MODELING THE TRANSPORT AND FATE OF CHROMIUM AND COPPER IN THE MAHONING RIVER

BY

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ABSTRACT

Modeling the Fate and Transport of Copper and Chromium in the Mahoning River

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The transport and fate of heavy metals in the aquatic environment has been of grave concern to the public, environmental engineers and regulatory agencies. To assess the physical quantities of heavy metals in various forms in an aquatic environment, water quality modeling is very useful. One model developed for this purpose by the USEPA scientists is MICHRIV (Michigan River Model). MICHRIV is a computer program which facilitates modeling the transport and fate of chemicals in rivers and streams. MICHRIV is a one dimensional steady state model. It calculates the suspended solids concentration in the water column given estimates of settling and resuspension rates, solids concentration in the bed, and depth of water and active bed. Chemical concentrations are calculated along the length of the river in both the water column and sediment bed.

Modeling with MICHRIV was performed for chromium and copper in the Mahoning River. Estimates of heavy metals loadings into the river were based on the Ohio EPA's permissible limits of Waste Load Allocation. The initial model inputs for the various kinetic parameters in the model were based on literature values. The calibrated model results show good agreement with the available field data for 1989. Sensitivity analyses were performed for the heavy metals loadings, settling and resuspension velocities, and partition coefficient. The predictions of the model shows that heavy metal concentrations in the water column would drop dramatically if the current loadings were reduced by half. Further studies are recommended to identify the historical flows and loadings to the river during and prior to the industrial era in the Mahoning Valley.

Dedication

By the grace of God and the prayers of my family members I was able to successfully complete my thesis. It is my intention and deep desire that all my learning and understanding should culminate in glorifying my Lord and Savior Jesus Christ. For the Word of God, The Holy Bible says "The fear of the Lord is the beginning of wisdom and the knowledge of the Holy is understanding".

ACKNOWLEDGEMENTS

I have had the opportunity to perform my thesis under my advisor Dr. Scott Martin, who had been a continuous source of inspiration and encouragement throughout my graduate program. I benefitted immensely from his invaluable teaching, comments, and timely suggestions. My sincere thanks to the faculty and staff of the Department of Civil Engineering for providing all the necessary facilities for the completion of my thesis.

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CHAPTER 1

INTRODUCTION

The fate of chemicals in a flowing river can be predicted reasonably with complex mass balance equations and mathematical models calibrated by adjusting under certain controlling parameters and factors. These models can be invaluable in determining the limitations to be set in order to meet various water quality standards to preserve or enhance the water that is an essential requirement in our everyday lives [1]. Given the limited resources of ground water, there is a need to conserve and preserve the surface water resources. Almost 50% of the population in the United States depends on surface water [2]. Although the Mahoning River, downstream of Warren, is not presently used as potable water, there is still a serious threat to the biological life in the river [3].

One group of toxicants responsible for causing diseases in tne aquatic life are the heavy metals that have been discharged at high concentrations into the river. Hence there is a need for restricting the discharge of these toxicants [4]. However, no concrete steps can be taken to improve the polluted river unless the amounts of these toxicants in different forms are quantified. This can be done by combining chemical analysis and water quality modeling. Also, water quality modeling can be used to make predictions of the transport and fate of heavy metals in a river and gain a better understanding of the processes [1].

1.1 Historical Background On the Mahoning River

The Mahoning River originates southeast of Alliance, Ohio, and flows over a stretch of 108.3 miles, passing north of Newton Falls and then arcing to the east and southeast, flowing through Leavittsburg, Warren, Niles, McDonald, Girard, Youngstown, Campbell, Struthers and Lowellville. It then crosses the state line into Pennsylvania and joins the Shenango River to form the Beaver River. The Mahoning River has a drainage area of approximately 1133 square miles in Mahoning and Trumbull counties. The six major tributaries that discharge into the river are West Branch, Eagle Creek, Meander Creek, Mosquito Creek, Mill Creek and Yellow Creek. The average discharge of the river at Lowellville, during the last 46 years was 1,118 cu ft/sec. Figure 1-1 shows the location of the river and its major tributaries [5].

For nearly a century, the river served as a source of water supply to the industries located along the river. These industries drew water directly from the river, used it for industrial processes, and discharged it with little or no treatment into the river. Peak water use by the industries during the 1960's was 1.5 billion gallons per day [3]. By 1964, all of the communities had primary wastewater treatment facilities, but none had secondary treatment plants.

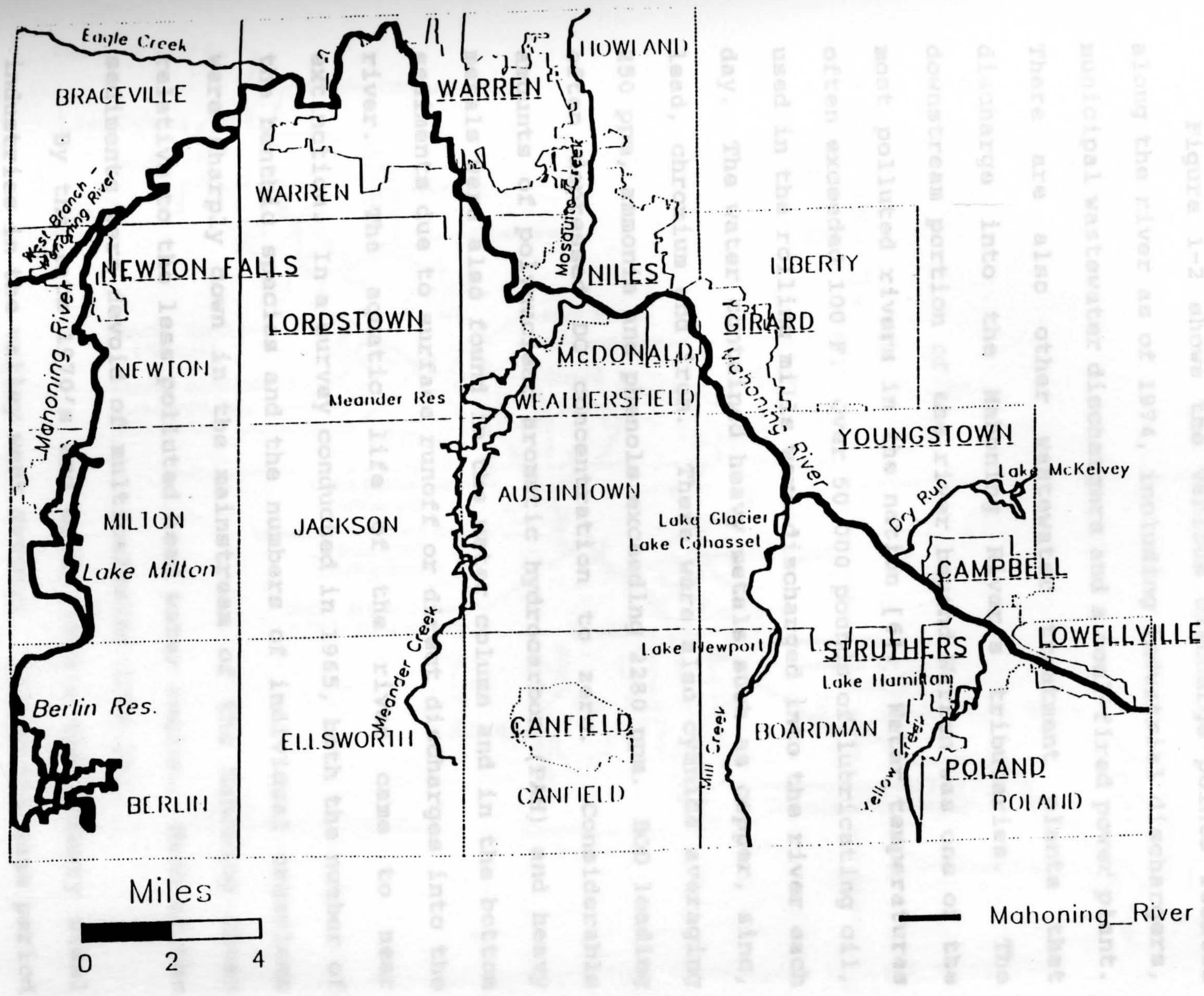

Figure 1-1: Sketch showing the course of the Mahoning River.

Figure 1-2 shows the various discharge points located along the river as of 1974, including industrial dischargers, municipal wastewater dischargers and a coal-fired power plant. There are also other wastewater treatment plants that discharge into the Mahoning River's tributaries. The downstream portion of the river beyond Warren was one of the most polluted rivers in the nation [6]. Water temperatures often exceeded 100 F. Over 50,000 pounds of lubricating oil, used in the rolling mills were discharged into the river each day. The water contained heavy metals such as copper, zinc, lead, chromium and iron. There were also cyanide averaging 250 ppm, ammonia and phenols exceeding 2280 ppm. BOD loading often depressed DO concentration to zero. Considerable amounts of polynuclear aromatic hydrocarbon (PAH) and heavy metals were also found in the water column and in the bottom sediments due to surface runoff or direct discharges into the river. The aquatic life of the river came to near extinction. In a survey conducted in 1965, both the number of the benthic species and the numbers of individual organisms were sharply down in the mainstream of the Mahoning River relative to the less polluted head water region. Much of the sediments were devoid of multicellular life [3].

By the late 1970's and early 1980's the primary steel industries in the valley went defunct. During the same period the US Clean Water Act was being implemented in the Valley. By 1990 all of the major communities except Lowellville had

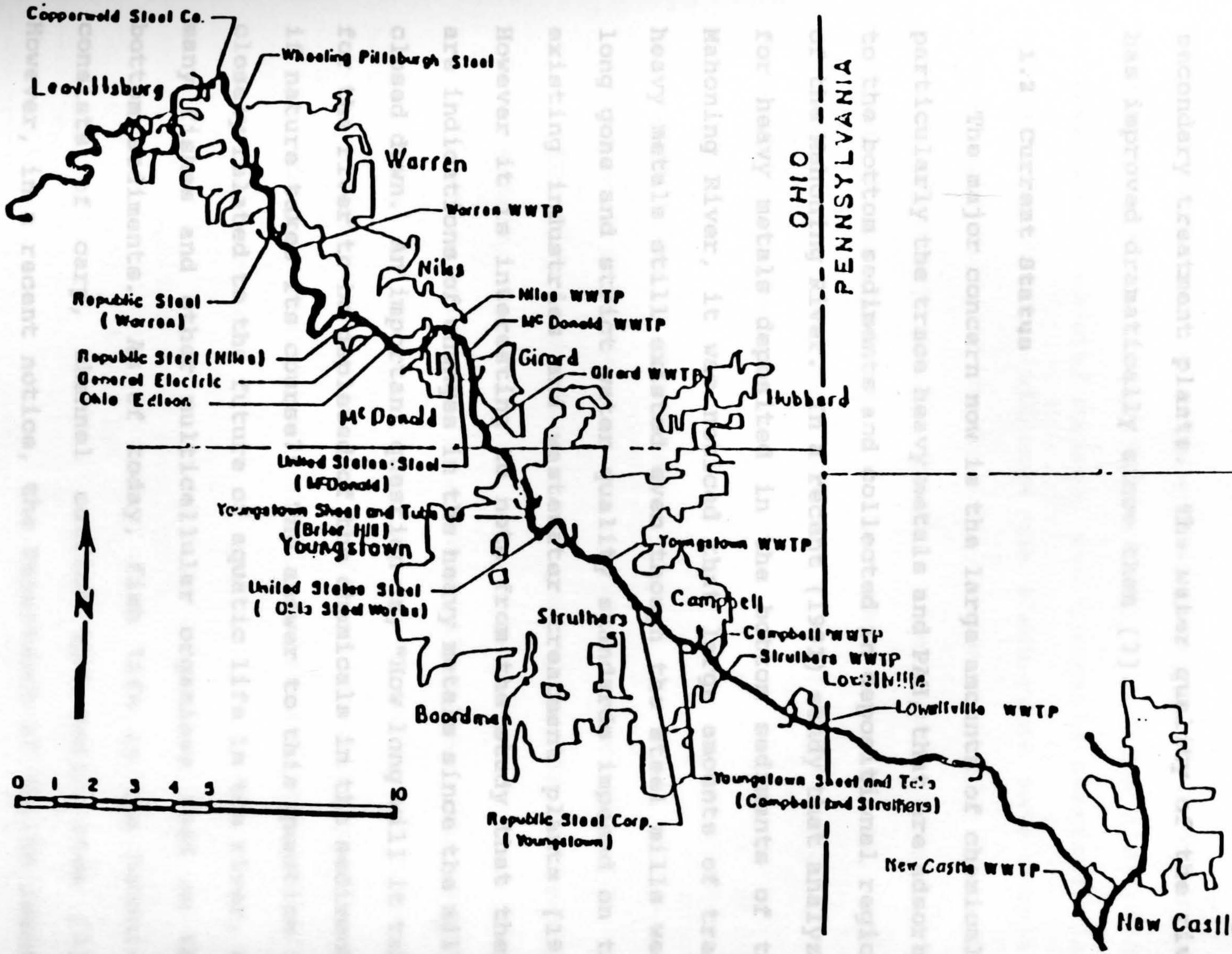

Figure 1-2: Location of Industrial and Municipal Dischargers Located Along the Mahoning River.

secondary treatment plants. The water quality of the river has improved dramatically since then [3].

1.2 Current Status

The major concern now is the large amounts of chemicals, particularly the trace heavy metals and PAH, that are adsorbed to the bottom sediments and collected in depositional regions of the Mahoning River. In a recent (1991) study that analyzed for heavy metals deposited in the bottom sediments of the Mahoning River, it was noticed that large amounts of trace heavy metals still existed even though the steel mills were long gone and strict water quality standards imposed on the existing industries and wastewater treatment plants [19]. However it is interesting to note from the study that there are indications of changes in the heavy metals since the mills closed down. An important question is, "How long will it take for the river to be depleted of the chemicals in the sediments if nature takes its course?" The answer to this question is closely related to the future of aquatic life in the river, as many fishes and other multicellular organisms feed on the bottom sediments. As of today, fish life in the Mahoning consists of carp, channel catfish and small bass [3]. However, in a recent notice, the Department of Health issued a health advisory against swimming, wading or consuming fish from the Mahoning (between Warren and the state line), due to high levels of PAH in the bottom sediments [4]. In 1989 the

Ohio EPA required that all the industrial dischargers as well as the wastewater treatment plants comply with new limitations on loadings of several organic and inorganic chemicals into the Mahoning River. Although the dischargers have complied with the standards of the Ohio EPA, there are still noticeable amounts of heavy metals in the river water column [7]. Upstream of Leavittsburg, the river was, and still is, clean. The communities there have used the river for water supply and recreational purposes.

1.4 Objectives of the Study

The main objectives of this study were to:

1. Identify historical water quality trends for heavy metals;
2. Develop input data sets for application of the MICHRIV model for selected heavy metals (chromium and copper);
3. Calibrate the model and perform a sensitivity analysis for post-industrial conditions, based on the available field data.

CHAPTER 2

LITERATURE REVIEW

2.1 Factors Affecting the Fate of Heavy Metals in a River

The movement and fate of heavy metals in natural water systems is influenced by the distribution between the dissolved phase and the particulate phase. Under normal physio-chemical conditions, the most important phenomena that have a bearing on this distribution are adsorption and desorption [8]. pH and biological solids are major factors that influence adsorption and desorption [9]. Transport processes also play an important role in the accumulation of heavy metals in a river [10].

2.1.1 Adsorption and Desorption

Adsorption occurs in the water column when a dissolved metal ion with a positive charge passes in the direct vicinity of a negatively charged site on the surface of a suspended particle. Due to the difference in the charge, the dissolved metal and suspended particle have affinity for each other. In addition to electrostatic and physical adsorption, metal ions may be chemically adsorbed by forming covalent bonds with functional groups on the particle surface. Desorption occurs when electrostatic attraction decreases or when a covalent bond is broken, forcing the metal ion back into the solution. The chemical properties of the adsorbing chemical, as well as concentration of the adsorbing solids, determine the rates of reaction and the resulting equilibrium conditions. The equilibrium condition is commonly defined by the ratio between solid phase and dissolved concentrations, otherwise known as the partition coefficient. This coefficient is a function of various characteristics of adsorbate and adsorbent [11].

There are five major mechanisms by which heavy metals can accumulate on riverine solids. They are (1) adsorptive bonding on fine-grained substances, (2) precipitation of discrete metals compounds (3) co-precipitation of metals by hydrous Fe and Mn oxides and by metal carbonates, (4) association with organic molecules and (5) incorporation into crystalline minerals. Distinction between precipitation and adsorption is as follows (1) adsorption is a two dimensional, surface layer process while precipitation is a three dimensional crystal buildup, and (2) in adsorption, solution adsorbate concentration is controlled by surface site concentration. Metal adsorption is similar to the formation of soluble complexes, with the only difference being that the ligand in the reaction is a surface site [12].

Partitioning of heavy metals between solid phase and aqueous phase is usually described by the "distribution coefficient" for heavy metals, although it may be referred to as partitioning coefficient or binding constant in some cases [8]. Partition coefficients are also commonly used to quantify the distribution of organic pollutants between the aqueous and the particulate phases in natural aquatic systems

[12]. The mathematical formulation for partitioning is given as follows [10]:

$$C_P/C = K_D M \qquad [2\text{-}1]$$

Where:

K_D = distribution (or partition) coefficient, L/kg;

C_P = the concentration of metal in the particulate phase, μg/L;

C = Concentration of metal in the dissolved phase, μg/L;

M = Concentration of solids, kg/L.

2.1.2 pH Factor

Studies have shown that pH is a very influential parameter in governing metal adsorption. It affects both the type of surface sites and the speciation of metal ions in solution through hydrolysis. Experiments have shown that metal ion adsorption on surface sites may increase rapidly over a very narrow range of 1-2 pH units [9].

2.1.3 Biological Solids

In most river systems adsorption is the dominant binding mechanism. Only in situations where there are large concentrations of biological solids, will sorption into biomass play a significant role [13].

2.1.4 Transport

The transport of a dissolved chemical in surface waters is influenced by the velocity of the current or advective transport. Describing the transport of an adsorbed chemical requires knowledge of sediment movement within the surface water, including sedimentation and resuspension/scouring. Turbulent diffusion and dispersion are also important processes in predicting the environmental transport of a chemical contaminant in surface waters [14].

2.1.4.1 Advection

Advection refers to the movement of dissolved or fine particulate material at a current velocity in any of three directions, namely longitudinal, lateral or transverse, and vertical.

2.1.4.2 Sedimentation

Suspended sediment particles and adsorbed chemicals are transported downstream at nearly the mean current velocity. "In addition, they are transported vertically downward by their mean sedimentation velocity. Generally, silt and clay-size particles settle according to Stoke's Law, in proportion to the square of the particle diameter and the difference between sediment and water densities" [10]:

$$W = 8.64\left(\frac{g}{18}\mu\right)(\rho_s - \rho_w)\, d_s^2 \qquad (2\text{-}2)$$

Where:

W = Particle settling velocity, ft/sec;

ρ_s = Density of sediment particle, 2- 2.7 g/cm^3;

ρ_w = Density of water, 1 g/cm^3;

g = Gravitational constant, 981 cm/sec^2;

d_s = Sediment particle diameter, mm;

μ = Absolute viscosity of water, 0.01 poise (g/cm.sec) @ 20°.

Generally, it is the fine silt and clay sized particles that carry most of the mass of adsorbed chemical. These materials have very small settling velocities, on the order of 0.3-1.0 m/day for clays of 2-4 μm nominal diameter and 3-30 m/day for silts of 10-20 μm nominal diameter.

Once the particle reaches the bed, a certain probability exists that it can be scoured from the bed sediment and resuspended. The difference between sedimentation and resuspension represents net sedimentation. Often it is possible to utilize a net sedimentation rate constant in a pollutant fate model to account for both the processes.

2.1.4.3 Scour and Resuspension

Quantitative relationships to predict scour and resuspension of cohesive sediments are difficult to develop due to the number of variable involved. Based on calibration studies a resuspension velocity of about 1 to 30 mm/yr has been recommended. Under steady state conditions, the sedimentation of suspended sediment must be equal to the scour and resuspension [10].

2.1.4.4 Diffusion

An important process that occurs in a river system and affects the distribution of heavy metals is diffusion. When a concentration gradient exists between two regions, such as the water column and interstitial water in the bottom sediments, the constituent experiencing the gradient trends to move from areas of high concentration to areas of low concentration due to random thermal motion of molecules. The process continues until local equilibrium is attained. Due to the movement of river water over the bottom sediments, local equilibrium is never reached and diffusion occurs continuously throughout the course of the river [10].

2.1.4.5 Dispersion

Dispersion results from the mixing of surface waters under turbulent conditions. It is enhanced when turbulence is coupled with temporal and spatial variations in velocity within the body. Dead zones cause back mixing of water and the eventual spread of dissolved chemical pulses that is characteristic of dispersion [10].

2.1.5 Other Factors

The accumulation of chemicals in a river is also affected by other processes such as:

(1) volatilization

(2) hydrolysis

(3) oxidation

(4) photo-transformation

(5) biological transformation.

Except for hydrolysis, these processes usually have a limited effect on heavy metals, but may be important for organic chemicals [10].

2.2 Water Quality Modeling

2.2.1 Introduction

"Models are necessary to both describe and predict water quality conditions. Current modeling provides a rational, descriptive framework for analysis of existing problems and provides limited predictive capability that cannot be achieved by simply monitoring or measuring water quality. Descriptive modeling can be very useful for extrapolating data. The use of models to describe water quality conditions in the river segments between dispersed sampling locations is superior to any crude linear extrapolation" [1].

There has been a tendency to think of the collection of monitoring data and modeling as separate approaches to describing water quality. Generally, the monitoring data are collected too infrequently and at locations that are spatially too disperse to support intensive modeling studies, but there is a close interdependence of data collection and modeling that could be used to guide the design of sampling programs for intensive water quality studies.

Calibrated models can be used to define cause-effect relationships that monitoring studies cannot definitively identify. Nevertheless, without calibration data, modeling holds little or no advantage over simple monitoring programs [1].

2.2.2 Theory and Basic Principles of Mass Balance

The most important basic principle underlying water quality modeling is that of conservation of mass. Modeling involves performing a mass balance for defined control volumes over a specified period of time. Essentially, this is an accounting of material of various types in a defined volume of water or a number of water volumes. This principle can be applied to any substance whose transformation kinetics are known [1].

The mass balance is performed by accounting for all materials entering and leaving a defined volume of water plus accounting for all changes in mass of a constituent by physical, chemical, and biological processes. A general mass balance has the following form:

Accumulation within the control volume = Mass Inputs - Mass Outflows + Reactions - (2-3)

The conservation of mass is not the only first principle employed in water quality modeling. An important aspect of a mass balance involves accounting for the effect of water movement. In advanced models, the principle of conservation of momentum may be used to describe the movement of water and suspended materials in the system.

2.3.1 Modeling Heavy Metals with MICHRIV

MICHRIV is a one dimensional, steady-state, mass balance model that was developed specifically for predicting the fate of toxicant in a river or stream. This computer model is applicable to systems where transport is dominated by advection. Since toxicants often have significant interactions with solids and bed sediments, these compartments were included in the model framework. Also, kinetic decay processes known to affect some environmental contaminants are included as first order rate processes [15].

An important concern to toxicologists is dissolved toxicant concentrations [16]. MICHRIV predicts dissolved, total and particulate toxicant concentrations as a function of river length in both water and stream bed. The model simulates two compartments, water and bed sediments and two phases, dissolved and particulate within each compartment. The general model framework is presented in Figure 2-1.

2.3.2 Model Assumptions

The following assumptions were made in developing the mass balance equations for a given river segment in MICHRIV [16]:

(1) The solids and toxicants in the water column and bed are at steady state; that is, accumulation terms are zero and no model conditions change with time.

(2) The system is dominated by advection, therefore

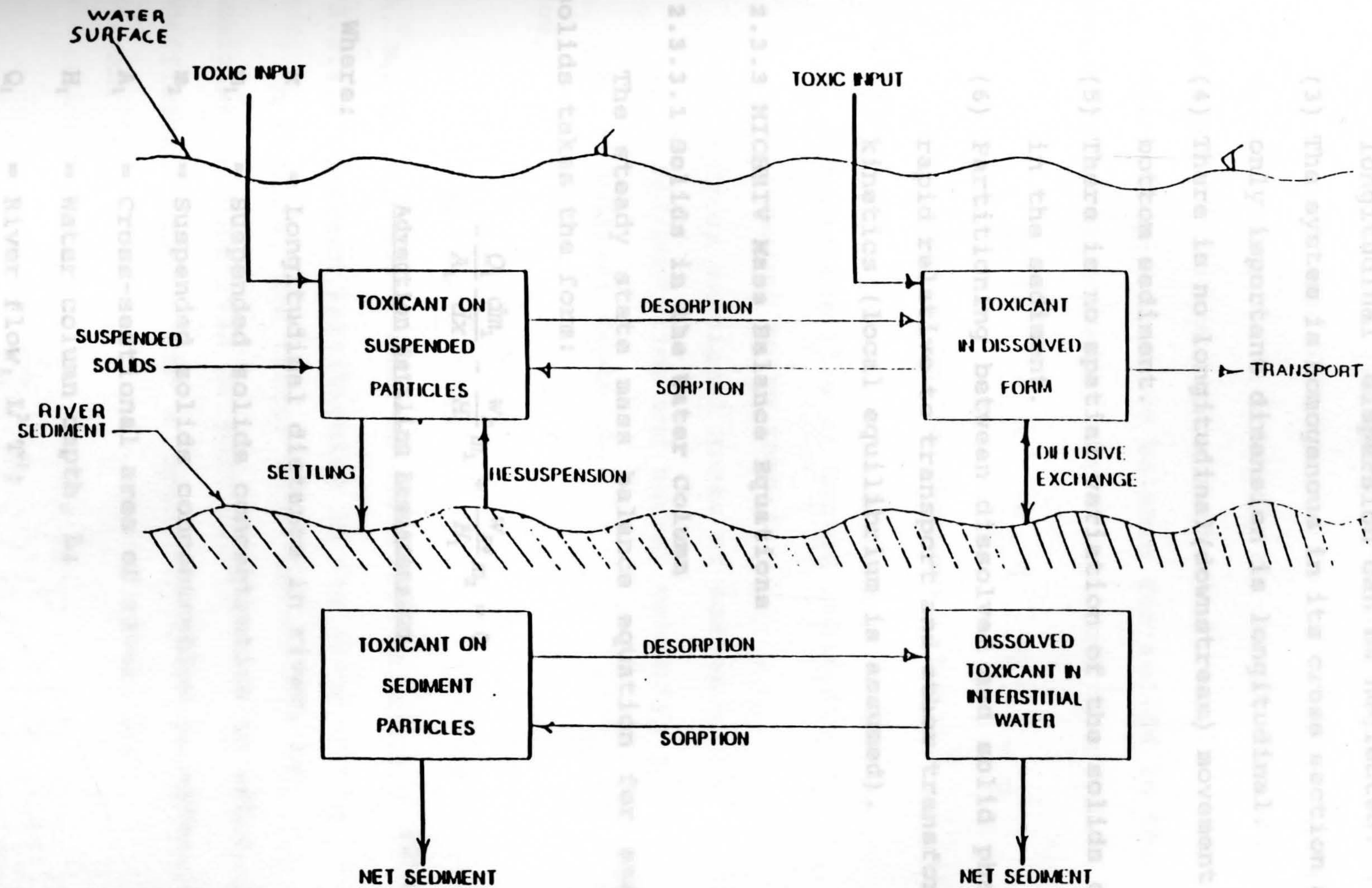

Figure 2-1: Schematic Diagram Representing the Various Physical and Chemical Processes Affecting Metal Distribution Within A River.

longitudinal dispersion can be neglected.

(3) The system is homogenous in its cross section and the only important dimension is longitudinal.

(4) There is no longitudinal(downstream) movement of the bottom sediment.

(5) There is no spatial variation of the solids content in the sediment.

(6) Partitioning between dissolved and solid phases is rapid relative to transport and other transformation kinetics (local equilibrium is assumed).

2.3.3 MICHRIV Mass Balance Equations

2.3.3.1 Solids in the Water Column

The steady state mass balance equation for suspended solids takes the form:

$$-\frac{Q_1}{A_1}\frac{dm_1}{dx} - \frac{w_S}{H_1}m_1 + \frac{w_{rs}}{H_1}m_2 = 0$$

Advection Settling Resuspension (2-4)

Where:

x = Longitudinal distance in river, L;

m_1 = Suspended solids concentration in water, ML^{-3}

m_2 = Suspended solids concentration in water, ML^{-3};

A_1 = Cross-sectional area of river, L^2;

H_1 = Water column depth, L;

Q_1 = River flow, L^3 T^{-1};

w_s = Settling (depositional) velocity in the water column, L T^{-1};

w_{rs} = Resuspension velocity for bottom sediments, L T^{-1}.

2.3.3.2 Solids in the Bottom Sediments

The steady-state mass balance for solids in the bottom sediments is described by the following processes:

$$-\frac{Q_2}{A_2}\frac{dm_2}{dx} + \frac{w_s\, m_1}{H_2} - \frac{w_{rs}\, m_2}{H_2} - \frac{w_d\, m_2}{H_2} = 0$$

<u>Advection</u> <u>Settling</u> <u>Resuspension</u> <u>Burial</u> (2-5)

Where:

Q_2 = Advective flow of bottom sediments L^2, (assumed to be zero);

A_2 = Cross sectional areas of sediment, L^2;

w_d = Sedimentation and burial velocity, L T^{-1};

H_2 = Sediment depth, L.

Now,

$$w_d = w_s\,\frac{m_1}{m_2} - w_{rs} \qquad (2\text{-}5a)$$

m_1, m_2, w_d, w_{rs}, and w_s same as described previously.

2.3.3.3 Toxicant Partitioning in the Water Column

In MICHRIV, the factor which determines the fraction of toxicant in dissolved or particulate form is the partition coefficient (K_{P1}). For a specific chemical in the water column:

$$K_{p1} = \frac{r_1}{C_{d1}} \qquad (2\text{-}6)$$

Where:

K_{p1} = Partition coefficient in the water column, $L^3 M^{-1}$;

r_1 = Mass of chemical per unit mass of solid;

C_{d1} = Dissolved chemical concentration in the water column, $M L^{-3}$

$$C_{d1} = f_{d1} C_{T1} \quad (2\text{-}7)$$

$$\text{and, } C_{P1} = f_{P1} C_{T1} \quad (2\text{-}8)$$

where:

C_{P1} = Particulate chemical concentration in water column, $M L^{-3}$;

C_{T1} = Total chemical concentration in the water column;

f_{d1} = Fraction dissolved chemical in the water column;

f_{P1} = Fraction particulate in the water column.

So,

$$f_{P1} = \frac{K_{P1}\, m_1}{(1+K_{P1}\, m_1)} \quad (2\text{-}9)$$

$$f_{d1} = \frac{1}{(1+K_{P1} m_1)} \quad (2\text{-}10)$$

The two toxicant fractions in the bottom sediments, particulate (f_{P2}) and dissolved (f_{d2}), are determined in a similar manner. Partition coefficient are assumed to be known from experimentation or field calibration.

2.3.3.4 Toxicant in the Bottom Sediment

The steady state mass balance equation for the toxicant in the bed sediment is:

Advection **Settling** **Diffusion In**

$$-\frac{Q_2}{A_2}\frac{dC_{T2}}{dx}+\frac{W_s\, f_{P1}\, C_{T1}}{H_2}+\frac{K_L\, f_{d1}\, C_{T1}}{H_2}\ .....$$

$$...-\frac{(W_{rs}+W_d)\, f_{P2}C_{T2}}{H_2}-\frac{K_L f_{d2}C_{T2}}{H_2}-K_2 C_{T2}=0$$

Resuspension & Burial **Diffusion Out** **Decay** (2-11)

Where

C_{T2} = Total toxicant concentration in the sediment, $M\ L^{-3}$;

K_L = Diffusion velocity specified by the user, $L\ T^{-1}$;

K_2 = Decay rate constant specified by the user, T^{-1};

Here,

$$K_L = E/L_C$$

Where E = Diffusion coefficient, $L\ T^{-1}$;

L_C = Characteristic length, L.

Since $Q_2 = 0$, equation 2-11 reduces to an algebraic equation relating C_{T2} directly to C_{T1}.

2.3.3.5 Toxicant in the water column

The steady state mass balance equation in the water column is given by the following equation [16]:

Advection **Decay** **Settling**

$$-\frac{Q_1}{A_1}\frac{dC_{T1}}{dX}-K_1 C_{T1}-\frac{W_S f_{P1} C_{T1}}{H_1}\ ...$$

$$...-\frac{K_L f_{d1} C_{T1}}{H_1}+\frac{W_{rs} f_{P2} C_{T2}}{H_1}+\frac{K_L f_{d2} C_{T2}}{H_1}=0$$

Diffusion Out **Resuspension** **Diffusion In**

2.4. Historical Data on Heavy Metals in the Mahoning River.

2.4.1 Water Column Data

2.4.1.1 STORET Data

Data on concentrations of several heavy metals in the Mahoning River water column are available in STORET. STORET is a USEPA database that contains measured concentrations of several pollutants and water quality parameters at a number of locations along the Mahoning River. The most extensive data sets are available for sampling points at First Street in Lowellville and Leavitt Road in Leavittsburg. Data on heavy metals, including chromium, copper, iron, zinc, lead, cadmium and nickel were recorded on a monthly basis from the year 1973 to the year 1991 [17].

2.4.1.2 Unpublished YSU Data

The Civil Engineering Department at Youngstown State University collected monthly samples of water from the Mahoning River between November, 1988 and July, 1989, and analyzed them for concentrations of trace heavy metals. Key locations selected for sample collections were Leavittsburg, Warren, McDonald, Youngstown, Struthers and Lowellville [18].

2.4.2 Bottom Sediments

An analysis of heavy metals in the Mahoning River bottom sediments was also performed by Evan [19] on grab samples collected at sampling points from Mile Point 11.1 to Mile Point 57.5. This reach includes the upstream section of the river in the vicinity of Newton Falls, as well as the industrialized regions between Warren and the Pennsylvania state line. The metals analyzed included manganese, copper, zinc, cadmium, nickel, lead, chromium and iron.

From the observation made from the data, it is clear that the upstream section of the river above Warren had low concentrations of heavy metals, while downstream of Warren concentrations increased greatly. This is due to the fact that several industries discharged large quantities of pollutants into the river. Localized peak concentrations were also observed at various locations in McDonald, Youngstown and Struthers. The concentration of copper ranged from a low of 6 mg/kg at mile point 57.5, upstream of Warren to a high of 2700 mg/kg at mile point 15.1, downstream of Struthers. Another peak value of 1865 mg/kg was also observed at mile point 21.75, downstream of Youngstown, which also had dischargers such as Republic Steel, Youngstown Wastewater Treatment Plant (WWTP) and several small industries [19].

CHAPTER 3

DATA REDUCTION AND MODEL CALIBRATION

3.1 Collection of Data for MICHRIV Input

The MICHRIV model requires the following input data for model calibration: river geometry, river segmentation, flows and loadings to the river, settling velocity and resuspension velocity in the river.

3.1.1 River Geometry

The section under consideration is a winding stretch of 33.19 miles, starting at mile point 43.78 (Km point 70.13) at the USGS gage in Leavittsburg and ending at mile point 10.59 (Km point 16.96) at the Lowellville Waste Water Treatment Plant (WWTP) discharge. Figure 3-1 shows the stretch under consideration including all the major tributaries as well as the boundaries of reaches chosen for this study.

The area of cross-section of the river was deduced from maps drawn by the US Army Corps of Engineers. Elevations of the surface of the water as well as the bottom of the river channel at several locations along the river were available from the maps. From these elevations the depth of the river was calculated at several Points along the cross-section. The width of the river was directly measured from the map [20]. Using the trapezoidal method, the area of cross-sections of the river were calculated. Table 3.1 gives the cross-sectional area of the river at key places.

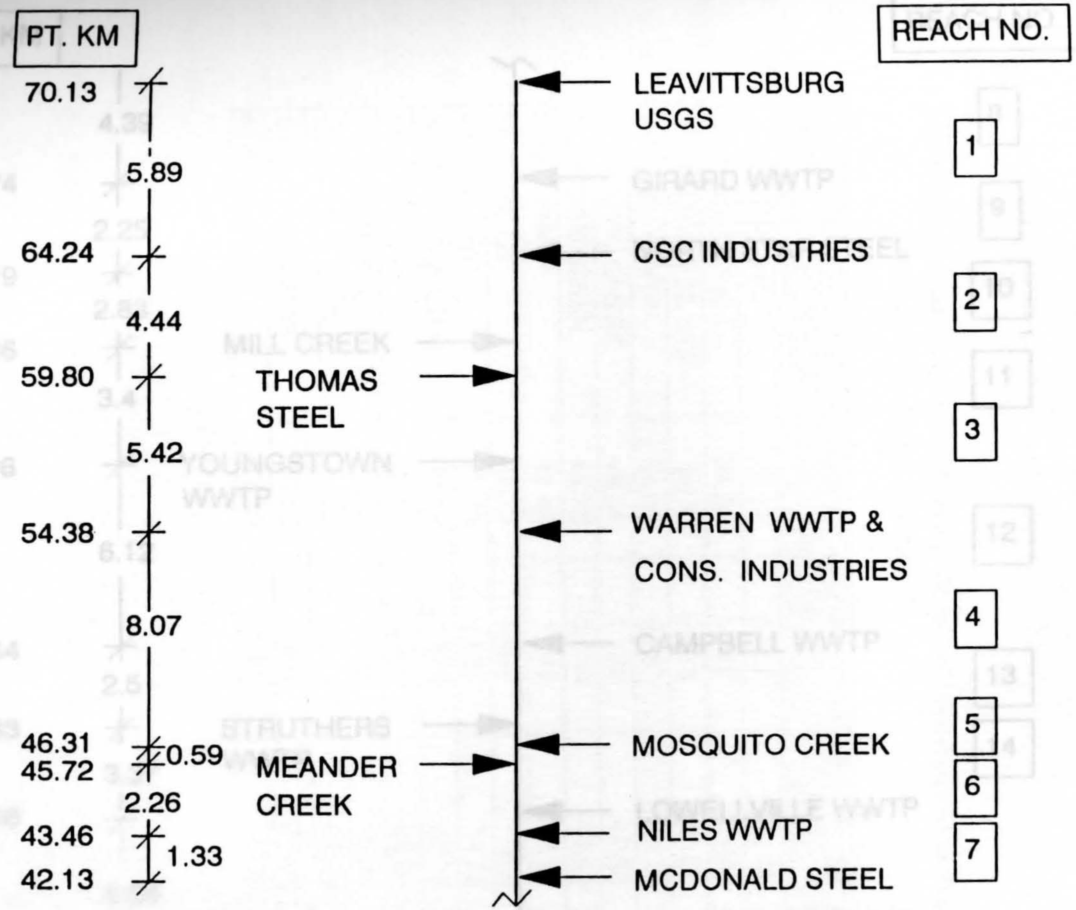

Figure 3-1: A Schematic Diagram showing the Reaches and Location of Points of Discharges to the Mahoning River between Lowellville and Leavittsburg.

Figure 3-1 Continued.....

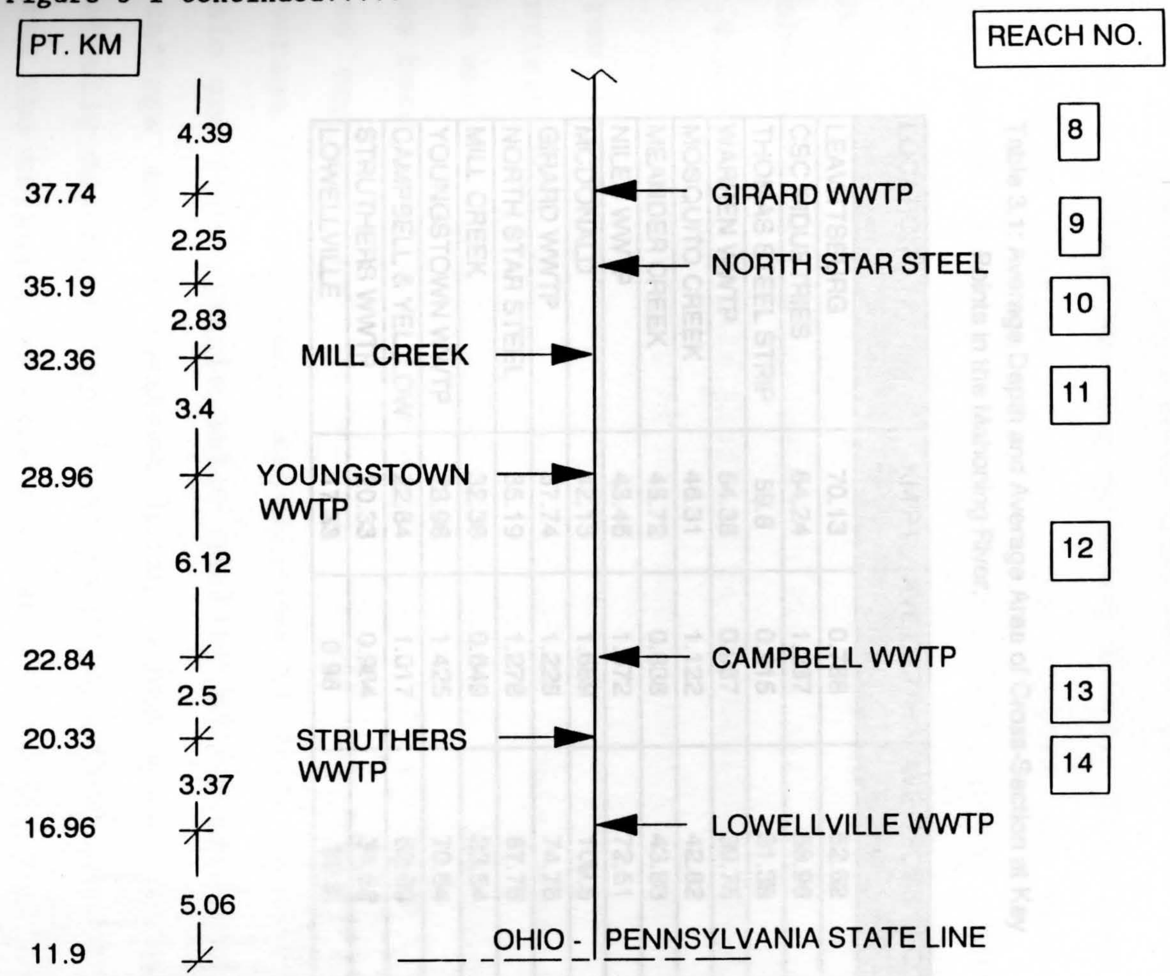

Table 3.1: Average Depth and Average Area of Cross-Section at Key Points in the Mahoning River.

LOCATION	KM PT	AVE DEPTH m	AVE CROSS SEC. m^2
LEAVITTSBURG	70.13	0.788	52.62
CSC INDUSTRIES	64.24	1.237	58.96
THOMAS STEEL STRIP	59.8	0.915	31.39
WARREN WWTP	54.38	0.987	39.75
MOSQUITO CREEK	46.31	1.122	42.82
MEANDER CREEK	45.72	0.838	43.83
NILES WWTP	43.46	1.672	72.51
MCDONALD	42.13	1.689	109.5
GIRARD WWTP	37.74	1.225	74.76
NORTH STAR STEEL	35.19	1.278	87.76
MILL CREEK	32.36	0.649	23.54
YOUNGSTOWN WWTP	28.96	1.425	70.64
CAMPBELL & YELLOW	22.84	1.017	62.09
STRUTHERS WWTP	20.33	0.984	34.62
LOWELLVILLE	17.33	0.95	38.8

3.1.2 Flows and Loadings

3.1.2.1 Flows in the Mahoning River

The data for the average flows in the river was available for a record of fifty years from National Water Data Exchange (NAWDEX). NAWDEX also had a record of the flows in the tributaries into the Mahoning River. The flows of major tributaries that were taken into account are Yellow Creek, Mill Creek, Meander Creek and Mosquito Creek. The average flows for all tributaries and discharges considered are given in Table 3.2 [21]. A profile of the average flows in the Mahoning River is presented in Figure 3-2.

3.1.2.2 Heavy Metals Loadings to the Mahoning River

The loadings of heavy metals into the Mahoning River from various point sources were estimated from an Ohio Environmental Agency (OEPA) report [7]. This report contained the waste load allocation for Mahoning River dischargers which has been in effect since March 1989. The loadings of chromium and copper, used in the data input for MICHRIV, are the average limiting loads established by OEPA in order to meet Ohio and Pennsylvania water quality standards. The assumed loadings may be somewhat high, since some industries may actually discharge less than the permissible limit. Loadings from the tributaries were available from the YSU unpublished data. Calculations were performed to convert the concentration given in $\mu g/L$ to kg/d. Tables 3.3a and 3.3b

Table 3.2: Discharges into the Mahoning River.

LOCATIONS OF SOURCES	KM POINT	FLOWS m^3/s
CSC INDUSTRIES CORP.	64.24	0.0734
THOMAS STRIP STEEL	59.8	0.047
WARREN WWTP	54.38	3.135
MOSQUITO CREEK	46.31	3.3722
MEANDER CREEK	45.72	1.249
NILES WWTP	43.46	0.28
MCDONALD WWTP	42.13	0.0875
GIRARD WWTP	37.74	0.219
NORTH STAR STEEL	35.19	0.0138
MILL CREEK	32.36	1.646
YOUNGSTOWN WWTP	28.96	1.533
CAMPBELL WWTP	22.84	0.169
STRUTHERS WWTP	20.33	0.26

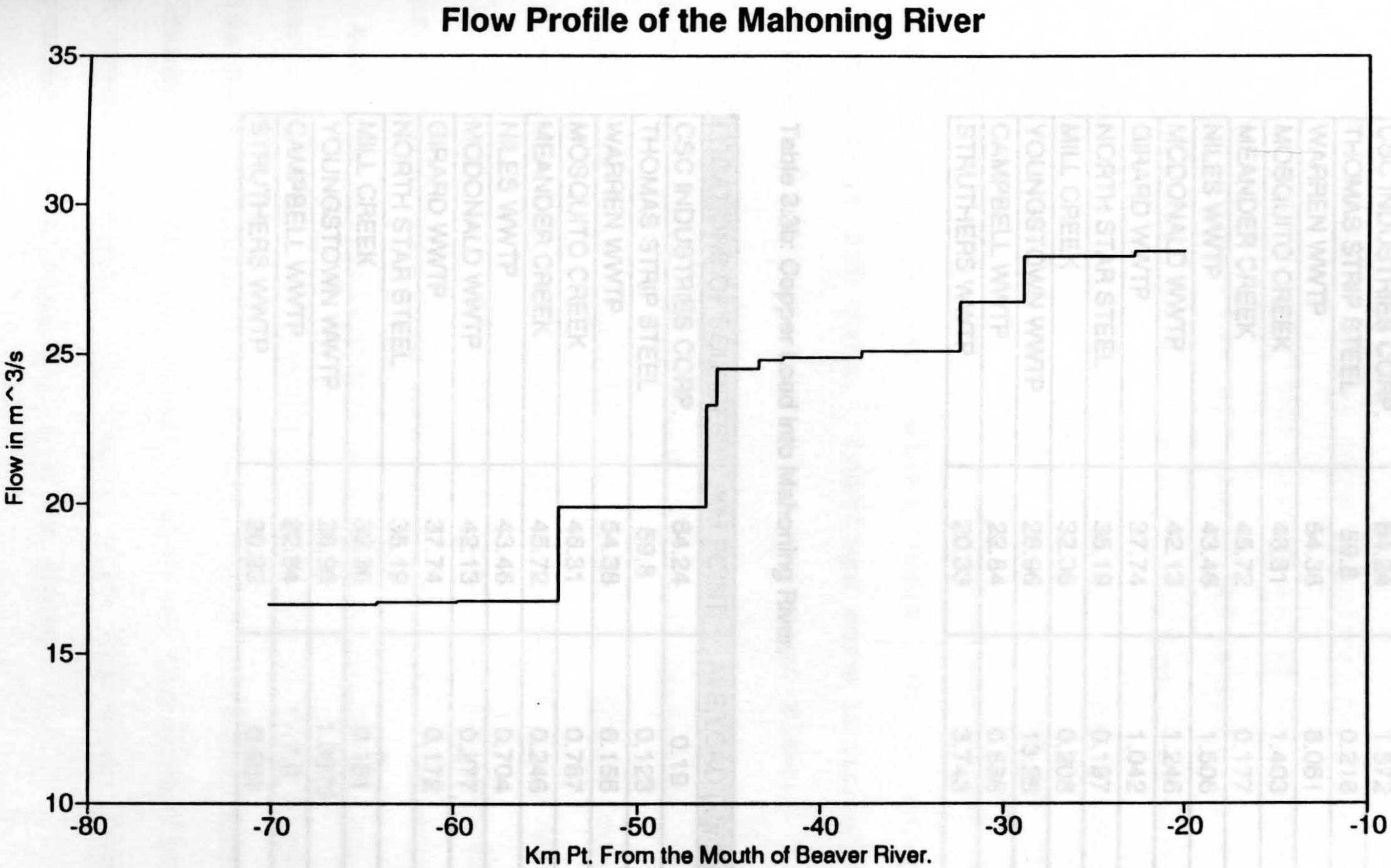

Figure 3-2: A Sketch showing the Profile of the Mahoning River Mean Flows in m^3/s vs Km from the Mouth of the Beaver River (Between Lowellville and Leavittsburg) [21].

Table 3.3a: Chromium Load into Mahoning River.

LOCATIONS OF SOURCES	KM POINT	AVE LOAD (kg/d)
CSC INDUSTRIES CORP.	64.24	1.572
THOMAS STRIP STEEL	59.8	0.218
WARREN WWTP	54.38	8.061
MOSQUITO CREEK	46.31	1.403
MEANDER CREEK	45.72	0.177
NILES WWTP	43.46	1.506
MCDONALD WWTP	42.13	1.246
GIRARD WWTP	37.74	1.042
NORTH STAR STEEL	35.19	0.197
MILL CREEK	32.36	0.208
YOUNGSTOWN WWTP	28.96	13.25
CAMPBELL WWTP	22.84	0.536
STRUTHERS WWTP	20.33	3.743

Table 3.3b: Copper Load into Mahoning River.

LOCATIONS OF SOURCES	KM POINT	AVE LOAD (kg/d)
CSC INDUSTRIES CORP.	64.24	0.19
THOMAS STRIP STEEL	59.8	0.123
WARREN WWTP	54.38	6.156
MOSQUITO CREEK	46.31	0.787
MEANDER CREEK	45.72	0.246
NILES WWTP	43.46	0.704
MCDONALD WWTP	42.13	0.277
GIRARD WWTP	37.74	0.172
NORTH STAR STEEL	35.19	–
MILL CREEK	32.36	0.131
YOUNGSTOWN WWTP	28.96	1.3975
CAMPBELL WWTP	22.84	7.8
STRUTHERS WWTP	20.33	0.681

gives the summary of the loadings of chromium and copper, respectively.

3.1.2.3 Suspended Solids Loadings to the Mahoning River

The MICHRIV model also required an input of suspended solids loadings at various points along the river in terms of kg/day. The mass flux of suspended solids in a river or a stream is equal to flow times average concentration. Peak flows affect the mean load greatly. Peak flows cause large inputs of allochthonous material from erosion and runoff as well as increases in scour and resuspension of bed and bank sediments. Suspended Solids data for a range of flows available from YSU data. Loadings were calculated from mean suspended solids concentration and mean flow.

Data on incoming suspended solids concentration in the tributaries were collected at YSU between 07/13/88 and 07/28/89 (Martin unpublished data). These concentrations included the suspended solids discharged from WWTP's, small scale industries and possible load due to runoff flow into these tributaries . The average, standard deviation and count for each major tributary was calculated on an electronic spread sheet and is presented in Table 3.4a. Since suspended solids data tributaries was extremely limited, the loading to the Mahoning River was simply taken as the mean flow times the mean concentration. In Table 3.4b the mean flows and the suspended solids load in kg/d is shown.

Table 3.4a: Summary of Suspended Solids Concentrations in Mahoning River Tributaries [18].

SOURCES	MEAN (mg/L)	STD. DEV.	COUNT
YELLOW CREEK	8.92	9.25	6
MILL CREEK	25.8	10.91	6
MEANDER CREEK	5.95	2.2	6
MOSQUITO CREEK	25.4	6.98	6

Table 3.4b: Discharges and Estimated Suspended Solids Load to the Mahoning River from the Tributaries.

SOURCES	FLOW (m^3/s)	SS LOAD (kg/d)
YELLOW CREEK	0.169	658
MILL CREEK	1.249	3689
MEANDER CREEK	1.646	6477
MOSQUITO CREEK	3.372	7461

3.2. Estimation of Model Coefficients

Before starting calibration, it was necessary to define reasonable ranges for certain model coefficients, and select starting values. The coefficients required in the MICHRIV are settling velocity for suspended solids, resuspension velocity, and partition coefficient.

3.2.1. Resuspension Velocity

Under steady state conditions, the sedimentation of suspended solids must equal the scour and resuspension of sediment. Quantitative relationships to predict scour and resuspension of cohesive sediments are difficult to develop due to the number of variables involved. A recommended resuspension velocities is about 1 to 30 mm/yr (2.73×10^{-10} m/d to 8.2×10^{-5} m/d) based on model calibration studies [10].

3.2.2 Partition Coefficient

A study was performed to approximate the partition coefficient of heavy metals in the water column with field data collected from 15 streams and rivers. The metals copper, zinc, cadmium, chromium, lead and nickel were combined since there were no systematic difference in partitioning between these metals. The partition coefficient ranged from about 10^2 - 10^5 L/kg. An appropriate first approximation to the water column partition coefficient for these metals indicated is given by the equation:

$$K_p = \frac{250000}{m} \quad [3.1]$$

where K_p is the partition coefficient, L/kg; and m is the suspended solids in mg/L [22].

3.3. Calibration Data

MICHRIV was applied to model concentrations of chromium (Cr) and copper (Cu) in the Mahoning River. The model was first established to give reasonable predictions of suspended solids concentration in the river. Then, calibrations are made based on the total concentration of toxicant as well as concentration in the particulate and dissolved forms, both in the water column and bottom sediments. The data used for calibration came from three sources namely unpublished data collected at YSU, the STORET database [17] and Evan [19].

3.3.1 YSU Data

Data on total and dissolved concentrations of heavy metals and suspended solids in the Mahoning River water column were collected in the monitoring studies at YSU [18].

3.3.1.1 Total Concentrations of Metals in the Water Column

The concentrations of copper and chromium were measured at six locations from Lowellville to Leavittsburg from 11/03/88 till 7/28/89. The data consisted of measurements on six sets of samples taken at intervals of approximately one month and from the six sampling locations. The Tables 3.5a and 3.5b show the concentration trends for chromium and copper, respectively [18].

3.3.1.2 Suspended Solids Concentrations

Data on suspended solids were collected frequently from 07/13/88 to 07/28/89 at six sampling sites along the river, and are summarized in Table 3.6 [18].

3.3.2 STORET Database

The total concentrations of several heavy metals have been monitored for many years by the Ohio EPA and other agencies. The only continuous records available are at stations in Leavittsburg (upstream of Warren) and Lowellville (downstream of Struthers). A summary of these concentrations is shown in Appendix A. The database also provided information on the suspended solids concentrations at several locations in the river [17]. A summary of the available data is presented in Table 3.7.

3.3.3 Heavy Metals in the Bottom Sediments

The data available for the concentrations of heavy metals in the bottom sediments were recorded in terms of mg of metal/kg of dry sediment by Evan [19]. It was necessary

Table 3.5a: Concentration of Chromium in the Mahoning River Water Column [18] .

SAMPLING STATION	KM POINT	TOTAL (ug/L)			DISSOLVED (ug/L)		
		MEAN	STD DEV	COUNT	MEAN	STD DEV	COUNT
LEAVITTSBURG	70.13	4.18	2.02	6	1.86	1.42	6
WARREN	56.8	7.32	3.5	6	3.66	3.84	6
MCDONALD	43.72	15.2	7.58	6	2.52	1.26	6
YOUNGSTOWN	24.36	18.1	16	6	2.81	1.5	6
STRUTHERS	20.34	15.4	6.06	6	3.4	1.71	6
LOWELLVILLE	17.33	22.3	12.9	6	2.32	0.75	6

Table 3.5b: Concentration of Copper in the Mahoning River Water Column [18] .

SAMPLING STATION	KM POINT	TOTAL (ug/L)			DISSOLVED (ug/L)		
		MEAN	STD DEV	COUNT	MEAN	STD DEV	COUNT
LEAVITTSBURG	70.13	7.55	5.07	4	3.38	3.41	4
WARREN	56.8	7.89	4.67	5	3.58	2.46	5
MCDONALD	43.72	15.77	6.35	5	3.02	1.08	5
YOUNGSTOWN	24.36	10.6	6.43	6	2.63	0.99	6
STRUTHERS	20.34	10.9	5.08	6	3.42	1.72	6
LOWELLVILLE	17.33	20.09	9.46	5	3.39	1.88	5

Table 3.6: Concentrations of Suspended Solids in mg/L in the Mahoning River (Summary of YSU Data).

SAMPLING STATIONS	MEAN(mg/l)	STD DEV	COUNT
LEAVITTSBURG	24.41	14.74	24
WARREN	22.32	16.89	24
MCDONALD	21.91	13.56	24
YOUNGSTOWN	26.53	17.69	24
STRUTHERS	32.45	19.87	24
LOWELVILLE	31.14	19.7	24

Table 3.7: Concentrations of Suspended Solids in mg/L in the Mahoning River (Summary of STORET Data).

SAMPLING STATIONS	NUMBER	MEAN(mg/L)	STD. DEV.
LOWELLVILLE-FIRST ST.	128	25	23.89
OHIO-PA ST. LINE	48	77.93	86.06
LOWELLVILLE	1	90	
THIRD ST. BDG.	9	27	23.58
STRUTHERS BRIDGE ST.	33	45.85	66.18
CEDAR ST. BRIDGE	1	31	
UPSTREAM OF I-680	1	23	
DIV. ST., YOUNGSTOWN	15	14.81	10.88
LIBERTY ST. BRIDGE	3	22.66	17.56
TRUMBULL (UPSTREAM)	28	14.27	14.47
TRUMBULL (DOWNSTRE	17	8.01	17.57
BELMONT AVE BRIDGE	3	28.3	17.89
NILES WEST PARK AVE	49	26.71	40.96
WEST PARK AVE BRIDGE	49	26.71	40.96
WARREN SOUTH ST	42	18.06	24.54
MAIN ST BRIDGE	1	32	
LEAVITTSBURG RD	101	19.41	26.97
ROUTE 5 BRIDGE	6	24.5	12.1

to convert the above units into mg/L form to match the units of model predictions.

The porosity of the bottom sediments plays an important role in the estimation of the total concentration of the heavy metals in the bottom sediments. Porosity is defined as:

$$\phi = Porosity = \frac{Volume\ of\ pore\ Space}{Total\ Volume}$$

$$(1 - \phi) = \frac{Volume\ of\ Solids}{Total\ Volume}$$

The porosity of the sediments in the upper strata is incorporated in the calculation of total concentration in the sediments by the following equations [22]:

$$C_{TV} = C_{PV} + C_{DV} \qquad [3.2]$$

Where:

C_{TV} = Total concentration of toxicant in the sediment, μg/L;

C_{PV} = Concentration of particulate toxicant in the sediment, μg/L;

C_{DV} = Concentration of dissolved toxicant in the sediment, μg/L total sediment volume.

$$C_{DV} = \phi \times C_D \qquad [3.3]$$

Where:

C_D = Concentration of the dissolved toxicant in the sediment pore water, μg/L pore water volume.

Using the following notation:

$$C_{PS} = \frac{(mg\ Metal)}{(kg\ Dry\ Sediment)}$$

$$C_{PV} = \frac{(mg\ Metal)}{(L\ Bulk\ Volume)}$$

Usually C_{PV} is much greater than C_{DV}, so:

$$C_{TV} = C_{PV} = C_{PS}\ (S\ \gamma_W)\ (1-\phi) \qquad [3.4]$$

Where:

S = Specific gravity of sediments = (2 - 2.6); [22]

γ = Specific weight of water, gm/L.

Values of C_{PS} were obtained from Evan [19]. Then, based on the above equation and an assumption of 0.75 as porosity,and specific weight of sediment as 2.45, the conversions were made and are presented in Table 3.8.

3.4 Model Calibration

The calibration of a model is usually based on experience. Although initial literature values are available, the appropriate values for the model parameters are obtained by performing several runs of the model and using trial and error to match model predictions with field data. Important parameters that govern the concentrations and forms of toxicants in MICHRIV are the kinetic coefficients (settling and resuspension velocities), and the partition coefficient [10]. For the purpose of calibration, the YSU data was

Table 3.8: Concentration of Chromium and Copper in the Mahoning River Bottom Sediments [19].
K =2.45*1*(1-0.75)

MILE POINT	KM POINT	Cs (Cu) mg/kg	Cs (Cr) mg/kg	K	Cv (Cu) ug/L	Cv (Cr) ug/L
11.1	17.7822	199	43	0.6125	121887.5	26337.5
12.2	19.5444	212	45	0.6125	129850	27562.5
13.5	21.627	236	129	0.6125	144550	79012.5
14.6	23.3892	2357	91.6	0.6125	1443663	56105
15.1	24.1902	2700	154.1	0.6125	1653750	94386.25
15.7	25.1514	145	45	0.6125	88812.5	27562.5
16.4	26.2728	113	42	0.6125	69212.5	25725
16.6	26.5932	59	34	0.6125	36137.5	20825
17	27.234	110	45	0.6125	67375	27562.5
17.6	28.1952	283	50	0.6125	173337.5	30625
18.3	29.3166	71	36	0.6125	43487.5	22050
18.9	30.2778	98	50	0.6125	60025	30625
19.4	31.0788	117	47	0.6125	71662.5	28787.5
21.3	34.1226	1864	115.3	0.6125	1141700	70621.25
21.75	34.8435	1865	76.1	0.6125	1142313	46611.25
22.2	35.5644	197	119	0.6125	120662.5	72887.5
22.8	36.5256	98	50	0.6125	60025	30625
23.2	37.1664	144	80	0.6125	88200	49000
23.9	38.2878	134	74	0.6125	82075	45325
24.3	38.9286	154	21	0.6125	94325	12862.5
25.2	40.3704	37	42	0.6125	22662.5	25725
25.7	41.1714	443	183	0.6125	271337.5	112087.5
26.2	41.9724	215	322	0.6125	131687.5	197225
26.75	42.8535	186	260	0.6125	113925	159250
27.4	43.8948	77	51	0.6125	47162.5	31237.5
28.4	45.4968	103	51	0.6125	63087.5	31237.5
29.9	47.8998	168	145	0.6125	102900	88812.5
31.2	49.9824	485	65	0.6125	297062.5	39812.5
31.6	50.6232	156	126	0.6125	95550	77175
32.5	52.065	126	101	0.6125	77175	61862.5

Table 3.8 continued . .

MILE POINT	KM POINT	Cs (Cu) mg/kg	Cs (Cr) mg/kg	K	Cv (Cu) ug/L	Cv (Cr) ug/L
32.8	52.5456	107	101	0.6125	65537.5	61862.5
33.5	53.667	546	231	0.6125	334425	141487.5
34.7	55.5894	510	74	0.6125	312375	45325
36	57.672	88	43	0.6125	53900	26337.5
37.2	59.5944	155	81	0.6125	94937.5	49612.5
37.8	60.5556	291	174	0.6125	178237.5	106575
38.2	61.1964	1238	92	0.6125	758275	56350
38.8	62.1576	779	193	0.6125	477137.5	118212.5
39.4	63.1188	950	133	0.6125	581875	81462.5
40.6	65.0412	125	140	0.6125	76562.5	85750
41.8	66.9636	124	263	0.6125	75950	161087.5
42.8	68.5656	233	429	0.6125	142712.5	262762.5
43.2	69.2064	485	910	0.6125	297062.5	557375
43.8	70.1676	42	139	0.6125	25725	85137.5
44.2	70.8084	13	24	0.6125	7962.5	14700
44.8	71.7696	12	23	0.6125	7350	14087.5
45.6	73.0512	23	27	0.6125	14087.5	16537.5
46.4	74.3328	17	29	0.6125	10412.5	17762.5
47.3	75.7746	20	22	0.6125	12250	13475
48.2	77.2164	17	24	0.6125	10412.5	14700
49.2	78.8184	16	21	0.6125	9800	12862.5
50.2	80.4204	36	35	0.6125	22050	21437.5
51.25	82.1025	29	36	0.6125	17762.5	22050
52.4	83.9448	16	22	0.6125	9800	13475
53.2	85.2264	21	28	0.6125	12862.5	17150
53.9	86.3478	19	31	0.6125	11637.5	18987.5
54.9	87.9498	15	27	0.6125	9187.5	16537.5
56.1	89.8722	18	24	0.6125	11025	14700
56.7	90.8334	13	21	0.6125	7962.5	12862.5
57.4	91.9548	16	19	0.6125	9800	11637.5
57.5	92.115	6	11	0.6125	3675	6737.5

considered instead of the STORET database for the following reasons: (1) The STORET data had concentrations of heavy metals for only two sites, namely Lowellville and Leavittsburg, which were insufficient for comparison with the calibrated values; (2) The MICHRIV model predicts concentrations of total, dissolved and particulate concentrations in the water column. The STORET database had total concentrations only whereas the YSU data had total and dissolved concentrations; and (3) The concentration data recorded in the STORET database were based on higher detection limits using the flame atomic absorption (AA) method. The concentrations predicted by the model are often below this limit, making the comparison difficult. A more sensitive technique called graphite furnace AA was used to achieve lower detection limits in collecting the YSU data.

3.4.1 Input Data Structure

The MICHRIV model input basically consisted of two data sets. The first data set contained the boundary conditions and the second contained the variables. The boundary conditions included the number of reaches, the background flow, background toxicant concentration in the water column, background suspended solids concentration and the number of segments per print [16]. The second set consisted of incoming flows, loadings of toxicant and suspended solids, and the kinetic and partition coefficients. This model was calibrated for two metals namely chromium and copper. Summaries of all input data for the calibrated model are presented in Chapter 4.

3.4.2 Approach to Calibration

The model requires that the river be divided into reaches. Wherever there is a change in one of the input parameters a new reach has to be started. The parameters that govern the start of a new reach are points of discharge, incoming flows from the tributaries, and change in the width or depth of the river. Hence the area of cross-section, flow and loading within a reach are assumed constant [16].

The Mahoning River was divided into fourteen reaches with the first reach starting at mile point 43.78 (km point 70.13) at Leavittsburg and the last ending at mile point 12.69 (16.96) in Lowellville [23]. Branches converging or diverging from the Mahoning River were not prominent and hence were not considered while modeling. Though the cross-sectional area of the river varies from point to point, for the purpose of modeling an average cross-sectional area had to be considered within a reach. A clear schematic representation of how the reaches were decided is shown in Figure 3-1.

The model has a provision for flows such as the surface runoff flow. As the runoff flows were practically impossible to quantify, these flows were not considered while modeling. Since MICHRIV can also be used for organic toxicants, there are also provisions for including the processes of volatilization, hydrolysis, photolysis, and biological decay. All of these processes were neglected for copper and chromium [16].

The model was first calibrated for suspended solids by adjusting the settling and resuspension velocities. Then, the loadings for copper were entered and calibration was obtained by adjusting the partition coefficient. To support this prediction, another calibration for chromium was performed keeping all the input values the same except for the loading and the partition coefficient. All MICHRIV input is in metric units and hence necessary conversions were made. The results of the model calibration are discussed in the next chapter.

CHAPTER 4

RESULTS OF MODEL CALIBRATION

The calibrations were performed for chromium and copper and the simulation results for total, dissolved and particulate concentrations in the water column as well as in the bottom sediments is presented as plots. The simulation results for suspended solids concentrations are also presented. The MICHRIV model output for copper and chromium concentrations are presented in Appendix C. The calibration values for all input parameters are presented in Tables 4.1 and 4.2 for chromium and copper, respectively.

4.1 Suspended Solids

It is obvious from the plot of suspended solids (SS) versus river kilometer (km) point in Figure 4-1 that the simulated values make a near perfect fit of the field data. A comparison of field data from six sampling stations [18] and the calibrated model output is shown. The predicted concentrations start from a low of 20 mg/L at the upstream end of the river in Leavittsburg and gradually increase to 32 mg/L at Struthers, reflecting the actual measured concentrations at these sampling stations. Small peaks in predicted concentration were observed at locations where flows into the river occurred. This is due to the scouring or resuspension of the sediments near these inlets. But farther downstream

Table 4.1: Input Data for Model Calibration of Chromium Concentration in the Mahoning River.

INPUT DATA FILE FOR CHROMIUM															
NUMBER OF REACH	K	14													
BACK GROUND FLOW	Q1(CU.M/S)	16.66274													
TOXICANT INFLOW CONC.	CO(UG/L)	4.18													
SUS.SOLIDS INFLOW CONC.	SSO(MG/L)	24.2													
BOUNDARIES		REACH1	REACH2	REACH3	REACH4	REACH5	REACH6	REACH7	REACH8	REACH9	REACH10	REACH11	REACH12	REACH13	REACH14
NUMBER OF DX PER PRINT	NDXP														
DUMMY1	DUMMY1														
DUMMY2	DUMMY2														
DECAY RATE CONSTANT (BED)	K2(1/DAY)														
VOLATILIZATION VELOCITY	KV(M/DAY)														
BIOLOGIC. DECAY CONSTANT	KB(1/DAY)														
HYDROLYSIS RATE CONSTANT	KH(1/DAY)														
PARTITION COEF.(WATER)	P1(1/KG)	140000	140000	140000	140000	140000	140000	140000	140000	140000	140000	140000	140000	140000	140000
PARTITION COEF.(BED)	P2(1/KG)	140000	140000	140000	140000	140000	140000	140000	140000	140000	140000	140000	140000	140000	140000
INPUT LOAD SUS. SOLIDS	WKS(KG/DAY)	0	0	0	0	7461	647	0	0	0	0	3689	0	658	0
INPUT LOAD TOXICANT	WK(KG/DAY)	0	1.572	0.218	8.061	1.403	0.177	1.506	1.246	1.042	0.197	0.208	13.249	0.536	3.743
RESUSPENSION VELOCITY	WU(M/DAY)	1E-05	7.5E-05	7.8E-05	7.5E-05	7.5E-05	7E-05	6.5E-05	8E-05	8.5E-05	8.5E-05	0.00011	0.00014	0.00012	3.5E-05
SEDIMENT DIFFUSION VEL.	KD(M/D)	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
INPUT FLOW INSIDE REACH	DQ(CU.M/DAY)	0	0	0	0	0	0	0	0	0	0	0	0	0	0
AVE. AREA OF CROSS SEC.	AREA(SQM)	52.62	58.96	31.389	39.749	42.82	43.83	72.51	109.51	74.76	87.76	23.54	70.64	62.09	34.62
KM PT AT START OF REACH	PTKM(KM)	70.13	64.24	59.8	54.38	46.31	45.72	43.46	42.13	37.74	35.19	32.36	28.96	22.84	20.33
INTEG. LENGTH THRO REACH	DX(M)	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000
INPUT FLOW	QK(CU.M/S)	0	0.0734	0.0473	3.13	3.3722	1.249	0.28	0.0875	0.219	0.0138	1.646	1.533	0.169	0.262
SETTLING VELOCITY	SV(M/DAY)	1	1.1	1.2	1.2	1.05	1.04	1.03	1.02	1.3	1.3	1.3	1.35	0.7	0.4
PHOTOLYSIS RATE	KP(1/DAY)														
REACH LENGTH	REACH(M)	5890	4440	5420	8070	590	2260	1330	4390	2550	2830	3400	6120	2510	3370
SUS. SOL. CONC (BED)	M2(MG/L)	500000	500000	500000	500000	500000	500000	500000	500000	500000	500000	500000	500000	500000	500000
AVE.DEPTH WATER COLUMN	H1(M)	0.79	1.24	0.92	0.99	1.12	0.84	1.67	1.69	1.23	1.28	0.65	1.42	1.02	0.98
AVE. DEPTH ACTIVE BED	H2(M)	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1

Table 4.2: Input Data for Model Calibration of Copper Concentration in the Mahoning River.

INPUT DATA FILE FOR COPPER															
NUMBER OF REACH	K	14													
BACK GROUND FLOW	Q1(CU.M/S)	16.662744													
TOXICANT INFLOW CONC.	CO(UG/L)	7.5													
SUS.SOLIDS INFLOW CONC.	SSO(MG/L)	24.2													
BOUNDARIES		REACH1	REACH2	REACH3	REACH4	REACH5	REACH6	REACH7	REACH8	REACH9	REACH10	REACH11	REACH12	REACH13	REACH14
NUMBER OF DX PER PRINT	NDXP														
DUMMY1	DUMMY1														
DUMMY2	DUMMY2														
DECAY RATE CONSTANT (BED)	K2(1/DAY)														
VOLATILIZATION VELOCITY	KV(M/DAY)														
BIOLOGIC. DECAY CONSTANT	KB(1/DAY)														
HYDROLYSIS RATE CONSTANT	KH(1/DAY)														
PARTITION COEF.(WATER)	P1(1/KG)	95000	95000	95000	95000	95000	95000	95000	95000	95000	95000	95000	95000	95000	95000
PARTITION COEF.(BED)	P2(1/KG)	95000	95000	95000	95000	95000	95000	95000	95000	95000	95000	95000	95000	95000	95000
INPUT LOAD SUS. SOLIDS	WKS(KG/DAY)	0	0	0	0	7461	6477	0	0	0	0	3689	0	658	0
INPUT LOAD TOXICANT	WK(KG/DAY)	0	0.19	0.123	6.156	0.787	0.246	0.704	0.277	0.172	0	0.13	3.975	7.8	0.681
RESUSPENSION VELOCITY	WU(M/DAY)	1E-05	7.5E-05	7.8E-05	7.5E-05	7.5E-05	7E-05	6.5E-05	8E-05	8.5E-05	8.5E-05	0.00011	0.00014	0.00012	3.5E-05
SEDIMENT DIFFUSION VEL.	KD(M/D)	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
INPUT FLOW INSIDE REACH	DQ(CU.M/DAY)	0	0	0	0	0	0	0	0	0	0	0	0	0	0
AVE. AREA OF CROSS SEC.	AREA(SQM)	52.62	58.96	31.389	39.749	42.82	43.83	72.51	109.51	74.76	87.76	23.54	70.64	62.09	34.62
KM PT AT START OF REACH	PTKM(KM)	70.13	64.24	59.8	54.38	46.31	45.72	43.46	42.13	37.74	35.19	32.36	28.96	22.84	20.33
INTEG. LENGTH THRO REACH	DX(M)	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000
INPUT FLOW	QK(CU.M/S)	0	0.0734	0.0473	3.135	3.3722	1.249	0.28	0.0875	0.219	0.0138	1.646	1.533	0.169	0.262
SETTLING VELOCITY	SV(M/DAY)	1	1.1	1.2	1.2	1.05	1.04	1.03	1.02	1.3	1.3	1.3	1.35	0.7	0.4
PHOTOLYSIS RATE	KP(1/DAY)														
REACH LENGTH	REACH(M)	5890	4440	5420	8070	590	2260	1330	4390	2550	2830	3400	6120	2510	3370
SUS. SOL. CONC (BED)	M2(MG/L)	500000	500000	500000	500000	500000	500000	500000	500000	500000	500000	500000	500000	500000	500000
AVE.DEPTH WATER COLUMN	H1(M)	0.79	1.24	0.92	0.99	1.12	0.84	1.67	1.69	1.23	1.28	0.65	1.42	1.02	0.98
AVE. DEPTH ACTIVE BED	H2(M)	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1

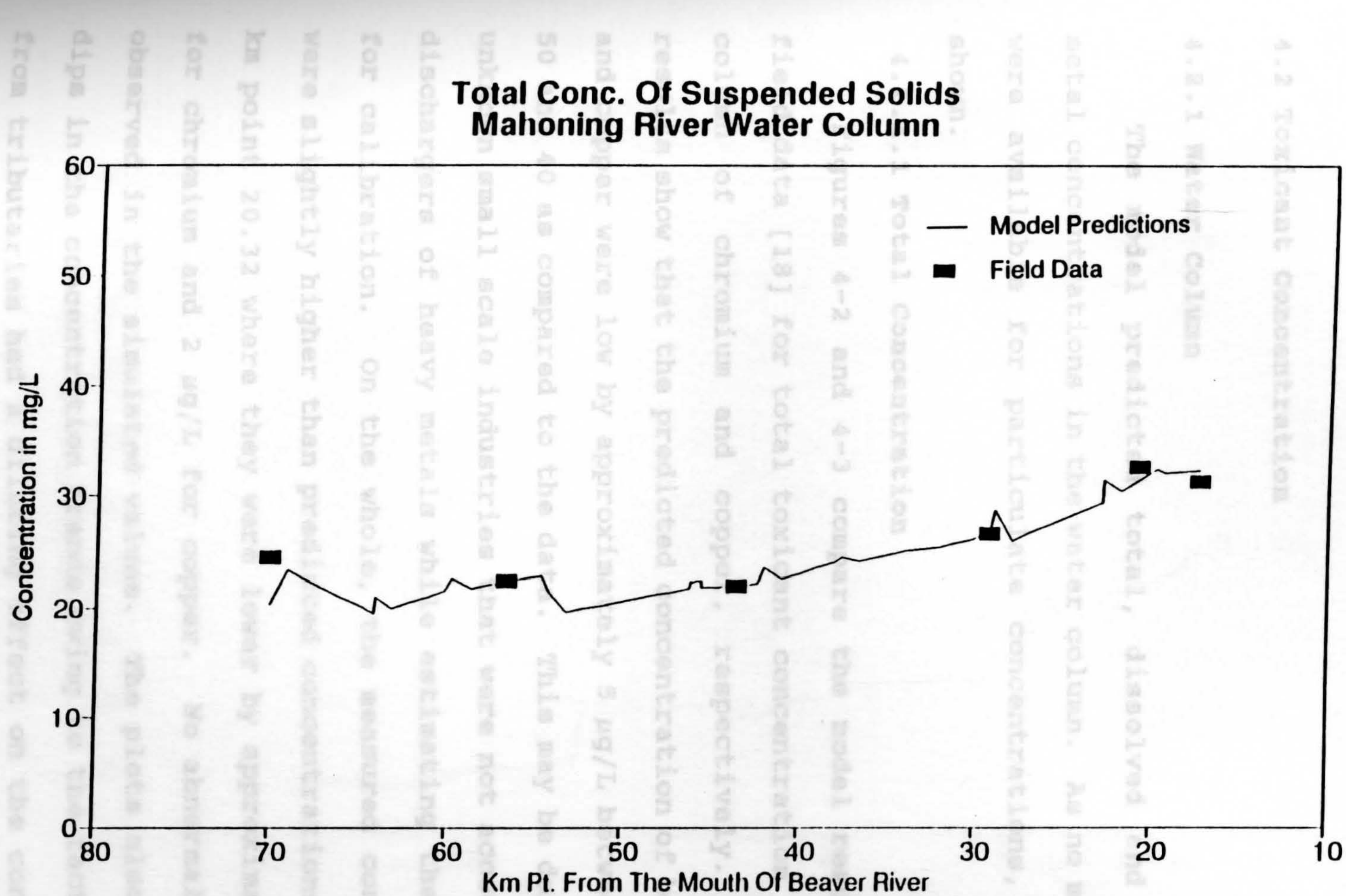

Figure 4-1: Total Concentration of Suspended Solids (in mg/L) in the Mahoning River Water Column vs Km from the Mouth of the Beaver River. Comparison of Calibrated Model Predictions and Field Data.

from these inlets the concentrations decreased. On the whole the curve has an upward trend in the downstream direction.

4.2 Toxicant Concentration

4.2.1 Water Column

The model predicted total, dissolved and particulate metal concentrations in the water column. As no measured data were available for particulate concentrations, no plot is shown.

4.2.1.1 Total Concentration

Figures 4-2 and 4-3 compare the model results and the field data [18] for total toxicant concentration in the water column of chromium and copper, respectively. The model results show that the predicted concentration of both chromium and copper were low by approximately 5 $\mu g/L$ between km points 50 and 40 as compared to the data. This may be due to several unknown small scale industries that were not accounted for as dischargers of heavy metals while estimating the input load for calibration. On the whole, the measured concentrations were slightly higher than predicted concentrations, except at km point 20.32 where they were lower by approximately 4 $\mu g/L$ for chromium and 2 $\mu g/L$ for copper. No abnormal peaks were observed in the simulated values. The plots also show a few dips in the concentration trends owing to the fact that flows from tributaries had a diluting effect on the concentration.

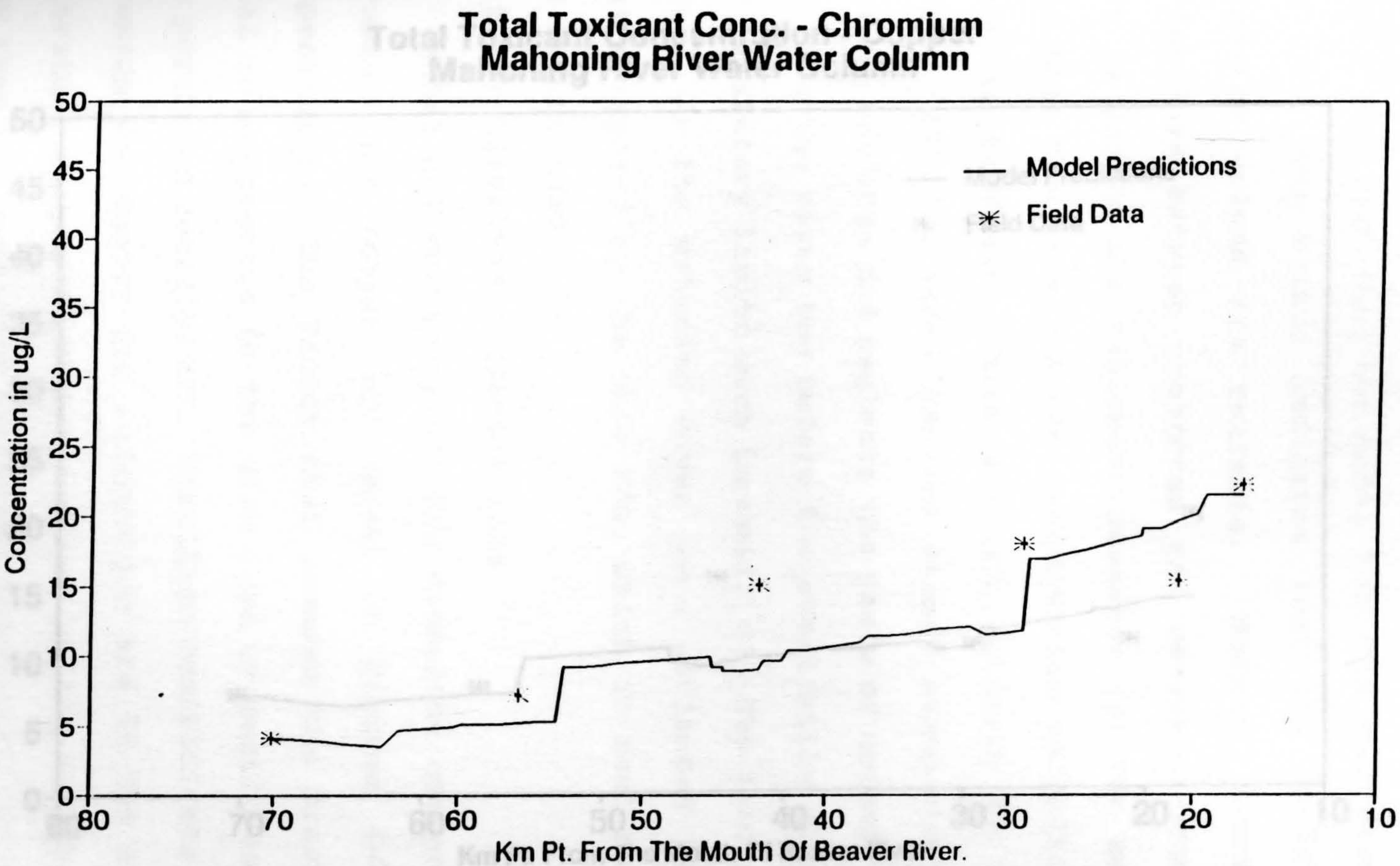

Figure 4-2: Total Concentration of Chromium (in µg/L) in the Mahoning River Water Column vs Km from the Mouth of the Beaver River. Comparison of Calibrated Model Predictions and Field data.

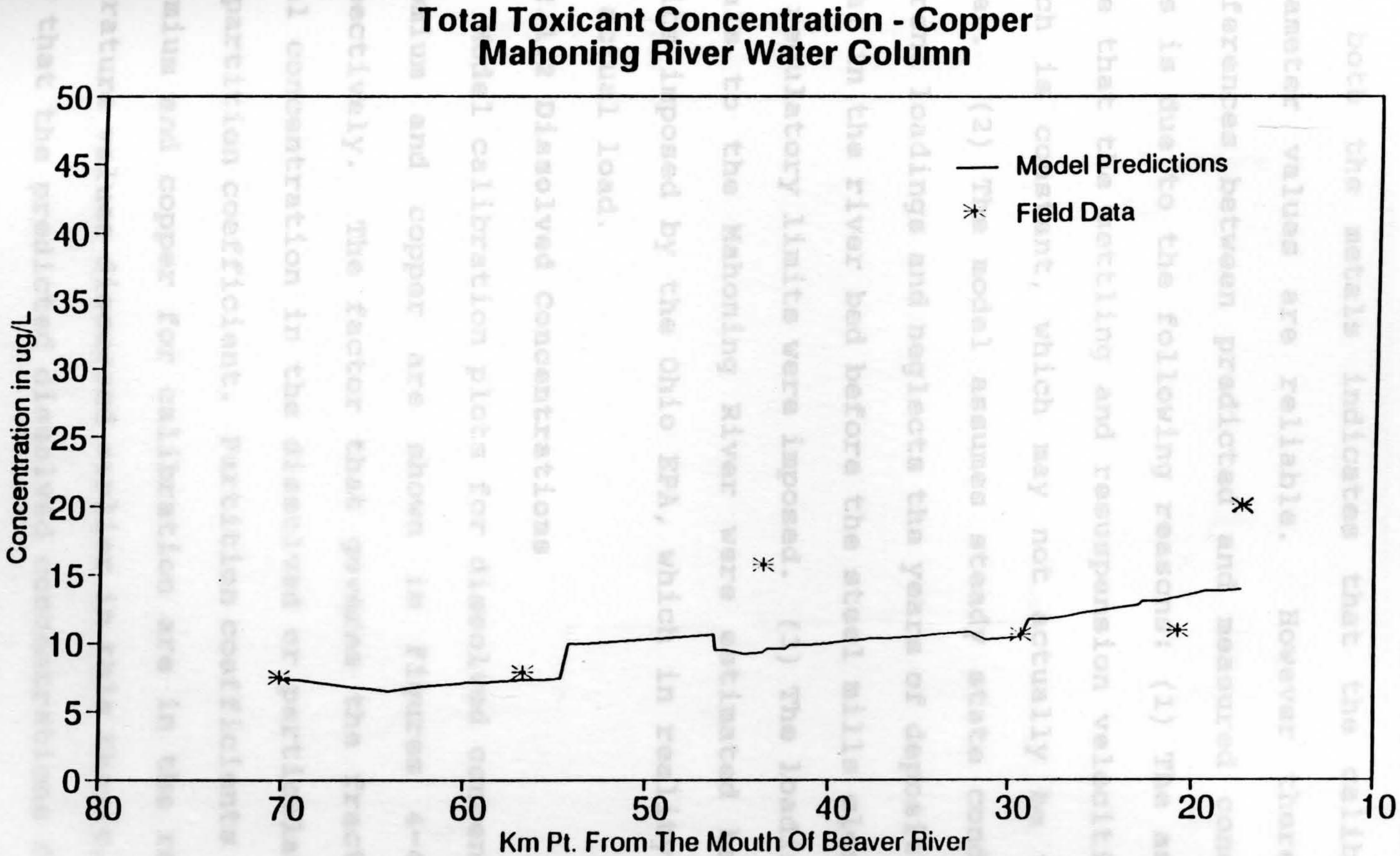

Figure 4-3: Total Concentration of Copper (in μg/L) in the Mahoning River Water Column vs Km from the Mouth of the Beaver River. Comparison of Calibrated Model Predictions and Field Data.

The simulated values show a significant similarity in the concentration trends between copper and chromium along the river. The fact that the model fits the data reasonably well for both the metals indicates that the calibrated input parameter values are reliable. However there are minor differences between predicted and measured concentrations. This is due to the following reasons: (1) The assumption is made that the settling and resuspension velocities within a reach is constant, which may not actually be true in the river. (2) The model assumes steady state conditions with current loadings and neglects the years of deposition of heavy metal in the river bed before the steel mills closed down and any regulatory limits were imposed. (3) The loadings of heavy metals to the Mahoning River were estimated based on the limits imposed by the Ohio EPA, which in reality may not be the actual load.

4.2.1.2 Dissolved Concentrations

Model calibration plots for dissolved concentrations of chromium and copper are shown in Figures 4-4 and 4-5, respectively. The factor that governs the fraction of the total concentration in the dissolved or particulate forms is the partition coefficient. Partition coefficients assumed for chromium and copper for calibration are in the range of the literature values discussed earlier in this thesis. The plots show that the predicted dissolved concentrations for both of the metals in the upstream section of the river (between km

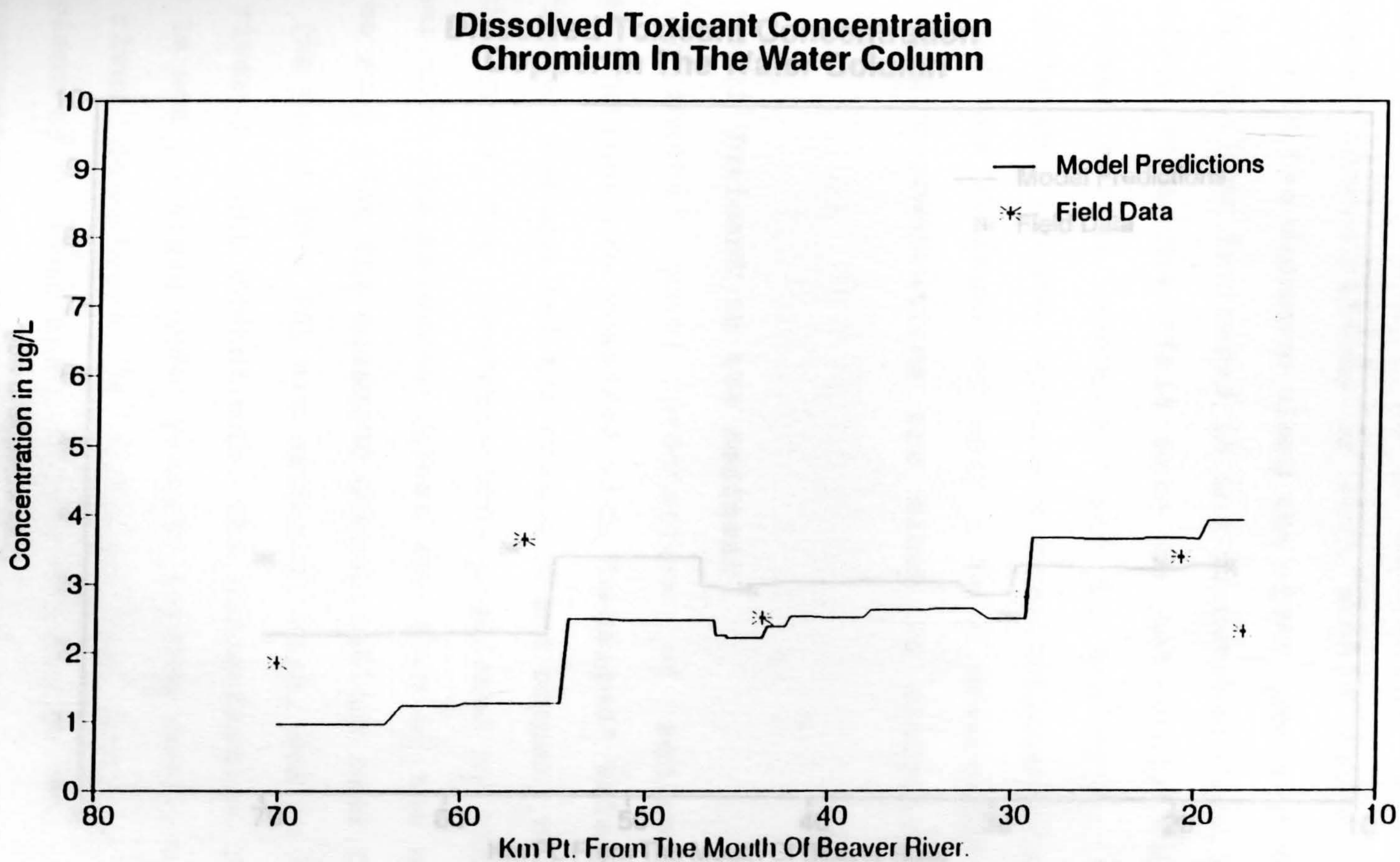

Figure 4-4: Dissolved Concentration of Chromium (in $\mu g/L$) in the Mahoning River Water Column vs Km from the Mouth of the Beaver River. Comparison of Calibrated Model Predictions and Field Data.

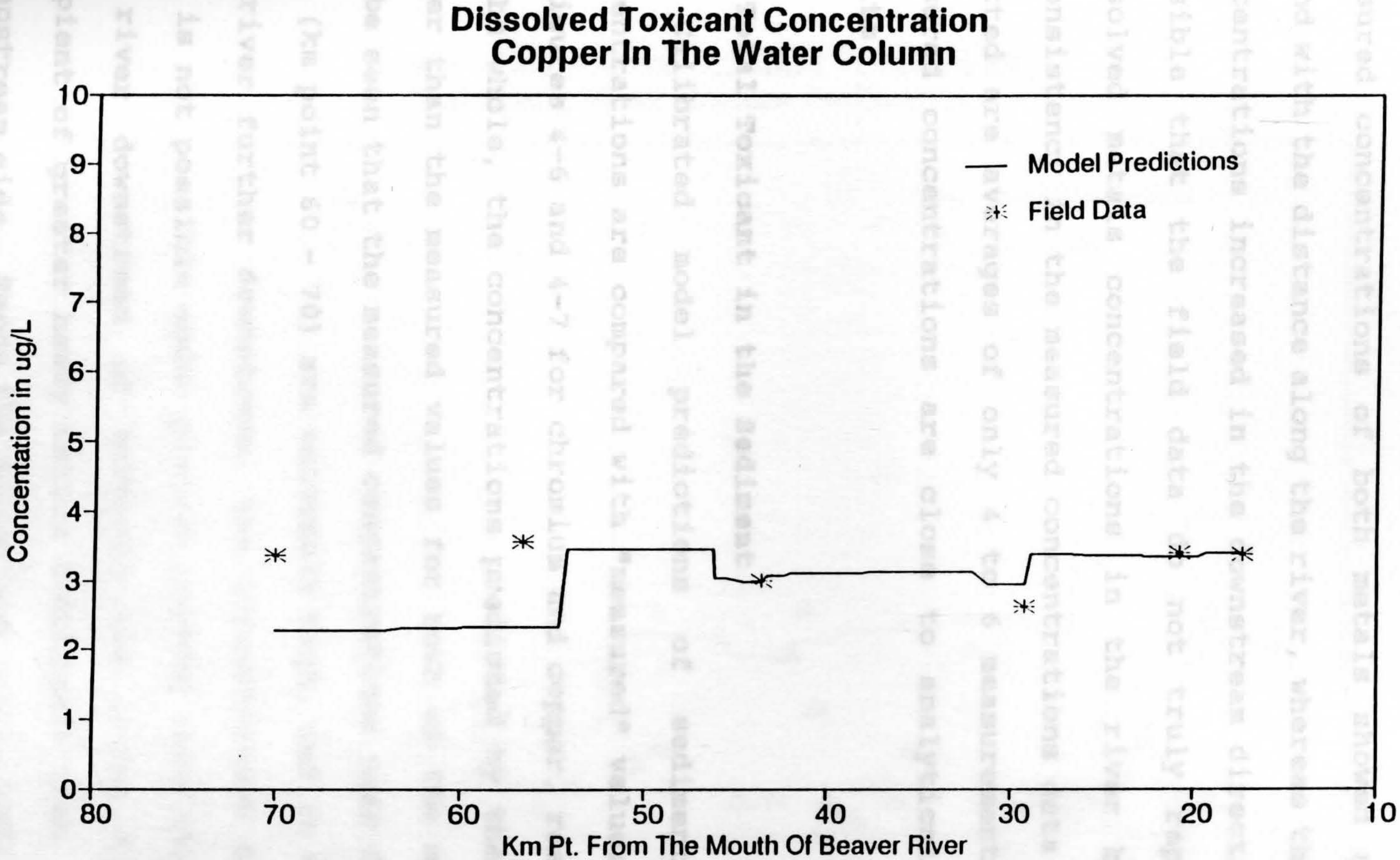

Figure 4-5: Dissolved Concentration of Copper (in μg/L) in the Mahoning River Water Column vs Km from the Mouth of the Beaver River. Comparison of Calibrated Model Predictions and Field Data.

points 70.33 and 56.5 are low by 1 to 2 μg/L. The concentration curves are mostly flat between major discharge points on the river. It is interesting to note that the measured concentrations of both metals showed no definite trend with the distance along the river, whereas the predicted concentrations increased in the downstream direction. It is possible that the field data do not truly represent the dissolved metals concentrations in the river because (1) Inconsistency in the measured concentrations data (2) Values plotted are averages of only 4 to 6 measurements: and (3) Measured concentrations are close to analytical detection limits.

4.2 Total Toxicant in the Sediment

Calibrated model predictions of sediment toxicant concentrations are compared with "measured" values form [19] in Figures 4-6 and 4-7 for chromium and copper, respectively. On the whole, the concentrations predicted by the model are higher than the measured values for both of the metals. It can be seen that the measured concentrations near Copperweld, Inc. (km point 60 - 70) are extremely high, and in the rest of the river further downstream, the concentration drops down. This is not possible under present loading conditions because the river downstream of McDonald (Km point 42.13 is a recipient of greater heavy metals discharges than the upstream side. Hence the downstream concentrations should

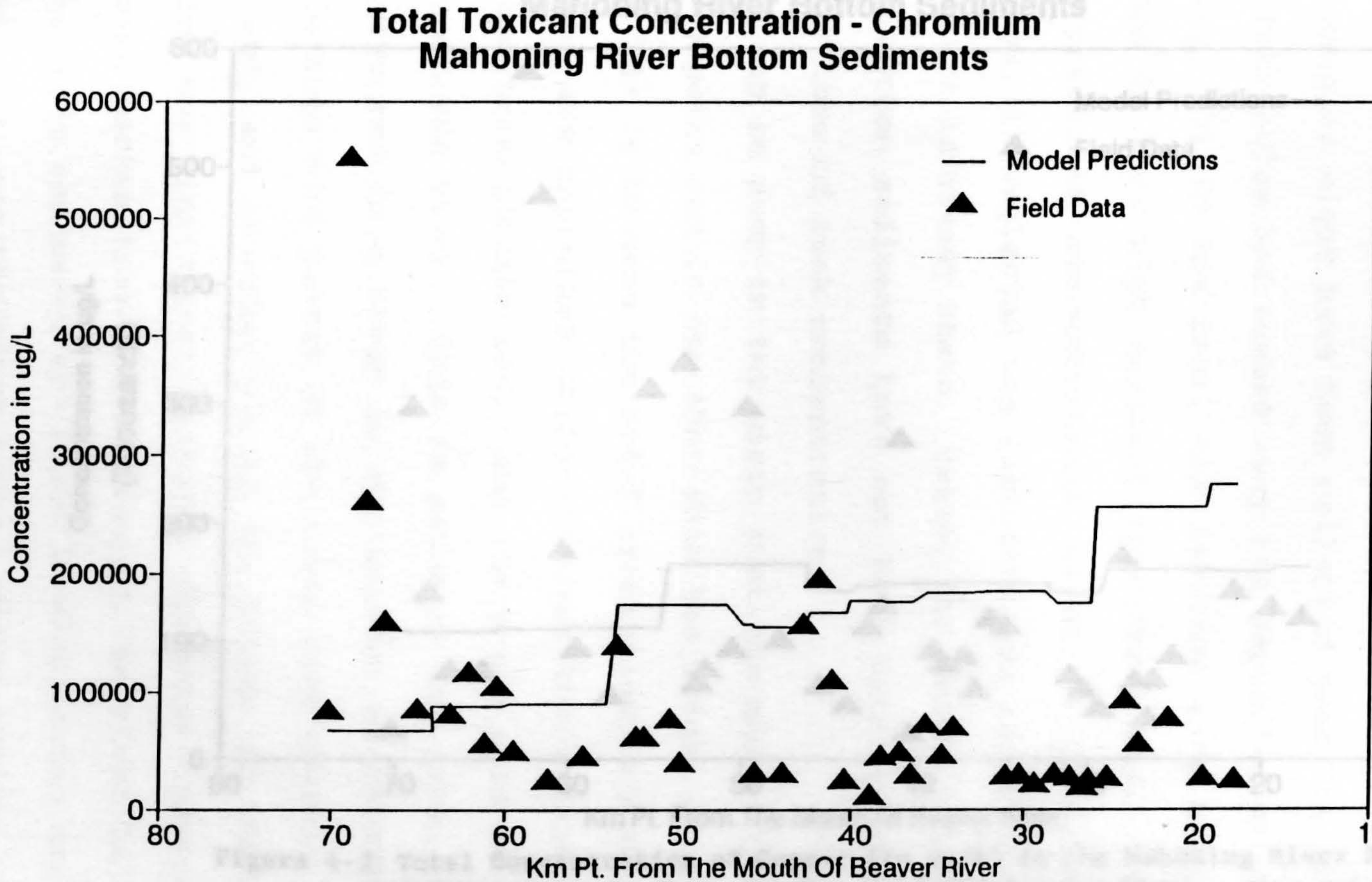

Figure 4-6: Total Concentration of Chromium in ($\mu g/L$) in the Mahoning River Bottom Sediments vs Km from the Mouth of the Beaver River. Comparison of Calibrated Model Predictions and Field Data.

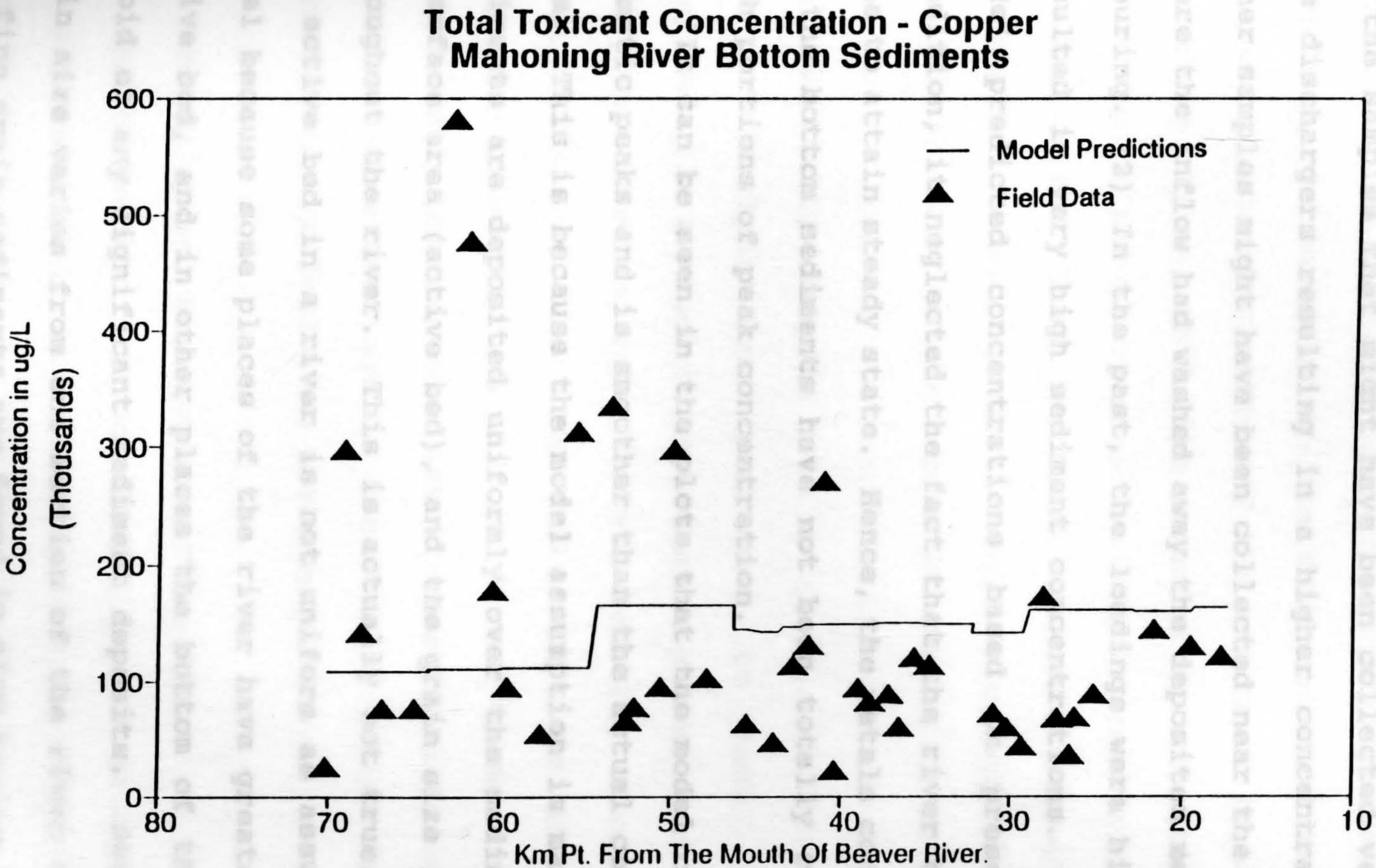

Figure 4-7: Total Concentration of Copper (in μg/L) in the Mahoning River Bottom Sediments vs Km from the Mouth of the Beaver River. Comparison of Calibrated Model Predictions and Field Data.

at least be similar if not higher. The following is an attempt to explain this trend: (1) The difference may be due to the samples that might have been collected very close to the dischargers resulting in a higher concentration, while other samples might have been collected near the tributaries where the inflow had washed away the deposited metals due to scouring. (2) In the past, the loadings were higher, which resulted in very high sediment concentrations. While the model predicted concentrations based on present loading condition, it neglected the fact that the river takes a long time to attain steady state. Hence, the metals conçentrations in the bottom sediments have not been totally removed from such portions of peak concentration.

It can be seen in the plots that the model curve has no dramatic peaks and is smoother than the actual concentration data. This is because the model assumption is made that the sediments are deposited uniformly over the sediment water-interface area (active bed), and the grain size is constant throughout the river. This is actually not true. Firstly, the active bed in a river is not uniform as assumed by the model because some places of the river have greater depth of active bed, and in other places the bottom of the river is devoid of any significant sediment deposits. Secondly, the grain size varies from one section of the river to another. The fine grain sediments are found in slow moving sections of the river and near the river banks; coarse grained sediments are found in the fast moving sections of the river and near the center of the channel. Fine grain sediments have a greater partition coefficient than coarse grained sediments. Therefore, in sections of the river where fine grains are present, the concentrations of the toxicants in the sediments tend to be higher. While the measured concentrations indicate the ranges of actual toxicant concentrations in the different sections of the river, the model assumes a uniform grain size and deposition resulting in a smooth curve that represents the average sediments metals concentrations.

4.3 Sensitivity Analysis

An analysis was performed to test the model's sensitivity to changes in loadings and other input parameters. The influence of resuspension and settling velocities on the concentration of the suspended solids in the river was evaluated. Analysis was also performed to see the effect of variations in loadings and partition coefficients on predicted toxicant concentrations. Results of this analysis are discussed in the following paragraphs.

4.3.1 Settling and Resuspension Velocities

The concentrations of metals in the water column are directly related to the concentration of suspended solids. Hence it is important to test the sensitivity of the model to changes in parameters that could affect the suspended solids concentration. The input parameters settling velocity and resuspension velocity have a great influence on the suspended solids concentrations in a river. The analysis was performed by increasing and decreasing the settling and resuspension velocities by 25% in all the reaches. The model-generated results are shown in Figure 4-8 and Figure 4-9 for settling and resuspension velocities, respectively. A 25% reduction in the settling velocity throughout all fourteen reaches resulted in a higher concentration of suspended solids in the water column than the original value. A 25 % increase showed a lower concentration in the water column. Differences increased gradually from zero at the upstream end (Km point 70.13) to about 4 mg/L at Struthers. A similar trend was shown when the resuspension velocity was changed, except that it showed the reverse effect. A 25% decrease of the resuspension velocity showed a lower concentration curve and a 25% increase showed a higher concentration curve. The differences between these curves and the calibrated model results ranged from Zero at Km point 70.13 to 6.3 mg/L at km point 17.33. The model was slightly more sensitive to resuspension velocity than to settling velocity.

The changes in the input values for settling and resuspension did not affect the difference of values between the dissolved and particulate forms. That is, when the values of settling and resuspension were decreased or increased, the concentrations of the dissolved and particulate forms

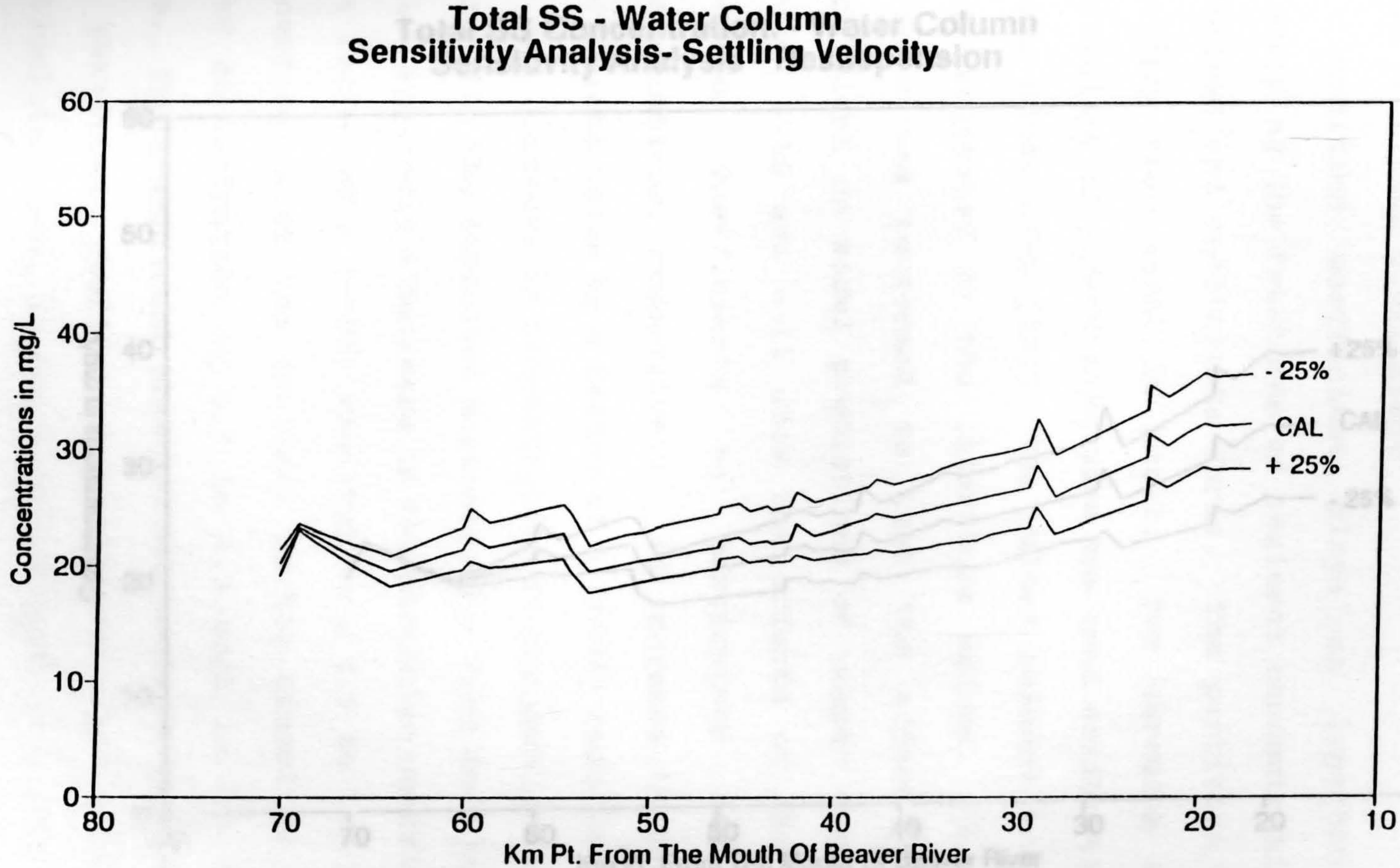

Figure 4-8: Sensitivity Analysis Results for Suspended Solids Concentration with Variations in the Settling Velocity. Concentration of Suspended Solids (in mg/L) vs Km from the Mouth of the Beaver River.

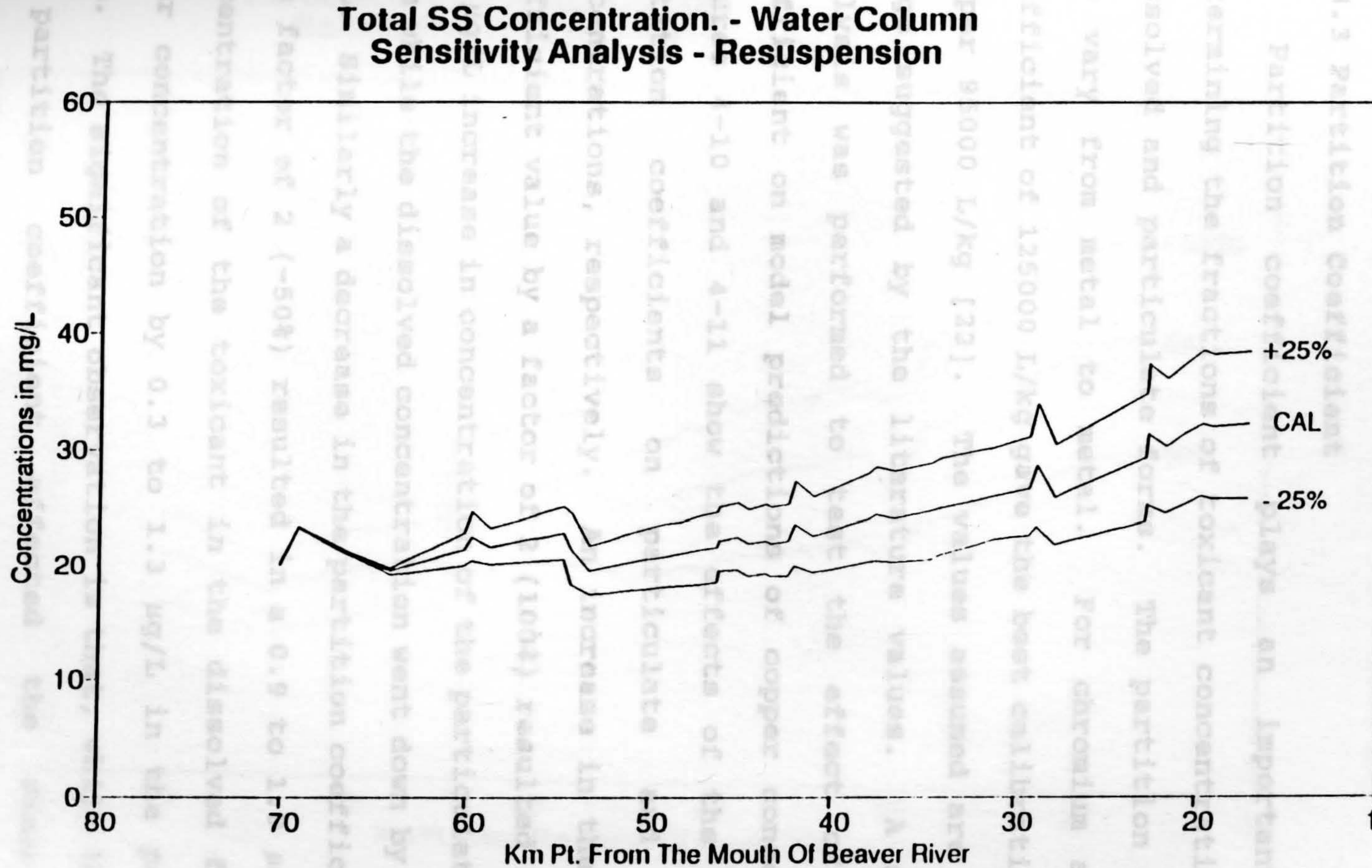

Figure 4-9: Sensitivity Analysis Results for Suspended Solids Concentration with Variations in the Resuspension Velocity. Concentration of Suspended Solids (in mg/L) vs Km from the Mouth of the Beaver River.

decreased or increased while maintaining the difference in values proportionately.

4.3.3 Partition Coefficient

Partition coefficient plays an important role in determining the fractions of toxicant concentrations in dissolved and particulate forms. The partition coefficient may vary from metal to metal. For chromium a partition coefficient of 125000 L/kg gave the best calibration, and for copper 95000 L/kg [22]. The values assumed are within the range suggested by the literature values. A sensitivity analysis was performed to test the effect of partition coefficient on model predictions of copper concentrations. Figures 4-10 and 4-11 show the effects of the changes in partition coefficients on particulate and dissolved concentrations, respectively. An increase in the partition coefficient value by a factor of 2 (100%) resulted in a 0.9 to 2.0 μg/L increase in concentration of the particulate toxicant form while the dissolved concentration went down by 0.9 to 1.3 μg/L. Similarly a decrease in the partition coefficient value by a factor of 2 (-50%) resulted in a 0.9 to 1.9 μg/L higher concentration of the toxicant in the dissolved form and a lower concentration by 0.3 to 1.3 μg/L in the particulate form. The significant observation is that, while the changes in partition coefficient affected the dissolved and particulate forms, it had little effect on the total

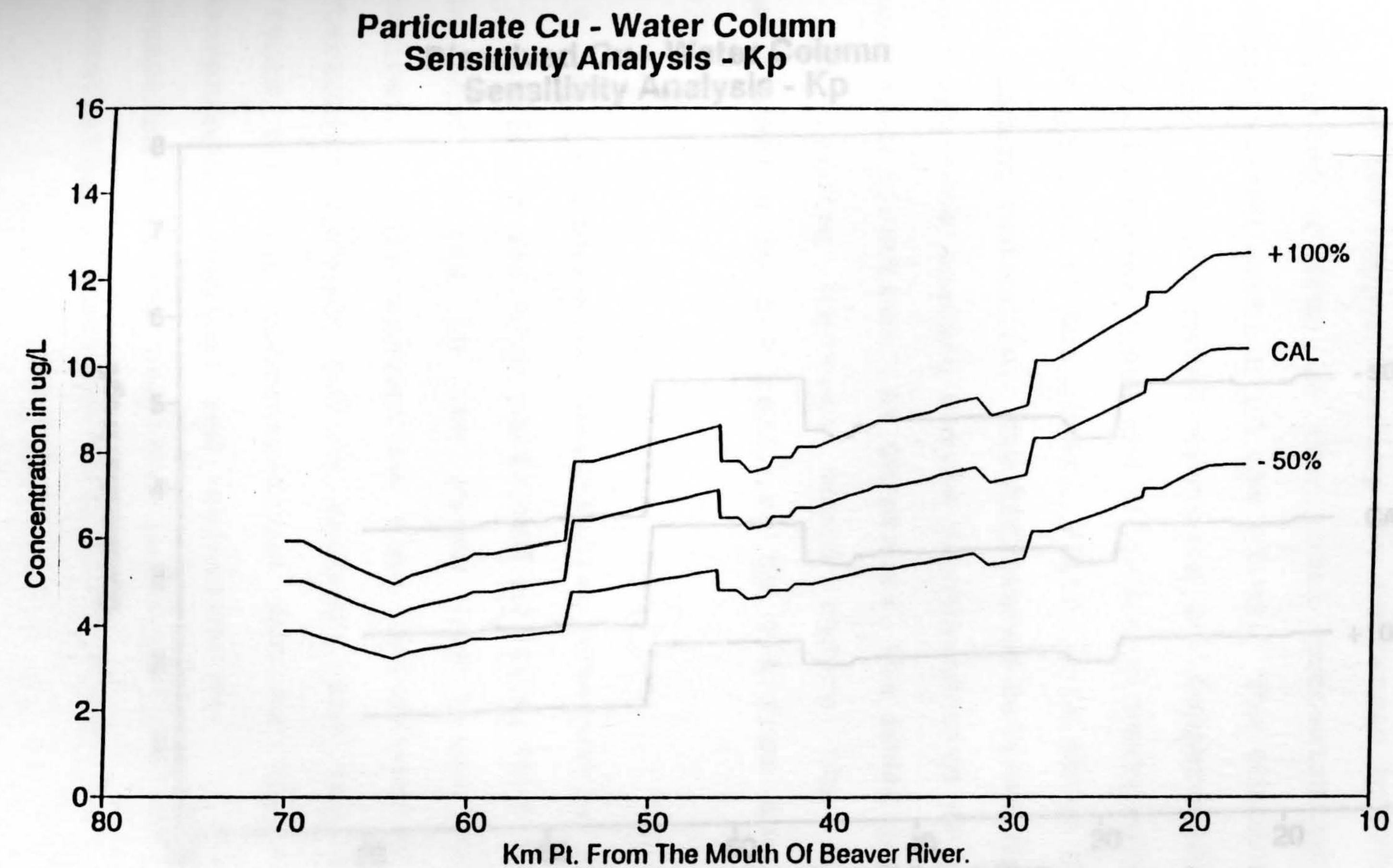

Figure 4-10: Sensitivity Analysis Results for Particulate Concentration of Copper in the Water Column With Variations in the Partition Coefficient. Concentration of Particulate Copper (in μg/L) vs Km from the Mouth of the Beaver River.

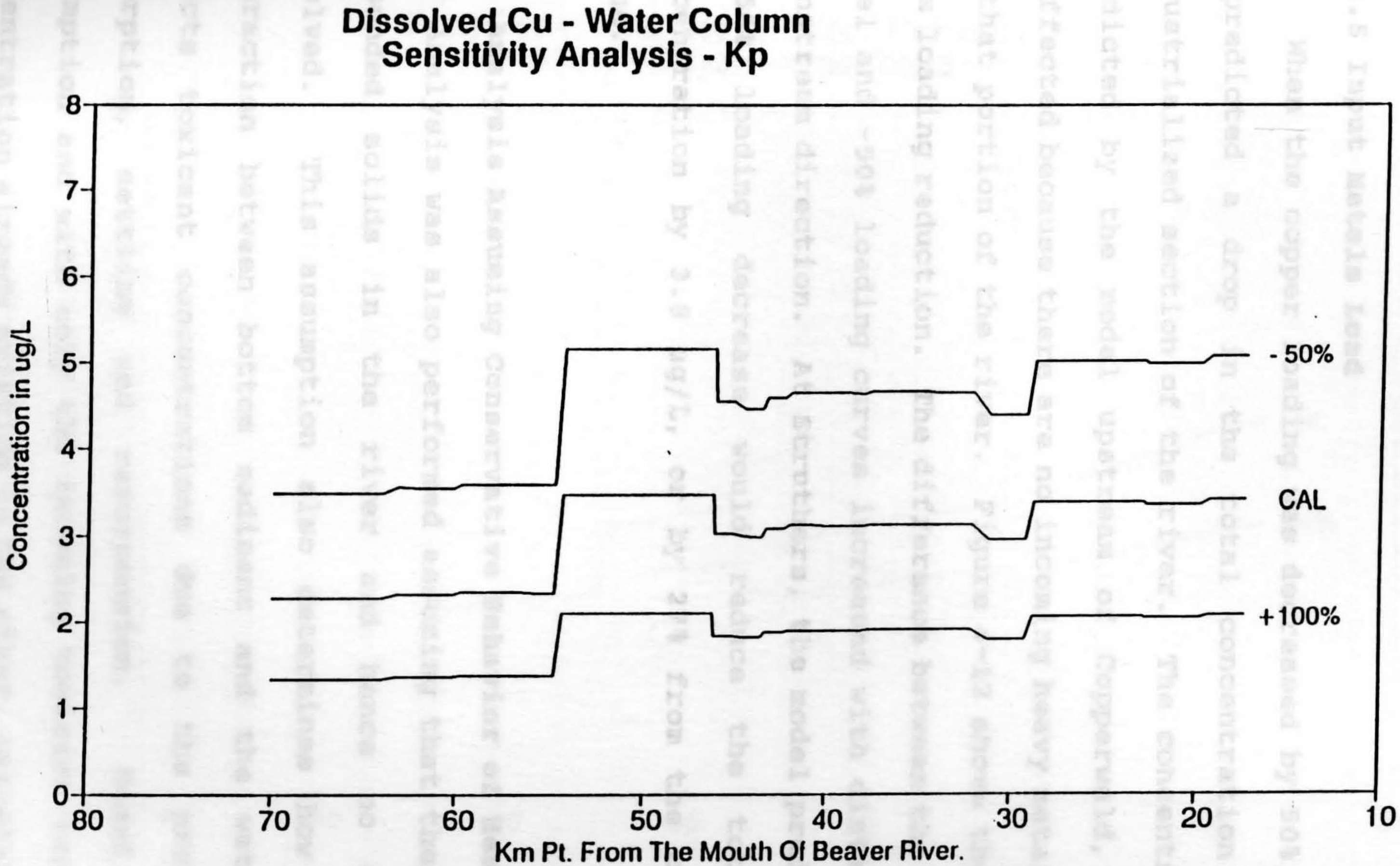

Figure 4-11: **Sensitivity Analysis Results for Dissolved Concentration of Copper in the Water Column With Variations in the Partition Coefficient. Concentration of Dissolved Copper (in $\mu g/L$) vs Km from the Mouth of the Beaver River.**

concentration. The total concentration remained almost similar in both the cases.

4.3.5 Input Metals Load

When the copper loading was decreased by 50%, the model a predicted a drop in the total concentration along the industrialized section of the river. The concentrations predicted by the model upstream of Copperweld, Inc. were unaffected because there are no incoming heavy metals loadings in that portion of the river. Figure 4-12 shows the effect of this loading reduction. The difference between the calibrated model and -50% loading curves increased with distance in the downstream direction. At Struthers, the model predicted that a 50% loading decrease would reduce the total copper concentration by 3.8 μg/L, or by 27% from the calibration value.

4.4 Analysis Assuming Conservative Behavior of Heavy Metals

Analysis was also performed assuming that there were no suspended solids in the river and hence no adsorption involved. This assumption also determines how much the interaction between bottom sediment and the water column affects toxicant concentrations due to the processes of adsorption, settling and resuspension. Based on this assumption and with only the incoming toxicant load and the concentration already existing in the river, calculations were

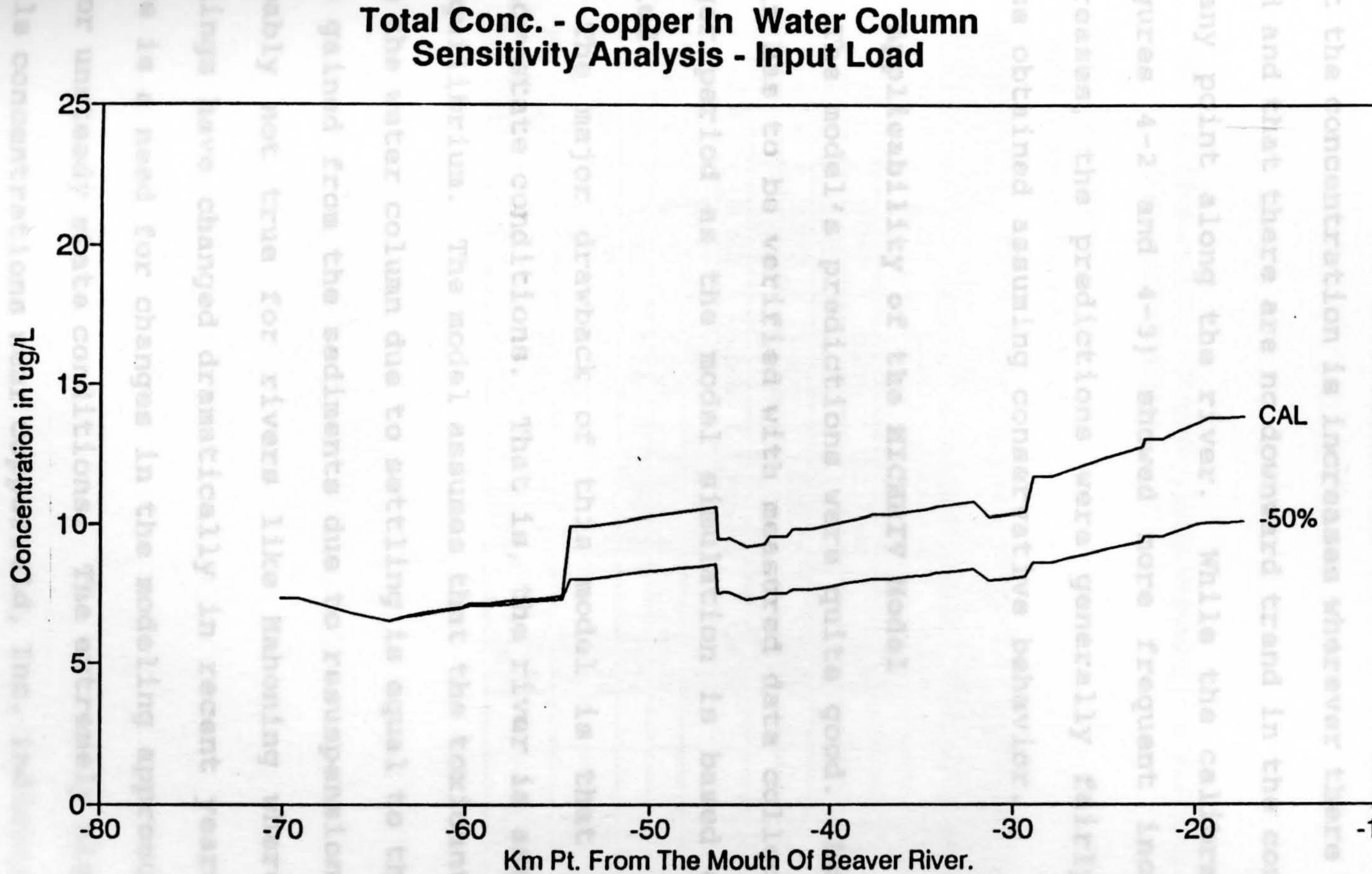

Figure 4-12: Sensitivity Analysis Results for Total Concentration of Copper in the Water Column Varying the Copper Load. Concentration of Total Copper (in μg/L) vs Km from the Mouth of the Beaver River

performed for chromium and copper. The Tables 4.3 and 4.4 shows the concentrations. Figures 4-13 and 4-14 show the behavior of the two metals. In these two cases it can be seen that the concentration is increases wherever there is an input load and that there are no downward trend in the concentration at any point along the river. While the calibrated curves (Figures 4-2 and 4-3) showed more frequent increases and decreases, the predictions were generally fairly close to those obtained assuming conservative behavior.

4.5 Applicability of the MICHRIV Model

The model's predictions were quite good. However this claim has to be verified with measured data collected over a longer period as the model simulation is based on a short period.

The major drawback of this model is that it assumes steady-state conditions. That is, the river is assumed to be at equilibrium. The model assumes that the toxicant mass lost from the water column due to settling is equal to the toxicant mass gained from the sediments due to resuspension. This is probably not true for rivers like Mahoning where toxicant loadings have changed dramatically in recent years. Hence, there is a need for changes in the modeling approach to adapt it for unsteady state conditions. The extremely high measured metals concentrations near Copperweld, Inc. indicated that the bottom sediments in the Mahoning River are not at steady-state

Table 4.3: Concentration of Chromium in the Mahoning River Assuming Conservative Behavior.

Base Flow = 16.66 m^3/s
Inital Concentration = 4.18 ug/L

KM POINT	INFLOW m^3/s	INPUT LOAD kg/d	INPUT LOAD kg/s	TOTAL FLOW m^3/s	TOTAL CONC. ug/l
70.13	0.000	0.000	0.00E+00	16.66	4.18
64.24	0.073	1.572	1.82E-05	16.73	5.27
59.8	0.047	0.218	2.52E-06	16.78	5.42
54.38	3.135	8.061	9.33E-05	19.92	10.10
46.31	3.372	1.404	1.62E-05	23.29	10.80
45.72	1.249	0.177	2.05E-06	24.54	10.88
43.46	0.280	1.506	1.74E-05	24.82	11.59
42.13	0.088	1.246	1.44E-05	24.90	12.16
37.74	0.219	1.042	1.21E-05	25.12	12.64
35.19	0.014	0.197	2.28E-06	25.14	12.74
32.36	1.646	0.208	2.41E-06	26.78	12.83
28.96	1.533	13.249	1.53E-04	28.32	18.24
22.84	0.169	0.054	6.20E-07	28.49	18.26
20.33	0.262	3.743	4.33E-05	28.75	19.77

Table 4.4: Concentration of Copper in the Mahoning River Assuming Conservative Behavior.

Base flow = 16.66 m^3/s
Initial Concentration = 7.5 ug/L

KM POINT	INFLOW m^3/s	INPUT LOAD kg/d	kg/s	TOTAL FLOW m^3/s	TOTAL CONC. ug/L
70.13	0.000	0.000	0.00E+00	16.66	7.50
64.24	0.073	0.190	2.20E-06	16.73	7.63
59.8	0.047	0.123	1.42E-06	16.78	7.72
54.38	3.135	6.156	7.13E-05	19.92	11.29
46.31	3.372	0.787	9.11E-06	23.29	11.68
45.72	1.249	0.246	2.85E-06	24.54	11.80
43.46	0.280	0.704	8.15E-06	24.82	12.13
42.13	0.088	0.277	3.21E-06	24.90	12.26
37.74	0.219	0.172	1.99E-06	25.12	12.34
35.19	0.014	0.000	0.00E+00	25.14	12.34
32.36	1.646	0.131	1.52E-06	26.78	12.39
28.96	1.533	3.975	4.60E-05	28.32	14.02
22.84	0.169	0.078	9.03E-07	28.49	14.05
20.33	0.262	0.681	7.88E-06	28.75	14.32

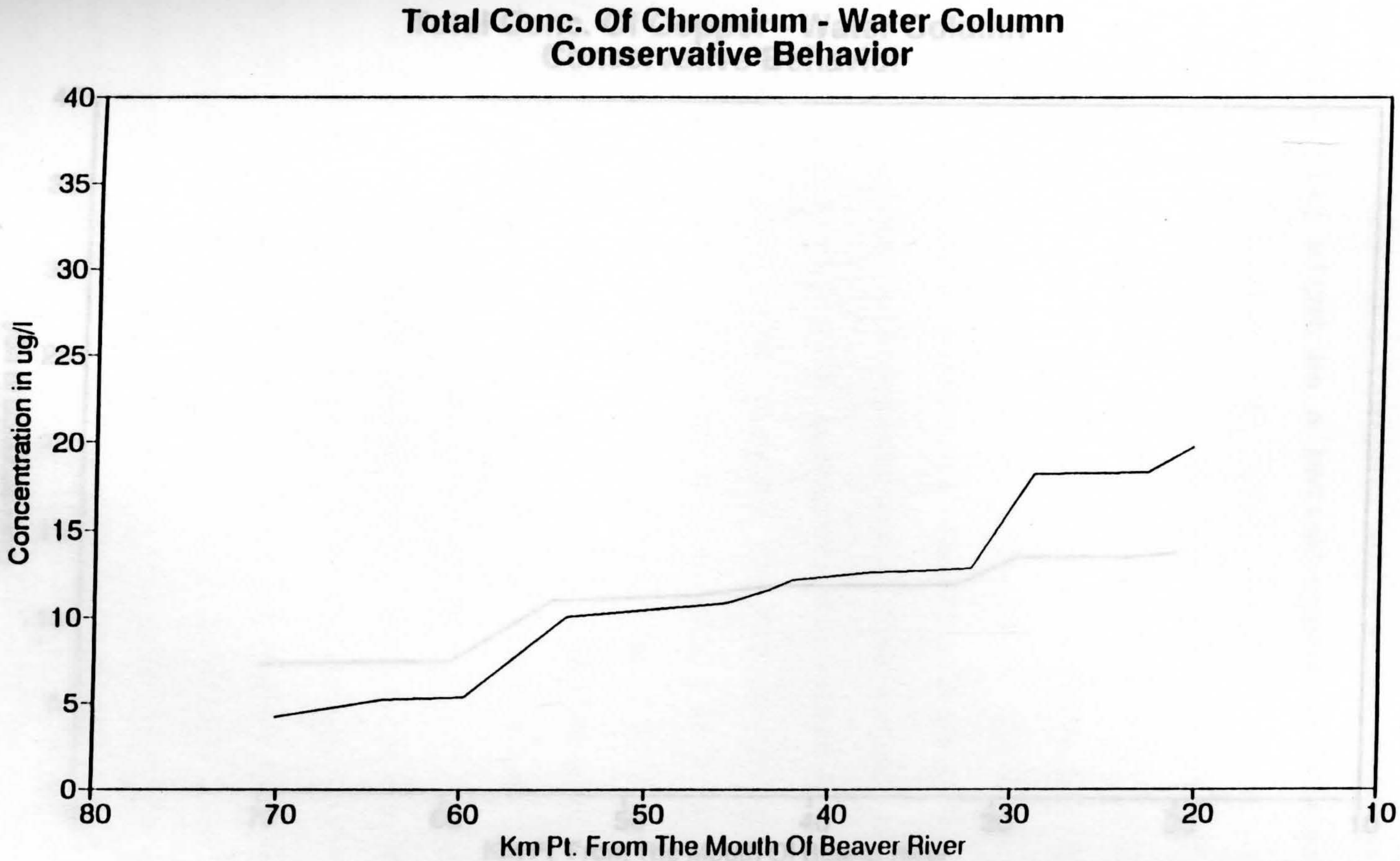

Figure 4-13: Total Concentration of Chromium in the Water Column Assuming Conservative Behavior. Concentration (in $\mu g/L$) vs Km from the Mouth of the Beaver River.

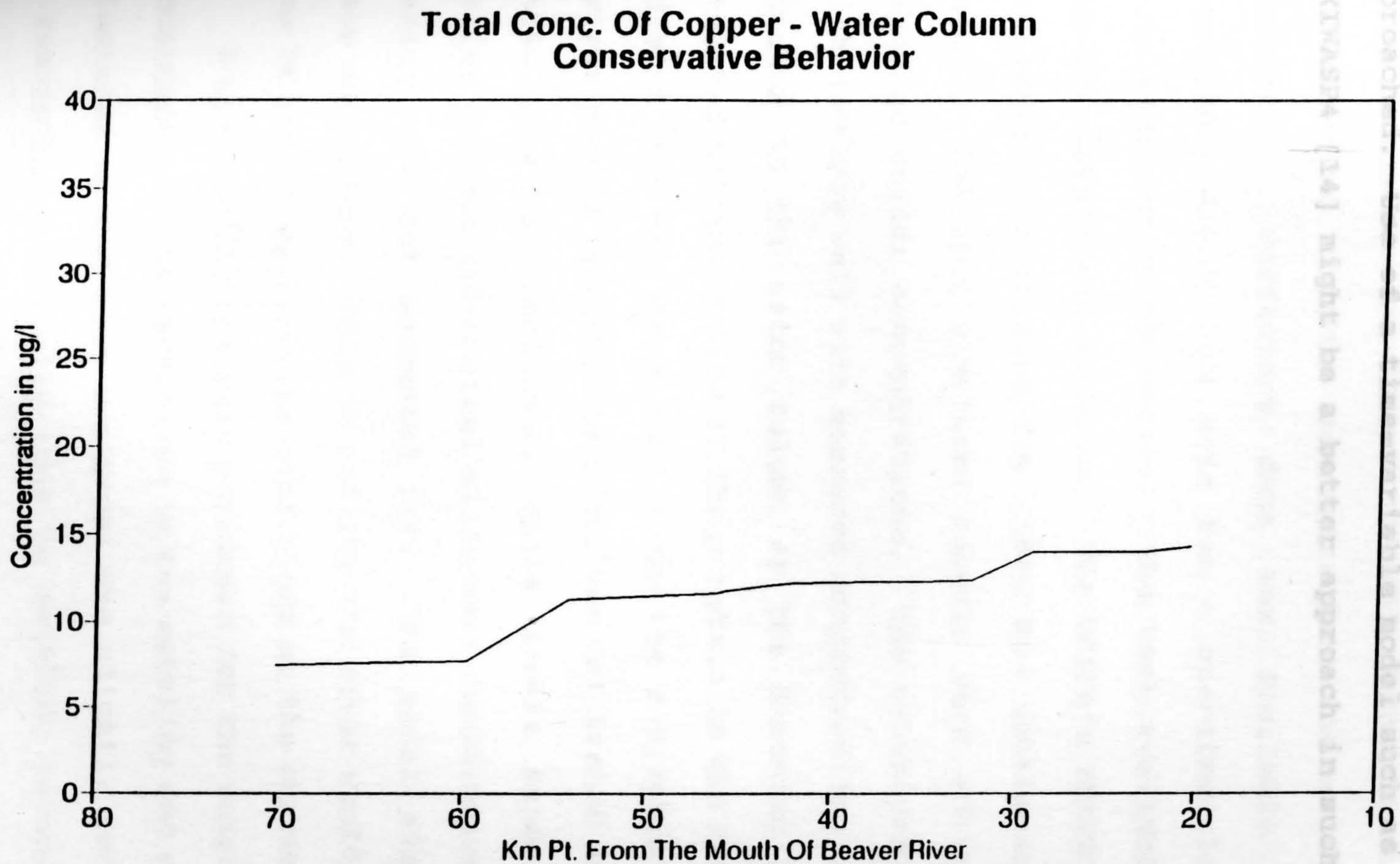

Figure 4-14: Total Concentration of Copper in the Water Column Assuming Conservative Behavior. Concentration (in $\mu g/L$) vs Km from the Mouth of the Beaver River.

with current loads. The continued collection of metals data on the water column and bottom sediments would allow evaluation of the rate at which steady-state is being approached. Use of a time-variable model such as the USEPA's TOXIWASP4 [14] might be a better approach in such cases.

CHAPTER 5

CONCLUSIONS AND RECOMMENDATIONS

Information on flows, channel geometry, heavy metals loadings and insitu concentrations were reviewed and tabulated. Sufficient data was available to develop preliminary input data sets for a one-dimensional, steady state model of heavy metals. The best available data sets were for copper and chromium. The USEPA's MICHRIV model was successfully calibrated for these two metals and suspended solids. The best simulated results were achieved for the suspended solids concentrations. The calibrated also model matched fairly well with measured concentrations of copper and chromium in the water column of the Mahoning River. The simulated concentrations of these metals in the river's bottom sediment did not agree well with the available data. One obvious reason is that, the model was calibrated under current (1989) loading conditions, while metals deposited during earlier periods (when steel mills were functioning) of higher loading were not accounted for. The model assumed steady state conditions, while in reality the river would take a long time to attain equilibrium conditions at the current loadings.

A sensitivity analysis performed for the suspended solids concentration with variations in the settling and resuspension velocities showed that the model was slightly more sensitive to resuspension velocity than to settling velocity. The calibration values of key model coefficients fell within the range of literature values.

A more precise calibration of the sediment concentrations of metals, can be achieved by a model that can work under unsteady state conditions. This study has shown that a time variable model such as USEPA's TOXIWASP4 [14] may be a better approach.

Also, monitoring of metals in the water column and bottom sediments should be continued to allow evaluation of the rate at which steady state is being approached.

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Appendix A

Table A1: Concentration of Heavy Metals in the Mahoning River at Leavittsburg-Leavitt Rd.(STORET Data: 1973-1991).

DATE	TOTAL Cd (ug/l)	TOTAL Cr (ug/l)	TOTAL Cu (ug/l)	TOTAL Fe. (ug/l)	TOTAL Ni (ug/l)	TOTAL Zn (ug/l)	TOTAL Pb (ug/l)
73/01/05				500.0			
73/01/11				600.0			
73/01/17				400.0			
73/01/23				400.0			
73/01/31				600.0			
73/02/07				1300.0			
73/02/15				500.0			
73/02/21				900.0			
73/02/27				500.0			
73/03/08				1000.0			
73/03/14				900.0			
73/03/23				300.0			
73/03/27				700.0			
73/04/06				1900.0			
73/04/12				700.0			
73/04/18				500.0			
73/04/27				2600.0			
73/05/03				1000.0			
73/05/09				1000.0			
73/05/18				600.0			
73/05/22				800.0			
73/05/31				800.0			
73/06/08				1000.0			
73/06/14				700.0			
73/06/20				1800.0			
73/06/27				500.0			
73/07/05	0.0	10.0	20.0	1100.0		0.0	0.0
73/07/11	0.0	10.0	0.0	1200.0		0.0	0.0
73/07/18			10.0	1500.0		1900.0	0.0
73/08/27		10.0		900.0		0.0	
73/09/18				1000.0		0.0	
73/10/16				800.0		0.0	
MEAN	0.0	10.0	10.0	906.3	0.0	316.7	0.0
STD. DE	0.0	0.0	8.2	483.4	0.0	708.1	0.0
COUNT	2.0	3.0	3.0	32.0	. 0.0	6.0	3.0
74/01/10			10.0	400.0		0.0	
74/01/23	0.0		0.0	1100.0		0.0	
74/02/07	0.0		0.0	600.0		0.0	
74/02/20			0.0	600.0			
74/03/06	0.0		0.0	1300.0			0.0
74/03/20	0.0		0.0	600.0			
74/04/03	0.0	0.0	0.0	6500.0		0.0	
74/04/17	0.0		0.0	800.0		0.0	60.0
74/05/01	0.0		0.0	1400.0			
74/05/15				1200.0		0.0	
74/05/29	0.0		0.0	1000.0		0.0	0.0
74/06/13			0.0	900.0		0.0	0.0
74/06/28			0.0	900.0		0.0	0.0
74/07/10			0.0	1000.0		0.0	0.0
74/07/24			0.0	1000.0		0.0	
74/08/07			0.0	1380.0		50.0	
74/08/21			0.0	1000.0		0.0	
74/09/04			0.0	1400.0		0.0	
74/09/18			0.0	1300.0		0.0	0.0
74/10/02							
74/11/13							
74/12/18	0.0		0.0			0.0	
MEAN	0.0	0.0	0.5	1283.2		3.1	8.6
STD. DE	0.0	0.0	2.2	1263.3		12.1	21.0
COUNT	9.0	1.0	19.0	19.0		16.0	7.0
75/02/13	10.0	30.0	30.0			30.0	
75/03/12							
75/04/24							
75/05/22			30.0			30.0	10.0
75/07/02							
75/10/16							
MEAN	10.0	30.0	30.0			30.0	10.0
STD. DE	0.0	0.0	0.0			0.0	0.0
COUNT	1.0	1.0	2.0			2.0	1.0
77/08/18	5.0	30.0	30.0	740.0	100.0	30.0	8.0
77/09/21		30.0	30.0	970.0	100.0	30.0	6.0
77/10/26		30.0	30.0	540.0	100.0	30.0	5.0
77/11/17		50.0	50.0	13800.0	100.0	500.0	50.0
MEAN	5.0	35.0	35.0	4012.5	100.0	147.5	17.3
STD. DE	0.0	8.7	8.7	5652.9	0.0	203.5	18.9
COUNT	1.0	4.0	4.0	4.0	4.0	4.0	4.0
78/01/03		30.0	30.0	710.0	100.0	50.0	19.0
78/02/02	5.0	30.0	30.0		100.0	80.0	13.0
78/03/09			30.0	620.0		70.0	
78/04/05	5.0	30.0	30.0	2040.0	100.0	30.0	5.0
78/05/10	5.0		30.0	1658.0	100.0	30.0	6.0
78/06/14			30.0	930.0			

Table A1 Continued....

78/07/26	5.0	30.0	30.0	1000.0	100.0	30.0	8.0
78/08/09							
78/09/20							
78/10/27	5.0	30.0	30.0		100.0	30.0	84.0
78/11/15				460.0			
78/12/07	5.0		30.0	560.0	100.0	30.0	10.0
MEAN	5.0	30.0	30.0	997.3	100.0	43.8	20.7
STD. DE	0.0	0.0	0.0	528.3	0.0	19.3	26.2
COUNT	6.0	5.0	9.0	8.0	7.0	8.0	7.0
79/01/02	5.0	30.0	30.0	3200.0	100.0	30.0	56.0
79/02/01							
79/03/07				990.0			28.0
79/04/04	5.0	30.0	30.0	3000.0	100.0	30.0	13.0
79/05/09							
79/06/19							
79/07/02				900.0			6.0
79/08/13	5.0	30.0	30.0	1000.0	100.0	30.0	8.0
79/09/24				1840.0			6.0
79/10/17							
79/11/13	5.0	30.0	30.0	660.0	100.0	30.0	5.0
79/12/27				2520.0			5.0
MEAN	5.0	30.0	30.0	1763.8	100.0	30.0	15.9
STD. DE	0.0	0.0	0.0	956.2	0.0	0.0	16.8
COUNT	4.0	4.0	4.0	8.0	4.0	4.0	8.0
80/01/14				1730.0			5K
80/02/07	5k		30K	710.0	100K	30.0	5K
80/03/05				630.0			10K
80/04/09				2400.0			
80/05/21	5K	30K	30K	1260.0	100K	30.0	5.0
80/06/23	1K	100.0	10K	1000.0	40K	5.0	5K
80/07/16	1K	40K	10.0	850.0	40K	25.0	9.0
80/07/28	1K	40K	5K	840.0	40K	5K	5K
80/08/11	1K	40K	5K	1000.0	50.0	5.0	5K
80/08/27	1K	40K	5.0	1080.0	40K	5K	10.0
80/09/08	1K	40K	5K	840.0	40K	15.0	8.0
80/09/22	1K	40K	5K	930.0	40K	15.0	5K
80/10/06	1K	40K	5K	740.0	40K	10.0	5K
80/11/17	5K	30K	30K	210.0	100K	30K	5K
80/12/08				340.0			
MEAN	0.0	25.0	1.4	970.7	4.5	12.3	2.5
STD. DE	0.0	28.7	3.1	515.2	14.4	11.2	3.8
COUNT	13.0	11.0	11.0	15.0	11.0	11.0	13.0
81/01/13				410.0			
81/02/11	5K	30K	30K	1090.0	100K	30.0	10K
81/03/11				510.0			
81/04/01				970.0			
81/05/05	5k	30K	30K	660.0	100K	30K	5K
81/06/10				2400.0			
81/07/08				1010.0			
81/08/26	5K	30K	30K	1040.0	100K	30.0	6.0
81/10/20	5K	30K	30K	550.0	100K	30.0	5K
81/12/15	.5K	30K	10K	430.0	30K	10K	5K
MEAN	0.0	0.0	0.0	907.0	0.0	18.0	1.2
STD. DE	0.0	0.0	0.0	558.2	0.0	14.7	2.4
COUNT	10.0	5.0	5.0	10.0	6.0	5.0	5.0
82/01/13	.5K	30K	10K	1470.0	40K	10K	5K
82/03/29	.5K	30K	10.0	750.0	40K	10.0	7.0
82/04/22							
82/05/20		30K	10K	710.0	40K	10K	
82/06/10							
82/08/25	.5K	30K	10K	860.0	40K	30.0	7.0
82/09/28	.5K	30K	10.0	830.0	40K	20.0	4.0
82/10/14							
82/11/17							
82/12/06	.5K	30K	10K	610.0	40K	10K	2.0
MEAN	0.0	0.0	3.3	871.7	0.0	10.0	4.0
STD. DE	0.0	0.0	4.7	279.7	0.0	11.5	2.8
COUNT	9.0	7.0	6.0	6.0	9.0	6.0	5.0
83/01/11							
83/02/17	.5K	30K	10K	560.0	40K	10K	2.0
83/03/03							
83/04/18							
83/05/02							
83/06/13							
83/07/21	.5K	30K	10K	980.0	40K	10K	2.0
83/08/18	.5K	30K	10K	870.0	40K	60.0	4.0
83/09/01	.5K	30K	10K	880.0	40K	10.0	2.0
83/10/13	.2K	30K	10K	540.0	40K	15.0	2.0
83/11/03		30K	10K	520.0	40K	15.0	2K
MEAN	0.0	0.0	0.0	725.0	0.0	16.7	2.0
STD. DE	0.0	0.0	0.0	188.7	0.0	20.3	1.2
COUNT	5.0	6.0	6.0	6.0	6.0	6.0	6.0
84/01/10	.2K	30K	10K	600.0	40K	10	3.0
84/03/07	.2	30K	10K	760.0	40K	15	2.0
84/04/10			10K	750.0	40K	10K	2K

Table A1 Continued...

84/05/08			10K	760.0		10K	2K
84/06/28			10	1190.0	10K		2.0
84/07/17	.2K		10K	1030.0		20	3
84/08/27			15	990.0		20	2
84/09/11	.2K	30K	10K	870.0	50	15	2
84/10/09	.2K	30K	10K	650.0	40K	10	2K
84/12/26	.2K	30K	10K	490.0	40K	10K	2K
MEAN	0.0	0.0	0.0	809.0	0.0	0.0	0.7
STD.DEV	0.0	0.0	0.0	202.4	0.0	0.0	1.1
COUNT	6.0	5.0	10.0	10.0	7.0	9.0	10.0
85/01/23	.2K		10	480.0	40K	10	2.0
85/02/20	.2K	30K	10K	600.0	40K	10	4.0
85/03/07			10K	1130.0	40K	15	
85/04/17			10K	840.0	40K	10K	4.0
85/05/23			10K	950.0	40K	10K	3.0
85/06/17			10K	1280.0	40K	15	3.0
85/07/24	.2K	30K	10K	940.0	40K	10K	
85/08/21			10K	780.0	40K	10K	4.0
85/09/04			10K	690.0	40K	10K	2.0
85/10/08	.2K	30K	25	560.0	40K	10	2K
85/11/13	.2K	30K	15	1020.0	40K	15	5.0
85/12/10			10K	670.0	40K	65	3.0
MEAN	0.0	0.0	0.0	828.7	0.0	0.0	3.0
STD.DEV	0.0	0.0	0.0	229.8	0.0	0.0	1.3
COUNT	5.0	4.0	12.0	12.0	12.0	12.0	10.0
86/01/16	.2K		10K	630.0	40K	10K	3.0
86/02/19		30K	10K	1740.0	200K	30.0	2.0
86/03/26	.2K	30K	10K	1020.0	40K	10.0	5.0
86/04/16	.2K	30K	10K	920.0	40K	20.0	2.0
86/05/08	.2K	30K	10K	1320.0	40K	20.0	2K
86/06/10	.2K	30K	10K	1890.0	40K	10K	3.0
86/07/10	.2K	30K	10	2810.0	40K	205.0	3.0
86/08/13	.2K	30K	10K	2020.0	40K	40.0	4.0
86/09/24	.2K	30K	10K	2190.0	40K	30.0	4.0
86/10/08	.2K	30K	10K	2510.0	40K	25.0	5.0
86/11/12	.2K	30K	10K	1040.0	40K	10.0	3.0
86/12/10	.2K		10K	2910.0	40K	25.0	4.0
MEAN	0.0	0.0	0.0	1750.0	0.0	34.6	3.2
STD.DEV	0.0	0.0	0.0	735.9	0.0	52.7	1.3
COUNT	11.0	10.0	12.0	12.0	12.0	12.0	12.0
87/01/06	.2K	30K	10K	1280.0	40K	35.0	8.0
87/02/04	.2K	30K	10K	1070.0	40K	15.0	4.0
87/03/19	.2K	30K	10K	1180.0	40K	10.0	3.0
87/04/09	.2K	30K	10K	3800.0	40K	30.0	5.0
87/05/28	.2K	30K	10K	2360.0	40K	20.0	3.0
87/06/18	.2K	30K	10K	2080.0	40K	15.0	4.0
87/07/23	.2K	30K	10K	2040.0	40K	15.0	4.0
87/08/20	.2K	30K	10K	2310.0	40K	10K	4.0
87/09/16	.2K	30K	10K	1940.0	40K	60.0	5.0
87/10/26	.2K	30K	10K	1080.0	40K	10K	3.0
87/11/23		30K	10K	540.0	40K	10K	2K
87/12/17		30K	10K	1200.0	40K	10K	2K
MEAN	0.0	0.0	0.0	1738.3	0.0	16.7	3.6
STD.DEV	0.0	0.0	0.0	833.0	0.0	17.2	2.1
COUNT	10.0	12.0	12.0	12.0	12.0	12.0	12.0
88/01/28							
88/02/29							
88/03/21							
88/04/27							
88/05/26							
88/06/07							
88/06/30							
88/07/19							
88/08/11	.2K	30K	10K	1080.0	40K	15.0	2.0
88/09/07	.2K	30K	10	1460.0	40K	20.0	2K
88/10/05	.2K	30K	10K	1380.0	40K	20.0	2K
88/11/02	.2K	30K	10K	530.0	40K	30.0	2K
88/11/30	.2K	30K	10K	750.0	40K	35.0	2K
MEAN	0.0	0.0	0.0	1040.0	0.0	24.0	0.0
STD.DEV	0.0	0.0	0.0	357.2	0.0	7.3	0.0
COUNT	5.0	5.0	5.0	5.0	5.0	5.0	5.0
89/01/24				500.0	40K	10K	11.0
89/02/02				730.0	40K	10K	2K
89/03/28				1070.0	0.0	10K	2K
89/04/24	.2K	30K	10K	1290.0	40K	80	2K
89/05/16	.2K	30K	10K	3370.0	40K	25	5.0
89/06/17	.2K	30K	65	1830.0	40K	20	3.0
89/07/24	.2K	30K	40	1420.0	40K	25	3.0
89/08/21	.2K	30K	40	1130.0	40K	15	3.0
89/09/21	.2K	30K	10K	1380.0	40K	15	14.0
89/10/25	.2K	30K	10K	930.0	40K	10K	2K
89/11/14	.2K	30K	10K	520.0	40K	10K	2K
89/12/28	.2K	30K	10K	420.0	40K	10K	2K
MEAN	0.0	0.0	0.0	1365.6	0.0	0.0	3.1
STD.DEV	0.0	0.0	0.0	767.5	0.0	0.0	4.5
COUNT	9.0	9.0	9.0	12.0	12.0	12.0	12.0

Table A1 Continued...

90/01/03	.2K	30K	10K	1180.0	40K	15	2K
90/02/20	.2K	30K	10K	1370.0	40K	10K	2K
90/03/19	.2K	30K	10K	1440.0		10	2K
90/04/26	.2K	30K	10K	1730.0	40K	15	9
90/05/29	.2K	30K	10K	2150.0		15	2
90/06/27	.2K	30K	10K	1780.0	40K	10K	2
90/07/31	.2K	30K	10K	3960.0	40K	15	2K
90/08/29	.2K	30K	10K	1240.0		35	2
90/09/24	.2K	30K	10K	1960.0	40K	10	2K
90/10/25	.2K	30K	10K	1480.0	40K	10K	2K
90/11/15	.2K	30K	10K	710.0	40K	60	2K
90/12/10	.2K	30K	10K	570.0	0.0	10K	11
MEAN	0.0	0.0	0.0	1630.8	0.0	0.0	0.0
STD.DEV	0.0	0.0	0.0	831.2	0.0	0.0	0.0
COUNT	12.0	12.0	12.0	12.0	10.0	12.0	12.0
91/01/15	.2K	30K	10K	1540.0	40K	10K	2K
91/02/21	.2K	30K	10K	2450.0	40K	10	2K
91/03/21	.2K	30K	10K	1000.0	40K	10K	2K
MEAN	0.0	0.0	0.0	1663.3	0.0	0.0	0.0
STD.DEV	0.0	0.0	0.0	598.3	0.0	0.0	0.0
COUNT	3.0	3.0	3.0	3.0	3.0	3.0	3.0

Table A2: Concentration of Heavy Metals in the Mahoning River at Lowellville-First St.(STORET Data:1973-1991).

DATE	TOTAL Cd (ug/l)	TOTAL Cr (ug/l)	TOTAL Cu (ug/l)	TOTAL Fe. (ug/l)	TOTAL Ni (ug/l)	TOTAL Zn (ug/l)	TOTAL Pb (ug/l)
73/01/05				2800.0			
73/01/11				5500.0			
73/01/17				7800.0			
73/01/23				5500.0			
73/01/31				1900.0			
73/02/07				8800.0			
73/02/15				6700.0			
73/02/21				4500.0			
73/02/27				5000.0			
73/03/08				6000.0			
73/03/14				4100.0			
73/03/23				2800.0			
73/03/27				4300.0			
73/04/06				9700.0			
73/04/12				3100.0			
73/04/18				2200.0			
73/04/27				3600.0			
73/05/03		0.0		3300.0			
73/05/09		0.0		5300.0			
73/05/18				2400.0			
73/05/22				5000.0			
73/05/31				2800.0			
73/06/08				3800.0			
73/06/14				3300.0			
73/06/20				5300.0			
73/06/27				3100.0			
73/07/05	0.0			2900.0		200.0	0.0
73/07/11	0.0		20.0	3500.0		100.0	0.0
73/07/18			10.0	2600.0		100.0	0.0
73/08/27				1800.0		200.0	
73/09/18				2100.0		300.0	
73/10/16				3600.0		200.0	
MEAN	0.0	0.0	15.0	4196.9	0.0	183.3	0.0
STD. DEV	0.0	0.0	5.0	1934.0	0.0	68.7	0.0
COUNT	2.0	2.0	2.0	32.0	0.0	6.0	3.0
74/01/10			20.0	4600.0		200.0	
74/01/23	0.0		20.0	3300.0		200.0	
74/02/07	0.0		40.0	4400.0		300.0	
74/02/20			0.0	7000.0		700.0	
74/03/06	0.0		0.0	4400.0			0.0
74/03/20	0.0		0.0	2800.0			
74/04/03	200.0	20.0	0.0	5900.0		200.0	
74/04/17	0.0		0.0	3300.0		100.0	800.0
74/05/01	0.0		50.0			900.0	
74/05/15	0.0	20.0	0.0	4300.0		0.0	0.0
74/05/29	0.0		30.0	2800.0		200.0	0.0
74/06/13	0.0		30.0	2800.0		100.0	
74/06/28			0.0	2800.0		100.0	0.0
74/07/10	0.0		20.0	2800.0		100.0	0.0
74/07/24			0.0	2400.0		0.0	
74/08/07	0.0		0.0	2400.0		130.0	
74/08/21			0.0	2900.0		130.0	0.0
74/09/04			0.0	4300.0		200.0	
74/09/18			20.0	3800.0		100.0	0.0
74/10/02			0.0	4900.0		200.0	
74/10/16			20.0	3900.0		220.0	
74/10/30			10.0	4600.0		280.0	0.0
74/11/13			0.0			280.0	0.0
74/12/18	0.0		0.0			180.0	
MEAN	15.4	20.0	10.8	3619.0	0.0	217.3	80.0
STD. DEV	53.3	0.0	14.7	1167.7	0.0	201.3	240.0
COUNT	13.0	2.0	24.0	21.0	0.0	22.0	10.0
75/01/16							
75/02/13	10.0	40.0	40.0			340.0	25.0
75/03/12	10.0	30.0	40.0			230.0	210.0
75/04/06			30.0			170.0	30.0
75/04/24			3.0			310.0	40.0
75/05/22			30.0			360.0	55.0
75/07/02			30.0	1440.0		140.0	10.0
75/10/16			30.0			200.0	23.0
75/12/17	10.0	50.0	60.0	4700.0		390.0	30.0
MEAN	10.0	40.0	32.9	3070.0	0.0	267.5	52.9
STD. DEV	0.0	8.2	14.8	1630.0	0.0	86.3	60.6
COUNT	3.0	3.0	8.0	2.0	0.0	8.0	8.0
76/01/22		0.0					0.0
76/02/26			0.0				
76/03/24	10.0	30.0	30.0	2900.0		150.0	27.0
76/04/21							
76/05/06							
76/06/17	10.0	30.0	30.0	2710.0		130.0	15.0
76/07/07							
76/08/18							
76/09/23	5.0	70.0	30.0			310.0	16.0
76/10/06							
76/10/28							
76/11/23		30.0	230.0	4230.0		130.0	12.0
76/12/29		40.0	30.0	3990.0		140.0	10.0

Table A2 Continued...

MEAN	8.3	33.3	58.3	3457.5	0.0	172.0	13.3
STD. DEV	2.4	20.5	77.5	661.4	0.0	69.4	8.0
COUNT	3.0	6.0	6.0	4.0	0.0	5.0	6.0
77/01/27				3740.0	100.0	340.0	32.0
77/02/24			70.0		110.0	880.0	230.0
77/03/17			30.0			250.0	22.0
77/04/28				2660.0		280.0	62.0
77/05/18		30.0	30.0	1090.0		110.0	11.0
77/06/16	5.0	30.0	30.0	1790.0	100.0	210.0	35.0
77/07/20		30.0	30.0	1250.0		100.0	22.0
77/08/18	5.0	30.0	30.0	1910.0	100.0	100.0	22.0
77/09/21		30.0	30.0	3000.0	100.0	160.0	22.0
77/10/26		30.0	30.0	2400.0	100.0	140.0	9.0
77/11/17		30.0	30.0	1900.0	100.0	30.0	5.0
MEAN	5.0	30.0	34.4	2193.3	101.4	236.4	42.9
STD. DEV	0.0	0.0	12.6	798.6	3.5	221.3	61.0
COUNT	2.0	7.0	9.0	9.0	7.0	11.0	11.0
78/01/03		30.0	30.0		100.0	180.0	22.0
78/02/02	5.0	30.0	30.0		100.0	210.0	28.0
78/03/09				2470.0		180.0	
78/04/05	5.0	30.0	30.0	4060.0	100.0	170.0	32.0
78/05/10	5.0		70.0	4900.0	100.0	160.0	23.0
78/05/17							
78/06/14				1600.0			
78/07/26	5.0	30.0	30.0	1370.0	100.0		17.0
78/08/09				1790.0			
78/09/20				1770.0			
78/10/27	5.0	30.0		3110.0	100.0	30.0	480.0
78/11/15				2500.0			
78/12/07	5.0		30.0	4700.0	100.0	160.0	36.0
MEAN	5.0	30.0	36.7	2829.0	100.0	155.7	91.1
STD. DEV	0.0	0.0	14.9	1245.4	0.0	53.7	158.9
COUNT	6.0	5.0	6.0	10.0	7.0	7.0	7.0
79/01/02	5.0	70.0	40.0	*******	100.0	470.0	144.0
79/02/01				5000.0	100.0		
79/03/07				2970.0			104.0
79/04/04	5.0	30.0	30.0	6600.0		140.0	44.0
79/05/09				1360.0	100.0		
79/06/19				1530.0			
79/07/02				1500.0			32.0
79/08/13	5.0	40.0	30.0	1300.0		70.0	20.0
79/09/24				2590.0	100.0		17.0
79/10/17				2510.0			
79/11/13	5.0	30.0	30.0	2930.0	100.0	90.0	37.0
79/12/27				5900.0			31.0
MEAN	5.0	42.5	32.5	4515.8	100.0	192.5	53.6
STD. DEV	0.0	16.4	4.3	4976.6	0.0	162.2	42.6
COUNT	4.0	4.0	4.0	12.0	5.0	4.0	8.0
80/01/14				4100.0			21.0
80/02/07	5.0		30.0	2580.0	100.0	130.0	26.0
80/03/05				2250.0			27.0
80/04/09				2500.0			
80/05/21	5K	30K	30.0	1350.0	100.0	60.0	14.0
80/06/23	1K	100.0	10K	840.0	40.0	70.0	8.0
80/07/16	1K	40K	5.0	970.0	50.0	60.0	8.0
80/07/28	1K	40K	10.0	2120.0	50.0	100.0	22.0
80/08/11	1K	70.0	10.0	1230.0	60.0	55.0	12.0
80/08/27	1K	40K	5K	1040.0	40K	145.0	13.0
80/09/08	1K	40K	5.0	700.0	40K	50.0	6.0
80/09/22	1K	40K	5K	710.0	40K	85.0	9.0
80/10/06	1K	40K	5K	840.0	40K	120.0	5K
80/11/17	5K	30K	30K	1180.0	100K	270.0	29.0
80/12/08				1480.0			
MEAN	0.4	42.5	8.2	1592.7	36.4	104.1	15.0
STD. DEV	1.3	33.4	10.9	915.4	37.7	61.0	8.8
COUNT	13.0	11.0	11.0	15.0	11.0	11.0	13.0
81/01/13				2970.0			
81/02/11	5K	30.0	30.0	*******	100K	220.0	47.0
81/03/11				1960.0			
81/04/01				4100.0			
81/05/05	30K	30K	30K	2140.0	100K	50.0	16.0
81/06/10				3600.0			
81/07/08				940.0			
81/08/26	5K	30K	30K	770.0	100K	50.0	10.0
81/10/20	5K	30K	30K	1500.0	100K	30K	12.0
81/12/15	.5K	30K	15.0	940.0	30K	195.0	11.0
MEAN	0.0	6.0	9.0	3032.0	0.0	103.0	19.2
STD. DEV	0.0	12.0	12.0	2994.2	0.0	87.6	14.0
COUNT	10.0	5.0	5.0	10.0	6.0	5.0	5.0
82/01/13	.5K	30K	10.0	1430.0	40K	255.0	5K
82/03/29	.5K	30K	20.0	1010.0	40K	40.0	8.0
82/04/29				88.0			
82/05/11		30K	15.0	600.0	40K	120.0	8.0
82/06/10							
82/08/11	1K	20.0	15.0	1160.0	40K	105.0	23.0
82/09/14	.5K	30K	15.0	570.0	40K	90.0	5.0
82/10/14							
82/11/03	.5K	30K	20.0	930.0	40K	80.0	15.0
82/12/06	.5K	30K	10.0	1230.0	40K	185.0	8.0

Table A2 Continued....

MEAN	0.0	2.5	15.0	877.3	0.0	125.0	9.6
STD. DEV	0.0	6.6	3.8	408.9	0.0	67.0	6.9
COUNT	10.0	8.0	7.0	8.0	10.0	7.0	7.0
83/01/11							
83/02/17	.5K	30K	10K	980.0	40K	160.0	14.0
83/03/03							
83/04/18							
83/05/02							
83/06/13							
83/07/21	.5K	30K	10K	440.0	40K	45.0	2.0
83/08/18	.5K	30K	10K	360.0	40K	40.0	4.0
83/09/01	.5K	30K	10K	480.0	40K	50.0	4.0
83/10/13	.2K	30K	10K	630.0	40K	85.0	5.0
83/11/03	0.2	30K	10.0	1330.0	40K	150.0	13.0
83/12/19							
MEAN	0.0	0.0	1.4	703.3	0.0	88.3	7.0
STD. DEV	0.1	0.0	3.5	344.4	0.0	49.4	4.7
COUNT	12.0	7.0	7.0	6.0	12.0	6.0	6.0
84/01/10	0.2	40.0	10K	1340.0	40K	200.0	13.0
84/03/07	0.2	30K	15.0	1580.0	40K	100.0	20.0
84/04/10			10K	910.0	40K	50.0	5.0
84/05/08			10K	1230.0		65.0	6.0
84/06/28			10.0	690.0	40K		5.0
84/07/17			10K	1400.0		70.0	11.0
84/08/27			10.0	510.0		50.0	4.0
84/09/11	0.2	30K	10K	890.0	60.0	200.0	5.0
84/10/09	.2K	30K	10K	640.0	40K	85.0	7.0
84/12/26	.2K	30K	10K	740.0	40K	70.0	3.0
MEAN	0.1	4.0	3.5	993.0	8.6	98.9	7.9
STD. DEV	0.1	12.0	5.5	349.0	21.0	56.0	5.0
COUNT	10.0	10.0	10.0	10.0	7.0	9.0	10.0
85/01/23	0.3	30K	15.0	1000.0	50.0	190.0	10.0
85/02/20	0.3	30K	15.0	1050.0	40K	230.0	7.0
85/03/07	2.0	30.0	10K	1870.0	40K	70.0	9.0
85/04/17	.2K	30K	10K	540.0	40K	40.0	5.0
85/05/23	.2K	30K	10K	620.0	40K	40.0	3.0
85/06/17'	42.0		10.0	830.0	40K	130.0	9.0
85/07/24	.2K	30K	10K	480.0	40K	40.0	
85/08/21	.2K	30K	10K	650.0	40K	10K	5.0
85/09/04			10K	720.0	40K	40.0	15.0
85/10/08	.2K	30K	25.0	570.0	40K	35.0	10.0
85/11/13	.2K	30K	15.0	1460.0	40K	125.0*	18.0
85/12/10			10K	1240.0	40K	45.0	4.0
MEAN	3.7	2.5	6.7	919.2	4.2	82.1	8.6
STD. DEV	11.6	8.3	8.5	407.4	13.8	67.8	4.4
COUNT	12.0	12.0	12.0	12.0	12.0	12.0	11.0
86/01/16							
86/02/19							
86/03/26	.2K	30K	15.0	920.0	40K	75.0	18.0
86/04/16	.2K	30K	10K	810.0	40K	80.0	8.0
86/05/08	.2K	30K	20.0	1890.0	40K	190.0	11.0
86/06/10	.2K	30K	10K	1160.0	40K	60.0	5.0
86/07/10	0.2	30K	20.0	7030.0	40K	10K	24.0
86/08/13	.2K	30K	10K	650.0	40K	20.0	4.0
86/09/24	.2K	30K	10.0	2790.0	40K	140.0	14.0
86/10/08	.2K	30K	10K	2560.0	40K	85.0	15.0
86/11/12	.2K	30K	10K	800.0	40K	65.0	7.0
86/12/10	.2K	30K	10K	2800.0	40K	65.0	11.0
MEAN	0.0	0.0	5.4	2141.0	0.0	78.0	11.7
STD. DEV	0.1	0.0	8.0	1823.3	0.0	51.5	5.9
COUNT	12.0	12.0	12.0	10.0	12.0	10.0	10.0
87/01/06	.2K	30K	10K	980.0	40K	115.0	4.0
87/02/04	.2K	30K	10K	1120.0	40K	815.0	8.0
87/03/19	.2K	30K	15.0	1190.0	40K	70.0	8.0
87/04/09	.2K	30K	10K	2180.0	40K	60.0	7.0
87/05/28	.2K	30K	10K	540.0	40K	50.0	6.0
87/06/18	.2K	30K	10K	410.0	40K	45.0	4.0
87/07/23	0.2	30K	10K	670.0	40K	45.0	5.0
87/08/20	.2K	30K	10K	500.0	40K	30.0	5.0
87/09/16	.2K	30K	10K	660.0	40K	35.0	10.0
87/10/26	.2K	30K	10K	1030.0	40K	90.0	17.0
87/11/23	.2K	30K	10K	650.0	40K	45.0	6.0
87/12/17	.2K	30K	10K	2010.0	40K	100.0	10.0
MEAN	0.0	0.0	1.3	995.0	0.0	125.0	7.5
STD.DEV	0.1	0.0	4.1	549.3	0.0	209.6	3.5
COUNT	12.0	12.0	12.0	12.0	12.0	12.0	12.0
88/01/28	.2K	30K	10K	1040.0	40K	75.0	10.0
88/02/29			10K	870.0	40K	30.0	5.0
88/03/21			10K	910.0		60.0	5.0
88/04/27			10K	720.0	40K	30.0	12.0
88/05/26			10K	740.0	40K	45.0	5.0
88/06/07			10K	530.0		30.0	7.0
88/07/13			10K	1400.0		70.0	9.0
88/O8/11			10K	1830.0	40K	90.0	13.0
88/09/07			10K	2220.0	40K	115.0	10.0
88/10/05			10K	1230.0	40K	75.0	9.0
88/11/02	.2K	30K	10K	980.0	40K	100.0	9.0
88/11/30	.2K	30K	10K	1330.0	40K	75.0	6.0
MEAN	ERR	0.0	0.0	1148.3	0.0	66.3	8.3
STD.DEV	0.0	0.0	0.0	468.2	0.0	27.0	2.6

Table A2 Continued...

COUNT	12.0	12.0	12.0	12.0	12.0	12.0	12.0
89/01/24	.2K	30K	10K	650.0	40K	45.0	16.0
89/02/02	0.2	30K	10K	1030.0	40K	75.0	7.0
89/03/28	.2K	30K	10K	820.0	40K	270.0	10.0
89/04/24	.2K	30K	10K	1580.0	40K	190.0	11.0
89/05/16	.2K	30K	10.0	2580.0	40K	95.0	12.0
89/06/13	.2K	30K	125.0	2080.0	40K	110.0	20.0
89/07/24	.2K	30K	35.0	1390.0	40K	60.0	12.0
89/08/21	.2K	30K	45.0	1110.0		60.0	20.0
89/09/21	.2K	30K	15.0	1510.0	40K	90.0	11.0
89/10/25	.2K	30K	10K	1070.0	40K	35.0	4.0
89/11/19	.2K	30K	10K	1040.0	40K	30.0	6.0
89/12/28	.2K	30K	10K	420.0	40K	30.0	12.0
MEAN	1.5	0.0	19.2	1270.0	0.0	90.8	11.8
STD.DEV	0.1	0.0	35.1	573.1	0.0	69.0	4.8
COUNT	12.0	12.0	12.0	12.0	12.0	12.0	12.0
90/01/03	.2K	30K	10K	1990.0	40K	35.0	7.0
90/02/20	.2K	40.0	15.0	1420.0	40K	25.0	3.0
90/03/19	.2K	30K	10K	1040.0	40K	35.0	6.0
90/04/26	.2K	30K	10K	1080.0	40K	25.0	8.0
90/05/29	.2K	30K	10K	1980.0		50.0	12.0
90/06/27	.2K	30K	10K	1630.0	40K	30.0	13.0
90/07/31	.2K	30K	10K	6340.0	40K	85.0	21.0
90/08/29	.2K	30K	10K	1390.0		30.0	7.0
90/09/24	.2K	30K	10K	2140.0	40K	30.0	5.0
90/10/25	.2K	30K	10K	1640.0	40K	20.0	4.0
90/11/15	.2K	30K	10K	660.0	40K	10K	2K
90/12/10	.2K	30K	10K	610.0	40K	10.0	2.0
MEAN	0.0	3.3	1.3	1823.3	0.0	31.3	7.3
STD.DEV	0.0	11.1	4.1	1443.1	0.0	20.2	5.5
COUNT	12.0	21.0	12.0	12.0	12.0	12.0	12.0
91/01/15	.2K	30K	10K	1210.0	40K	10K	2K
91/02/21	.2K	30K	10K	3560.0	40K	30.0	5.0
91/03/21	.2K	30K	10K	870.0		20.0	5.0
MEAN	0.0	0.0	0.0	1880.0	0.0	16.7	3.3
STD.DEV	0.0	0.0	0.0	1196.0	0.0	12.5	2.4
COUNT	12.0	12.0	12.0	12.0	12.0	12.0	12.0

APPENDIX B

Table B1: Summary of the Input Data for Model Calibration of Chromium.

RUNID: DATE: 10/21/1992 TIME: 20:17:27

INITIAL CONDITIONS

NUMBER OF REACHES = 14
KM FROM MOUTH = 70.13
NUMBER OF SYSTEMS = 2

INITIAL FLOW, QB - M^3/SEC = 16.66
SUSPENDED SOLIDS - MG/L = 24.200
TOXICANT CONC - UG/L = 4.180

SYSTEM INPUT LOAD(KG/DAY) 1 = 6.017
SYSTEM INPUT LOAD(KG/DAY) 2 = 34834.062

RUNID: DATE: 10/21/1992 TIME: 20:17:27

REACH INPUT VARIABLES

RATES:

REACH NUM	KV M/DAY	KH 1/DAY	KB 1/DAY	KP 1/DAY	KD M/DAY	K1 1/DAY	K2 1/DAY
1	0.00	0.00	0.00	0.00	0.01	0.00	0.00
2	0.00	0.00	0.00	0.00	0.01	0.00	0.00
3	0.00	0.00	0.00	0.00	0.01	0.00	0.00
4	0.00	0.00	0.00	0.00	0.01	0.00	0.00
5	0.00	0.00	0.00	0.00	0.01	0.00	0.00
6	0.00	0.00	0.00	0.00	0.01	0.00	0.00
7	0.00	0.00	0.00	0.00	0.01	0.00	0.00
8	0.00	0.00	0.00	0.00	0.01	0.00	0.00
9	0.00	0.00	0.00	0.00	0.01	0.00	0.00
10	0.00	0.00	0.00	0.00	0.01	0.00	0.00
11	0.00	0.00	0.00	0.00	0.01	0.00	0.00
12	0.00	0.00	0.00	0.00	0.01	0.00	0.00
13	0.00	0.00	0.00	0.00	0.01	0.00	0.00
14	0.00	0.00	0.00	0.00	0.01	0.00	0.00

RUNID: DATE: 10/21/1992 TIME: 20:17:27

FLOW AND RIVER CHARACTERISTICS

REACH NUM	WATER DEPTH M	THICKNESS OF BED M	SETTLING VELOCITY M/DAY	RESUSPENSION RATE M/DAY	X-SEC AREA M^2	INCRMNTL FLOW M^3/SEC	CONC. OF BED SOLIDS MG/L	DISCHARGE FLOW M^3/SEC
1	0.79	0.100000	1.000000	0.00001000	52.62	0.00000	500000.00	0.00000
2	1.24	0.100000	1.100000	0.00007500	58.96	0.00000	500000.00	0.07340
3	0.92	0.100000	1.200000	0.00007800	31.39	0.00000	500000.00	0.04730
4	0.99	0.100000	1.200000	0.00007500	39.75	0.00000	500000.00	3.13500
5	1.12	0.100000	1.050000	0.00007500	42.82	0.00000	500000.00	3.37220
6	0.84	0.100000	1.040000	0.00007000	43.83	0.00000	500000.00	1.24900
7	1.67	0.100000	1.030000	0.00006500	72.51	0.00000	500000.00	0.28000
8	1.69	0.100000	1.020000	0.00008000	109.51	0.00000	500000.00	0.08750
9	1.23	0.100000	1.300000	0.00008500	74.76	0.00000	500000.00	0.21900
10	1.28	0.100000	1.300000	0.00008500	87.76	0.00000	500000.00	0.01380
11	0.65	0.100000	1.300000	0.00011000	23.54	0.00000	500000.00	1.64600
12	1.42	0.100000	1.350000	0.00014000	70.64	0.00000	500000.00	1.53300
13	1.02	0.100000	0.700000	0.00012000	62.09	0.00000	500000.00	0.16900
14	0.98	0.100000	0.400000	0.00003500	34.62	0.00000	500000.00	0.26200

RUNID: DATE: 10/21/1992 TIME: 20:17:27

INTEGRATION VARIABLES

REACH NUM	DX M	NDXP	LENGTH OF REACH M	KILOMETER POINT
1	1000.	1	5890.0	70.130
2	1000.	1	4440.0	64.240
3	1000.	1	5420.0	59.800
4	1000.	1	8070.0	54.380
5	100.	1	590.0	46.310
6	1000.	1	2260.0	45.720
7	1000.	1	1330.0	43.460
8	1000.	1	4390.0	42.130
9	1000.	1	2550.0	37.740
10	1000.	1	2830.0	35.190
11	1000.	1	3400.0	32.360
12	1000.	1	6120.0	28.960
13	1000.	1	2510.0	22.840
14	1000.	1	3370.0	20.330

RUNID: DATE: 10/21/1992 TIME: 20:17:27

SYSTEM AND REACH DEPENDANT VARIABLES

REACH NUM	PARTITION WATER(PI1) L/KG	PARTITION BED (PI2) L/KG	INPUT LOAD SOL(WTL) KG/DAY	INPUT LOAD TOX(WTL) KG/DAY
1	0.1400E+06	0.1400E+06	0.0000E+00	0.0000E+00
2	0.1400E+06	0.1400E+06	0.0000E+00	0.1572E+01
3	0.1400E+06	0.1400E+06	0.0000E+00	0.2180E+00
4	0.1400E+06	0.1400E+06	0.0000E+00	0.8061E+01
5	0.1400E+06	0.1400E+06	0.7461E+04	0.1403E+01
6	0.1400E+06	0.1400E+06	0.6477E+03	0.1770E+00
7	0.1400E+06	0.1400E+06	0.0000E+00	0.1506E+01
8	0.1400E+06	0.1400E+06	0.0000E+00	0.1246E+01
9	0.1400E+06	0.1400E+06	0.0000E+00	0.1042E+01
10	0.1400E+06	0.1400E+06	0.0000E+00	0.1970E+00
11	0.1400E+06	0.1400E+06	0.3689E+04	0.2080E+00
12	0.1400E+06	0.1400E+06	0.0000E+00	0.1325E+02
13	0.1400E+06	0.1400E+06	0.6580E+03	0.5360E+00
14	0.1400E+06	0.1400E+06	0.0000E+00	0.3743E+01

Table B2: Summary of the Input Data for Model Calibrations of Copper in the Mahoning River.

RUNID: DATE: 11/12/1992 TIME: 13: 6:50

INITIAL CONDITIONS

NUMBER OF REACHES = 14
KM FROM MOUTH = 70.13
NUMBER OF SYSTEMS = 2

INITIAL FLOW, QB - M^3/SEC = 16.66
SUSPENDED SOLIDS - MG/L = 24.200
TOXICANT CONC - UG/L = 7.500

SYSTEM INPUT LOAD(KG/DAY) 1 = 10.796
SYSTEM INPUT LOAD(KG/DAY) 2 = 34834.062

RUNID: DATE: 11/12/1992 TIME: 13: 6:50

INITIAL CONDITIONS

NUMBER OF REACHES = 14
KM FROM MOUTH = 70.13
NUMBER OF SYSTEMS = 2

INITIAL FLOW, QB - M^3/SEC = 16.66
SUSPENDED SOLIDS - MG/L = 24.200
TOXICANT CONC - UG/L = 7.500

SYSTEM INPUT LOAD(KG/DAY) 1 = 10.796
SYSTEM INPUT LOAD(KG/DAY) 2 = 34834.062

RUNID: DATE: 11/12/1992 TIME: 13: 6:50

REACH INPUT VARIABLES

RATES:

REACH NUM	KV M/DAY	KH 1/DAY	KB 1/DAY	KP 1/DAY	KD M/DAY	K1 1/DAY	K2 1/DAY
1	0.00	0.00	0.00	0.00	0.01	0.00	0.00
2	0.00	0.00	0.00	0.00	0.01	0.00	0.00
3	0.00	0.00	0.00	0.00	0.01	0.00	0.00
4	0.00	0.00	0.00	0.00	0.01	0.00	0.00
5	0.00	0.00	0.00	0.00	0.01	0.00	0.00
6	0.00	0.00	0.00	0.00	0.01	0.00	0.00
7	0.00	0.00	0.00	0.00	0.01	0.00	0.00
8	0.00	0.00	0.00	0.00	0.01	0.00	0.00
9	0.00	0.00	0.00	0.00	0.01	0.00	0.00
10	0.00	0.00	0.00	0.00	0.01	0.00	0.00
11	0.00	0.00	0.00	0.00	0.01	0.00	0.00
12	0.00	0.00	0.00	0.00	0.01	0.00	0.00
13	0.00	0.00	0.00	0.00	0.01	0.00	0.00
14	0.00	0.00	0.00	0.00	0.01	0.00	0.00

RUNID: DATE: 11/12/1992 TIME: 13: 6:50

FLOW AND RIVER CHARACTERISTICS

REACH NUM	WATER DEPTH M	THICKNESS OF BED M	SETTLING VELOCITY M/DAY	RESUSPENSION RATE M/DAY	X-SEC AREA M^2	INCRMNTL FLOW M^3/SEC	CONC. OF BED SOLIDS MG/L	DISCHARGE FLOW M^3/SEC
1	0.79	0.100000	1.000000	0.00001000	52.62	0.00000	500000.00	0.00000
2	1.24	0.100000	1.100000	0.00007500	58.96	0.00000	500000.00	0.07340
3	0.92	0.100000	1.200000	0.00007800	31.39	0.00000	500000.00	0.04730
4	0.99	0.100000	1.200000	0.00007500	39.75	0.00000	500000.00	3.13500
5	1.12	0.100000	1.050000	0.00007500	42.82	0.00000	500000.00	3.37220
6	0.84	0.100000	1.040000	0.00007000	43.83	0.00000	500000.00	1.24900
7	1.67	0.100000	1.030000	0.00006500	72.51	0.00000	500000.00	0.28000
8	1.69	0.100000	1.020000	0.00008000	109.51	0.00000	500000.00	0.08750
9	1.23	0.100000	1.300000	0.00008500	74.76	0.00000	500000.00	0.21900
10	1.28	0.100000	1.300000	0.00008500	87.76	0.00000	500000.00	0.01380
11	0.65	0.100000	1.300000	0.00011000	23.54	0.00000	500000.00	1.64600
12	1.42	0.100000	1.350000	0.00014000	70.64	0.00000	500000.00	1.53300
13	1.02	0.100000	0.700000	0.00012000	62.09	0.00000	500000.00	0.16900
14	0.98	0.100000	0.400000	0.00003500	34.62	0.00000	500000.00	0.26200

RUNID: DATE: 11/12/1992 TIME: 13: 6:50

INTEGRATION VARIABLES

REACH NUM	DX M	NDXP	LENGTH OF REACH M	KILOMETER POINT
1	1000.	1	5890.0	70.130
2	1000.	1	4440.0	64.240
3	1000.	1	5420.0	59.800
4	1000.	1	8070.0	54.380
5	100.	1	590.0	46.310
6	1000.	1	2260.0	45.720
7	1000.	1	1330.0	43.460
8	1000.	1	4390.0	42.130
9	1000.	1	2550.0	37.740
10	1000.	1	2830.0	35.190
11	1000.	1	3400.0	32.360
12	1000.	1	6120.0	28.960
13	1000.	1	2510.0	22.840
14	1000.	1	3370.0	20.330

RUNID: DATE: 11/12/1992 TIME: 13: 6:50

SYSTEM AND REACH DEPENDANT VARIABLES

REACH NUM	PARTITION WATER(PI1) L/KG	PARTITION BED (PI2) L/KG	INPUT LOAD SOL(WTL) KG/DAY	INPUT LOAD TOX(WTL) KG/DAY
1	0.9500E+05	0.9500E+05	0.0000E+00	0.0000E+00
2	0.9500E+05	0.9500E+05	0.0000E+00	0.1900E+00
3	0.9500E+05	0.9500E+05	0.0000E+00	0.1230E+00
4	0.9500E+05	0.9500E+05	0.0000E+00	0.6156E+01
5	0.9500E+05	0.9500E+05	0.7461E+04	0.7870E+00
6	0.9500E+05	0.9500E+05	0.6477E+03	0.2460E+00
7	0.9500E+05	0.9500E+05	0.0000E+00	0.7040E+00
8	0.9500E+05	0.9500E+05	0.0000E+00	0.2770E+00
9	0.9500E+05	0.9500E+05	0.0000E+00	0.1720E+00
10	0.9500E+05	0.9500E+05	0.0000E+00	0.0000E+00
11	0.9500E+05	0.9500E+05	0.3689E+04	0.1310E+00
12	0.9500E+05	0.9500E+05	0.0000E+00	0.3975E+01
13	0.9500E+05	0.9500E+05	0.6580E+03	0.7800E-01
14	0.9500E+05	0.9500E+05	0.0000E+00	0.6810E+00

APPENDIX C

Table C1: Summary of MICHRIV Output for Chromium.

RUNID: DATE: 10/21/1992 TIME: 20:17:27

OUTPUT CONCENTRATION SUMMARY

RIVER : Mahoning

SYSTEM OF : Chromium

REACH	WATER MAX CONC UG/L	KMPT	WATER MIN CONC UG/L	KMPT	SEDIMENT MAX CONC UG/L	KMPT	SEDIMENT MIN CONC UG/L	KMPT
1	4.0650	70.1300	3.5635	65.1300	66787.7969	65.1300	66699.9609	70.1300
2	4.9702	61.2400	4.7235	64.2400	87107.0703	64.2400	86986.2187	61.2400
3	5.3653	55.8000	5.1613	59.8000	89542.9453	59.8000	89475.7500	55.8000
4	10.0312	47.3800	9.3191	54.3800	174388.5156	54.3800	174136.2344	47.3800
5	9.3267	45.8100	9.2846	46.3100	157895.6875	46.3100	157894.6250	45.8100
6	9.1204	44.7200	9.0291	45.7200	155638.2344	45.7200	155609.8437	44.7200
7	9.7854	43.4600	9.7854	43.4600	167249.3437	43.4600	167249.3437	43.4600
8	11.0168	39.1300	10.5098	42.1300	176954.2344	42.1300	176756.5312	39.1300
9	11.7326	35.7400	11.5155	37.7400	184111.2344	37.7400	184030.8437	35.7400
10	12.1511	33.1900	11.9329	35.1900	185384.5156	35.1900	185298.5625	33.1900
11	11.8347	30.3600	11.6100	32.3600	175157.8125	32.3600	175106.8437	30.3600
12	18.6291	23.9600	16.9695	28.9600	256576.7500	28.9600	256013.2656	23.9600
13	20.1742	20.8400	19.2240	22.8400	256679.3437	22.8400	256416.7969	20.8400
14	21.6069	18.3300	21.5340	20.3300	275285.5625	20.3300	275282.1875	18.3300

MODEL OUTPUT
SUSPENDED SOLIDS SYSTEM

KILOMETERS RIVER MOUTH	LOCATION WITHIN REACH METERS	WATER MG/L	BED MG/L	TOTAL LOAD KG/DAY	INPUT LOAD KG/DAY	SEDIMENTATION RATE M/DAY	TRAVEL TIME HOURS	STREAM FLOW M**3/SEC
70.13	0.0000E+00	20.23	0.5000E+06	0.3483E+05	0.0000E+00	0.3666E-04	0.0000E+00	16.66
69.13	1000.	23.33	0.5000E+06	0.3483E+05	0.0000E+00	0.3666E-04	0.8774	16.66
68.13	2000.	22.50	0.5000E+06	0.3358E+05	0.0000E+00	0.3500E-04	1.755	16.66
67.13	3000.	21.71	0.5000E+06	0.3239E+05	0.0000E+00	0.3341E-04	2.632	16.66
66.13	4000.	20.95	0.5000E+06	0.3124E+05	0.0000E+00	0.3190E-04	3.509	16.66
65.13	5000.	20.23	0.5000E+06	0.3015E+05	0.0000E+00	0.3045E-04	4.387	16.66
64.13	6000.	19.54	0.5000E+06	0.2911E+05	0.0000E+00	0.2907E-04	5.264	16.66
64.13	6000.	19.54	0.5000E+06	0.2911E+05	0.0000E+00	0.2907E-04	5.264	16.66
64.24	0.0000E+00	20.96	0.5000E+06	0.2812E+05	0.0000E+00	-0.3106E-04	5.264	16.73
63.24	1000.	19.97	0.5000E+06	0.2812E+05	0.0000E+00	-0.3106E-04	6.243	16.73
62.24	2000.	20.47	0.5000E+06	0.2887E+05	0.0000E+00	-0.2996E-04	7.222	16.73
61.24	3000.	20.96	0.5000E+06	0.2960E+05	0.0000E+00	-0.2889E-04	8.200	16.73
60.24	4000.	21.43	0.5000E+06	0.3030E+05	0.0000E+00	-0.2786E-04	9.179	16.73
60.24	4000.	21.43	0.5000E+06	0.3030E+05	0.0000E+00	-0.2786E-04	9.179	16.73
59.80	0.0000E+00	22.56	0.5000E+06	0.3098E+05	0.0000E+00	-0.2597E-04	9.179	16.78
58.80	1000.	21.68	0.5000E+06	0.3098E+05	0.0000E+00	-0.2597E-04	9.699	16.78
57.80	2000.	21.98	0.5000E+06	0.3143E+05	0.0000E+00	-0.2525E-04	10.22	16.78
56.80	3000.	22.28	0.5000E+06	0.3187E+05	0.0000E+00	-0.2454E-04	10.74	16.78
55.80	4000.	22.56	0.5000E+06	0.3230E+05	0.0000E+00	-0.2385E-04	11.26	16.78
54.80	5000.	22.84	0.5000E+06	0.3271E+05	0.0000E+00	-0.2319E-04	11.78	16.78
54.80	5000.	22.84	0.5000E+06	0.3271E+05	0.0000E+00	-0.2319E-04	11.78	16.78
54.38	0.0000E+00	21.39	0.5000E+06	0.3311E+05	0.0000E+00	-0.2802E-04	11.78	19.92
53.38	1000.	19.58	0.5000E+06	0.3311E+05	0.0000E+00	-0.2802E-04	12.33	19.92
52.38	2000.	19.90	0.5000E+06	0.3369E+05	0.0000E+00	-0.2724E-04	12.89	19.92
51.38	3000.	20.21	0.5000E+06	0.3424E+05	0.0000E+00	-0.2649E-04	13.44	19.92
50.38	4000.	20.52	0.5000E+06	0.3478E+05	0.0000E+00	-0.2575E-04	13.99	19.92
49.38	5000.	20.82	0.5000E+06	0.3531E+05	0.0000E+00	-0.2504E-04	14.55	19.92
48.38	6000.	21.11	0.5000E+06	0.3582E+05	0.0000E+00	-0.2435E-04	15.10	19.92
47.38	7000.	21.39	0.5000E+06	0.3632E+05	0.0000E+00	-0.2367E-04	15.66	19.92
46.38	8000.	21.66	0.5000E+06	0.3680E+05	0.0000E+00	-0.2302E-04	16.21	19.92
46.38	8000.	21.66	0.5000E+06	0.3680E+05	0.0000E+00	-0.2302E-04	16.21	19.92
46.31	0.0000E+00	22.37	0.5000E+06	0.4473E+05	7461.	-0.2826E-04	16.21	23.29
46.21	100.0	22.26	0.5000E+06	0.4473E+05	0.0000E+00	-0.2826E-04	16.26	23.29
46.11	200.0	22.29	0.5000E+06	0.4479E+05	0.0000E+00	-0.2820E-04	16.31	23.29
46.01	300.0	22.31	0.5000E+06	0.4484E+05	0.0000E+00	-0.2814E-04	16.37	23.29
45.91	400.0	22.34	0.5000E+06	0.4489E+05	0.0000E+00	-0.2809E-04	16.42	23.29
45.81	500.0	22.37	0.5000E+06	0.4495E+05	0.0000E+00	-0.2803E-04	16.47	23.29
45.71	600.0	22.39	0.5000E+06	0.4500E+05	0.0000E+00	-0.2798E-04	16.52	23.29
45.71	600.0	22.39	0.5000E+06	0.4500E+05	0.0000E+00	-0.2798E-04	16.52	23.29
45.72	0.0000E+00	21.86	0.5000E+06	0.4570E+05	647.7	-0.2452E-04	16.52	24.54
44.72	1000.	21.86	0.5000E+06	0.4570E+05	0.0000E+00	-0.2452E-04	17.01	24.54

MODEL OUTPUT
SUSPENDED SOLIDS SYSTEM

KILOMETERS RIVER MOUTH	LOCATION WITHIN REACH METERS	WATER MG/L	BED MG/L	TOTAL LOAD KG/DAY	INPUT LOAD KG/DAY	SEDIMENTATION RATE M/DAY	TRAVEL TIME HOURS	STREAM FLOW M**3/SEC
43.72	2000.	22.16	0.5000E+06	0.4635E+05	0.0000E+00	-0.2390E-04	17.51	24.54
43.72	2000.	22.16	0.5000E+06	0.4635E+05	0.0000E+00	-0.2390E-04	17.51	24.54
43.46	0.0000E+00	21.91	0.5000E+06	0.4698E+05	0.0000E+00	-0.1945E-04	17.51	24.82
42.46	1000.	22.11	0.5000E+06	0.4698E+05	0.0000E+00	-0.1945E-04	18.32	24.82
42.46	1000.	22.11	0.5000E+06	0.4698E+05	0.0000E+00	-0.1945E-04	18.32	24.82
42.13	0.0000E+00	23.55	0.5000E+06	0.4741E+05	0.0000E+00	-0.3399E-04	18.32	24.90
41.13	1000.	22.55	0.5000E+06	0.4741E+05	0.0000E+00	-0.3399E-04	19.54	24.90
40.13	2000.	23.06	0.5000E+06	0.4853E+05	0.0000E+00	-0.3296E-04	20.77	24.90
39.13	3000.	23.55	0.5000E+06	0.4962E+05	0.0000E+00	-0.3196E-04	21.99	24.90
38.13	4000.	24.02	0.5000E+06	0.5067E+05	0.0000E+00	-0.3100E-04	23.21	24.90
38.13	4000.	24.02	0.5000E+06	0.5067E+05	0.0000E+00	-0.3100E-04	23.21	24.90
37.74	0.0000E+00	24.44	0.5000E+06	0.5169E+05	0.0000E+00	-0.2226E-04	23.21	25.12
36.74	1000.	24.13	0.5000E+06	0.5169E+05	0.0000E+00	-0.2226E-04	24.04	25.12
35.74	2000.	24.44	0.5000E+06	0.5238E+05	0.0000E+00	-0.2146E-04	24.86	25.12
34.74	3000.	24.73	0.5000E+06	0.5305E+05	0.0000E+00	-0.2069E-04	25.69	25.12
34.74	3000.	24.73	0.5000E+06	0.5305E+05	0.0000E+00	-0.2069E-04	25.69	25.12
35.19	0.0000E+00	25.35	0.5000E+06	0.5369E+05	0.0000E+00	-0.1989E-04	25.69	25.14
34.19	1000.	25.04	0.5000E+06	0.5369E+05	0.0000E+00	-0.1989E-04	26.66	25.14
33.19	2000.	25.35	0.5000E+06	0.5439E+05	0.0000E+00	-0.1909E-04	27.63	25.14
32.19	3000.	25.65	0.5000E+06	0.5506E+05	0.0000E+00	-0.1832E-04	28.60	25.14
32.19	3000.	25.65	0.5000E+06	0.5506E+05	0.0000E+00	-0.1832E-04	28.60	25.14
32.36	0.0000E+00	26.33	0.5000E+06	0.5939E+05	3689.	-0.4240E-04	28.60	26.78
31.36	1000.	26.00	0.5000E+06	0.5939E+05	0.0000E+00	-0.4240E-04	28.84	26.78
30.36	2000.	26.33	0.5000E+06	0.6016E+05	0.0000E+00	-0.4155E-04	29.09	26.78
29.36	3000.	26.65	0.5000E+06	0.6093E+05	0.0000E+00	-0.4071E-04	29.33	26.78
29.36	3000.	26.65	0.5000E+06	0.6093E+05	0.0000E+00	-0.4071E-04	29.33	26.78
28.96	0.0000E+00	28.61	0.5000E+06	0.6167E+05	0.0000E+00	-0.7000E-04	29.33	28.32
27.96	1000.	25.93	0.5000E+06	0.6167E+05	0.0000E+00	-0.7000E-04	30.02	28.32
26.96	2000.	26.63	0.5000E+06	0.6343E+05	0.0000E+00	-0.6811E-04	30.72	28.32
25.96	3000.	27.31	0.5000E+06	0.6514E+05	0.0000E+00	-0.6627E-04	31.41	28.32
24.96	4000.	27.97	0.5000E+06	0.6681E+05	0.0000E+00	-0.6448E-04	32.10	28.32
23.96	5000.	28.61	0.5000E+06	0.6843E+05	0.0000E+00	-0.6274E-04	32.79	28.32
22.96	6000.	29.24	0.5000E+06	0.7000E+05	0.0000E+00	-0.6105E-04	33.49	28.32
22.96	6000.	29.24	0.5000E+06	0.7000E+05	0.0000E+00	-0.6105E-04	33.49	28.32
22.84	0.0000E+00	31.26	0.5000E+06	0.7220E+05	658.0	-0.7757E-04	33.49	28.49
21.84	1000.	30.31	0.5000E+06	0.7220E+05	0.0000E+00	-0.7757E-04	34.09	28.49
20.84	2000.	31.26	0.5000E+06	0.7458E+05	0.0000E+00	-0.7624E-04	34.70	28.49
19.84	3000.	32.20	0.5000E+06	0.7693E+05	0.0000E+00	-0.7493E-04	35.30	28.49
19.84	3000.	32.20	0.5000E+06	0.7693E+05	0.0000E+00	-0.7493E-04	35.30	28.49
20.33	0.0000E+00	32.04	0.5000E+06	0.7924E+05	0.0000E+00	-0.9424E-05	35.30	28.75
19.33	1000.	31.97	0.5000E+06	0.7924E+05	0.0000E+00	-0.9424E-05	35.64	28.75

MODEL OUTPUT
SUSPENDED SOLIDS SYSTEM

KILOMETERS RIVER MOUTH	LOCATION WITHIN REACH METERS	WATER MG/L	BED MG/L	TOTAL LOAD KG/DAY	INPUT LOAD KG/DAY	SEDIMENTATION RATE M/DAY	TRAVEL TIME HOURS	STREAM FLOW M**3/SEC
18.33	2000.	32.04	0.5000E+06	0.7941E+05	0.0000E+00	-0.9371E-05	35.97	28.75
17.33	3000.	32.10	0.5000E+06	0.7957E+05	0.0000E+00	-0.9318E-05	36.31	28.75
17.33	3000.	32.10	0.5000E+06	0.7957E+05	0.0000E+00	-0.9318E-05	36.31	28.75

MODEL OUTPUT
TOXICANT SYSTEM

KILOMETERS FROM MOUTH	LOCATION WITHIN REACH METERS	TOTAL UG/L	W A T E R DISSOLVED UG/L	PARTICULATE UG/L	TOTAL UG/L	S E D I M E N T DISSOLVED UG/L	PARTICULATE UG/L	TOTAL LOAD INPUT KG/DAY
70.13	0.0000E+00	4.065	0.9528	3.112	0.6670E+05	0.9528	0.6670E+05	0.0000E+00
69.13	1000.	4.065	0.9528	3.112	0.6670E+05	0.9528	0.6670E+05	0.0000E+00
68.13	2000.	3.955	0.9531	3.002	0.6672E+05	0.9531	0.6672E+05	0.0000E+00
67.13	3000.	3.850	0.9533	2.897	0.6673E+05	0.9533	0.6673E+05	0.0000E+00
66.13	4000.	3.750	0.9536	2.797	0.6675E+05	0.9536	0.6675E+05	0.0000E+00
65.13	5000.	3.655	0.9538	2.701	0.6677E+05	0.9538	0.6677E+05	0.0000E+00
64.13	6000.	3.563	0.9541	2.609	0.6679E+05	0.9541	0.6679E+05	0.0000E+00
64.13	6000.	3.563	0.9541	2.609	0.6679E+05	0.9541	0.6679E+05	0.0000E+00
64.24	0.0000E+00	4.724	1.244	3.479	0.8711E+05	1.244	0.8711E+05	1.572
63.24	1000.	4.724	1.244	3.479	0.8711E+05	1.244	0.8711E+05	0.0000E+00
62.24	2000.	4.809	1.244	3.565	0.8706E+05	1.244	0.8706E+05	0.0000E+00
61.24	3000.	4.891	1.243	3.648	0.8702E+05	1.243	0.8702E+05	0.0000E+00
60.24	4000.	4.970	1.243	3.728	0.8699E+05	1.243	0.8698E+05	0.0000E+00
60.24	4000.	4.970	1.243	3.728	0.8699E+05	1.243	0.8698E+05	0.0000E+00
59.80	0.0000E+00	5.161	1.279	3.882	0.8954E+05	1.279	0.8954E+05	0.2180
58.80	1000.	5.161	1.279	3.882	0.8954E+05	1.279	0.8954E+05	0.0000E+00
57.80	2000.	5.214	1.279	3.936	0.8952E+05	1.279	0.8952E+05	0.0000E+00
56.80	3000.	5.266	1.279	3.988	0.8951E+05	1.279	0.8951E+05	0.0000E+00
55.80	4000.	5.316	1.278	4.038	0.8949E+05	1.278	0.8949E+05	0.0000E+00
54.80	5000.	5.365	1.278	4.087	0.8948E+05	1.278	0.8947E+05	0.0000E+00
54.80	5000.	5.365	1.278	4.087	0.8948E+05	1.278	0.8947E+05	0.0000E+00
54.38	0.0000E+00	9.319	2.491	6.828	0.1744E+06	2.491	0.1744E+06	8.061
53.38	1000.	9.319	2.491	6.828	0.1744E+06	2.491	0.1744E+06	0.0000E+00
52.38	2000.	9.430	2.491	6.939	0.1743E+06	2.491	0.1743E+06	0.0000E+00
51.38	3000.	9.537	2.490	7.047	0.1743E+06	2.490	0.1743E+06	0.0000E+00
50.38	4000.	9.641	2.490	7.152	0.1743E+06	2.490	0.1743E+06	0.0000E+00
49.38	5000.	9.743	2.489	7.254	0.1742E+06	2.489	0.1742E+06	0.0000E+00
48.38	6000.	9.842	2.489	7.353	0.1742E+06	2.489	0.1742E+06	0.0000E+00
47.38	7000.	9.938	2.488	7.450	0.1742E+06	2.488	0.1742E+06	0.0000E+00
46.38	8000.	10.03	2.488	7.544	0.1741E+06	2.488	0.1741E+06	0.0000E+00
46.38	8000.	10.03	2.488	7.544	0.1741E+06	2.488	0.1741E+06	0.0000E+00
46.31	0.0000E+00	9.285	2.256	7.029	0.1579E+06	2.256	0.1579E+06	1.403
46.21	100.0	9.285	2.256	7.029	0.1579E+06	2.256	0.1579E+06	0.0000E+00
46.11	200.0	9.293	2.256	7.037	0.1579E+06	2.256	0.1579E+06	0.0000E+00
46.01	300.0	9.301	2.256	7.046	0.1579E+06	2.256	0.1579E+06	0.0000E+00
45.91	400.0	9.310	2.256	7.054	0.1579E+06	2.256	0.1579E+06	0.0000E+00
45.81	500.0	9.318	2.256	7.063	0.1579E+06	2.256	0.1579E+06	0.0000E+00
45.71	600.0	9.327	2.256	7.071	0.1579E+06	2.256	0.1579E+06	0.0000E+00
45.71	600.0	9.327	2.256	7.071	0.1579E+06	2.256	0.1579E+06	0.0000E+00
45.72	0.0000E+00	9.029	2.223	6.806	0.1556E+06	2.223	0.1556E+06	0.1770
44.72	1000.	9.029	2.223	6.806	0.1556E+06	2.223	0.1556E+06	0.0000E+00

MODEL OUTPUT
TOXICANT SYSTEM

KILOMETERS FROM MOUTH	LOCATION WITHIN REACH METERS	WATER TOTAL UG/L	WATER DISSOLVED UG/L	WATER PARTICULATE UG/L	SEDIMENT TOTAL UG/L	SEDIMENT DISSOLVED UG/L	SEDIMENT PARTICULATE UG/L	TOTAL LOAD INPUT KG/DAY
43.72	2000.	9.120	2.223	6.897	0.1556E+06	2.223	0.1556E+06	0.0000E+00
43.72	2000.	9.120	2.223	6.897	0.1556E+06	2.223	0.1556E+06	0.0000E+00
43.46	0.0000E+00	9.785	2.389	7.396	0.1672E+06	2.389	0.1672E+06	1.506
42.46	1000.	9.785	2.389	7.396	0.1672E+06	2.389	0.1672E+06	0.0000E+00
42.46	1000.	9.785	2.389	7.396	0.1672E+06	2.389	0.1672E+06	0.0000E+00
42.13	0.0000E+00	10.51	2.528	7.982	0.1770E+06	2.528	0.1770E+06	1.246
41.13	1000.	10.51	2.528	7.982	0.1770E+06	2.528	0.1770E+06	0.0000E+00
40.13	2000.	10.68	2.527	8.157	0.1769E+06	2.527	0.1769E+06	0.0000E+00
39.13	3000.	10.85	2.526	8.327	0.1768E+06	2.526	0.1768E+06	0.0000E+00
38.13	4000.	11.02	2.525	8.492	0.1768E+06	2.525	0.1768E+06	0.0000E+00
38.13	4000.	11.02	2.525	8.492	0.1768E+06	2.525	0.1768E+06	0.0000E+00
37.74	0.0000E+00	11.52	2.630	8.885	0.1841E+06	2.630	0.1841E+06	1.042
36.74	1000.	11.52	2.630	8.885	0.1841E+06	2.630	0.1841E+06	0.0000E+00
35.74	2000.	11.63	2.630	8.996	0.1841E+06	2.630	0.1841E+06	0.0000E+00
34.74	3000.	11.73	2.629	9.104	0.1840E+06	2.629	0.1840E+06	0.0000E+00
34.74	3000.	11.73	2.629	9.104	0.1840E+06	2.629	0.1840E+06	0.0000E+00
35.19	0.0000E+00	11.93	2.648	9.285	0.1854E+06	2.648	0.1854E+06	0.1970
34.19	1000.	11.93	2.648	9.285	0.1854E+06	2.648	0.1854E+06	0.0000E+00
33.19	2000.	12.04	2.648	9.397	0.1853E+06	2.648	0.1853E+06	0.0000E+00
32.19	3000.	12.15	2.647	9.504	0.1853E+06	2.647	0.1853E+06	0.0000E+00
32.19	3000.	12.15	2.647	9.504	0.1853E+06	2.647	0.1853E+06	0.0000E+00
32.36	0.0000E+00	11.61	2.502	9.108	0.1752E+06	2.502	0.1752E+06	0.2080
31.36	1000.	11.61	2.502	9.108	0.1752E+06	2.502	0.1752E+06	0.0000E+00
30.36	2000.	11.72	2.502	9.222	0.1751E+06	2.502	0.1751E+06	0.0000E+00
29.36	3000.	11.83	2.501	9.333	0.1751E+06	2.501	0.1751E+06	0.0000E+00
29.36	3000.	11.83	2.501	9.333	0.1751E+06	2.501	0.1751E+06	0.0000E+00
28.96	0.0000E+00	16.97	3.665	13.30	0.2566E+06	3.665	0.2566E+06	13.25
27.96	1000.	16.97	3.665	13.30	0.2566E+06	3.665	0.2566E+06	0.0000E+00
26.96	2000.	17.32	3.663	13.66	0.2564E+06	3.663	0.2564E+06	0.0000E+00
25.96	3000.	17.66	3.662	14.00	0.2563E+06	3.662	0.2563E+06	0.0000E+00
24.96	4000.	17.99	3.660	14.33	0.2562E+06	3.660	0.2562E+06	0.0000E+00
23.96	5000.	18.32	3.659	14.66	0.2561E+06	3.659	0.2561E+06	0.0000E+00
22.96	6000.	18.63	3.657	14.97	0.2560E+06	3.657	0.2560E+06	0.0000E+00
22.96	6000.	18.63	3.657	14.97	0.2560E+06	3.657	0.2560E+06	0.0000E+00
22.84	0.0000E+00	19.22	3.667	15.56	0.2567E+06	3.667	0.2567E+06	0.5360
21.84	1000.	19.22	3.667	15.56	0.2567E+06	3.667	0.2567E+06	0.0000E+00
20.84	2000.	19.70	3.665	16.04	0.2565E+06	3.665	0.2565E+06	0.0000E+00
19.84	3000.	20.17	3.663	16.51	0.2564E+06	3.663	0.2564E+06	0.0000E+00
19.84	3000.	20.17	3.663	16.51	0.2564E+06	3.663	0.2564E+06	0.0000E+00
20.33	0.0000E+00	21.53	3.933	17.60	0.2753E+06	3.933	0.2753E+06	3.743
19.33	1000.	21.53	3.933	17.60	0.2753E+06	3.933	0.2753E+06	0.0000E+00

MODEL OUTPUT

TOXICANT SYSTEM

KILOMETERS FROM MOUTH	LOCATION WITHIN REACH METERS	WATER TOTAL UG/L	WATER DISSOLVED UG/L	WATER PARTICULATE UG/L	SEDIMENT TOTAL UG/L	SEDIMENT DISSOLVED UG/L	SEDIMENT PARTICULATE UG/L	TOTAL LOAD INPUT KG/DAY
18.33	2000.	21.57	3.933	17.64	0.2753E+06	3.933	0.2753E+06	0.0000E+00
17.33	3000.	21.61	3.933	17.67	0.2753E+06	3.933	0.2753E+06	0.0000E+00
17.33	3000.	21.61	3.933	17.67	0.2753E+06	3.933	0.2753E+06	0.0000E+00

^[^R

Table C2: Summary of the MICHRIV Output for Copper.

RUNID: DATE: 11/12/1992 TIME: 13: 6:50

OUTPUT CONCENTRATION SUMMARY

RIVER : MAHONING RIVER

SYSTEM OF : COPPER

REACH	WATER MAX CONC UG/L	WATER MAX KMPT	WATER MIN CONC UG/L	WATER MIN KMPT	SEDIMENT MAX CONC UG/L	SEDIMENT MAX KMPT	SEDIMENT MIN CONC UG/L	SEDIMENT MIN KMPT
1	7.3140	70.1300	6.5029	65.1300	108163.5078	65.1300	108018.3516	70.1300
2	7.0299	61.2400	6.7177	64.2400	110138.7734	64.2400	110007.2578	61.2400
3	7.4165	55.8000	7.1630	59.8000	111214.5469	59.8000	111141.6797	55.8000
4	10.6085	47.3800	9.9342	54.3800	165007.0937	54.3800	164800.7344	47.3800
5	9.5097	45.8100	9.4712	46.3100	144447.5781	46.3100	144446.7500	45.8100
6	9.3110	44.7200	9.2274	45.7200	142443.6094	45.7200	142421.0000	44.7200
7	9.5919	43.4600	9.5919	43.4600	146948.4062	43.4600	146948.4062	43.4600
8	10.2646	39.1300	9.8381	42.1300	148704.0625	42.1300	148559.6250	39.1300
9	10.5235	35.7400	10.3474	37.7400	149285.1875	37.7400	149227.4844	35.7400
10	10.7868	33.1900	10.6111	35.1900	149169.4219	35.1900	149107.8750	33.1900
11	10.4540	30.3600	10.2735	32.3600	140637.3594	32.3600	140601.2969	30.3600
12	12.7815	23.9600	11.7390	28.9600	161018.5156	28.9600	160708.0000	23.9600
13	13.6329	20.8400	13.0410	22.8400	159697.1250	22.8400	159554.0469	20.8400
14	13.8474	18.3300	13.8045	20.3300	162423.4687	20.3300	162421.6406	18.3300

MODEL OUTPUT
TOXICANT SYSTEM

KILOMETERS FROM MOUTH	LOCATION WITHIN REACH METERS	WATER TOTAL UG/L	WATER DISSOLVED UG/L	WATER PARTICULATE UG/L	SEDIMENT TOTAL UG/L	SEDIMENT DISSOLVED UG/L	SEDIMENT PARTICULATE UG/L	TOTAL LOAD INPUT KG/DAY
43.72	2000.	9.311	2.998	6.313	0.1424E+06	2.998	0.1424E+06	0.0000E+00
43.72	2000.	9.311	2.998	6.313	0.1424E+06	2.998	0.1424E+06	0.0000E+00
43.46	0.0000E+00	9.592	3.094	6.498	0.1469E+06	3.094	0.1469E+06	0.7040
42.46	1000.	9.592	3.094	6.498	0.1469E+06	3.094	0.1469E+06	0.0000E+00
42.46	1000.	9.592	3.094	6.498	0.1469E+06	3.094	0.1469E+06	0.0000E+00
42.13	0.0000E+00	9.838	3.131	6.708	0.1487E+06	3.131	0.1487E+06	0.2770
41.13	1000.	9.838	3.131	6.708	0.1487E+06	3.131	0.1487E+06	0.0000E+00
40.13	2000.	9.985	3.129	6.855	0.1487E+06	3.129	0.1486E+06	0.0000E+00
39.13	3000.	10.13	3.128	6.998	0.1486E+06	3.128	0.1486E+06	0.0000E+00
38.13	4000.	10.26	3.128	7.137	0.1486E+06	3.128	0.1486E+06	0.0000E+00
38.13	4000.	10.26	3.128	7.137	0.1486E+06	3.128	0.1486E+06	0.0000E+00
37.74	0.0000E+00	10.35	3.143	7.205	0.1493E+06	3.143	0.1493E+06	0.1720
36.74	1000.	10.35	3.143	7.205	0.1493E+06	3.143	0.1493E+06	0.0000E+00
35.74	2000.	10.44	3.142	7.295	0.1493E+06	3.142	0.1493E+06	0.0000E+00
34.74	3000.	10.52	3.142	7.382	0.1492E+06	3.142	0.1492E+06	0.0000E+00
34.74	3000.	10.52	3.142	7.382	0.1492E+06	3.142	0.1492E+06	0.0000E+00
35.19	0.0000E+00	10.61	3.140	7.471	0.1492E+06	3.140	0.1492E+06	0.0000E+00
34.19	1000.	10.61	3.140	7.471	0.1492E+06	3.140	0.1492E+06	0.0000E+00
33.19	2000.	10.70	3.140	7.561	0.1491E+06	3.140	0.1491E+06	0.0000E+00
32.19	3000.	10.79	3.139	7.648	0.1491E+06	3.139	0.1491E+06	0.0000E+00
32.19	3000.	10.79	3.139	7.648	0.1491E+06	3.139	0.1491E+06	0.0000E+00
32.36	0.0000E+00	10.27	2.961	7.313	0.1406E+06	2.961	0.1406E+06	0.1310
31.36	1000.	10.27	2.961	7.313	0.1406E+06	2.961	0.1406E+06	0.0000E+00
30.36	2000.	10.36	2.960	7.404	0.1406E+06	2.960	0.1406E+06	0.0000E+00
29.36	3000.	10.45	2.960	7.494	0.1406E+06	2.960	0.1406E+06	0.0000E+00
29.36	3000.	10.45	2.960	7.494	0.1406E+06	2.960	0.1406E+06	0.0000E+00
28.96	0.0000E+00	11.74	3.390	8.349	0.1610E+06	3.390	0.1610E+06	3.975
27.96	1000.	11.74	3.390	8.349	0.1610E+06	3.390	0.1610E+06	0.0000E+00
26.96	2000.	11.96	3.388	8.571	0.1609E+06	3.388	0.1609E+06	0.0000E+00
25.96	3000.	12.17	3.387	8.786	0.1609E+06	3.387	0.1609E+06	0.0000E+00
24.96	4000.	12.38	3.386	8.996	0.1608E+06	3.386	0.1608E+06	0.0000E+00
23.96	5000.	12.58	3.384	9.200	0.1608E+06	3.384	0.1608E+06	0.0000E+00

MODEL OUTPUT
TOXICANT SYSTEM

KILOMETERS FROM MOUTH	LOCATION WITHIN REACH METERS	TOTAL UG/L	W A T E R DISSOLVED UG/L	PARTICULATE UG/L	TOTAL UG/L	S E D I M E N T DISSOLVED UG/L	PARTICULATE UG/L	TOTAL LOAD INPUT KG/DAY
70.13	0.0000E+00	7.314	2.274	5.040	0.1080E+06	2.274	0.1080E+06	0.0000E+00
69.13	1000.	7.314	2.274	5.040	0.1080E+06	2.274	0.1080E+06	0.0000E+00
68.13	2000.	7.136	2.275	4.862	0.1080E+06	2.275	0.1080E+06	0.0000E+00
67.13	3000.	6.967	2.275	4.692	0.1081E+06	2.275	0.1081E+06	0.0000E+00
66.13	4000.	6.805	2.276	4.529	0.1081E+06	2.276	0.1081E+06	0.0000E+00
65.13	5000.	6.650	2.276	4.374	0.1081E+06	2.276	0.1081E+06	0.0000E+00
64.13	6000.	6.503	2.277	4.226	0.1082E+06	2.277	0.1082E+06	0.0000E+00
64.13	6000.	6.503	2.277	4.226	0.1082E+06	2.277	0.1082E+06	0.0000E+00
64.24	0.0000E+00	6.718	2.319	4.399	0.1101E+06	2.319	0.1101E+06	0.1900
63.24	1000.	6.718	2.319	4.399	0.1101E+06	2.319	0.1101E+06	0.0000E+00
62.24	2000.	6.826	2.318	4.508	0.1101E+06	2.318	0.1101E+06	0.0000E+00
61.24	3000.	6.930	2.317	4.613	0.1100E+06	2.317	0.1100E+06	0.0000E+00
60.24	4000.	7.030	2.316	4.714	0.1100E+06	2.316	0.1100E+06	0.0000E+00
60.24	4000.	7.030	2.316	4.714	0.1100E+06	2.316	0.1100E+06	0.0000E+00
59.80	0.0000E+00	7.163	2.341	4.822	0.1112E+06	2.341	0.1112E+06	0.1230
58.80	1000.	7.163	2.341	4.822	0.1112E+06	2.341	0.1112E+06	0.0000E+00
57.80	2000.	7.229	2.341	4.888	0.1112E+06	2.341	0.1112E+06	0.0000E+00
56.80	3000.	7.293	2.341	4.953	0.1112E+06	2.341	0.1112E+06	0.0000E+00
55.80	4000.	7.356	2.340	5.016	0.1112E+06	2.340	0.1112E+06	0.0000E+00
54.80	5000.	7.417	2.340	5.077	0.1111E+06	2.340	0.1111E+06	0.0000E+00
54.80	5000.	7.417	2.340	5.077	0.1111E+06	2.340	0.1111E+06	0.0000E+00
54.38	0.0000E+00	9.934	3.474	6.460	0.1650E+06	3.474	0.1650E+06	6.156
53.38	1000.	9.934	3.474	6.460	0.1650E+06	3.474	0.1650E+06	0.0000E+00
52.38	2000.	10.04	3.473	6.566	0.1650E+06	3.473	0.1650E+06	0.0000E+00
51.38	3000.	10.14	3.472	6.668	0.1649E+06	3.472	0.1649E+06	0.0000E+00
50.38	4000.	10.24	3.472	6.768	0.1649E+06	3.472	0.1649E+06	0.0000E+00
49.38	5000.	10.34	3.471	6.865	0.1649E+06	3.471	0.1649E+06	0.0000E+00
48.38	6000.	10.43	3.471	6.959	0.1649E+06	3.471	0.1648E+06	0.0000E+00
47.38	7000.	10.52	3.470	7.050	0.1648E+06	3.470	0.1648E+06	0.0000E+00
46.38	8000.	10.61	3.469	7.139	0.1648E+06	3.469	0.1648E+06	0.0000E+00
46.38	8000.	10.61	3.469	7.139	0.1648E+06	3.469	0.1648E+06	0.0000E+00
46.31	0.0000E+00	9.471	3.041	6.430	0.1444E+06	3.041	0.1444E+06	0.7870
46.21	100.0	9.471	3.041	6.430	0.1444E+06	3.041	0.1444E+06	0.0000E+00
46.11	200.0	9.479	3.041	6.438	0.1444E+06	3.041	0.1444E+06	0.0000E+00
46.01	300.0	9.487	3.041	6.446	0.1444E+06	3.041	0.1444E+06	0.0000E+00
45.91	400.0	9.494	3.041	6.453	0.1444E+06	3.041	0.1444E+06	0.0000E+00
45.81	500.0	9.502	3.041	6.461	0.1444E+06	3.041	0.1444E+06	0.0000E+00
45.71	600.0	9.510	3.041	6.469	0.1444E+06	3.041	0.1444E+06	0.0000E+00
45.71	600.0	9.510	3.041	6.469	0.1444E+06	3.041	0.1444E+06	0.0000E+00
45.72	0.0000E+00	9.227	2.999	6.229	0.1424E+06	2.999	0.1424E+06	0.2460
44.72	1000.	9.227	2.999	6.229	0.1424E+06	2.999	0.1424E+06	0.0000E+00

MODEL OUTPUT
SUSPENDED SOLIDS SYSTEM

KILOMETERS RIVER MOUTH	LOCATION WITHIN REACH METERS	WATER MG/L	BED MG/L	TOTAL LOAD KG/DAY	INPUT LOAD KG/DAY	SEDIMENTATION RATE M/DAY	TRAVEL TIME HOURS	STREAM FLOW M**3/SEC
18.33	2000.	32.04	0.5000E+06	0.7941E+05	0.0000E+00	-0.9371E-05	35.97	28.75
17.33	3000.	32.10	0.5000E+06	0.7957E+05	0.0000E+00	-0.9318E-05	36.31	28.75
17.33	3000.	32.10	0.5000E+06	0.7957E+05	0.0000E+00	-0.9318E-05	36.31	28.75

MODEL OUTPUT
SUSPENDED SOLIDS SYSTEM

KILOMETERS RIVER MOUTH	LOCATION WITHIN REACH METERS	WATER MG/L	BED MG/L	TOTAL LOAD KG/DAY	INPUT LOAD KG/DAY	SEDIMENTATION RATE M/DAY	TRAVEL TIME HOURS	STREAM FLOW M**3/SEC
43.72	2000.	22.16	0.5000E+06	0.4635E+05	0.0000E+00	-0.2390E-04	17.51	24.54
43.72	2000.	22.16	0.5000E+06	0.4635E+05	0.0000E+00	-0.2390E-04	17.51	24.54
43.46	0.0000E+00	21.91	0.5000E+06	0.4698E+05	0.0000E+00	-0.1945E-04	17.51	24.82
42.46	1000.	22.11	0.5000E+06	0.4698E+05	0.0000E+00	-0.1945E-04	18.32	24.82
42.46	1000.	22.11	0.5000E+06	0.4698E+05	0.0000E+00	-0.1945E-04	18.32	24.82
42.13	0.0000E+00	22.55	0.5000E+06	0.4741E+05	0.0000E+00	-0.3399E-04	18.32	24.90
41.13	1000.	22.55	0.5000E+06	0.4741E+05	0.0000E+00	-0.3399E-04	19.54	24.90
40.13	2000.	23.06	0.5000E+06	0.4853E+05	0.0000E+00	-0.3296E-04	20.77	24.90
39.13	3000.	23.55	0.5000E+06	0.4962E+05	0.0000E+00	-0.3196E-04	21.99	24.90
38.13	4000.	24.02	0.5000E+06	0.5067E+05	0.0000E+00	-0.3100E-04	23.21	24.90
38.13	4000.	24.02	0.5000E+06	0.5067E+05	0.0000E+00	-0.3100E-04	23.21	24.90
37.74	0.0000E+00	24.44	0.5000E+06	0.5169E+05	0.0000E+00	-0.2226E-04	23.21	25.12
36.74	1000.	24.13	0.5000E+06	0.5169E+05	0.0000E+00	-0.2226E-04	24.04	25.12
35.74	2000.	24.44	0.5000E+06	0.5238E+05	0.0000E+00	-0.2146E-04	24.86	25.12
34.74	3000.	24.73	0.5000E+06	0.5305E+05	0.0000E+00	-0.2069E-04	25.69	25.12
34.74	3000.	24.73	0.5000E+06	0.5305E+05	0.0000E+00	-0.2069E-04	25.69	25.12
35.19	0.0000E+00	25.35	0.5000E+06	0.5369E+05	0.0000E+00	-0.1989E-04	25.69	25.14
34.19	1000.	25.04	0.5000E+06	0.5369E+05	0.0000E+00	-0.1989E-04	26.66	25.14
33.19	2000.	25.35	0.5000E+06	0.5439E+05	0.0000E+00	-0.1909E-04	27.63	25.14
32.19	3000.	25.65	0.5000E+06	0.5506E+05	0.0000E+00	-0.1832E-04	28.60	25.14
32.19	3000.	25.65	0.5000E+06	0.5506E+05	0.0000E+00	-0.1832E-04	28.60	25.14
32.36	0.0000E+00	26.33	0.5000E+06	0.5939E+05	3689.	-0.4240E-04	28.60	26.78
31.36	1000.	26.00	0.5000E+06	0.5939E+05	0.0000E+00	-0.4240E-04	28.84	26.78
30.36	2000.	26.33	0.5000E+06	0.6016E+05	0.0000E+00	-0.4155E-04	29.09	26.78
29.36	3000.	26.65	0.5000E+06	0.6093E+05	0.0000E+00	-0.4071E-04	29.33	26.78
29.36	3000.	26.65	0.5000E+06	0.6093E+05	0.0000E+00	-0.4071E-04	29.33	26.78
28.96	0.0000E+00	28.61	0.5000E+06	0.6167E+05	0.0000E+00	-0.7000E-04	29.33	28.32
27.96	1000.	25.93	0.5000E+06	0.6167E+05	0.0000E+00	-0.7000E-04	30.02	28.32
26.96	2000.	26.63	0.5000E+06	0.6343E+05	0.0000E+00	-0.6811E-04	30.72	28.32
25.96	3000.	27.31	0.5000E+06	0.6514E+05	0.0000E+00	-0.6627E-04	31.41	28.32
24.96	4000.	27.97	0.5000E+06	0.6681E+05	0.0000E+00	-0.6448E-04	32.10	28.32
23.96	5000.	28.61	0.5000E+06	0.6843E+05	0.0000E+00	-0.6274E-04	32.79	28.32
22.96	6000.	29.24	0.5000E+06	0.7000E+05	0.0000E+00	-0.6105E-04	33.49	28.32
22.96	6000.	29.24	0.5000E+06	0.7000E+05	0.0000E+00	-0.6105E-04	33.49	28.32
22.84	0.0000E+00	31.26	0.5000E+06	0.7220E+05	658.0	-0.7757E-04	33.49	28.49
21.84	1000.	30.51	0.5000E+06	0.7220E+05	0.0000E+00	-0.7757E-04	34.09	28.49
20.84	2000.	31.26	0.5000E+06	0.7458E+05	0.0000E+00	-0.7624E-04	34.70	28.49
19.84	3000.	32.20	0.5000E+06	0.7693E+05	0.0000E+00	-0.7493E-04	35.30	28.49
19.84	3000.	32.20	0.5000E+06	0.7693E+05	0.0000E+00	-0.7493E-04	35.30	28.49
20.33	0.0000E+00	32.04	0.5000E+06	0.7924E+05	0.0000E+00	-0.9424E-05	35.30	28.75
19.33	1000.	31.97	0.5000E+06	0.7924E+05	0.0000E+00	-0.9424E-05	35.64	28.75

MODEL OUTPUT
SUSPENDED SOLIDS SYSTEM

KILOMETERS RIVER MOUTH	LOCATION WITHIN REACH METERS	WATER MG/L	BED MG/L	TOTAL LOAD KG/DAY	INPUT LOAD KG/DAY	SEDIMENTATION RATE M/DAY	TRAVEL TIME HOURS	STREAM FLOW M**3/SEC
70.13	0.0000E+00	20.23	0.5000E+06	0.3483E+05	0.0000E+00	0.3666E-04	0.0000E+00	16.66
69.13	1000.	23.33	0.5000E+06	0.3483E+05	0.0000E+00	0.3666E-04	0.8774	16.66
68.13	2000.	22.50	0.5000E+06	0.3358E+05	0.0000E+00	0.3500E-04	1.755	16.66
67.13	3000.	21.71	0.5000E+06	0.3239E+05	0.0000E+00	0.3341E-04	2.632	16.66
66.13	4000.	20.95	0.5000E+06	0.3124E+05	0.0000E+00	0.3190E-04	3.509	16.66
65.13	5000.	20.23	0.5000E+06	0.3015E+05	0.0000E+00	0.3045E-04	4.387	16.66
64.13	6000.	19.54	0.5000E+06	0.2911E+05	0.0000E+00	0.2907E-04	5.264	16.66
64.13	6000.	19.54	0.5000E+06	0.2911E+05	0.0000E+00	0.2907E-04	5.264	16.66
64.24	0.0000E+00	20.96	0.5000E+06	0.2812E+05	0.0000E+00	-0.3106E-04	5.264	16.73
63.24	1000.	19.97	0.5000E+06	0.2812E+05	0.0000E+00	-0.3106E-04	6.243	16.73
62.24	2000.	20.47	0.5000E+06	0.2887E+05	0.0000E+00	-0.2996E-04	7.222	16.73
61.24	3000.	20.96	0.5000E+06	0.2960E+05	0.0000E+00	-0.2889E-04	8.200	16.73
60.24	4000.	21.43	0.5000E+06	0.3030E+05	0.0000E+00	-0.2786E-04	9.179	16.73
60.24	4000.	21.43	0.5000E+06	0.3030E+05	0.0000E+00	-0.2786E-04	9.179	16.73
59.80	0.0000E+00	22.56	0.5000E+06	0.3098E+05	0.0000E+00	-0.2597E-04	9.179	16.78
58.80	1000.	21.68	0.5000E+06	0.3098E+05	0.0000E+00	-0.2597E-04	9.699	16.78
57.80	2000.	21.98	0.5000E+06	0.3143E+05	0.0000E+00	-0.2525E-04	10.22	16.78
56.80	3000.	22.28	0.5000E+06	0.3187E+05	0.0000E+00	-0.2454E-04	10.74	16.78
55.80	4000.	22.56	0.5000E+06	0.3230E+05	0.0000E+00	-0.2385E-04	11.26	16.78
54.80	5000.	22.84	0.5000E+06	0.3271E+05	0.0000E+00	-0.2319E-04	11.78	16.78
54.80	5000.	22.84	0.5000E+06	0.3271E+05	0.0000E+00	-0.2319E-04	11.78	16.78
54.38	0.0000E+00	21.39	0.5000E+06	0.3311E+05	0.0000E+00	-0.2802E-04	11.78	19.92
53.38	1000.	19.58	0.5000E+06	0.3311E+05	0.0000E+00	-0.2802E-04	12.33	19.92
52.38	2000.	19.90	0.5000E+06	0.3369E+05	0.0000E+00	-0.2724E-04	12.89	19.92
51.38	3000.	20.21	0.5000E+06	0.3424E+05	0.0000E+00	-0.2649E-04	13.44	19.92
50.38	4000.	20.52	0.5000E+06	0.3478E+05	0.0000E+00	-0.2575E-04	13.99	19.92
49.38	5000.	20.82	0.5000E+06	0.3531E+05	0.0000E+00	-0.2504E-04	14.55	19.92
48.38	6000.	21.11	0.5000E+06	0.3582E+05	0.0000E+00	-0.2435E-04	15.10	19.92
47.38	7000.	21.39	0.5000E+06	0.3632E+05	0.0000E+00	-0.2367E-04	15.66	19.92
46.38	8000.	21.66	0.5000E+06	0.3680E+05	0.0000E+00	-0.2302E-04	16.21	19.92
46.38	8000.	21.66	0.5000E+06	0.3680E+05	0.0000E+00	-0.2302E-04	16.21	19.92
46.31	0.0000E+00	22.37	0.5000E+06	0.4473E+05	7461.	-0.2826E-04	16.21	23.29
46.21	100.0	22.26	0.5000E+06	0.4473E+05	0.0000E+00	-0.2826E-04	16.26	23.29
46.11	200.0	22.29	0.5000E+06	0.4479E+05	0.0000E+00	-0.2820E-04	16.31	23.29
46.01	300.0	22.31	0.5000E+06	0.4484E+05	0.0000E+00	-0.2814E-04	16.37	23.29
45.91	400.0	22.34	0.5000E+06	0.4489E+05	0.0000E+00	-0.2809E-04	16.42	23.29
45.81	500.0	22.37	0.5000E+06	0.4495E+05	0.0000E+00	-0.2803E-04	16.47	23.29
45.71	600.0	22.39	0.5000E+06	0.4500E+05	0.0000E+00	-0.2798E-04	16.52	23.29
45.71	600.0	22.39	0.5000E+06	0.4500E+05	0.0000E+00	-0.2798E-04	16.52	23.29
45.72	0.0000E+00	21.86	0.5000E+06	0.4570E+05	647.7	-0.2452E-04	16.52	24.54
44.72	1000.	21.86	0.5000E+06	0.4570E+05	0.0000E+00	-0.2452E-04	17.01	24.54