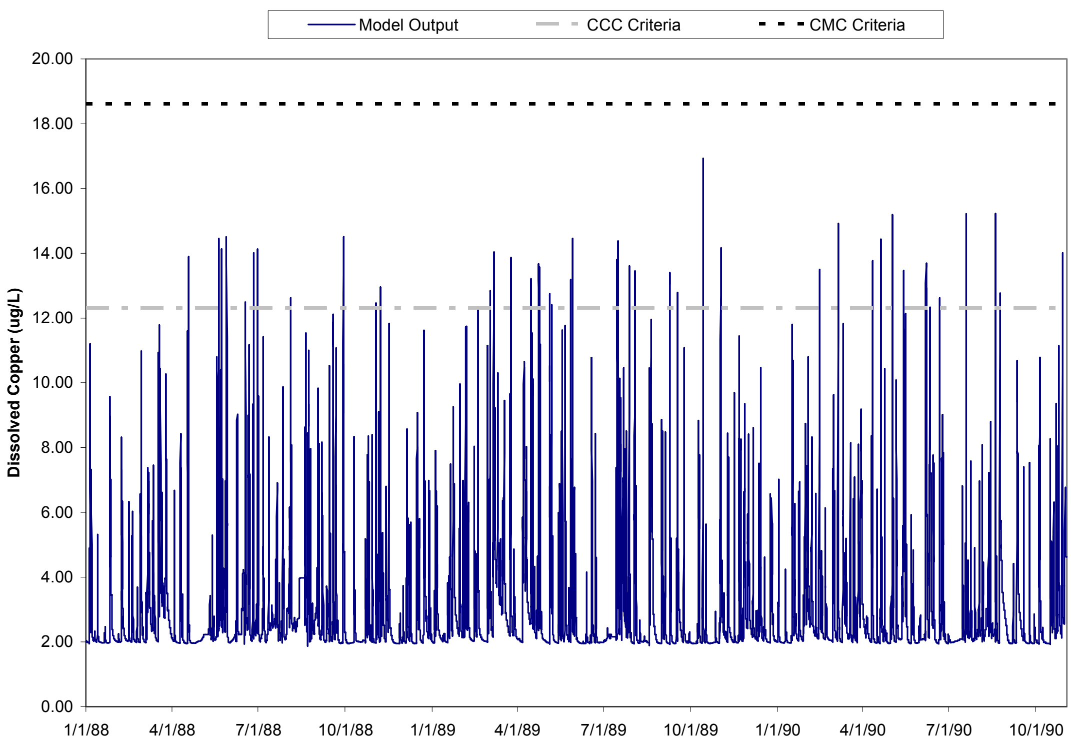

Figure 24: Three-year Model Results for Dissolved Copper

Examining Figure 24, Rock Creek never exceeds the acute criteria (CMC) for dissolved copper. Also, looking at the results at a finer scale for segment 7 (Figure 25), the exceedences of the chronic criteria (CCC) occur for very short periods of time (hours) before dropping to very low levels of dissolved copper. Consequently, sustained concentrations above the CCC were not simulated.

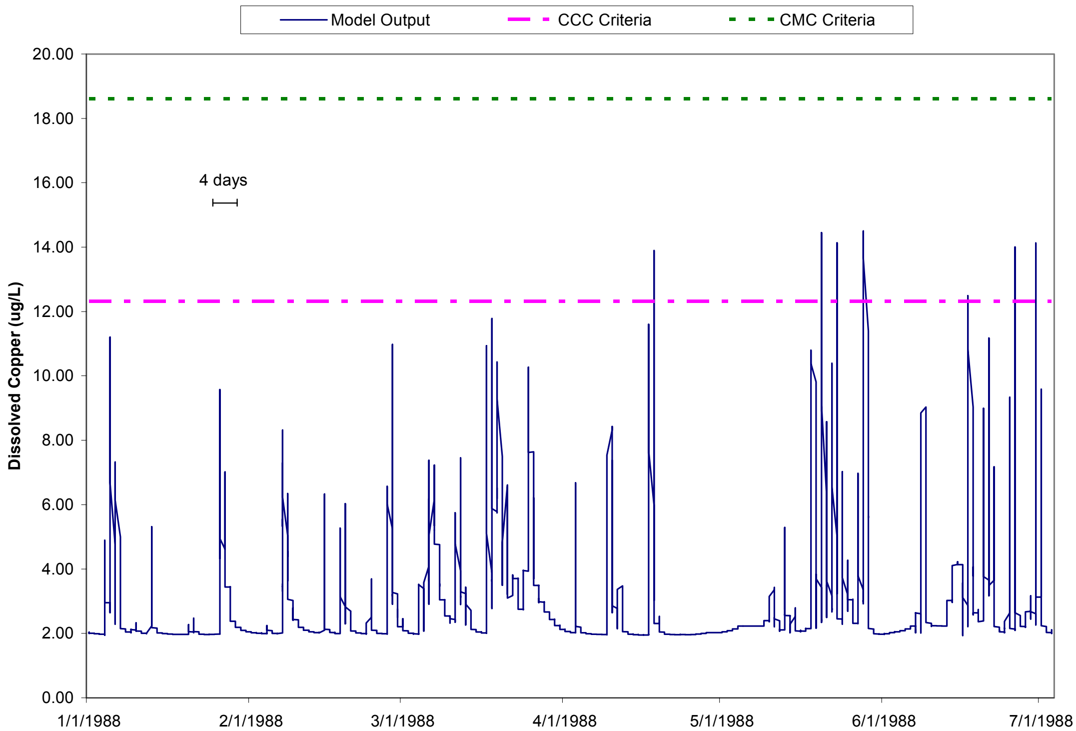

Figure 25: A Six-Month Selection of the Model Output for Dissolved Copper.

The segment 7 plots are typical for all Rock Creek segments. Table 2 shows the maximum dissolved copper value calculated for each month of the three-year period for six representative segments. The maximum four-day average dissolved copper concentration for six segments is presented in Table 3. Segment 1 is the model segment closest to the Potomac River. Segment 40 of the Rock Creek model is just downstream of the Maryland/District of Columbia boundary. A map showing the location of these six segments is presented in Figure 26. Using Tables 2 and 3, together with results from all other model segments, it was determined that dissolved copper does not exceed the acute or chronic criteria at any point during this three-year period.

Table 2: Maximum Dissolved Copper Concentration (ug/L) by Model Segment

Month/Year	1	7	12	17	18	40
January-88	15.60	15.71	15.71	15.80	15.59	6.04
February-88	9.81	9.89	10.11	10.48	9.74	4.43
March-88	10.85	11.20	10.81	11.30	10.66	4.34
April-88	10.70	10.98	10.82	11.17	10.77	3.45
May-88	11.61	11.78	11.41	11.71	11.28	7.81
June-88	13.78	13.90	14.31	14.64	14.29	2.69
July-88	14.43	14.50	14.59	14.63	14.64	3.18
August-88	14.17	14.13	14.24	14.49	14.07	5.04
September-88	11.49	11.42	11.45	11.44	11.03	5.05
October-88	12.31	12.62	12.84	13.22	12.77	5.05
November-88	14.48	14.51	14.39	15.06	14.98	4.94
December-88	8.45	8.40	8.56	8.89	8.25	2.70
January-89	12.78	12.95	12.87	13.08	12.63	3.76
February-89	11.73	11.62	11.67	11.68	11.27	4.06
March-89	9.91	9.97	10.02	10.36	9.79	7.04
April-89	12.35	12.34	12.33	12.46	12.11	3.71
May-89	14.00	14.04	13.83	14.07	14.30	5.23
June-89	13.51	13.67	13.67	14.02	13.64	7.19
July-89	14.19	14.46	14.34	14.73	14.68	5.90
August-89	10.60	10.78	10.63	10.82	10.28	2.34
September-89	14.17	14.38	14.48	14.59	15.48	4.23
October-89	13.49	13.46	13.27	13.58	13.47	6.30
November-89	13.27	13.40	13.35	13.64	13.19	5.03
December-89	16.89	16.93	16.99	17.12	17.06	2.81
January-90	13.79	14.17	13.82	14.15	14.93	4.61
February-90	10.47	10.47	10.70	10.99	10.44	3.20
March-90	11.89	11.81	11.84	11.80	11.38	3.80
April-90	13.68	13.50	13.72	13.47	13.54	4.43
May-90	14.71	14.91	14.84	15.08	15.11	6.47
June-90	14.39	14.44	14.54	14.56	14.29	3.60
July-90	14.94	15.19	15.08	15.49	15.24	4.66
August-90	13.52	13.70	13.90	13.96	13.42	7.40
September-90	15.09	15.22	15.26	15.36	15.23	2.79
October-90	15.10	15.23	15.03	15.39	15.34	5.64
November-90	10.71	10.69	10.67	10.70	10.47	8.03
December-90	13.95	14.01	13.98	13.98	13.68	4.81

Table 3: Maximum 4-day average Dissolved Copper Concentration (ug/L) by Model Segment

Month/Year	1	7	12	17	18	40
January-88	4.79	4.81	4.75	4.80	4.74	3.74
February-88	3.97	3.96	3.91	3.91	3.82	2.93
March-88	3.78	3.80	3.77	3.79	3.72	3.20
April-88	3.54	3.56	3.53	3.56	3.47	2.85
May-88	5.44	5.42	5.29	5.28	5.18	4.68
June-88	3.68	3.65	3.54	3.50	3.40	2.38
July-88	4.77	4.72	4.50	4.45	4.31	2.89
August-88	4.69	4.70	4.59	4.63	4.42	4.28
September-88	3.73	3.74	3.70	3.72	3.62	4.95
October-88	5.14	5.15	5.00	5.05	4.95	4.89
November-88	4.26	4.30	4.17	4.23	4.11	4.89
December-88	3.84	3.89	3.82	3.88	3.81	2.96
January-89	4.38	4.39	4.25	4.27	4.09	3.07
February-89	3.82	3.83	3.80	3.82	3.75	3.20
March-89	4.32	4.36	4.33	4.38	4.31	4.09
April-89	4.22	4.23	4.16	4.18	4.03	2.76
May-89	5.39	5.40	5.35	5.37	5.33	4.44
June-89	5.71	5.73	5.70	5.72	5.66	5.24
July-89	4.96	4.95	4.83	4.82	4.69	3.30
August-89	3.61	3.59	3.51	3.50	3.40	2.41
September-89	6.12	6.03	5.61	5.49	5.29	2.72
October-89	5.74	5.77	5.68	5.73	5.59	4.36
November-89	3.94	3.96	3.84	3.87	3.81	3.35
December-89	4.22	4.20	4.10	4.10	3.98	2.25
January-90	3.94	3.97	3.93	3.96	3.88	3.36
February-90	3.51	3.53	3.53	3.55	3.51	3.25
March-90	4.00	4.01	3.94	3.95	3.85	2.90
April-90	4.07	4.09	4.04	4.07	4.00	3.44
May-90	4.84	4.87	4.85	4.90	4.82	4.30
June-90	4.16	4.19	4.18	4.22	4.16	3.82
July-90	5.24	5.24	5.15	5.15	5.04	3.77
August-90	5.11	5.12	5.05	5.07	4.97	4.22
September-90	3.73	3.72	3.62	3.62	3.51	2.51
October-90	4.98	5.02	5.00	5.08	5.00	4.34
November-90	4.50	4.53	4.51	4.55	4.52	4.39
December-90	4.27	4.29	4.27	4.30	4.24	3.58

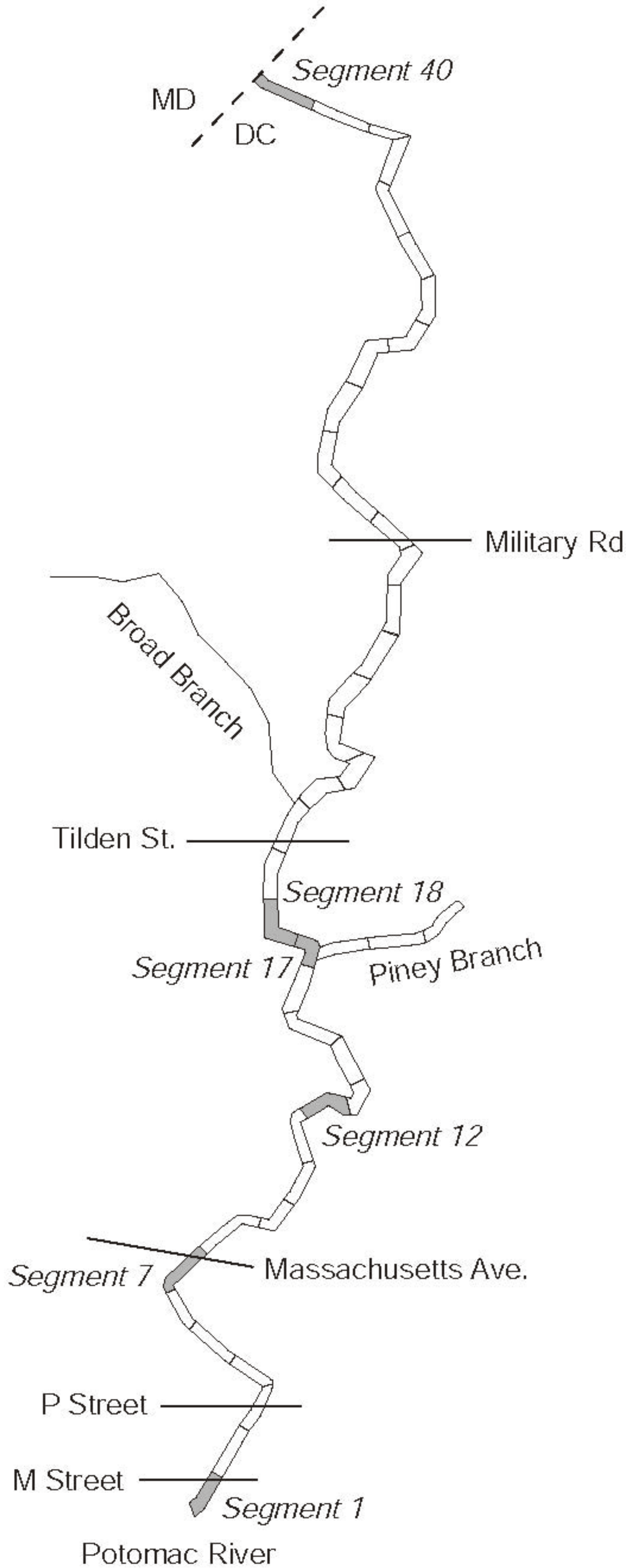

Figure 26: Model Segmentation for the Rock Creek Model

Zinc

The SWMM model for zinc used the same segmentation, transport parameters, and flows used in the copper model. Zinc concentrations for CSO and storm water inputs were determined from the existing data (Figure 27). Total zinc concentrations for CSOs was calculated as the average of all the data collected at the Piney Branch outfall for the LTCP. The concentration of total zinc in storm water was determined by averaging the storm water data collected in 1994,1995, and 2003 for DC DOH. These calculations resulted in total zinc concentrations of 110 ug/L for CSOs and 183 ug/L for all storm water within the District of Columbia.

Zinc was not part of the sampling program completed by LTI in 2003. Therefore, estimating the total zinc concentration at boundary of the District of Columbia was difficult. Using the data collected by DC DOH from 1994 to 2002 at the DC Line, two total zinc concentrations were calculated. The first was an estimate of the dry weather concentration of total zinc. Under many conditions, the total zinc concentration sampled by DOH was under the reporting limit of 20 ug/L. Therefore, it was assumed that the concentration of total zinc in Rock Creek would be half of the reporting limit, or 10.0 ug/L, under dry weather conditions. During wet weather conditions, the total zinc concentration would be higher. The total zinc concentration during wet weather was calculated as the average of all water quality samples at the DC boundary above the reporting limit. This value was calculated to be 41 ug/L. To determine when the wet or dry weather concentrations should be used in the SWMM model, the flow input at the DC boundary was used. HYSEP, a flow splitting program developed by the USGS, was run to separate the wet and dry weather flow conditions (Sloto, 1996). With the separation completed, appropriate concentrations could be used for the wet and dry weather conditions.

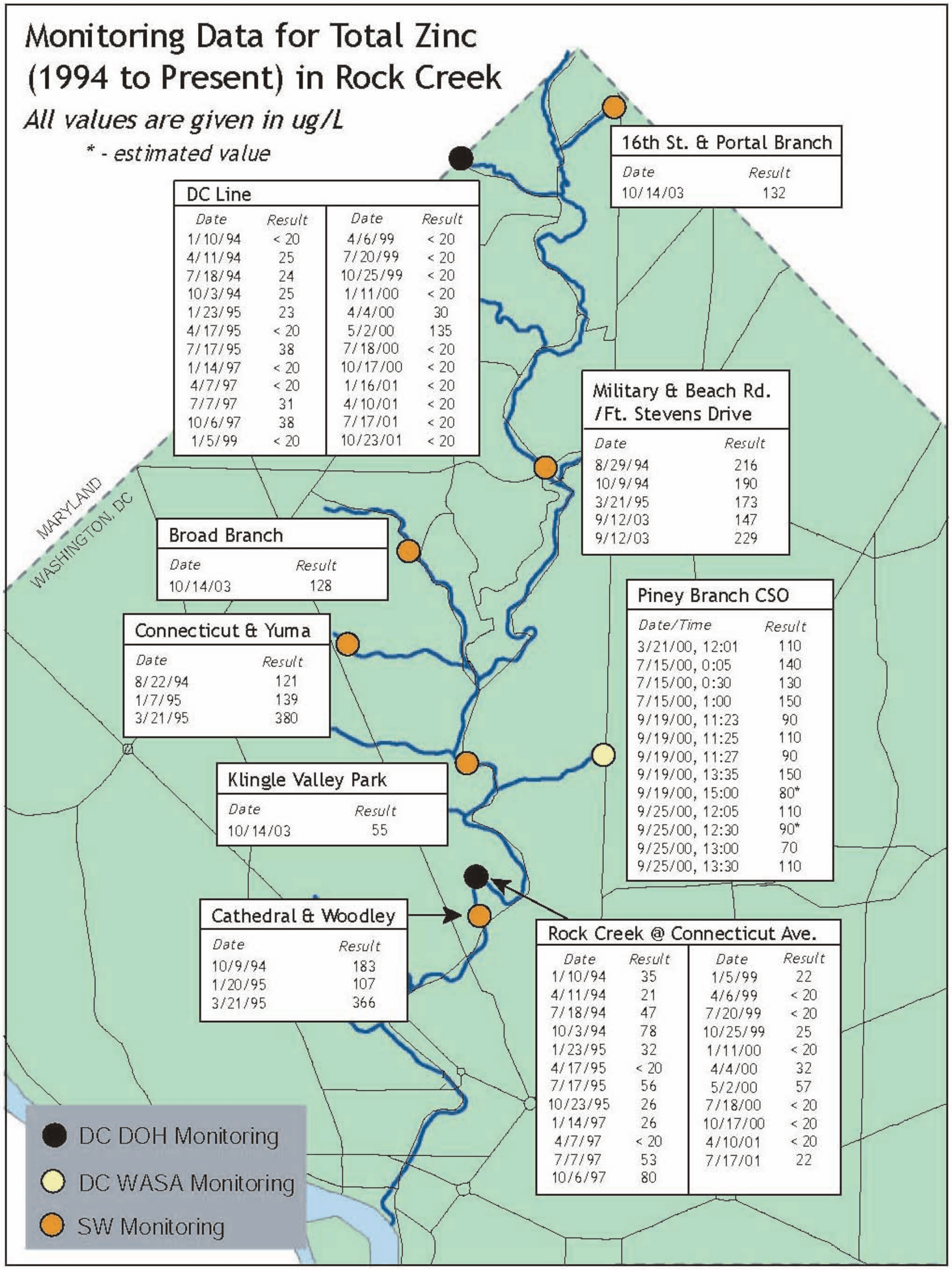

Figure 27: Total Zinc Data

After running the SWMM model, the total zinc concentrations were converted to dissolved zinc concentrations. Following the procedure used for copper, this was done using a partition coefficient. For zinc, the following relationship is given:

$$k_d = 1.25x10^6 * TSS(mg / L)^{-0.7038}$$

where the partition coefficient, k_d, is given in l/kg.

This formulation was used to determine the dissolved lead concentrations after running the SWMM model. The results of the three year simulation for dissolved lead at segment 7 (Massachsetts Avenue Bridge) of the Rock Creek model are presented in Figure 28. As shown, the model results for dissolved zinc do not exceed the chronic or acute criteria at any point during the three-year simulation.

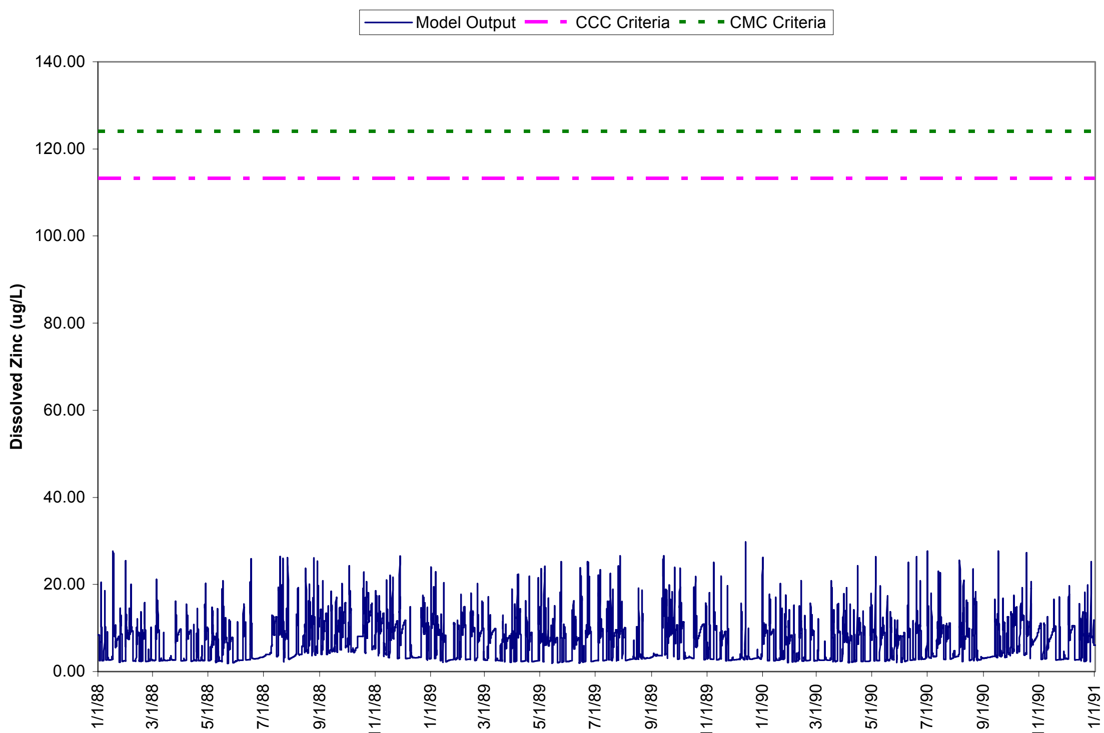

Figure 28: Three-year model results for Dissolved Zinc

Lead

The SWMM model for lead used the same segmentation, transport parameters, and flows used in the copper model. Lead concentrations for CSO and storm water inputs were determined from the existing data (Figure 29). Total Lead concentrations for CSOs were calculated as the average of all the data collected at the Piney Branch outfall for the LTCP. The concentration of total lead in storm water was determined by averaging all of the storm water data collected in 1994, 1995, and 2003 for DC DOH. These calculations resulted in total lead concentrations of 35 ug/L for CSOs and 36 ug/L for all storm water within the District of Columbia.

Lead was not part of the sampling program completed by LTI in 2003. Therefore, estimating the total lead concentration at boundary of the District of Columbia was difficult. Using the data collected by DC DOH from 1994 to 2002 at the DC/MD Line, two total lead concentrations were estimated. The first was an estimate of the dry weather total lead concentration. Under many conditions, the total lead concentration sampled by DOH was less than the detection limit of 5 ug/L. Therefore, it was assumed that the dry weather concentration of total lead in Rock Creek would be half of the reporting limit, or 2.5 ug/L. During wet weather conditions, the total lead concentration is higher. The total lead concentration during wet weather was calculated as the average of all water quality samples at the DC boundary above the reporting limit, 24 ug/L. To determine when the wet or dry weather concentrations should be used in the SWMM model, the flow input at the DC boundary was used. HYSEP, a flow splitting program developed by the USGS, was run to separate the wet and dry weather flow conditions (Sloto, 1996). With the separation completed, appropriate concentrations could be used for the wet and dry weather conditions.

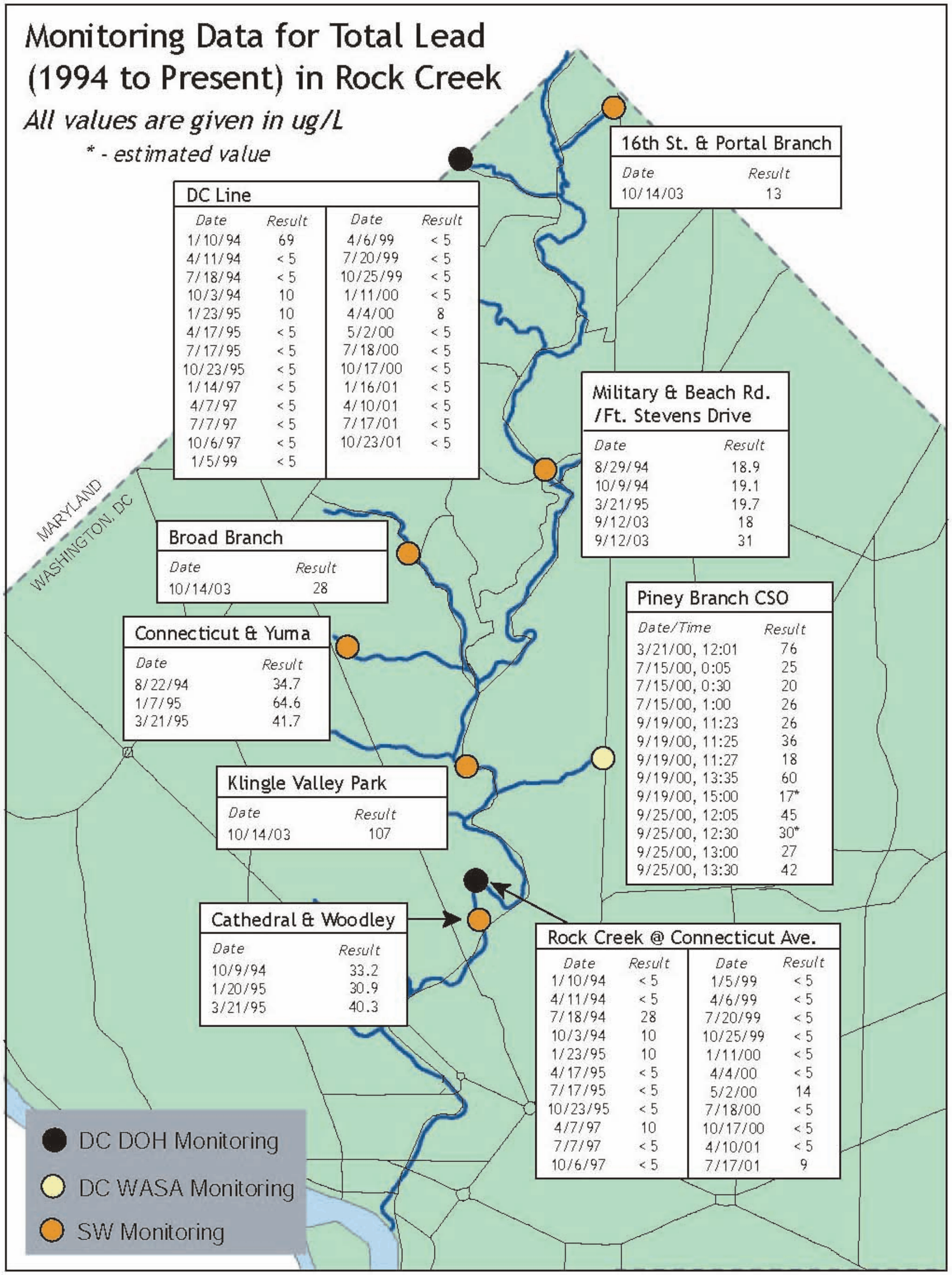

Figure 29: Total Lead Data

After running the SWMM model, the total lead concentrations were converted to dissolved lead concentrations. In the copper and zinc models, this was done using a partition coefficient. Unfortunately, no accurate relationship between TSS and the partition coefficient and lead exists. Therefore, a simple method was used to convert between total and dissolved lead. The DC water quality standards refer to 60 FR 2229, Table 2, where the factor converting total lead to dissolved lead is dependant on hardness. For a hardness of 110 mg/l, the relationship is:

Dissolved Lead = 0.777 * Total Lead

This relationship was used to determine the dissolved lead concentrations after running the SWMM model. The results of the three-year simulation for dissolved lead at segment 7 (Massachsetts Avenue Bridge) of the Rock Creek model are presented in Figure 30.

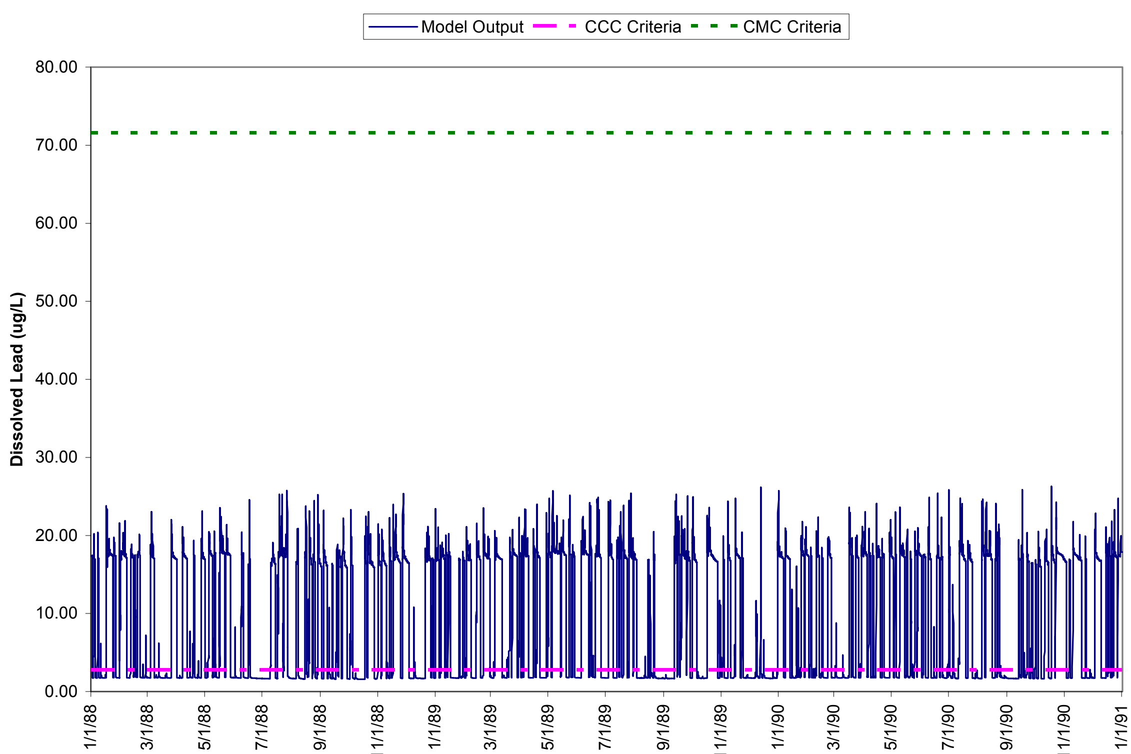

Figure 30: Three-year Model Results for Dissolved Lead

Examining Figure 30, Rock Creek never exceeds the acute criteria for dissolved lead. However, the model does predict that the Rock Creek will exceed the chronic standard for dissolved lead. Therefore, load reductions are needed for lead in Rock Creek. To meet the chronic standards during the entire three-year model simulation, the following load reductions were needed:

- CSO loads were reduced to match the load reductions specified in the LTCP. Through the provisions in the LTCP, the lead load will be reduced by 90 percent.
- All storm water loads (piped and parkland runoff) were reduced by 86 percent. This was needed to prevent violations in the downstream segments of the Rock Creek model.
- Upstream loads were reduced by 86 percent. This was needed to prevent violations in the upstream segments of the Rock Creek model.

The water quality criteria for dissolved lead are 71.63 ug/l (acute) and 2.79 ug/l (four-day average chronic). A five percent margin of safety was used and the model results for dissolved lead after load reductions are presented in Tables 4 and 5.

Table 4: Maximum Dissolved Lead Concentrations (ug/L) after Load Reductions

Month/Year	1	7	12	17	18	40
January-88	2.36	2.38	2.38	2.39	2.35	1.87
February-88	2.17	2.19	2.22	2.26	2.21	1.87
March-88	2.27	2.30	2.28	2.33	2.29	1.87
April-88	2.27	2.31	2.30	2.34	2.30	1.87
May-88	2.34	2.35	2.33	2.36	2.33	1.87
June-88	2.43	2.45	2.50	2.54	2.52	1.87
July-88	2.55	2.56	2.57	2.58	2.56	1.87
August-88	2.52	2.52	2.52	2.54	2.52	1.87
September-88	2.31	2.32	2.33	2.34	2.32	1.87
October-88	2.28	2.33	2.37	2.41	2.38	1.87
November-88	2.52	2.53	2.53	2.59	2.56	1.87
December-88	2.10	2.11	2.13	2.16	2.13	1.87
January-89	2.31	2.34	2.36	2.39	2.36	1.87
February-89	2.34	2.35	2.36	2.36	2.33	1.87
March-89	2.21	2.23	2.24	2.27	2.23	1.87
April-89	2.39	2.39	2.41	2.42	2.39	1.87
May-89	3.51	3.65	3.81	3.57	2.55	1.87
June-89	2.45	2.48	2.48	2.50	2.48	1.87
July-89	2.50	2.54	2.54	2.57	2.55	1.87
August-89	2.01	2.05	2.08	2.11	2.08	1.86
September-89	2.52	2.54	2.59	2.62	2.60	1.87
October-89	2.50	2.48	2.50	2.51	2.49	1.87
November-89	2.72	2.71	2.76	2.71	2.45	1.87
December-89	2.61	2.62	2.63	2.65	2.63	1.86
January-90	2.53	2.56	2.53	2.59	2.56	1.87
February-90	2.22	2.23	2.26	2.29	2.26	1.87
March-90	2.35	2.36	2.37	2.37	2.34	1.87
April-90	2.39	2.40	2.39	2.44	2.41	1.87
May-90	2.37	2.36	2.36	2.39	2.36	1.87
June-90	2.52	2.54	2.55	2.56	2.53	1.87
July-90	2.54	2.58	2.57	2.61	2.59	1.87
August-90	2.61	2.46	2.46	2.48	2.44	1.87
September-90	2.56	2.58	2.59	2.61	2.59	1.86
October-90	3.59	2.86	2.69	2.65	2.61	1.87
November-90	2.17	2.17	2.18	2.18	2.15	1.87
December-90	2.44	2.47	2.47	2.50	2.47	1.87

Table 5: Maximum 4-day Average Dissolved Lead Concentrations (ug/L) After Load Reductions

Month/Year	1	7	12	17	18	40
January-88	1.79	1.80	1.82	1.84	1.83	1.86
February-88	1.80	1.82	1.83	1.85	1.85	1.86
March-88	1.79	1.80	1.82	1.84	1.84	1.86
April-88	1.78	1.80	1.81	1.83	1.83	1.86
May-88	1.83	1.85	1.86	1.87	1.87	1.86
June-88	1.05	1.06	1.05	1.06	1.05	1.03
July-88	1.86	1.87	1.88	1.89	1.89	1.86
August-88	1.55	1.56	1.56	1.57	1.56	1.45
September-88	1.72	1.75	1.77	1.81	1.80	1.85
October-88	1.78	1.80	1.82	1.85	1.84	1.86
November-88	1.81	1.83	1.84	1.87	1.86	1.86
December-88	1.77	1.80	1.81	1.84	1.84	1.86
January-89	1.74	1.76	1.78	1.82	1.81	1.85
February-89	1.79	1.81	1.82	1.84	1.84	1.86
March-89	1.78	1.80	1.82	1.84	1.83	1.86
April-89	1.82	1.84	1.86	1.88	1.87	1.86
May-89	1.89	1.90	1.90	1.91	1.89	1.86
June-89	1.84	1.85	1.86	1.88	1.87	1.86
July-89	1.87	1.88	1.89	1.91	1.90	1.86
August-89	1.46	1.46	1.47	1.48	1.47	1.45
September-89	1.81	1.82	1.84	1.86	1.85	1.86
October-89	1.87	1.88	1.89	1.91	1.90	1.86
November-89	1.79	1.80	1.82	1.83	1.83	1.86
December-89	0.51	0.51	0.53	0.56	0.56	0.61
January-90	1.79	1.81	1.82	1.84	1.84	1.86
February-90	1.77	1.78	1.80	1.82	1.82	1.86
March-90	1.44	1.45	1.46	1.47	1.46	1.44
April-90	1.80	1.82	1.83	1.85	1.85	1.86
May-90	1.80	1.82	1.83	1.85	1.85	1.86
June-90	1.77	1.79	1.80	1.82	1.82	1.86
July-90	1.87	1.89	1.89	1.91	1.90	1.86
August-90	1.83	1.84	1.85	1.87	1.87	1.86
September-90	1.10	1.11	1.10	1.11	1.10	1.03
October-90	1.83	1.84	1.85	1.87	1.86	1.86
November-90	1.78	1.80	1.81	1.83	1.83	1.86
December-90	1.78	1.80	1.82	1.84	1.84	1.86

With upstream loads, storm water loads, and LTCP loads reduced, the instream lead concentrations were less than both the acute and chronic criteria.

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