A MODEL FOR TRANSPORT OF LAMPRICIDES

IN ST. MARYS RIVER

Final Report

by

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Abstract

This report describes the development and application of a chemical transport model to simulate the lampricide transport in the St. Marys River. The chemical transport model is based on depth-averaged two-dimensional advection-diffusion equation. The particle tracking method is used in the model to simulate the movement of chemical parcels in the river. The hydrodynamic model RMA-2V[BOSS 1993] is used to generate the velocity field. The chemical transport model uses the same triangular mesh system that the velocity computations use without having to interpolate. This improves the accuracy and the efficiency of the model. The smoothed particle hydrodynamics is used in calculating the concentration distribution.

The two-dimensional hydrodynamic model is calibrated using the water level data from the one-dimensional hydraulic model simulation and field velocity measurements using Acoustic Doppler Current Profiler (ADCP). The chemical transport model is calibrated using the data from two dye tests carried out in 1984 and 1996.

A scenario analysis for the effectiveness of TFM applications is carried out using the chemical transport model. An analysis of the effectiveness of Granular Bayer applications is also provided.

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Chapter 1 Introduction

In the 1930's sea lamprey made their way into the Great Lakes by means of ships. In the subsequent years, the sea lamprey grew at a tremendous rate. By 1950's fishing in the Great Lakes region was drastically affected and was getting closer to extinction. A major program of using lampricide to control sea lamprey initiated by the Great Lakes Fisheries Commission has had an important impact in reversing the trend. This successful program consisted of application of lampricide to kill sea lamprey during the vulnerable larval stage. Major studies conducted by the Great Lakes Fishery Commission revealed that a certain critical concentration of lampricide needs to be maintained for a specific minimum duration to provide a lethal dose.

The St. Marys River is the connecting waterway between Lake Superior and Lake Huron (Figure 1.1). The upstream portion of the river extends approximately 24 km from Whitefish Bay to the St. Marys Rapids at Sault Ste. Marie. This portion has a series of hydraulic structures such as compensating gates, shipping locks, and power generating facilities to control the outflow of Lake Superior. The lower portion of the river, about 76 km in length, consists of several channels, three large and numerous small islands, and lake-like areas. Total surface area of the river is about 732 km^2. Mean annual discharge for the river is 2,140 m^3/s. The St. Marys River is known to harbor large numbers of sea lamprey larvae and is the only such tributary to Lake Huron that is not treated with the lampricide.

A computer model can simulate the lampricide transport, provide critical

information needed to plan lampricide treatment by predicting the effectiveness of different possible treatment plans. Mathematical models provide an inexpensive and useful tool for studying the behavior of chemical transport in a river. Many mathematical models have been developed for simulating the transport and fate of toxic chemicals in rivers and lakes [Schnoor 1984; Thomann and DiToro 1983; Ambrose et al. 1983; 1988; McCorquodale et al. 1986; Halfon and Brueggemann 1990; Dickson et al. 1982; Onishi and Wise 1979; Baker 1980]. Most of these models are either one-dimensional or simple box-type models, in which the stream or lake is considered as a series of interconnected well-mixed volume segments. In a recent study, a computer model for chemical and oil spills in the upper St. Lawrence River was developed [Shen et al., 1995]. This integrated chemical/oil spill model, RSPILL, considers chemical transport, transformation and kinetic processes in both river water and bed sediment. The hydrodynamics of this model was simulated using a stream-tube approximation. This report presents the progress on the development of an improved two-dimensional computer model for simulating the transport and spreading of the lampricide in the upper St. Marys River. A complete two-dimensional shallow water wave simulation model is used to determine the flow field. The modified chemical transport model was first used to assist the planning and execution of a dye test experiment. The dye test data was used to further calibrate and validated the model. The validated model was used to perform effectiveness analyses of TFM and Granular Bayer application scenarios in the river.
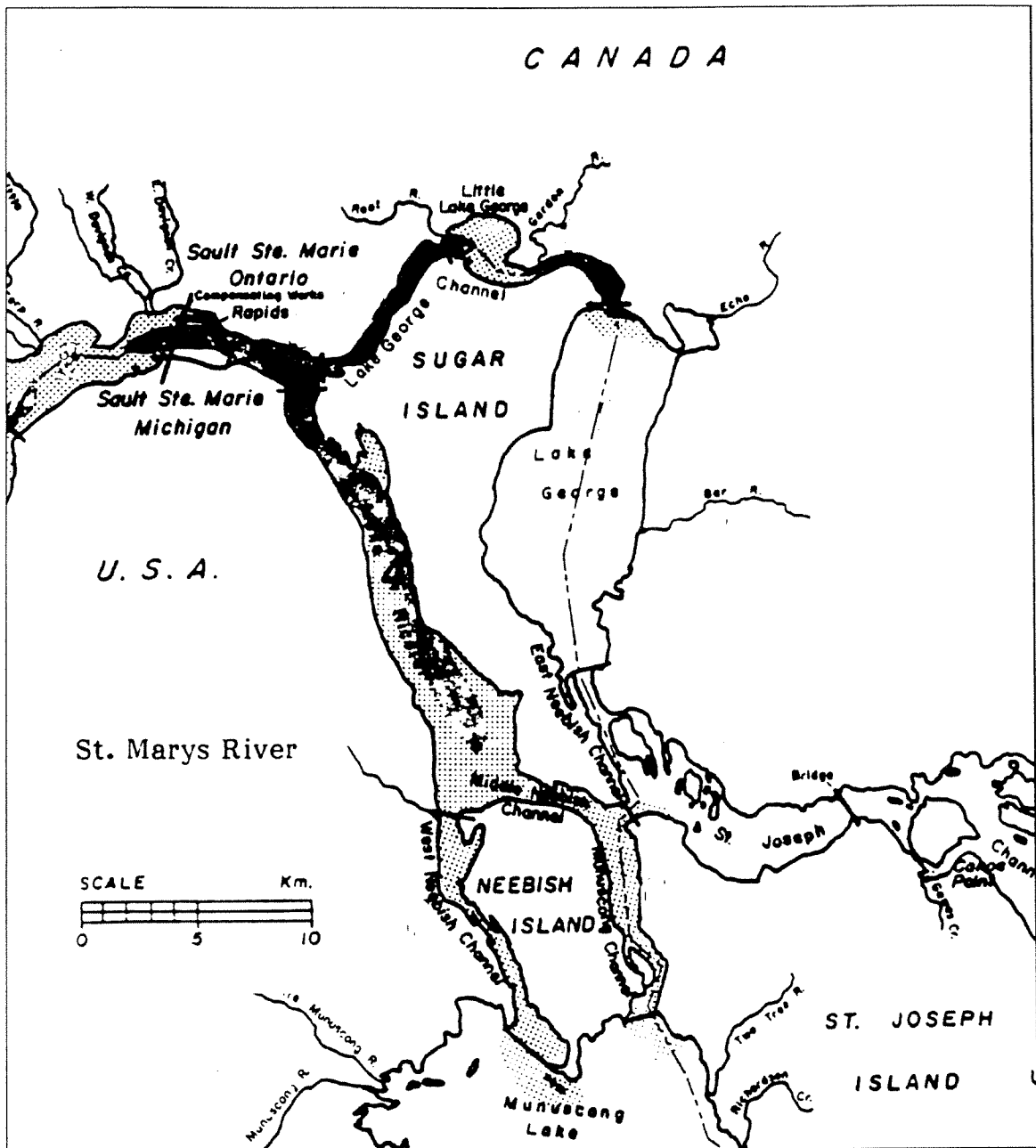
Figure 1-1 The St. Marys River

Chapter 2 Simulation of Hydrodynamics

Since the water current affects advection, spreading, and the exchange of chemical between the water column and the bed, analysis of the transport of a chemical in a river requires water velocity and depth distributions. A two-dimensional finite element model RMA-2V [Ariathurai, et al.1977] is used to simulate the current velocity and depth in the St. Marys River. This chapter describes the model equations, data preparation, and simulation results.

2.1   Introduction to RMA-2V Hydrodynamics Model

RMA-2V is a finite element solution of the Reynolds form of the Navier-Stokes equations for turbulent shallow water flow. The depth-averaged equations of fluid mass and momentum conservation in two dimensions used in the program RMA-2V are (Thomas and McAnally 1985):

$$\frac{\partial h}{\partial t} + \frac{\partial (uh)}{\partial x} + \frac{\partial (vh)}{\partial y} = 0 \tag{2.1}$$

$$\frac{\partial u}{\partial t} + u\frac{\partial u}{\partial x} + v\frac{\partial u}{\partial y} + g\frac{\partial h}{\partial x} + g\frac{\partial z_0}{\partial x} - \frac{\varepsilon_{xx}}{\rho}\frac{\partial^2 u}{\partial x^2} - \frac{\varepsilon_{xy}}{\rho}\frac{\partial^2 u}{\partial y^2} + \frac{gu}{C^2 h}\sqrt{u^2 + v^2} = 0 \tag{2.2}$$

$$\frac{\partial v}{\partial t} + u\frac{\partial v}{\partial x} + v\frac{\partial v}{\partial y} + g\frac{\partial h}{\partial y} + g\frac{\partial z_0}{\partial y} - \frac{\varepsilon_{yx}}{\rho}\frac{\partial^2 v}{\partial x^2} - \frac{\varepsilon_{yy}}{\rho}\frac{\partial^2 v}{\partial y^2} + \frac{gv}{C^2 h}\sqrt{u^2 + v^2} = 0 \tag{2.3}$$

in which,

t = time,

x, y = coordinates in x and y directions,

u, v = depth-averaged horizontal flow velocity in x - and y – directions, respectively,

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h = flow depth,

z_0 = bottom elevation,

g = gravity,

ε_{xx} = normal turbulent exchange coefficients in x - direction,

ε_{xy} = tangential turbulent exchange coefficients in x - direction,

ε_{yx} = tangential turbulent exchange coefficients in y - direction,

ε_{yy} = normal turbulent exchange coefficients in y - direction,

ρ = fluid density.

Bed friction force is calculated with Manning's equation. Eddy viscosity coefficients are used to define turbulence characteristics. Side boundaries are treated as either slip or static noslip. The model automatically recognizes dry elements and corrects the mesh accordingly. Boundary conditions may be water-surface elevations, velocities, or discharges and may occur inside the mesh as well as along the edges.

The original version of RMA-2V was RMA-2 [Norton, et al., 1973]. It was revised by Ariathurai, et al. [Ariathurai et al. 1977]. RMA-2 was based on a mass formulation. It was changed to a velocity formulation of the basic equations resulting in the "V" suffix on the code designator (RMA-2V).

RMA-2V should be used in subcritical flow systems, in which flow can be described by depth-averaged velocity.

2.2   Data Preparation

To run the model, two data files must be prepared: `.GEO` and `.BC`.

- GEO file
  GEO file is a geometric data file which includes finite element mesh information

and boundary definition information.

- BC file
  BC file is a boundary data file which includes the data for the boundaries in the model.

Figure 2-1 shows the relation between the data files and RMA-2V and its utility program GFGEN. The .GEO file can be created by using SMS [BOSS 1993]. The .GEO file is an ASCII format data file and can be edited by any editors. The .GEO file is converted into a binary format data file, .BIN file, before it is used by RMA-2V. RMA-2V reads the .BIN file and .BC file and solves the problem defined by these two data files. The resulting data file .SOL (solution file) is read and interpreted by SMS.

In this study, the shoreline, islands and contour lines were digitized from the National Oceanic and Atmosphere Administration (NOAA) hydrographic charts 14883 and 14884. The finite element mesh system as shown in Figure 2-2 was then generated from the bathymetric data using SMS.

The boundary conditions given were the discharge for upstream and the water level for downstream.

The Manning's coefficients used in the study fall into the range suggested in TABS manual and were adjusted during the calibration. The eddy viscosity used in the study was $1500 Ns/m^2$ for most parts of the river, and $1000 Ns/m^2$ for some of the shallow parts of the river.
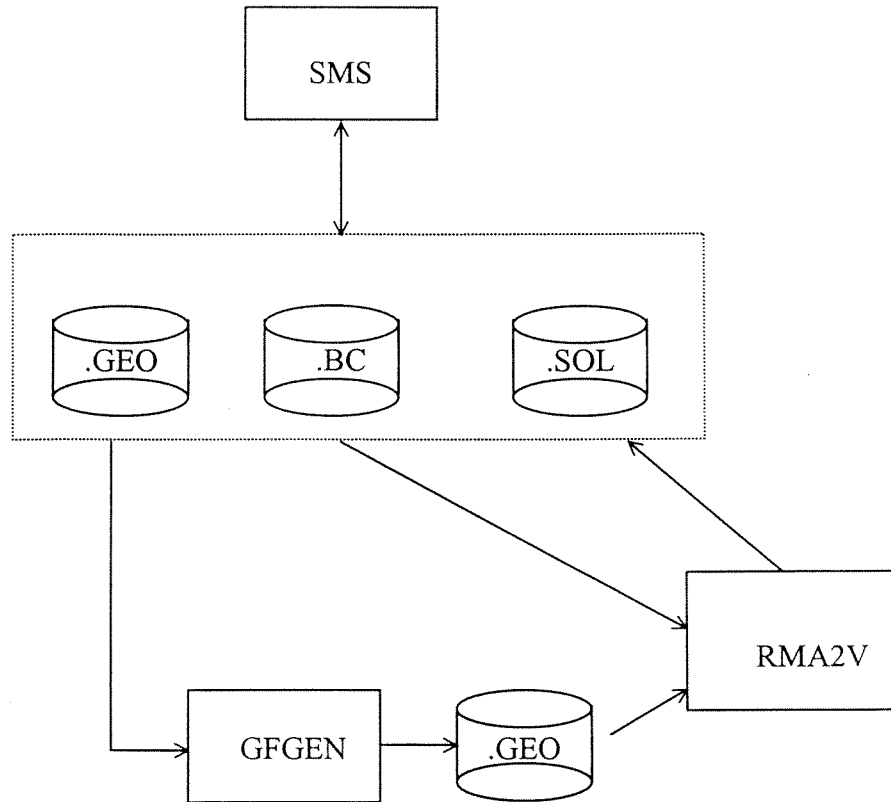
Figure 2-1 RMA2V and Data Files

2.3 Simulation Result

The hydrodynamic model is calibrated by adjusting Manning's coefficients for a discharge at 1614 m³/s. The calibrated Mannning's coefficient is shown in Figure 2-3. Figure 2-5 and Figure 2-6 show the comparisons of water level between the two-dimensional model and the one-dimensional simulation. Figure 2-7 and Figure 2-8 show the water depth and velocity distributions. The hydraulic model is run for a total discharge at 2770 m³/s which is the flow condition of field velocity measurement carried out by the Detroit District of the US Army Corps of Engineers using ADCP (J. Koschik, Personal Communication), during 27-28 August, 1996. Comparisons of the simulated velocity distribution and the field data are shown in Appendix A.
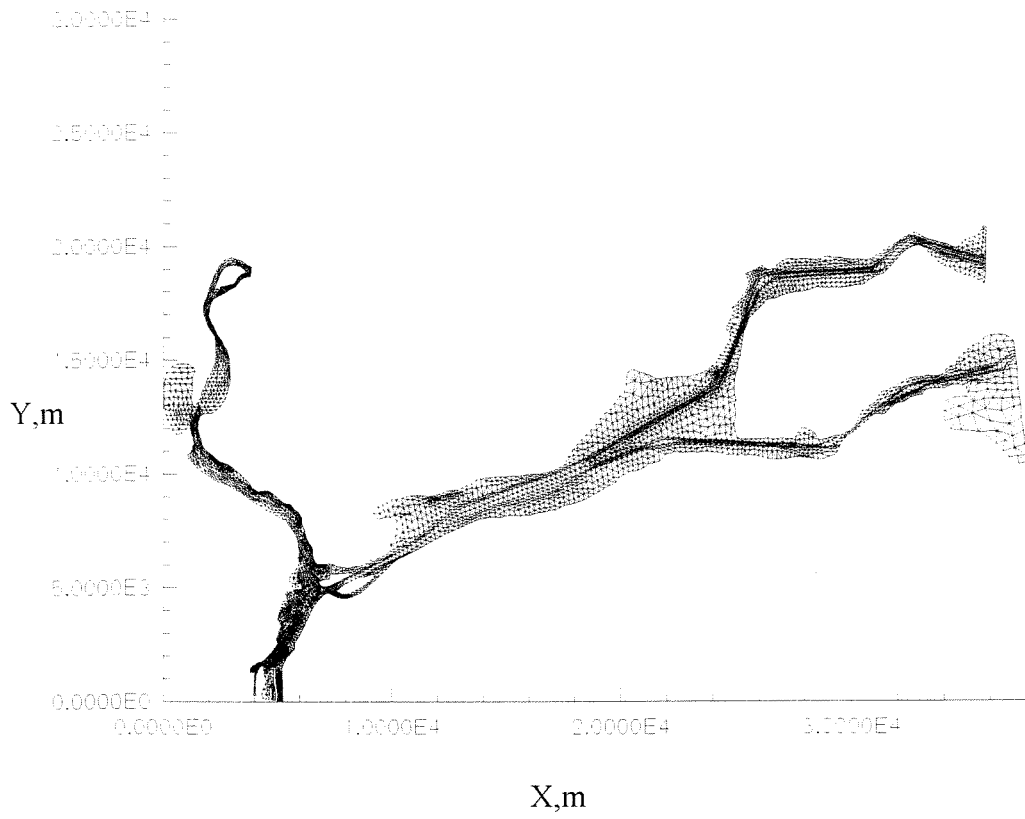
Figure 2-2 Finite element system of St. Marys River
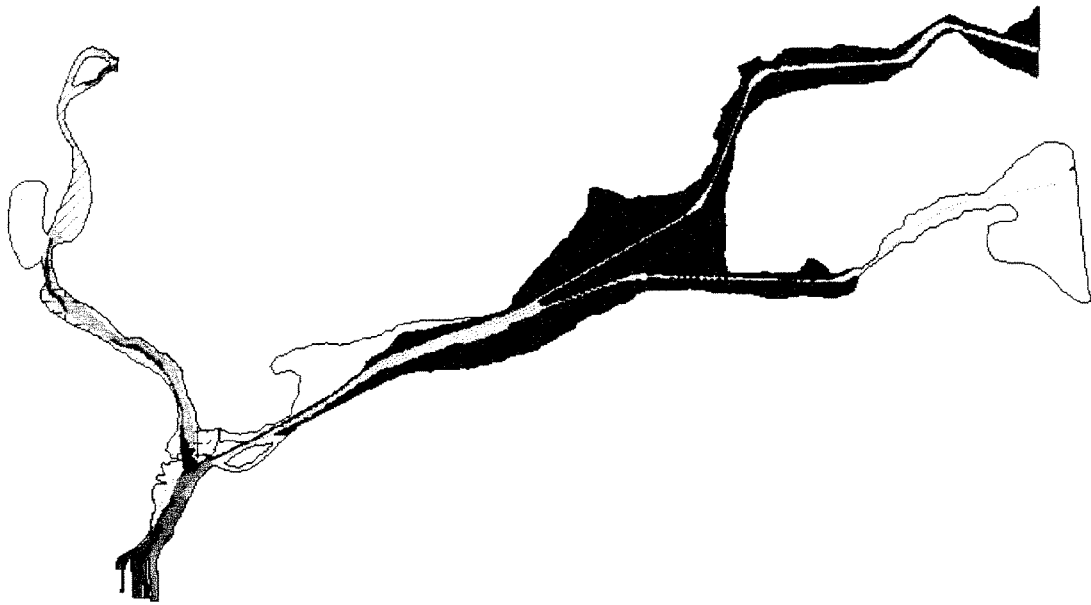
Figure 2-3 Manning's Coefficients

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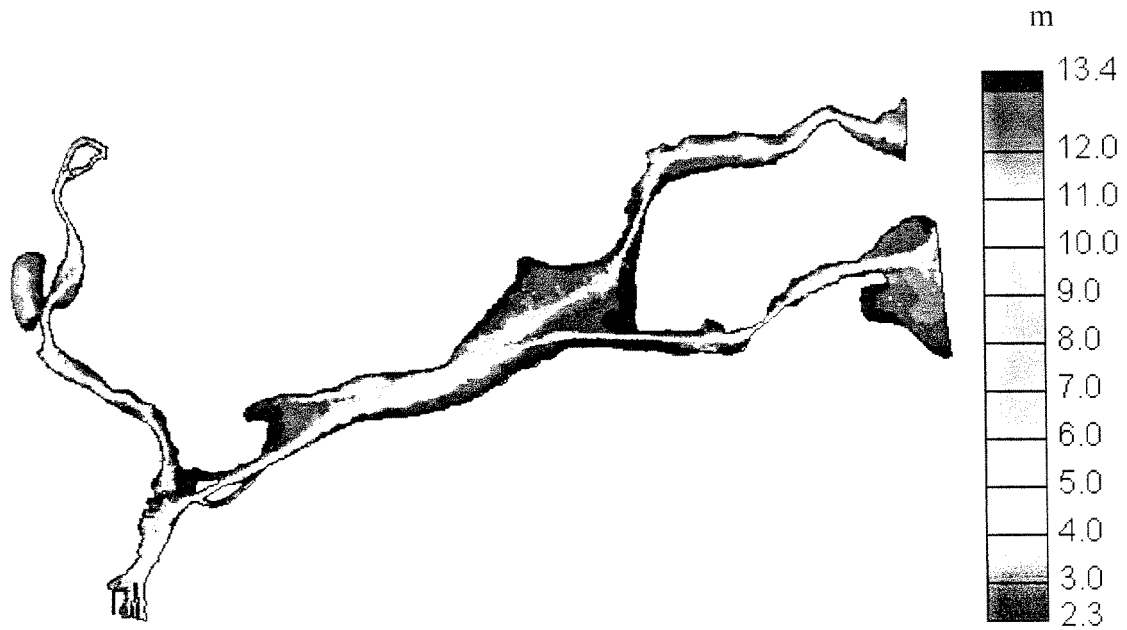
Figure 2-4 Riverbed Elevations Above the 162.583m Reference Level

1 - 2 - 9 - 10 channel

Reference Level: 162.583 m (from sea level)
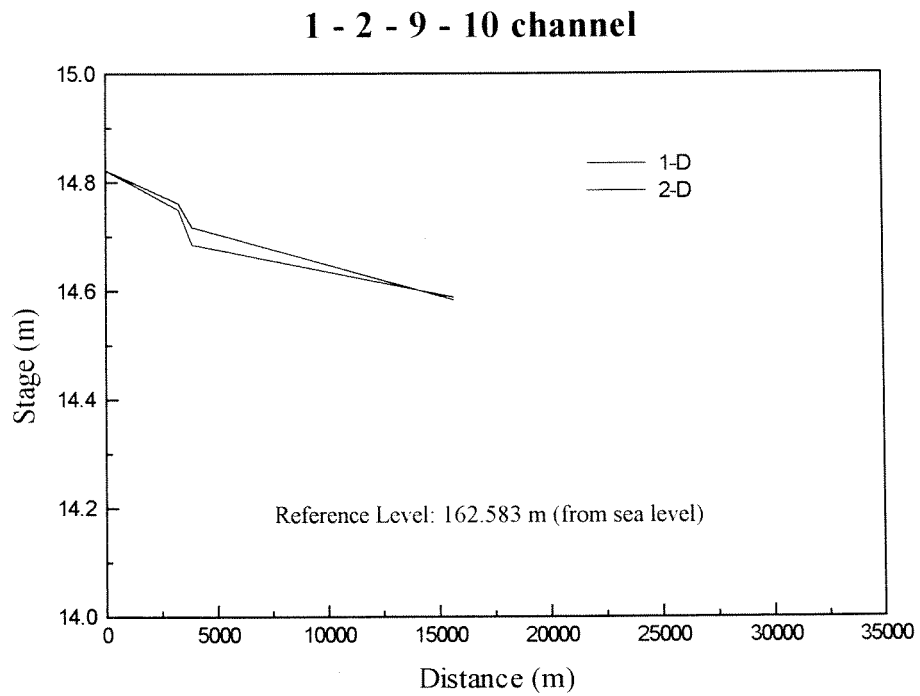
Figure 2-5 Comparison of water surface profiles along the North Channel

1 - 2 - 3 - 4 - 5 - 11 - 12 - 13 channel
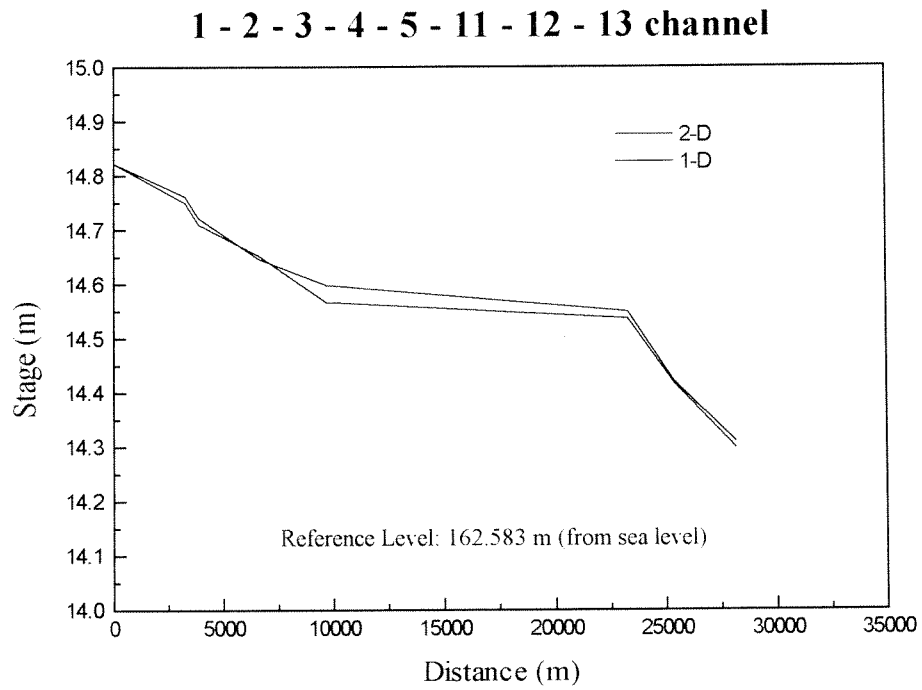
Figure 2-6 Comparison of water surface profiles along the South Channel
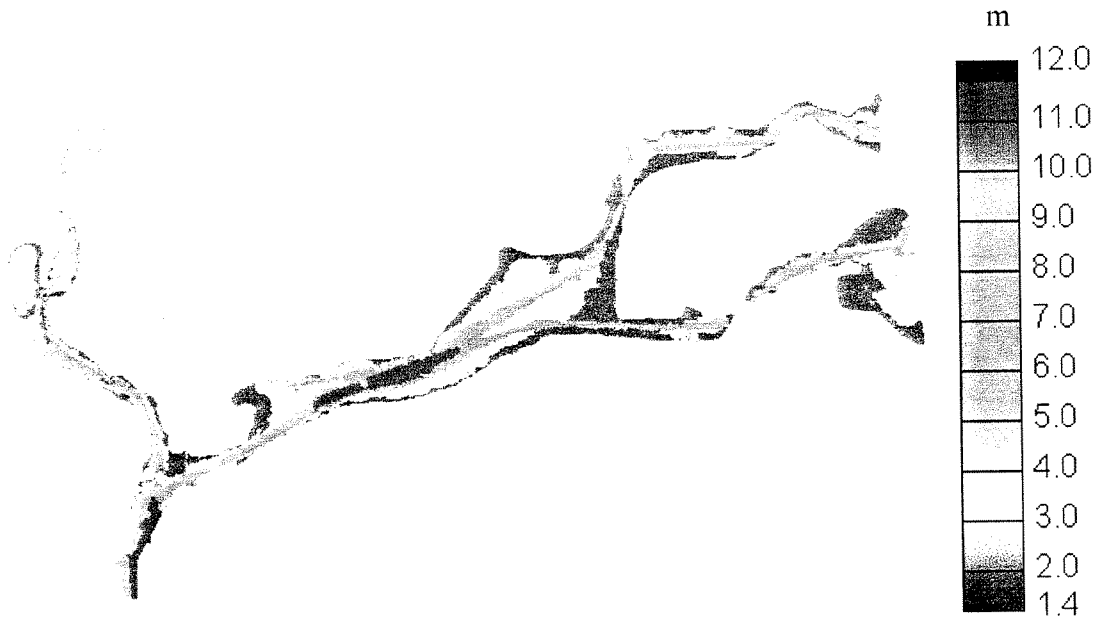
Figure 2-7 Distribution of Water Depth (m)
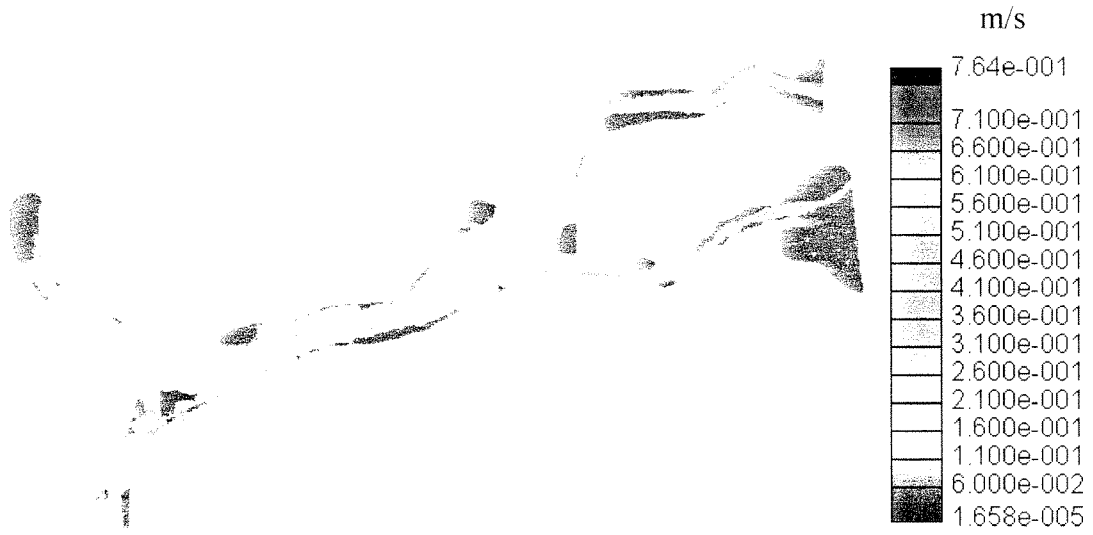
Figure 2-8 Velocity Distribution in the River (m/s)

Chapter 3 Chemical Transport Simulation

The chemical transport model considers that the chemical is well-mixed in the water column. Part of the chemical may be deposited on the bed. The water column is considered as layer 1 and the bed is considered as layer 2. Concentrations in these two layers are represented by their depth-averaged values. The sediment on the bed is considered to be transported along the bed under the influence of the fluid shear. Exchanges of sediment and chemical at the interface between the bed and the water column is considered in the model. Chemical can exist in both dissolved form or in particulate form absorbed to solids. In this section, the general formulation for this two-layer system is presented. However, in the application of the model to lampricide transport in St. Marys River, the sediment transport is neglected. Only one layer is required. The model is reduced to one layer model in this application.

3.1   Governing Equations

Consider an element of length Δx and width Δy, as shown in Figure 3.1. The governing equation of the total chemical concentration C_1 in the water column can be written as

$$\frac{\partial (C_1 h_1)}{\partial t} + \frac{\partial}{\partial x}(u_1 C_1 h_1) + \frac{\partial}{\partial y}(v_1 C_1 h_1) =$$

$$\frac{\partial}{\partial x}\left(h_1 D_x \frac{\partial C_1}{\partial x} \right) + \frac{\partial}{\partial y}\left(h_1 D_y \frac{\partial C_1}{\partial y} \right)$$

$$+ K_f \left(f_{d2} \frac{C_2}{\phi_2} - f_{d1} C_1 \right) - K_{d1} f_{d1} h_1 C_1$$

$$- k_l \left(-\frac{C_g}{H_e} + f_{d1} C_1 \right) - V_s f_{p1} C_1 + V_u f_{p2} C_2 \qquad (3.1)$$

Similarly, the equation for the total concentration in the moving bed sediment C_2 is

$$\frac{\partial (C_2 h_2)}{\partial t} + \frac{\partial}{\partial x}(u_2 C_2 h_2) + \frac{\partial}{\partial y}(v_2 C_2 h_2) =$$

$$- K_f \left(f_{d2} \frac{C_2}{\phi_2} - f_{d1} C_1 \right) - K_{d2} f_{d2} h_2 C_2 \qquad (3.2)$$

$$+ V_s f_{p1} C_1 - V_u f_{p2} C_2 - V_d f_{p2} C_2 - C_2 \left(V_s \frac{m_1}{m_2} - V_u - V_d \right)$$

in which, subscripts 1 and 2 denote water column and bed sediment layers, respectively; C = chemical concentration; h_1 = depth of flow; h_2 =depth of moving sediment layer; x, y, t = space and time variables; D_x, D_y = diffusion coefficients in x and y directions; u, v = components of depth-averaged velocity in x and y directions respectively; f_d = dissolved chemical as a fraction of the total chemical; f_p = chemical in particulate phase as a fraction of the total chemical; K_f = diffusion rate of dissolved chemical between the sediment and water column; K_d = dissolved chemical loss rate due to microbial decay, photolysis and hydrolysis; ϕ = porosity; k_l = overall volatilization transfer coefficient across air-water interface; V_s = settling velocity of particulate from water column to the bed sediment; V_u = resuspension velocity of sediment into the water column; V_d = loss velocity of chemical from sediment due to net sedimentation or burial; H_e = Henry's constant; C_g = vapor phase concentration.

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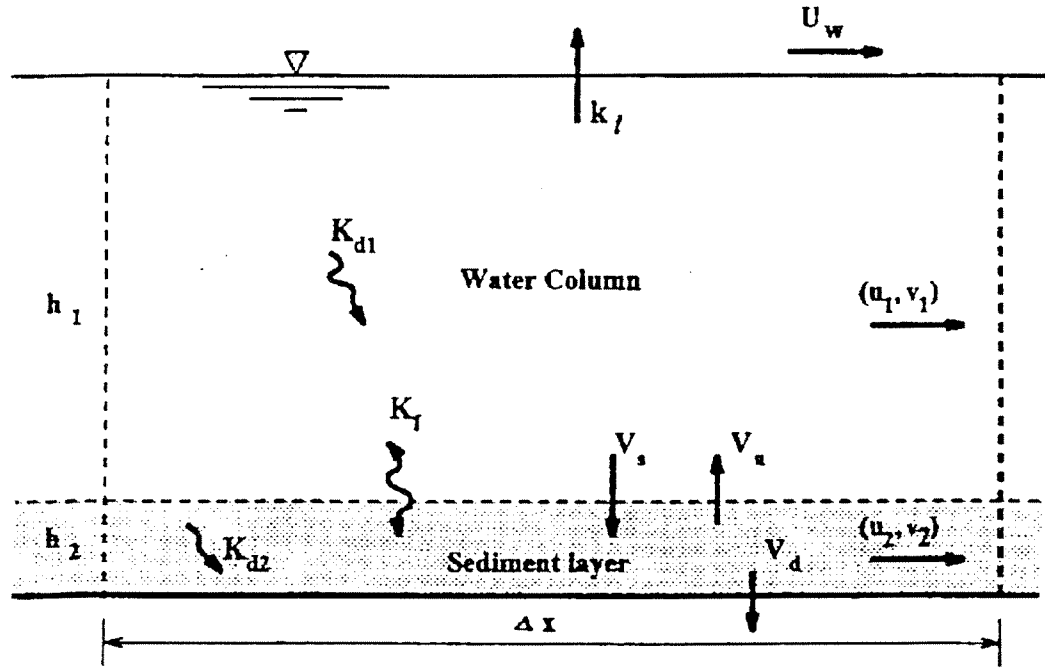
Figure 3-1 Chemical transfers in a differential element of width Δy

In Eq. 3.1, the third term on the right-hand side is the diffusive exchange of dissolved chemical between the sediment and the water column. The fourth and fifth terms are net chemical losses due to volatilization, photolysis, hydrolysis and biodegradation. The last two terms are the exchanges of the chemical in the particulate phase between the sediment and the water column.

Equations 3.1 and 3.2 can be written in Lagrangian form as

$$
h_1 \frac{DC_1}{Dt} = \frac{\partial}{\partial x}\left(h_1 D_x \frac{\partial C_1}{\partial x} \right) + \frac{\partial}{\partial y}\left(h_1 D_y \frac{\partial C_1}{\partial y} \right)
$$

$$
+ K_f \left(f_{d2} \frac{C_2}{\phi_2} - f_{d1} C_1 \right) - K_{d1} f_{d1} h_1 C_1 \tag{3.3}
$$

$$
- k_l \left(-\frac{C_g}{H_e} + f_{d1} C_1 \right) - V_s f_{p1} C_1 + V_u f_{p2} C_2
$$

and

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$$h_2 \frac{DC_2}{Dt} = -K_f \left(f_{d2} \frac{C_2}{\phi_2} - f_{d1} C_1 \right) - K_{d2} f_{d2} h_2 C_2$$
$$+ V_s f_{p1} C_1 - V_u f_{p2} C_2 - V_d f_{p2} C_2 - C_2 \left(V_s \frac{m_1}{m_2} - V_u - V_d \right) \qquad (3.4)$$

in which, m_1 and m_2 = solid concentrations defined as mass of solids per bulk volume of solids and water.

3.2 Numerical Scheme

The movement of the chemical in the river as described by Eqs. 3.1 and 3.2 is mainly governed by the advection and diffusion processes. These equations can be solved when chemical properties are known. In the present model, a Lagrangian discrete-parcel method [Shen et al. 1995] is used with modifications. In the Lagrangian discrete-parcel algorithm, both the chemical in the bed sediment and the chemical in the suspension are represented as an ensemble of a large number of small parcels. Each parcel has a set of time dependent spatial coordinates, and a mass associated with it. The movement of each parcel in the river is affected by the water current and the concentration of surrounding parcels. During each time step, all the parcels are first displaced according to the current or sediment velocities and a turbulent fluctuation component applied at their respective locations. The turbulent fluctuation component is simulated by using the random walk method [Fischer et al. 1979]. The fluctuation component depends on the diffusion coefficient and can be calculated as $\Delta x' = (2\Delta t D)^{1/2} \xi$, where D is the diffusion coefficient matrix, Δt is the time interval, and ξ is a vector of two independent normally distributed random variables with zero mean and unit variance. To account for the spatial variation of the water depth and the diffusion coefficient, an additional drift

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term[Kitanidis 1994; Hunter et al. 1993] should be added to the advection velocity. The iterative formula is shown in following equation:

$$x_{t+1} = x_t + (u_t + \nabla \cdot (\frac{1}{h} D)) \Delta t + (2 \Delta t D)^{1/2} \xi$$

in which, x_t is the current position of the particle, x_{t+1} is the postion of the particles at next time step, h is the water depth, D is the diffusion coefficient matrix, u_t is the water velocity at current position, Δt is the time interval, and ξ is a vector of two independent normally distributed random variables with zero mean and unit variance.

After all the parcels are displaced according to advection and diffusion, further modifications to parcel volume and location are introduced to account for mass exchanges and chemical reactions. Therefore, the mass of parcels changes with time. The number of parcels also increases with time during the simulation. If a large number of parcels are released in the river, and their discrete path and mass are followed and recorded as functions of time relative to a grid system in fixed space, then the concentration distribution of the pollutant in the water column or bed sediment can be computed using the smoothing interpolation method based on a two-dimensional Gaussian kernel or other kernel functions. The Lagrangian parcel approach requires an efficient book-keeping procedure rather than the solution of a large matrix associated with a conventional Eulerian finite-difference or finite-element method. The Lagrangian discrete parcel algorithm is inherently stable with respect to time, although the time step should be compatible with the grid size and velocity for numerical accuracy.

3.3 Smoothing and Interpolation of Concentration Using Kernel Functions

The concentration at the centers of each grid box can be calculated simply by adding up all the volumes of particles in the grid box and then dividing the total particle volume by the total water volume of the grid box. This algorithm is simple and efficient, but it can only give an average concentration over each grid box. In addition, since the chemical is represented by a finite number of discrete parcels, the concentration distribution may not be accurate and can fluctuate significantly if the number of parcels are small. Therefore, the algorithm requires a large number of parcels and a small grid box size if more detailed description of concentration distribution is required. A more efficient method is to use a smoothing interpolation method with kernel function based on Smoothed Particle Hydrodynamics (SPH)[Gingold and Monaghan 1977]. The basic equation of two-dimensional kernel interpolation can be written as:

$$\tilde{f}(r,h) = \sum \frac{f_j}{\langle n_j \rangle} W(r - r_j, h) \tag{3.5}$$

in which n_j is the number density, i.e. number of points per unit area at r_j, and $< >$ represents ensemble average, f_j is the function value at j, W is the kernel function, and h is the smooth length. Applying the basic equation to our problem, f_j is the area concentration calculated at location j, and interpolation equation becomes:

$$C(r,h)h_r = \sum_{j=1}^{N} \frac{V_j/a_j}{1/a_j} W(r - r_j, h) = \sum_{j=1}^{N} V_j W(r - r_j, h) \tag{3.6}$$

in which, V_j is the volume of particles at location j, a_j is the area, h_r is the depth at r, and $C(r,h)$ is the concentration at r, and W is the two-dimensional kernel function.

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A two-dimensional Gaussian kernel function for $W(r-r_j, h)$ is used:

$$W(r - r_j, h) = \frac{1}{h^2 \pi} e^{-\frac{(r-r_j)^2}{h^2}}$$ (3.7)

The kernel interpolation method eliminated the use of grid boxes in the concentration calculation. It can also reduce the fluctuation due to the limited number of parcels used in the simulation.

3.4   Model Implementation

Based on the analytical formulation presented, a computer model for chemical transport is developed for the St. Marys River. The model is based on a triangular schematization of the domain.

The rectangular schematization is widely used in the particle tracking method. In the rectangular gird schematization, the output of finite element simulation of hydrodynamics is first interpolated to the rectangular grid system, and the water velocity and flow depth at grid boxes are then used in the chemical transport model. Particle movements in the domain are calculated using the rectangular grid system. The advantage of this method is that obtaining the water velocity and depth at any particle location in the domain is easy. However, the rectangular schematization has some drawbacks. First, the interpolation from a finite element mesh to a grid system introduces numerical error. Second, to represent some locations in the domain where the domain shapes are complex, a small grid size has to be used for the whole domain although most of the domain may not require such small grid boxes. In addition, the grid box method can not accurately represent the complex river boundary. When particles move along a boundary that is not

parallel to the x-axis or y-axis, the paths of particles will be distorted by the step boundary.

To simulate rivers with complex shapes like St. Marys River, the model is implemented with the triangular finite-element schematization of the domain. Particle movements in the domain are calculated directly from the finite element mesh using shape functions.

$$u_x(x,y) = u_{x1}s_1(x,y) + u_{x2}s_2(x,y) + u_{x3}s_3(x,y)$$
$$u_y(x,y) = u_{y1}s_1(x,y) + u_{y2}s_2(x,y) + u_{y3}s_3(x,y)$$

In which, u_x and u_y are flow velocity at location (x, y) in x direction and y direction, respectively. (u_{x1}, u_{y1}), (u_{x2}, u_{y2}), and (u_{x3}, u_{y3}) are flow velocity vectors at nodes of finite element. $s_1(x, y)$, $s_2(x, y)$, and $s_3(x, y)$ are shape functions and are defined as

$$s_1(x,y) = (a_1 + b_1 x + c_1 y)/2\Delta$$
$$s_2(x,y) = (a_2 + b_2 x + c_2 y)/2\Delta$$
$$s_3(x,y) = (a_3 + b_3 x + c_3 y)/2\Delta$$

$$a_1 = x_2 y_3 - x_3 y_2$$
$$a_2 = x_3 y_1 - x_1 y_3$$
$$a_3 = x_1 y_2 - x_2 y_1$$

$$2\Delta = (a_1 + a_2 + a_3)$$

In which, (x_1, y_1), (x_2, y_2), and (x_3, y_3) are the coordinates of three nodes of triangular element.

The water velocity and water level at the nodes of triangular mesh system are generated by the hydraulic model. In this method, no mesh to grid transformation is needed and therefore no interpolation error is introduced at this step. The mesh system is

more flexible than the grid system to represent the irregular domain. However, the triangular mesh method requires more computation time because to identify the location of particles in triangular mesh is more difficult than in a rectangular grid system. The interpolation in triangular element consumes more time than the bilinear interpolation in the rectangular grid cell.

The finite element triangular mesh system of the hydraulic model can be used directly in the transportation model. Parcels will move in the mesh system and the advection velocity and water depth will be calculated using shape functions. Along the boundary, parcels will be reflected back into boundary to simulated the boundary condition that the gradient of concentration normal to the boundary is zero or the movement of parcels in the direction normal to the boundary is zero[Tompson et al 1988]. At each time step, the concentration is calculated at each node of the mesh system instead of at center of each grid cell in the grid system method.

At the beginning of the simulation, the user selects a number of parcels to represent the chemical being released into the river. The upper limit of this number only depends on the available memory of the computer. No recompilation the computer program is necessary.

In the St. Marys River simulations, chemical in the bed is assumed to be negligible due to the low sediment concentration. Therefore, only the water layer transport is considered.

Based on users input of the concentration of chemical released and the discharge of water, the total amount of chemical input at a chemical discharge location is obtained. In the model, dye or lampricide are considered as miscible non-reactive chemicals. Parcels

have equal volumes. A chemical discharge is treated either as an instantaneous input or a continuous input. When the input duration is zero the input is treated as instantaneous input. Otherwise, it is treated as a continuous effluent.

The computer code is written in ANSI C++. No compiler specific extensions have been used. The code has been tested on 32 bit machines with Microsoft Visual C++ 4.0 compilers on IBM PC-Compatible with 486, Pentium, and Pentium Pro CPU. They should be able to be recompiled and run on any other computer with 32bit ANSI C++ compiler.

Chapter 4 Model Calibration

The model calibration is based on two dye studies. The first dye study was conducted in the St. Marys River during December 7 to 10, 1981 [Great Lakes Fishery Commission, 1981]. This included a series of four dye studies. The purpose of the study was to observe the general dispersal pattern of dye released from various sites. A sketch for the maximum concentration pattern was given for each test. The results are generally indicative of the maximum concentration existed during the progression of the dye cloud. The distributions of concentration with respect to time are not available. These dye dispersal plots are somewhat qualitative but provide valuable data, which were used in the preliminary calibration of the computer model. The dye used was fluorescent Rhodamine WT , 20% aqueous. The dye injection sites were Edison Sault Electric Generation Station, Corps of Engineers Power Station, Compensating Gates, and the Canadian Lock, respectively. The results of calibration simulations for these four dye tests are presented in this section.

The second comprehensive dye study was carried out during August 10-12, 1996, for further model calibration. The dye release site was Great Lake Power Plant. The release of dye lasted 14 hours. This dye study covered a much larger area than the first dye study. Time dependent dye concentration distributions at selected cross-sections were obtained. The comparison between the observed dye concentration and model simulation is presented in section 4.5.

4.1   Case 1—Dye Study 1: Edison Sault Electric Application

On December 7, 1981, a total of 38.4 liters of dye was released at the Edison

Power Canal at Fort street in Sault Marie, Michigan during a 10 hour period from 0600 to

1600 hours. A fairly good mix of dye, horizontally and vertically, occurred in the power

canal. Since the power canal is too narrow to include in the model, the dye discharge site

for the simulation is considered to be at the Edison Sault Electric Power House with an

average concentration of 2.84 ppb and the release period from 0600 to 1200 hours.

Maximum observed and simulated dye concentrations are shown in Figs. 4.1 and

4.2. From these results, most of the dye from this source appears to go down the main

shipping channel south of Sugar Island. The leading edge of the dye flows relatively fast

along the main shipping channel and takes about 5 hours to reach Lake Nicolet. The

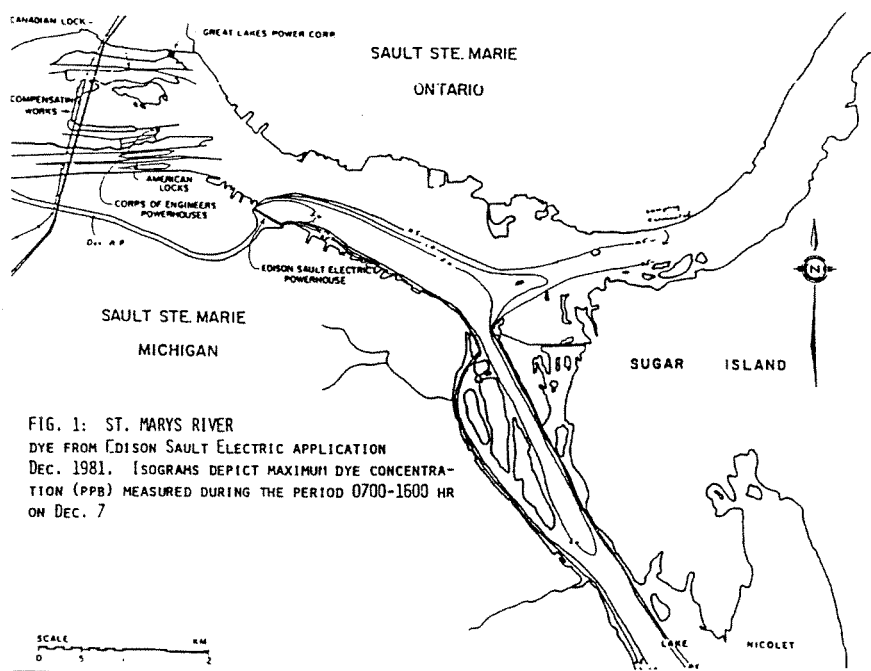simulation of dye dispersion compares relatively well with the observed data.

**Figure 4-1 Maximum dye concentration observed for the period 0700-1600 hrs on
Dec. 7 - Case 1**

time= 0 to 10 h

cct (ppb)

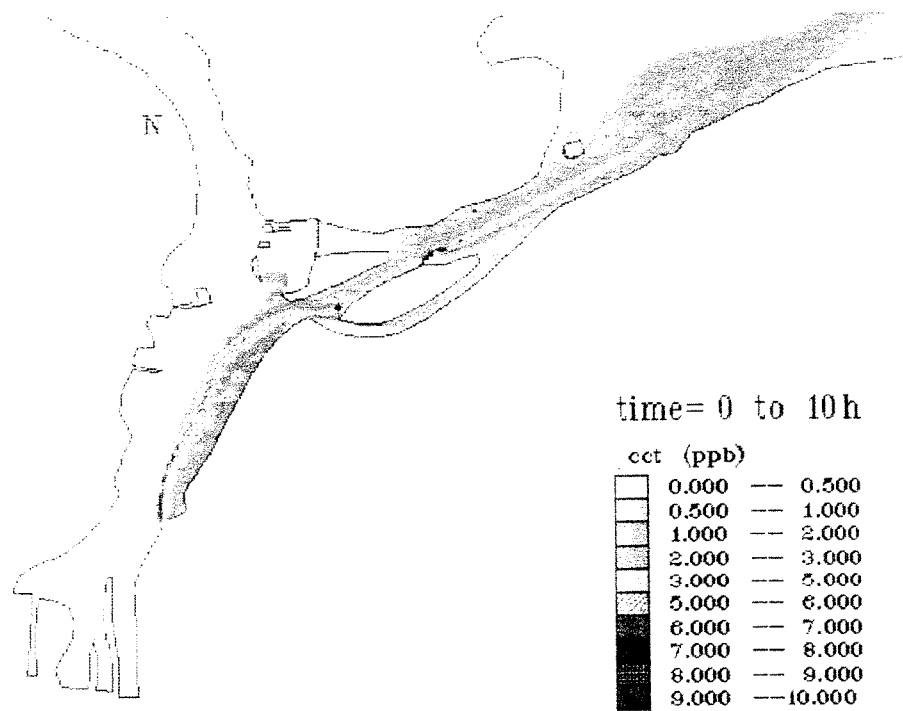|		
0.000	—	0.500
0.500	—	1.000
1.000	—	2.000
2.000	—	3.000
3.000	—	5.000
5.000	—	6.000
6.000	—	7.000
7.000	—	8.000
8.000	—	9.000
9.000	—	10.000

Figure 4-2 Simulated maximum dye concentration for the period 0600-1600 hrs on Dec. 7 during the 10 hours after the Edison Sault Electric application

4.2 Case 2—Dye Study 1: Corps of Engineers Application

On December 8, 1981, a total of 26.8 liters of dye was released at the Corps of Engineers Power House for a period of 5 hours from 0700 to 1200 hr. The average concentration of the dye discharge was 3.46 ppb.

Maximum observed and simulated dye concentrations are shown in Figs. 4.3 and 4.4. The dye released was split into two parts as it moved downstream. One part moved down the main shipping channel south of Sugar Island. The other part moved down the Canadian side of Sugar Island. The simulated result agrees reasonably well with the observed data. One noticeable difference is that the dye distribution from the simulation tends to bend to the American shore between the American Lock and Edison Sault

Electric Powerhouse. The reason for this bending is that the water discharge from the American Lock is very small and the discharge from the Corps of Engineers Power House was deflected toward the US side. Further downstream, the dye plume was deflected by the side discharge from the Edison Sault Power House back to the center of the river.
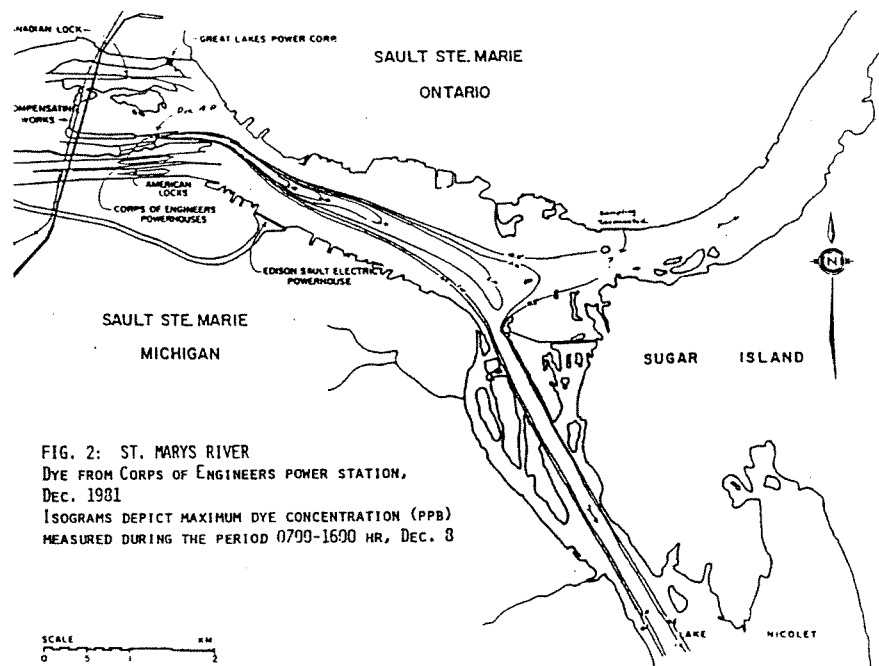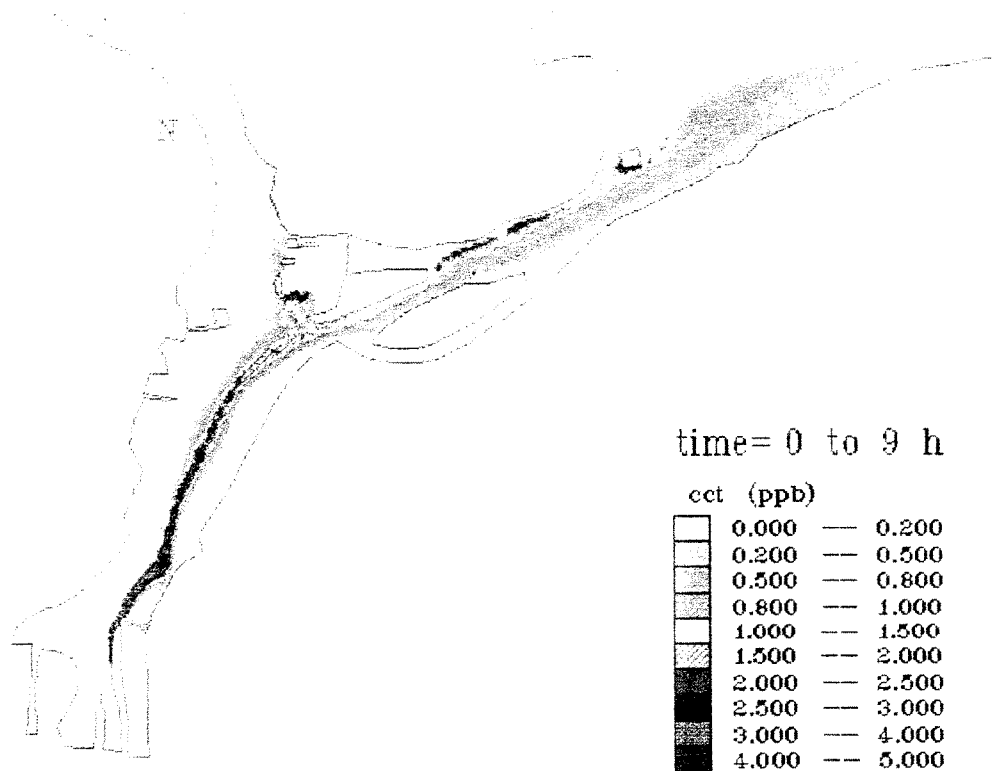

FIG. 2: ST. MARYS RIVER
DYE FROM CORPS OF ENGINEERS POWER STATION,
DEC. 1981
ISOGRAMS DEPICT MAXIMUM DYE CONCENTRATION (PPB)
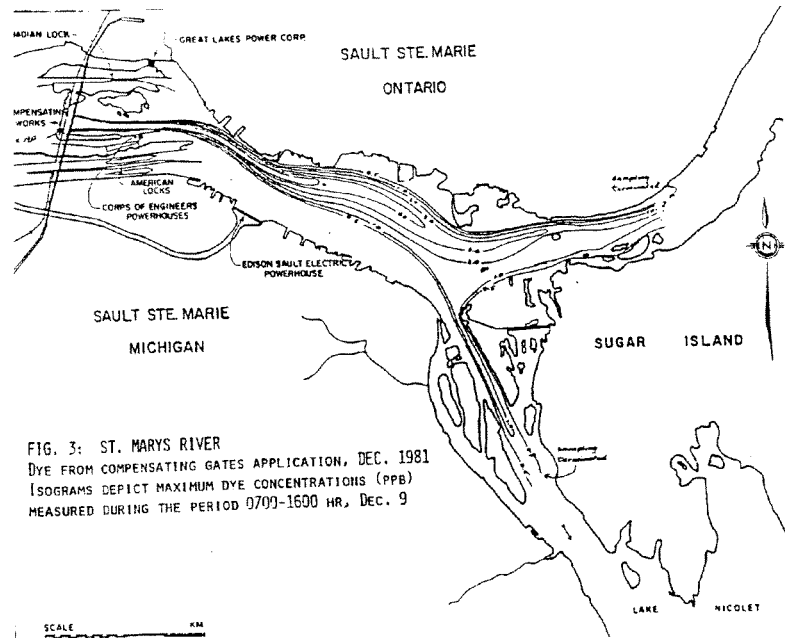MEASURED DURING THE PERIOD 0700-1600 HR, DEC. 8

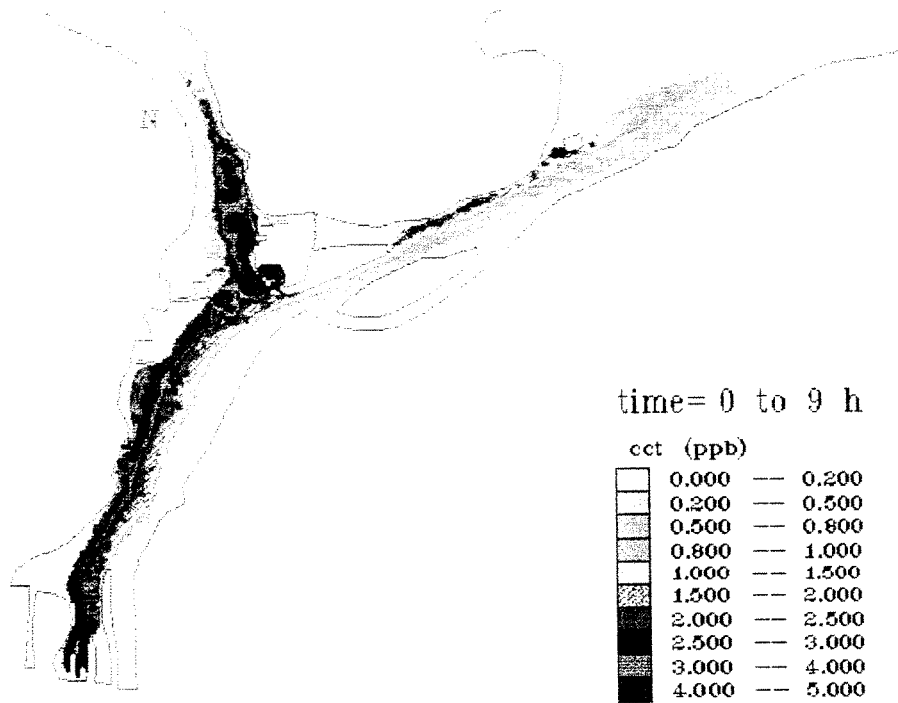**Figure 4-3 Maximum dye concentration observed during 0700-1600 hrs - Case 2**

Figure 4-4 Simulated maximum dye concentration for the period 0700-1600 hrs on Dec. 8 during the 9 hours after the Corps of Engineer Application

4.3 Case 3—Dye Study 1: Compensating Gates Application

On December 9, 1981, a total of 27 liters of dye was applied to the water passing over the St. Marys Rapids between the hours of 0730 and 1230. The average concentration of the dye discharge was 4.81 ppb and the duration of the discharge was 5 hours.

Maximum observed and simulated dye concentrations are shown in Figs. 4.5 and 4.6. Most of the dye from this source appears to go toward the Canadian Channel and moves slower than those in the two previous cases.

FIG. 3: ST. MARYS RIVER
DYE FROM COMPENSATING GATES APPLICATION, DEC. 1981
ISOGRAMS DEPICT MAXIMUM DYE CONCENTRATIONS (PPB)
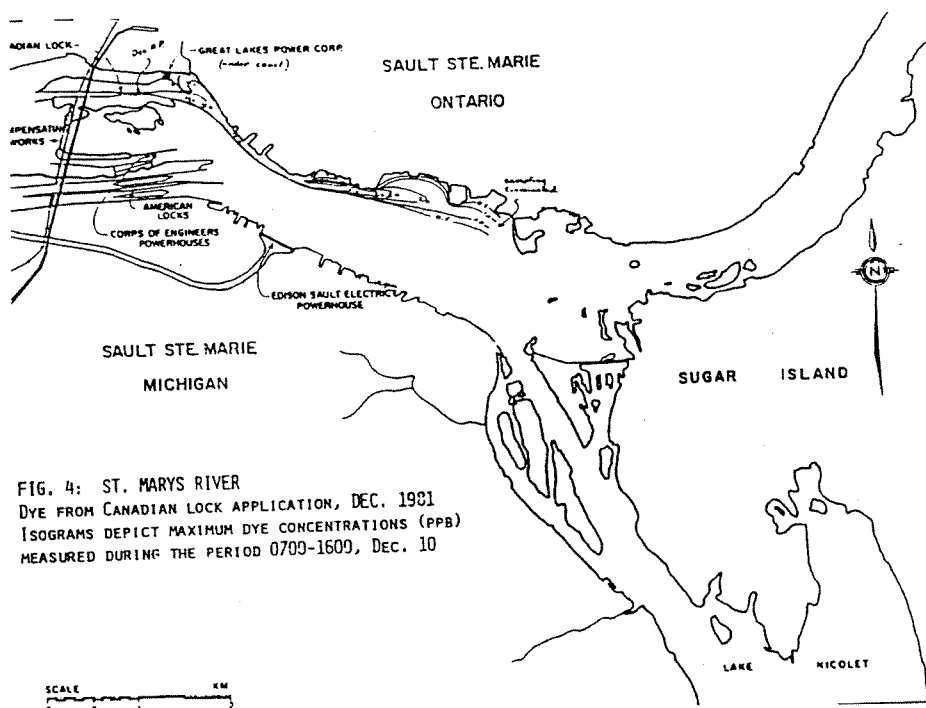MEASURED DURING THE PERIOD 0700-1600 HR, DEC. 9

Figure 4-5 Maximum dye concentration observed during 0700-1600 hrs - Case 3

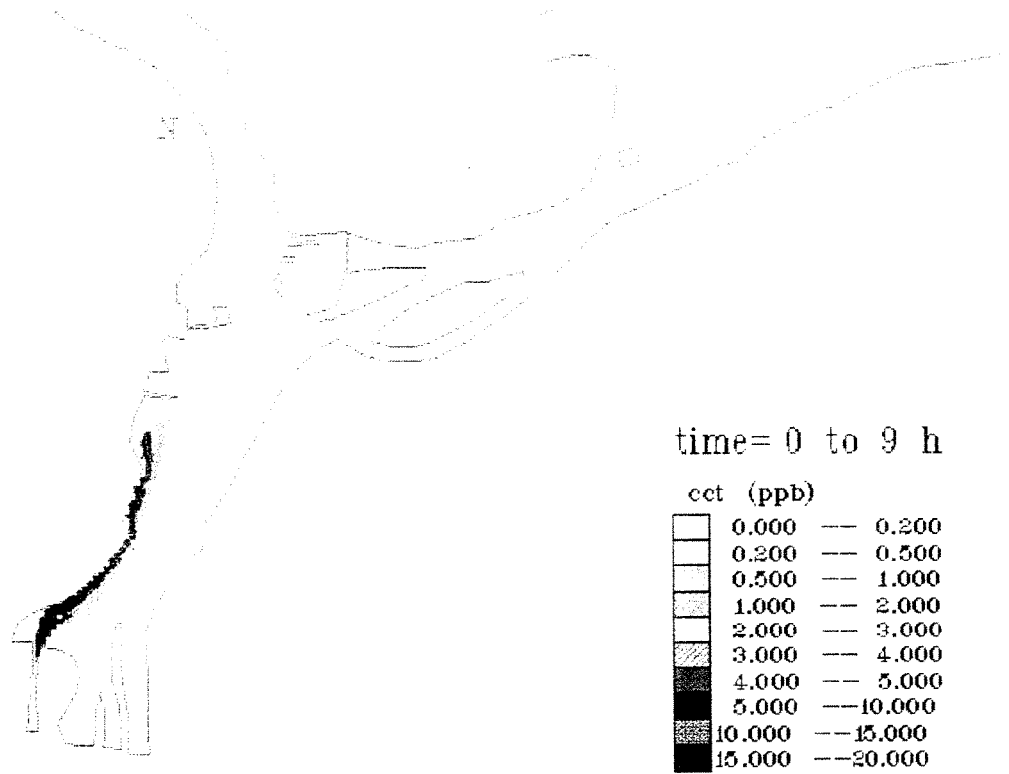**Figure 4-6 Simulated maximum dye concentration for the period 0700-1600 hrs on Dec. 9 during the 9 hours after the Compensating Gates Application**

4.4   Case 4—Dye Study 1: Canadian Lock Application

On December 10, 1981, a total of 20.0 liters of dye was applied to the downstream valve outlets on each side of the Canadian Lock from 07:15 to 13:05 hrs. The average concentration of the dye at the discharge site was 27.0 ppb and the duration of discharge was about 6 hours.

Maximum observed and simulated dye concentrations are shown in Figs. 4.7 and 4.8. This dye cloud tends to stay very close to the Canadian shore and fill in all the boat slips and bays. It took a long time for the dye to move down to the north channel between the mainland and the Sugar Island since the water flow is slow in the shallow region close to the shore.

FIG. 4: ST. MARYS RIVER
DYE FROM CANADIAN LOCK APPLICATION, DEC. 1981
ISOGRAMS DEPICT MAXIMUM DYE CONCENTRATIONS (PPB)
MEASURED DURING THE PERIOD 0700-1600, DEC. 10

Figure 4-7 Maximum dye concentration observed during 0700-1600 hrs - Case 4

28

time= 0 to 9 h

cct (ppb)

0.000	——	0.200
0.200	——	0.500
0.500	——	1.000
1.000	——	2.000
2.000	——	3.000
3.000	——	4.000
4.000	——	5.000
5.000	——10.000
10.000	——15.000
15.000	——20.000

Figure 4-8 Simulated maximum dye concentration for the period 0700-1600 hrs on Dec. 10 during the 9 hours after the Canadian Lock application

4.5   Case 5—Dye Study 2: Great Lake Power Plant Application

During August 10-12 1996, a comprehensive dye study was carried out on the upper St. Marys River.. The dye release began at 0600 hrs and ended at 2000 hrs from the Great Lake Power Plant. The average initial concentration of the dye discharge was 7 ppb.

Concentration was measured at several cross sections along the north channel and sourth channel. Figure 4.9 shows the location of these cross sections. The comparisons of observed and simulated dye concentrations are shown in Fig. 4.10 to Fig. 4.13. The dye released was split into two parts as it moved downstream. A small part of dye moved down the main shipping channel south of Sugar Island. The large part of dye moved down the north channel on the Canadian side of Sugar Island. The simulated result agrees reasonably well with the observed data. Figure 4-14 shows the simulated maximum concentration distributions and Fig 4-15 show the simulated result of duration in hours of exceeding lethal level 4.67 ppb.   Figure 4-16 shows the lethal area observed in the dye test.
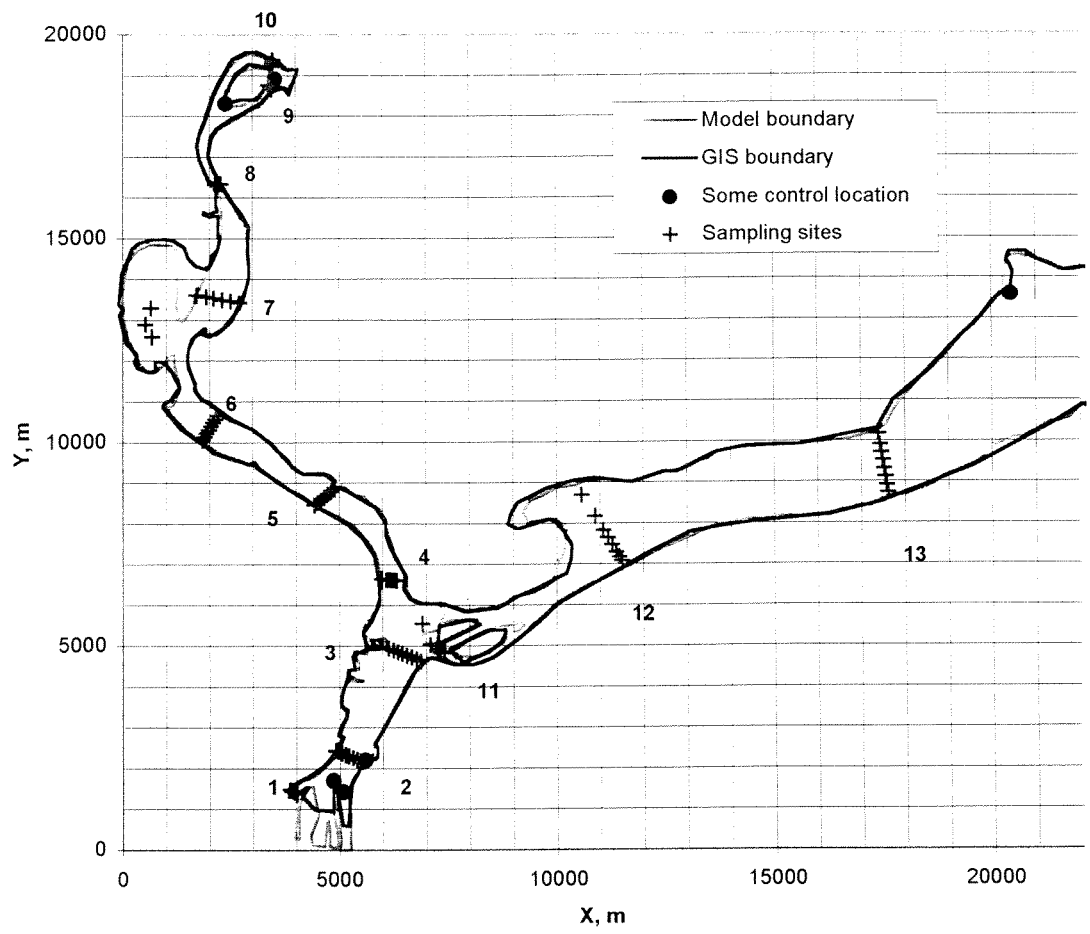
Figure 4-9 Domain map with dye sampling sites
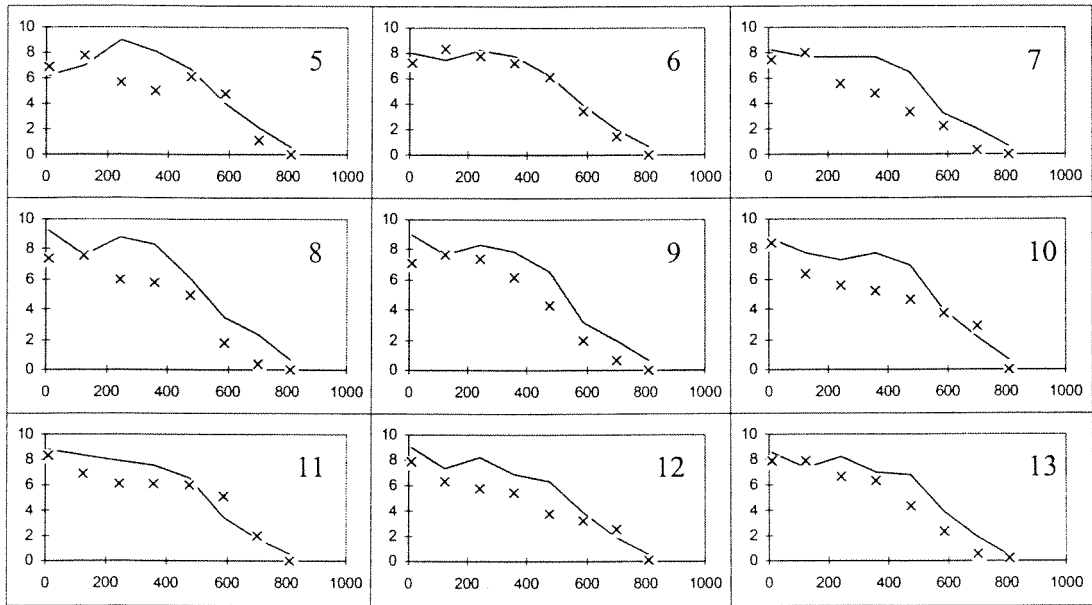
Figure 4-10 Cross Section Comparison - Cross Section 3
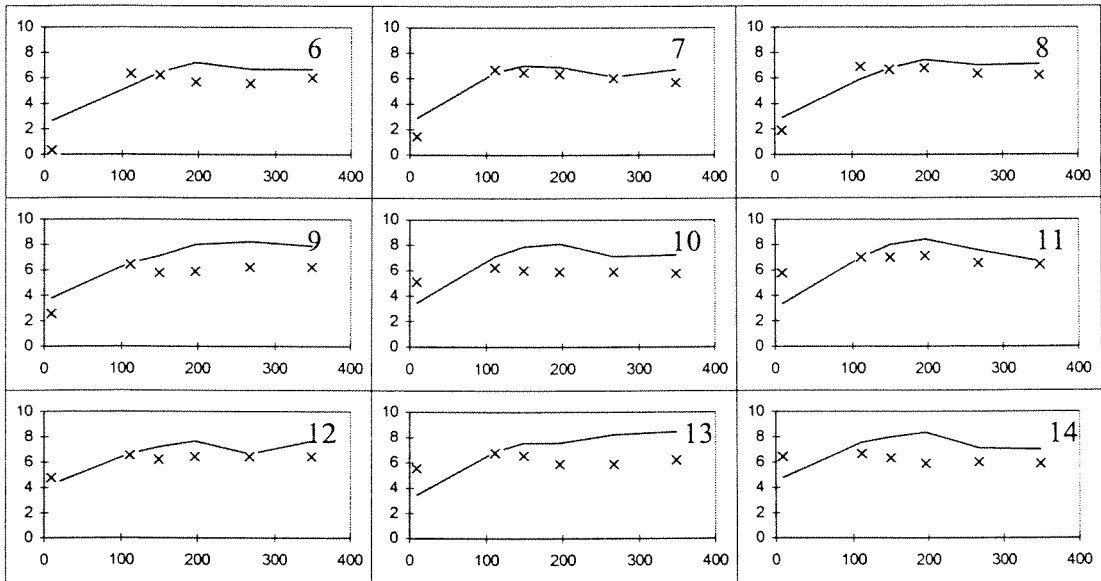
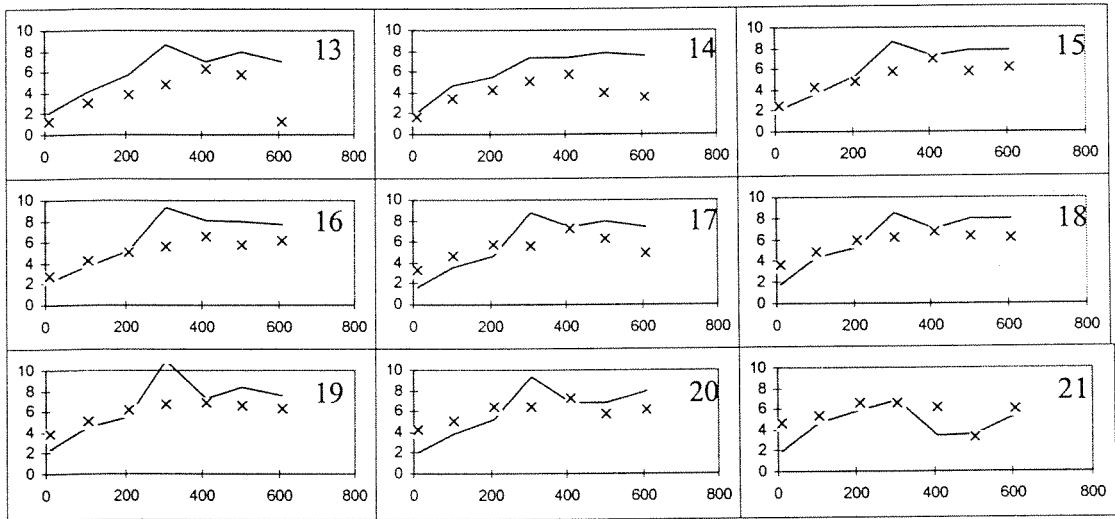**Figure 4-11 Cross Section Comparison - Cross Section 4**

Figure 4-12 Cross Section Comparison - Cross Section 5
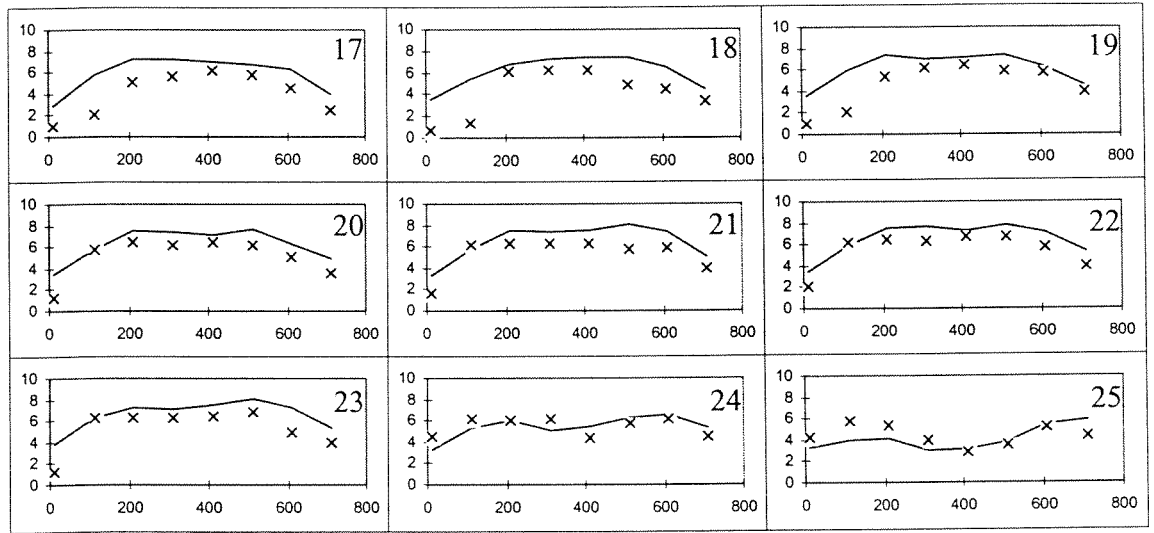

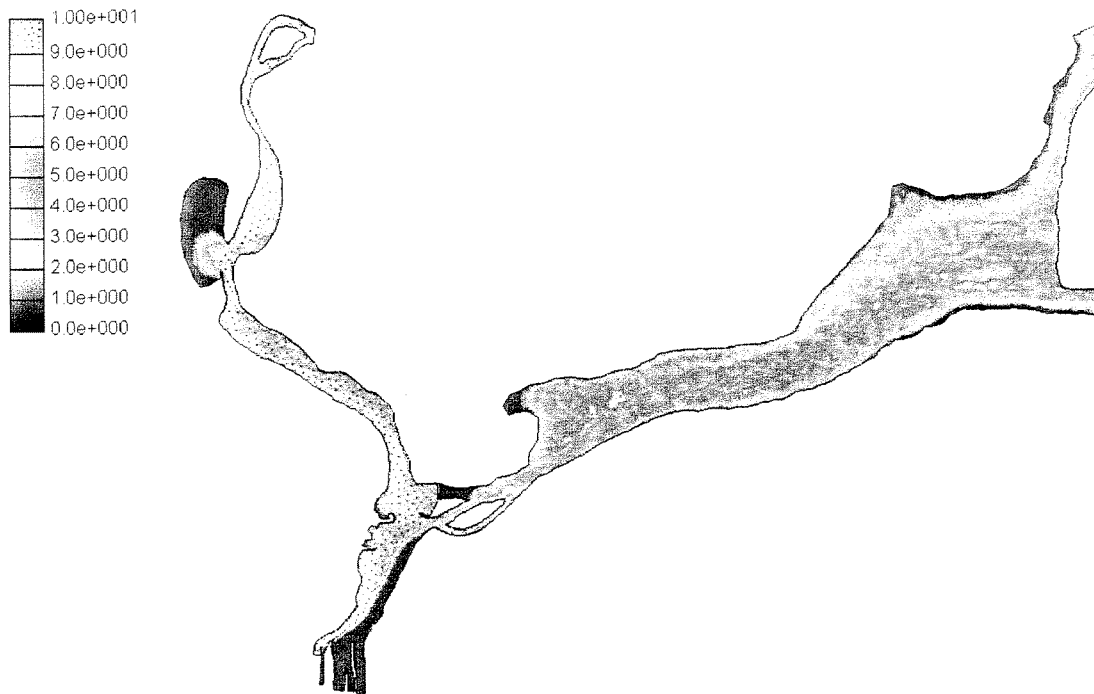**Figure 4-13 Cross Section Comparison - Cross Section 6**

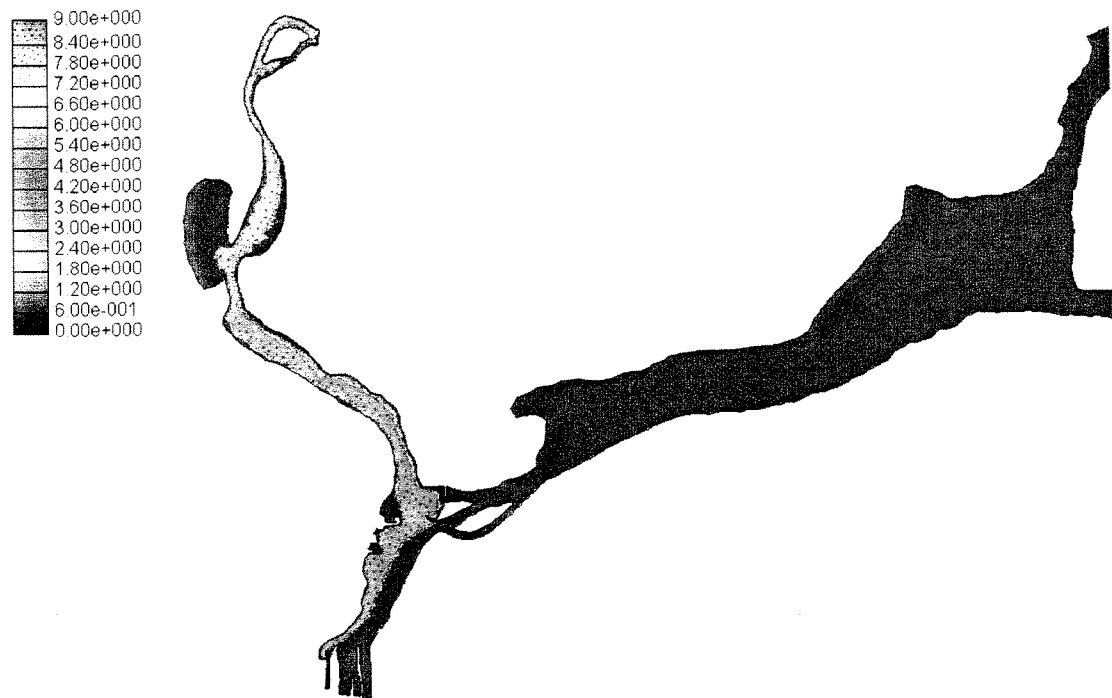**Figure 4-14 Case 5 – Dye Study 2: Simulated Maximum Concentration (ppb)**

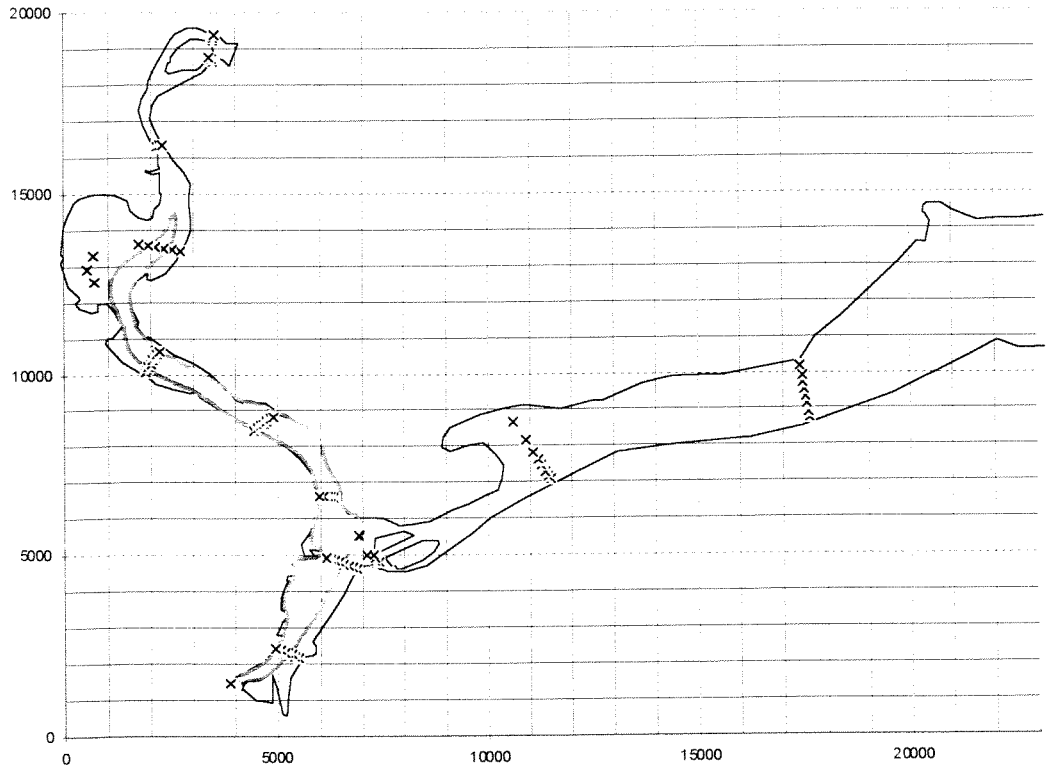**Figure 4-15 Case 5 – Dye Study 2: Duration of Dye Concentration Exceeding the Lethal Level of 4.67ppb (hours)**

Figure 4-16 Lethal Area Observed in Dye Test

Chapter 5 Scenario Simulations: TFM Application

The calibrated model is analyze different scenarios of TFM application. In the analysis of TFM application, 20 simulations with different combination of flow conditions and lampricide input conditions are made and the numbers of lamprey killed are calculated.

The 20 scenarios are composed of combinations of 5 different flow conditions (1-5) and 4 different lampricide input conditions (A-D). The flow conditions are shown in Table 5-1 and the lampricide input conditions are shown in Table 5-2.. The numbering of simulated scenarios is the combination of flow condition and lampricide input condition. The scenario with flow condition 1 and input condition A will be called as Scenario 1A, and the scenario with flow condition 5 and input condition D will be called as Scenario 5D.

The total discharge for each of these 20 scenarios is the same, at 60,000 cfs. Reducing the total discharge will save lampricide cost to achieve the same lampricide concentration in the river, but 60,000 cfs is the minimum discharge at which the power stations and other facilities can satisfy their minimum operating conditions. The five flow conditions differ in the distribution among Great Lake Power Station, Compensating Works, Corp of Engineer Power Station, and other facilities. The discharge of GLP in flow condition 1 is 22,000 cfs. It is increased by 2,000 cfs to 24,000 cfs in flow condition 2, 26,000 cfs in flow condition 3, 28,000 cfs in flow condition 4, and 30,000 cfs in flow condition 5. To keep the total discharge the same at 60,000 cfs, the discharge of COE is

reduced from 9,000 cfs in flow condition 1 to 7,000 cfs in flow condition 2 and 3, to 5,000cfs in flow condition 4, and to 3,000 cfs in flow condition 5, and the discharge of Compensating Works are reduced from 3,500 cfs in flow condition 1 and 2 to 1,500 cfs in flow condition 3, 4, and 5. The discharge of Edison Sault Power Plant is required not to be larger than 27,000 cfs for the normal operation of the plant. It is fixed at 25,000 cfs in all simulations.

Among the 4 different lampricide input conditions, lampricide is released only on GLP side in cases A and B. It is released both on GLP side and Edison Sault side in cases C and D. The initial concentrations of these scenarios are 2.4 ppm, and the lethal level is 1.6ppm, i.e. 2/3 of the initial concentration. The input duration is 16 hours for input condition A, 20 hours for input condition B, 14 hours for input condition C, and 16hours for input condition D.

Table 5-1 Flow conditions

| Flow Condition | Discharge, cfs | | | | |
	1	2	3	4	5
GLP	22,000	24,000	26,000	28,000	30,000
Edison	25,000	25,000	25,000	25,000	25,000
Rapid	3,500	3,500	1,500	1,500	1,500
COE	9,000	7,000	7,000	5,000	3,000
Lock	500	500	500	500	500
Total	60,000	60,000	60,000	60,000	60,000

Table 5-2 Lampricide input condition

Input Condition	Concentration/Duration			
	A	B	C	D
GLP	2.4ppm/16hour	2.4ppm/20hour	2.4ppm/14hour	2.4ppm/16hour
Edison	-	-	2.4ppm/14hour	2.4ppm/16hour

The model simulates the diffusion and advection of lampricide in the river and generates the lampricide concentration distribution hourly for the 48 hours of simulation period. Areas where the concentrations exceed the lethal level for durations longer than 9 hours is considered to be "Lethal areas". Both the maximum concentration distribution and the lethal area are presented in Appendix B for all scenarios. The number of lamprey larvae killed by lampricide is calculated for each scenario by superimposing the simulated lethal area plots on the larval density distribution map as shown in Figure 5-4.

Table 5-3 shows the summary of the simulation results. Scenario 4C is the most effective scenario in term of number of kills per dollars. Scenario 5D achieves the maximum total kill, but the kill per dollar of Scenario 5D is lower than Scenario 4C. Table 5-3 also shows the two-site release scenarios (C and D) are more effective than single-site release scenarios (A and B) in term of kill per dollar. However, the total costs of two-site release scenarios are much higher than single-site release scenarios although the total kills are higher. In the single input site scenarios, the lower the discharge of GLP is, the better kill-per-dollar, as show in Figure 5-2. The reason is more discharge from GLP means more lampricide input for the same initial concentration. More lampricide input at GLP causes more diluted lampricide on the south side of the channel. It therefore reduces the effectiveness on the south side of channel although the total kill increases. However, in the two-input site scenarios as shown in Figure 5-3, the kill-per-dollar

increases as the discharge of GLP increases from flow condition 1 to condition 4, then it decreases as flow discharge of GLP further increases to flow condition 5. That can be explained as that the total input increases in the two input site input scenarios will reduce the gap between lampricide clouds and improve the kill effectiveness. When the input of GLP increases from flow condition 4 to 5, the two clouds overlap each other and decrease the kill-per-dollar. In the single input site scenarios, increase the input will increase the total kill, but it will also decrease the kill-per-dollar because the more lampricide will be diluted to the south side of the channel.

From Table 5-3, the effectiveness of short input duration scenarios is better than that of long input duration scenarios for the same flow conditions. To further understand the relationship between input duration and the kill effectiveness, 12 different input duration ranging from (9 hours to 20 hours) are tested using flow condition 1. The simulation results are shown in Figure 5-1. The result shows that increasing input duration from 8 hours to 14 hours will improve kill-effectiveness. Further increasing input duration will increase total kill, but the kill-per-dollar will decrease slightly. The best input duration lies in the range from 14 hours to 16 hours.

Table 5-3 Effectiveness comparison of simulated scenarios

No.	Input Volume (m³)		Input Duration (hrs)	Input (10³ lb)	Total Kill (10³)	Kill/lb (1/lb)	Kill/Vol (10³/m³)	TFM Cost (million $)	Kill/$ (1/$)
	GLP	Edison							
1A	86.57			195	1270.7	6.64	14.68	5.84	0.218
2A	93.89			211	1317.0	6.35	14.03	6.33	0.208
3A	101.72	0	16	229	1371.0	6.10	13.48	6.86	0.200
4A	109.54			246	1426.6	5.89	13.02	7.39	0.193
5A	117.37			264	1420.7	5.48	12.10	7.92	0.179
1B	108.21			243	1334.0	5.58	12.33	7.30	0.183
2B	117.37			264	1420.7	5.48	12.10	7.92	0.179
3B	127.15	0	20	286	1449.0	5.16	11.40	8.57	0.169
4B	136.93			308	1459.5	4.82	11.15	9.23	0.158
5B	146.71			330	1467.3	4.53	10.00	9.89	0.148
1C	75.75			363	2329.0	6.53	14.44	10.9	0.214
2C	82.16			377	2563.4	6.92	15.28	11.3	0.227
3C	89.00	85.58	14	392	2827.0	7.33	16.19	11.8	0.240
4C	95.85			408	2991.8	**7.46**	**16.49**	12.2	**0.245**
5C	102.70			423	3064.8	7.37	16.28	12.7	0.241
1D	86.57			414	2618.2	6.43	14.20	12.4	0.211
2D	93.89			431	2776.4	6.55	14.48	12.9	0.215
3D	101.72	97.80	16	449	2914.3	6.61	14.61	13.5	0.216
4D	109.54			466	3122.4	6.81	15.06	14.0	0.223
5D	117.37			**483**	**3177.9**	6.68	14.77	**14.5**	0.219
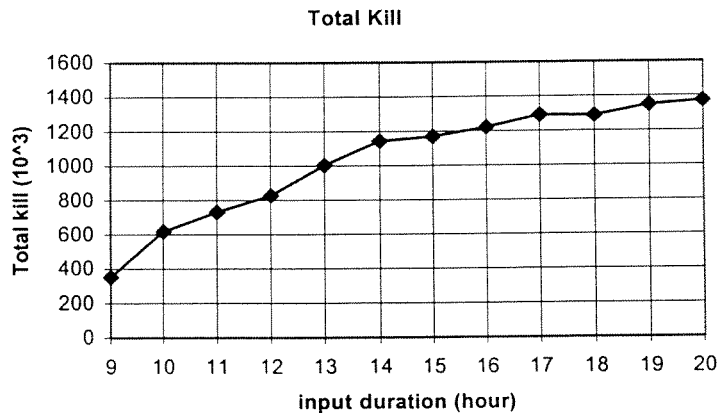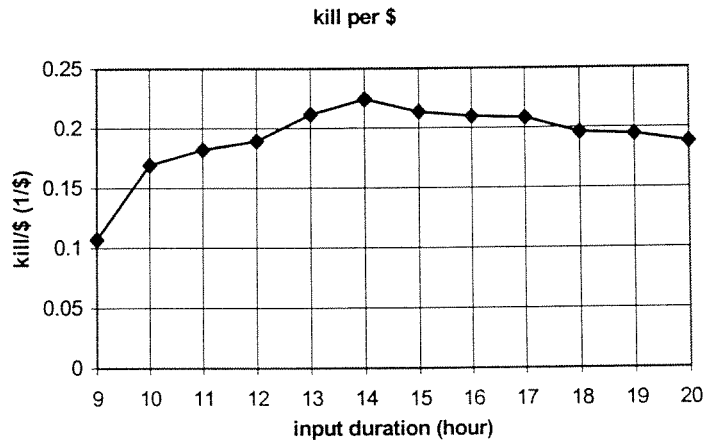
Figure 5-1 Effectiveness of different input durations

Kill per Dollar
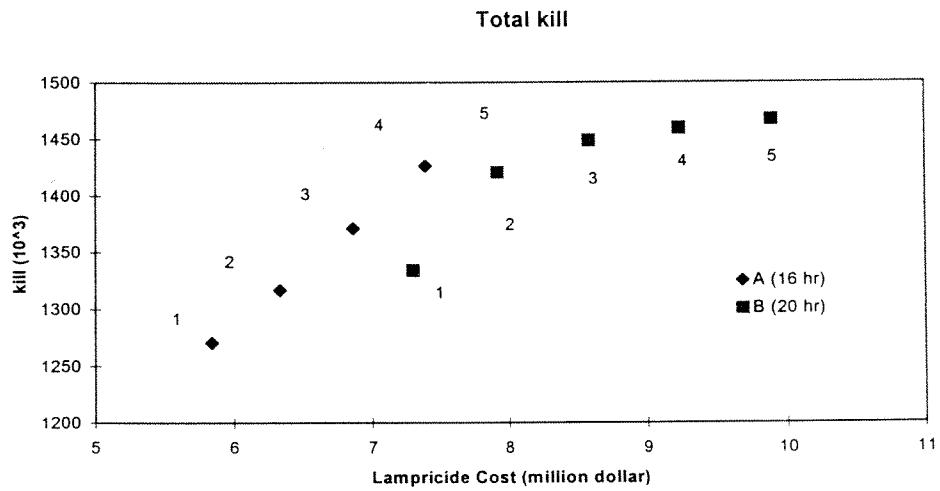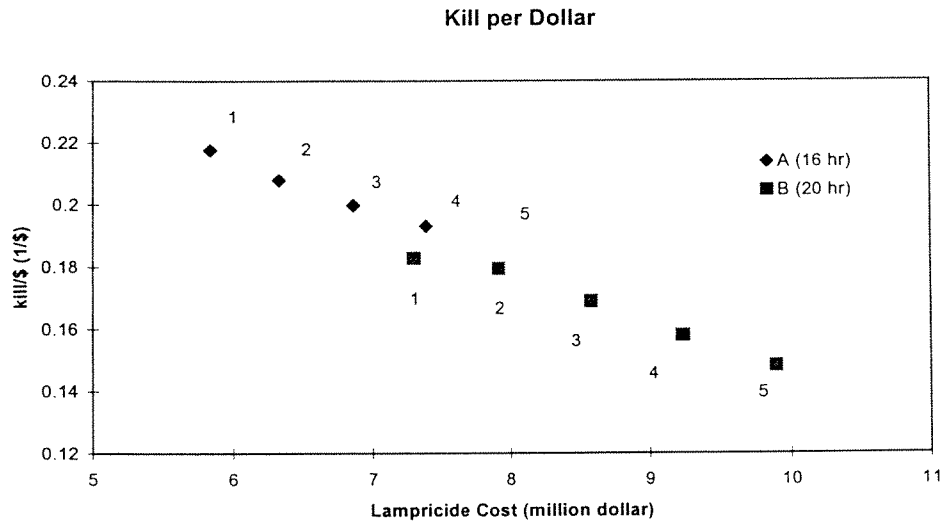
Total kill

Figure 5-2 Total kill and kill per dollar of single site input scenarios
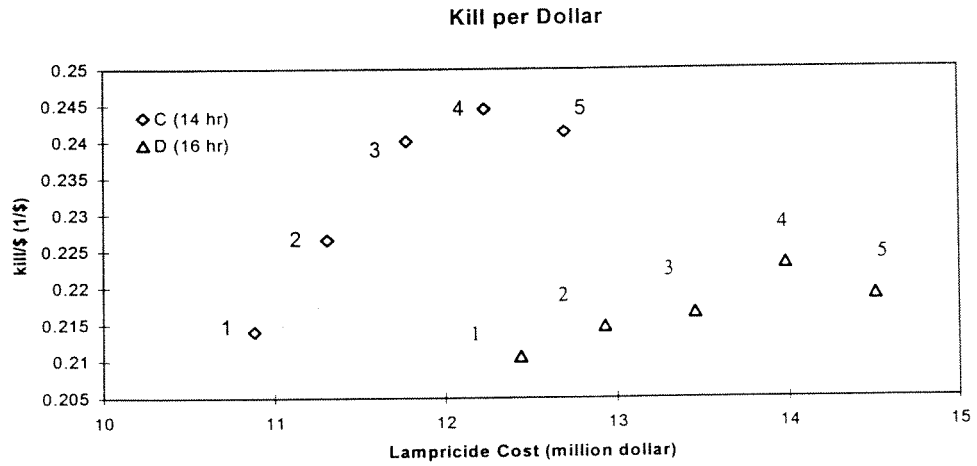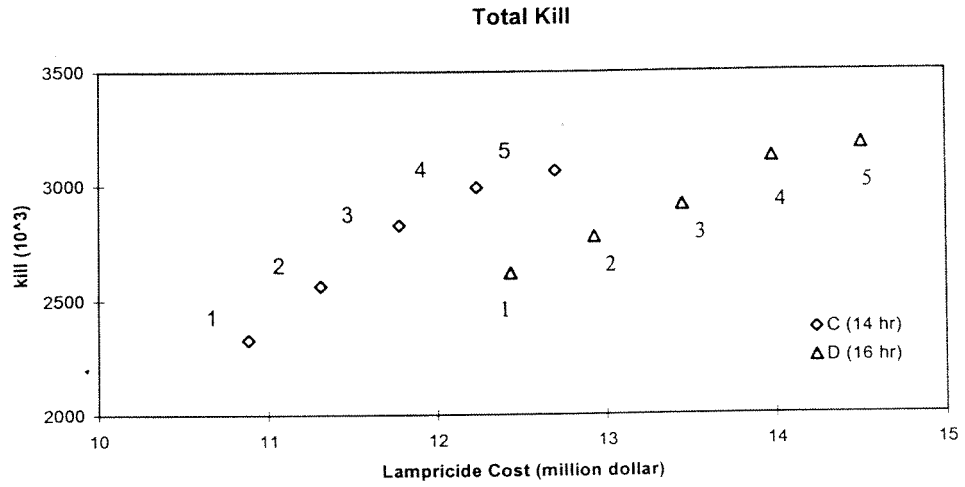
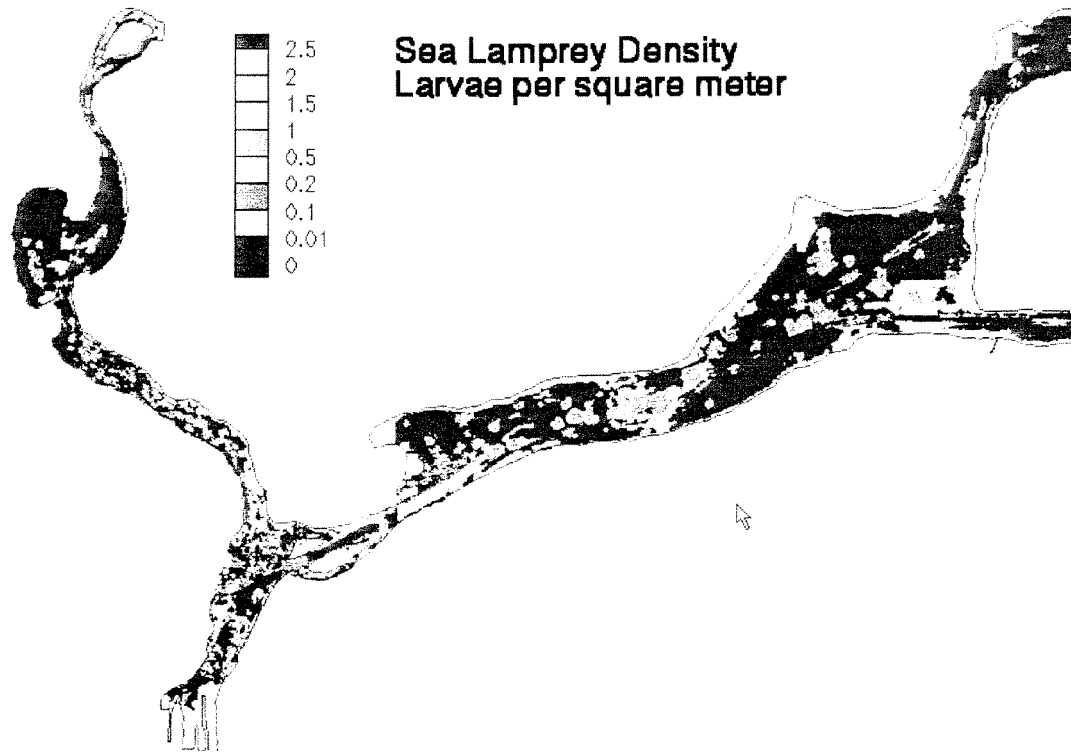**Figure 5-3 Total kill and kill per dollar of two-site input scenarios**

Figure 5-4 Sea Lamprey Density

Chapter 6 Scenario Study: Granular Bayer Application

The velocity at bottom of the river channel should not exceed certain level for Granular Bayer application to be effective. The required criterion is the flow velocity at a vertical distance of 1 inch from the channel is lower than 8 cm/s.

The vertical velocity profile for turbulent channel flows can be described by the logarithmic formula as:

$$u = \bar{u} + \frac{u_*}{\kappa}\left(\ln \frac{y}{h} + 1 \right)$$

In which u is velocity, $\bar{u}$ is depth-averaged velocity, u_* is shear velocity, κ is von-Karman's constant, y is distance from the bottom, and h is depth. The depth-averaged velocity is calculated in the 2-D hydrodynamic model. The shear velocity is defined as $u_* = \sqrt{ghS}$, g is gravity acceleration, and S is slope. In the St. Marys River, the u_* is relatively small.

It is found that the boundary between turbulent flow region and transient region In the St. Marys River study is in the range of 1 inch except some dead zone. In these dead zones, the mean velocity is much lower than 8 cm/s, therefore the velocity at 1 inch from bottom is lower than 8cm/s and the criterion is automatically satisfied. To simplify the analysis without sacrifice the accuracy, logarithmic profile is assumed for the whole river channel.

Bottom velocity distributions are calculated for three flow conditions: flow

conditions 1, 2, and 3, as described in Chapter 5.

Figure 6-2 shows the velocity at 1 inch from the river channel bottom for flow condition 1. It is shown in the figure that most of the area are covered by flow velocity lower than 8 cm/s, but the bottom velocity at the upstream part and main shipping channel of the downstream is greater than 8 cm/s.

Figure 6-1 and Figure 6-3 shows the velocity distributions at 0.5 inch and 2 inch respectively. The area where velocity greater than 8 cm/s increases when the distance from bottom decreases from 1 inch to 0.5 inch. It decreases when the distance increases to 2 inch. That means the result is sensitive to the criterion.

Figure 6-4 and Figure 6-6 shows the velocity distribution at 1 inch from bottom for flow condition 3 and flow condition 5. Figure 6-5 and Figure 6-7 shows the velocity distribution at 2 inch from bottom for flow condition 3 and flow condition 5. There is no significant difference between different flow conditions, but the area covered by velocity of 8 cm/s or higher decreases as the distance increases from 1 inch to 2 inch consistently for 3 flow conditions.

Two additional high discharge flow conditions are simulated to show the effect of total discharge on the velocity distribution at bottom of the St. Marys River. One flow condition is the same as the flow condition in dye study in 1996. The total discharge was 77,100 cfs. The allocation of total discharge among American Locks, Compensating Works, Corp of Engineer Power House, Edison Sault Power Station, and Great Lake Power Plant was 600 cfs, 3500 cfs, 11000 cfs, 26000 cfs, and 36000 cfs. The result is shown in Figure 6-8.

Another flow condition has an even higher total discharge, 110,000 cfs. 600 cfs comes from American Locks, 36400 cfs from Compensating Works, 11000 cfs from COE Power House, 26000 cfs from Edison Sault Power Station, and 36000 cfs from Great Lake Power Plant. The result is shown in Figure 6-9.

It is shown that the area covered by 8 cm/s or higher velocity is increased as the total discharge increased. In the upstream channel before the split, the width of the area covered by 8 cm/s or higher velocity is increased as the total discharge increased. After the split, the higher bottom velocity area is constrained in the main shipping channel on the south channel and the north channel.

Table 6.1 shows the lamprey population covered by 8 cm/s or lower velocity. If the bottom definition is changed from 1 inch to 0.5 inch, the lamprey population covered by 8 cm/s or lower velocity will increase from 88.21% to 93.46%. If the bottom definition is changed from 1 inch to 2 inch, the lamprey population covered by 8 cm/s or lower velocity will decrease from 88.21% to 73.51%. The difference between flow condition 1, 3, and 5 is small. The lamprey populations covered by 8 cm/s or lower velocity are around 88.5%. The higher the river total flow rate is, the lower coverage of 8 cm/s or lower velocity. In the dye test case, the flow rate is 77,100cfs and the coverage of 8cm/s or lower velocity is 79.51%. If the total flow rate is 110,000cfs, the coverage of 8cm/s or lower velocity is 70.51%.

Table 6-1 Lamprey population before and after application of grandular bayer under different flow condition

Flow condition	Flow rate	Bottom distance	Critical velocity	Total lamprey population	Lamprey population survived	Lamprey population killed	% of killed lamprey population
	cfs	inch	cm/s	x1000	x1000	x1000	%
Total							
1	60,000	0.5	8	4768.7	311.8	4456.9	93.46%
1	60,000	1	8	4768.7	562.1	4206.6	88.21%
1	60,000	2	8	4768.7	1263.3	3505.4	73.51%
3	60,000	1	8	4768.7	552.6	4216.1	88.41%
5	60,000	1	8	4768.7	525.5	4243.2	88.98%
Dye Study	77,100	1	8	4768.7	977.1	3791.7	79.51%
High	110,000	1	8	4768.7	1406.4	3362.3	70.51%
North Channel							
1	60,000	0.5	8	2326	178.6	2147.3	92.32%
1	60,000	1	8	2326	391.8	1934.2	83.16%
1	60,000	2	8	2326	615	1710.9	73.56%
3	60,000	1	8	2326	382.3	1943.7	83.56%
5	60,000	1	8	2326	355.2	1970.7	84.72%
Dye Study	77,100	1	8	2326	535.1	1790.8	76.99%
High	110,000	1	8	2326	707.5	1618.4	69.58%

48
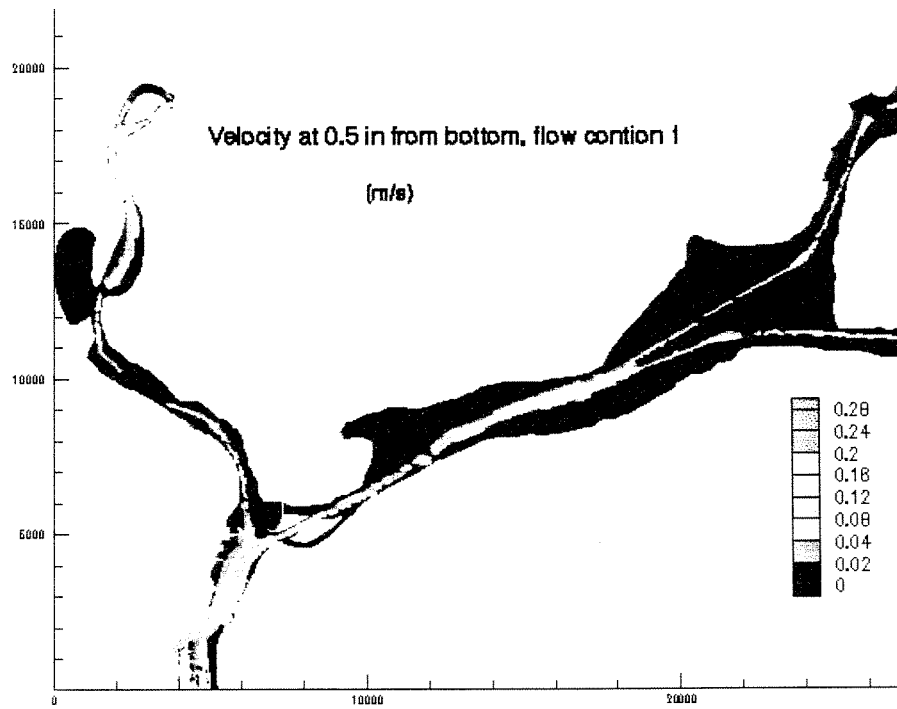
Figure 6-1 Velocity at 0.5 in from bottom, flow condition 1
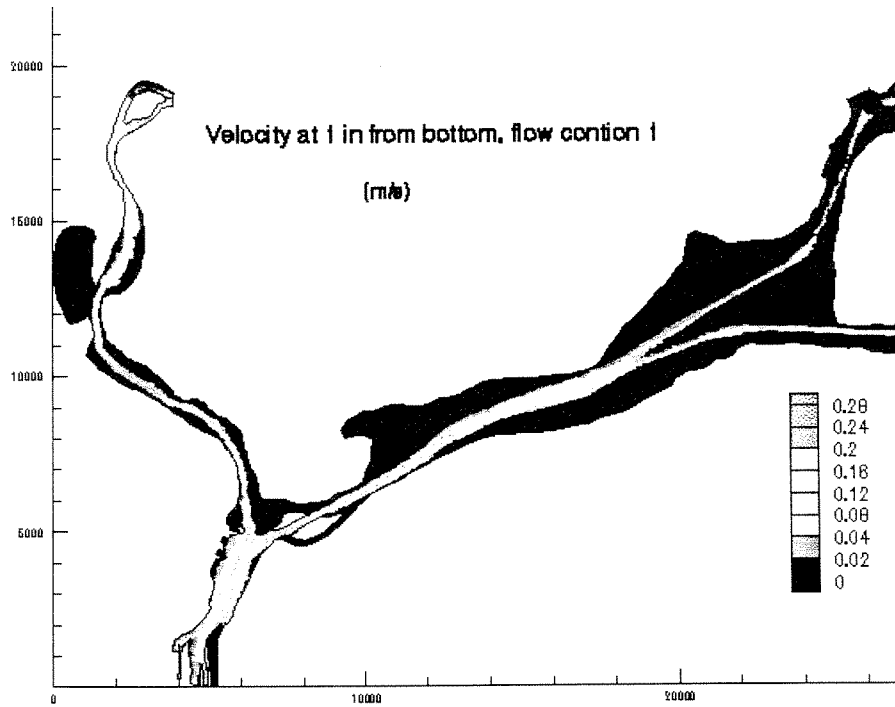
Figure 6-2 Velocity at 1 inch from bottom, flow condition 1
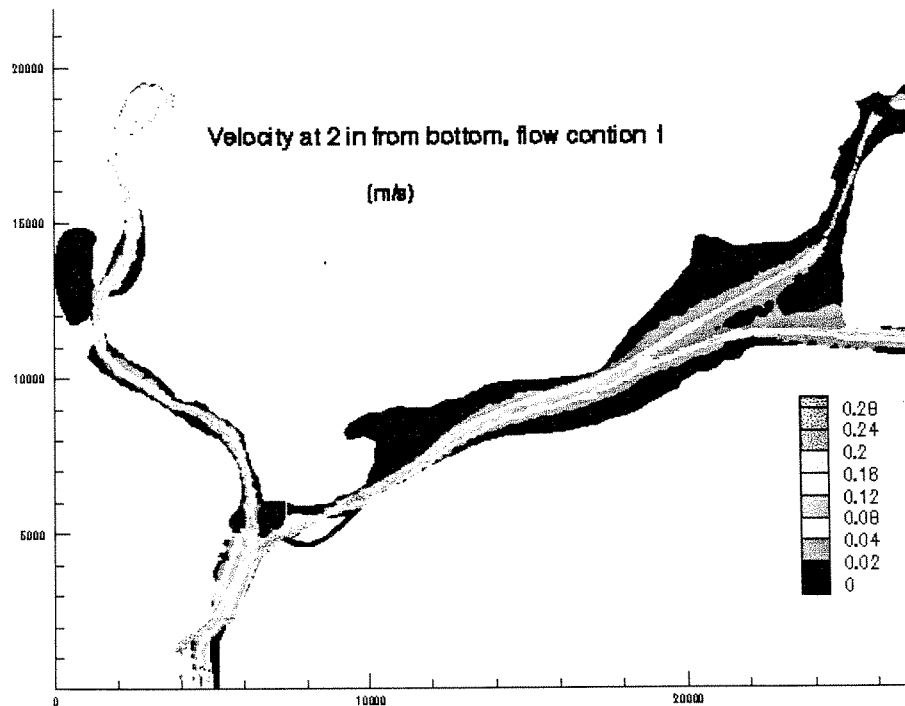
Figure 6-3 Velocity at 2 inch from bottom, flow condition 1
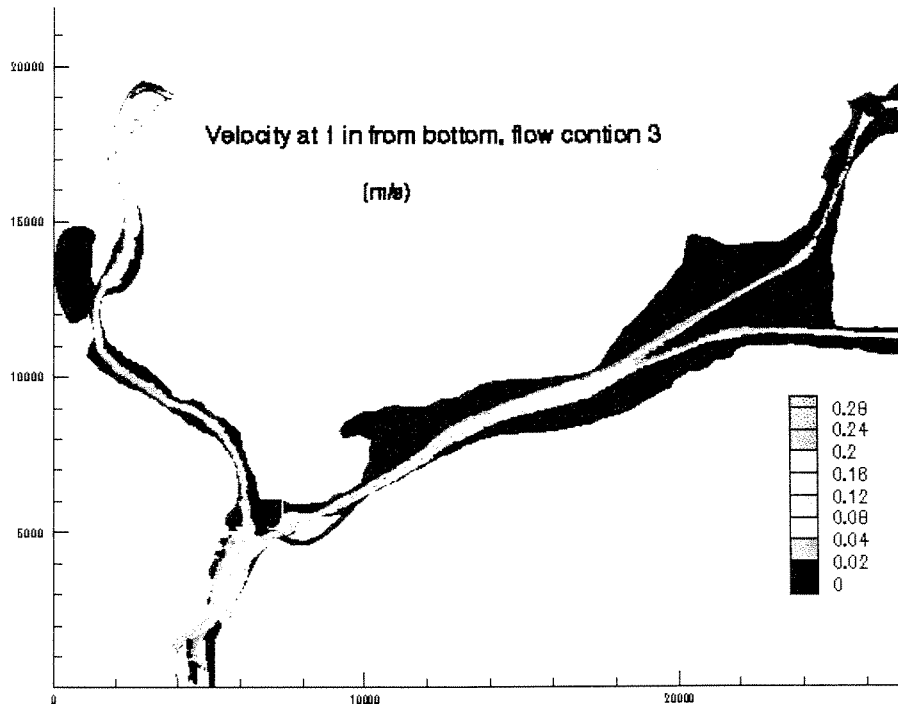
Figure 6-4 Velocity at 1 inch from bottom, flow condition 3
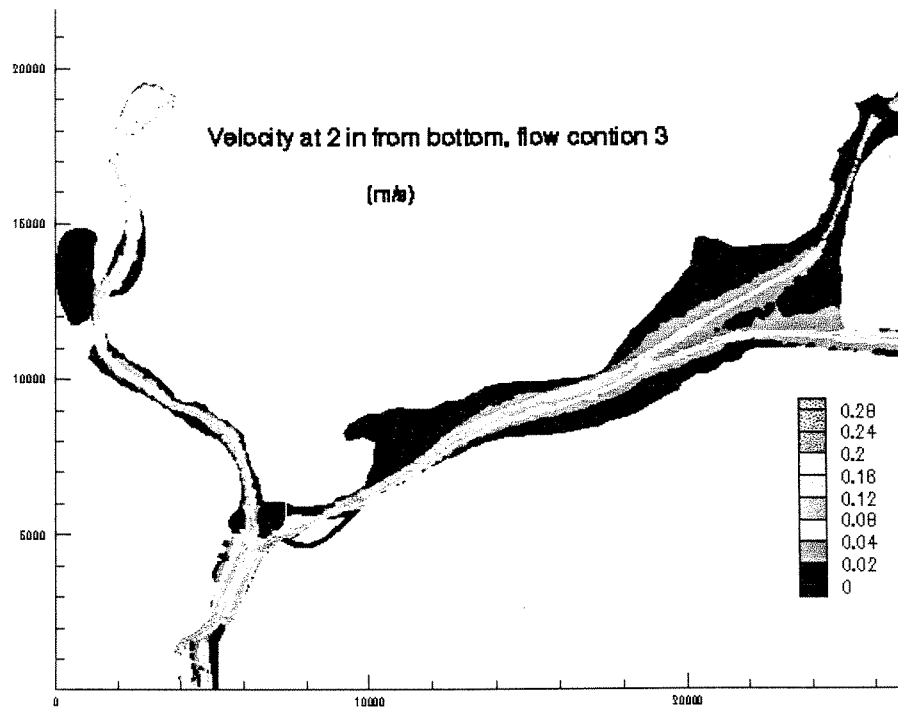
Figure 6-5 Velocity at 2 inch from bottom, flow condition 3
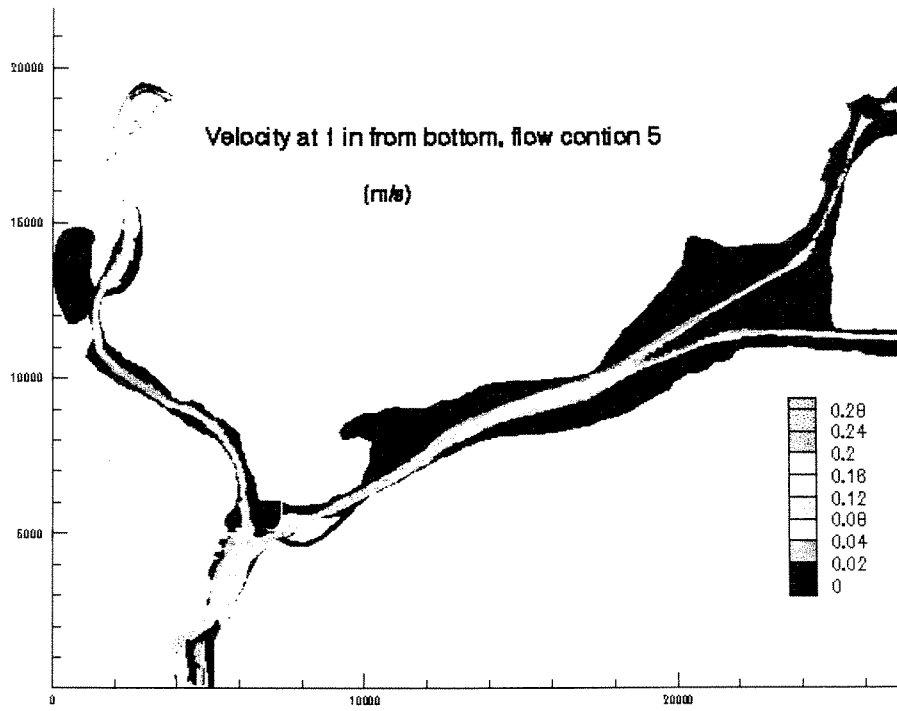
Figure 6-6 Velocity at 1 inch from bottom, flow condition 5
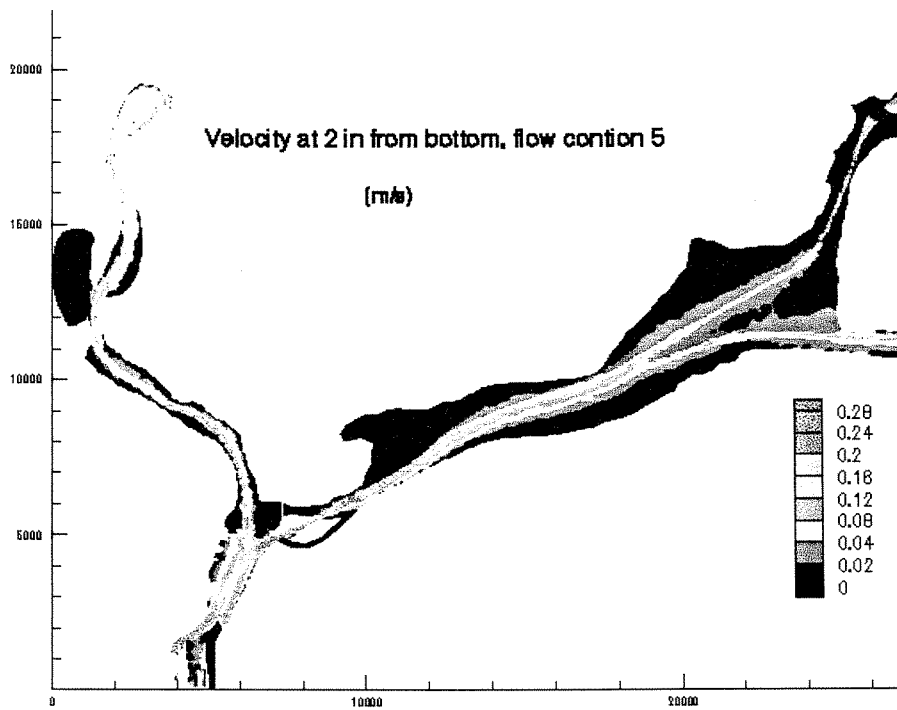
Figure 6-7 Velocity at 2 inch from bottom, flow condition 5
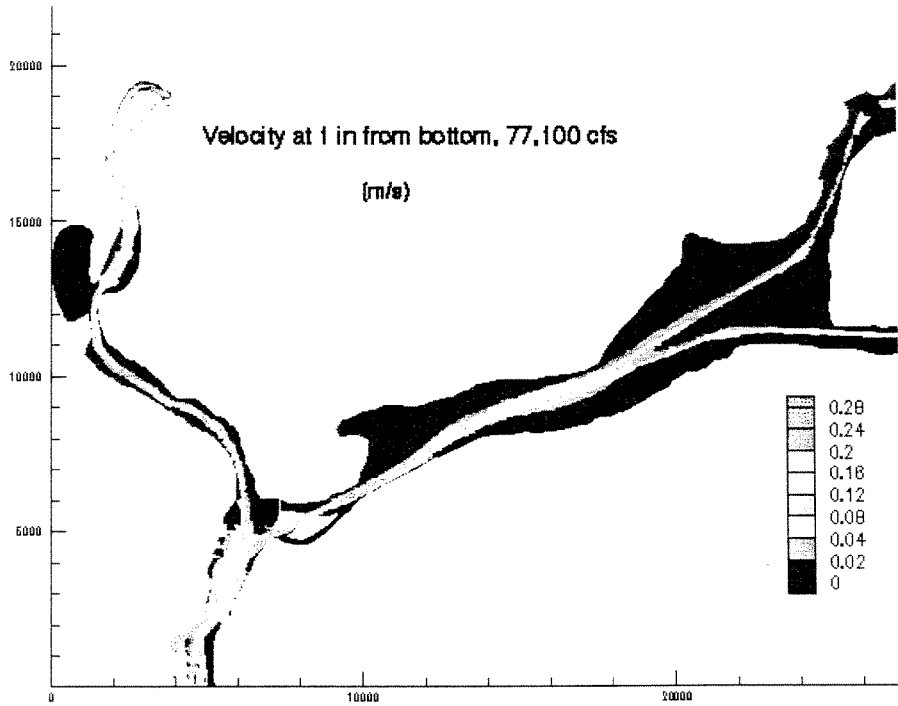
Figure 6-8 Velocity at 1 inch from bottom, 77,100 cfs
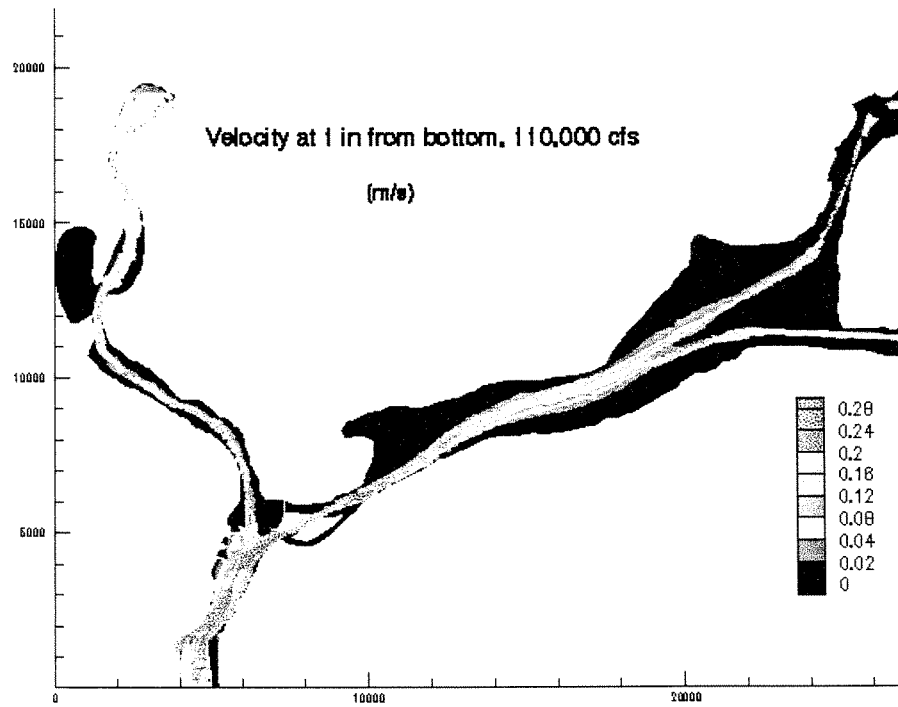
Figure 6-9 Velocity at 1inch from bottom, 110,000cfs

Chapter 7 Summary

This report describes the development and application of a chemical transport model for rivers. The model is applied to the upper St. Marys River to simulate the transport of lampricide. The hydrodynamics necessary for the model is computed based on a depth-averaged two-dimensional finite element model. The hydrodynamic model is calibrated by adjusting the Manning coefficient of the bed. The model is verified using the ADCP based field velocity measurements obtained by the Corps of Engineers.

The data from a number of dye tests conducted on the St. Marys River are used to calibrate the lampricide transport model. The model is used to evaluate alternative lampricide application strategies by simulating various lampricide applications. The effectiveness of the Granular Bayer application is analyzed by evaluating the near-bottom flow velocity in the river. The information supplied by this study will be useful for the planning of future lampricide applications.

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Appendix A. Comparison of Simulated and Measured Current Velocity

Velocity Simulation
and Measurement
Cross Section 2 & 2A

1 m/s
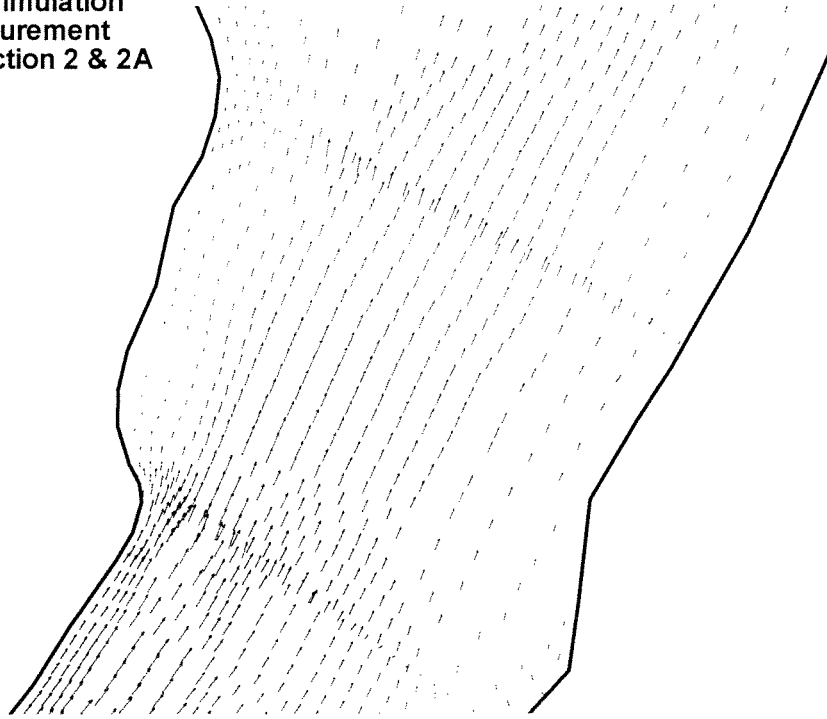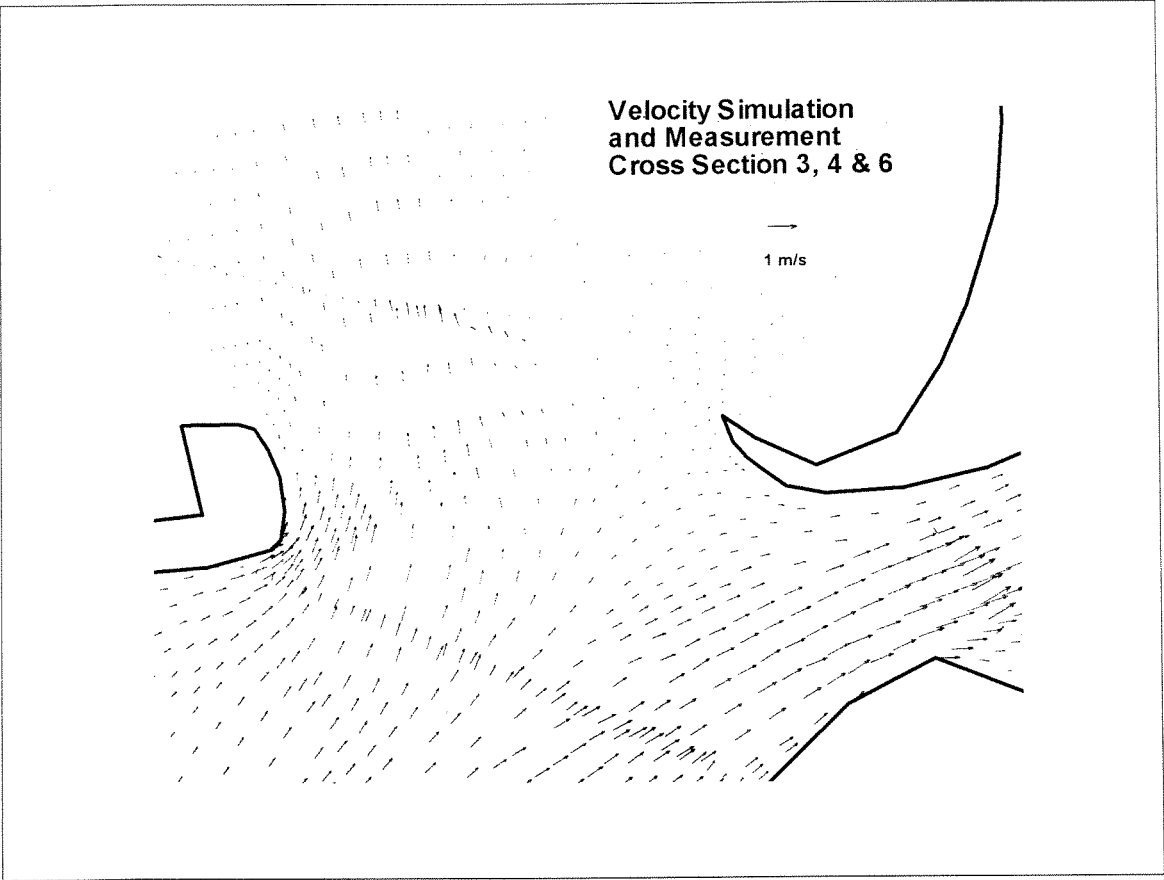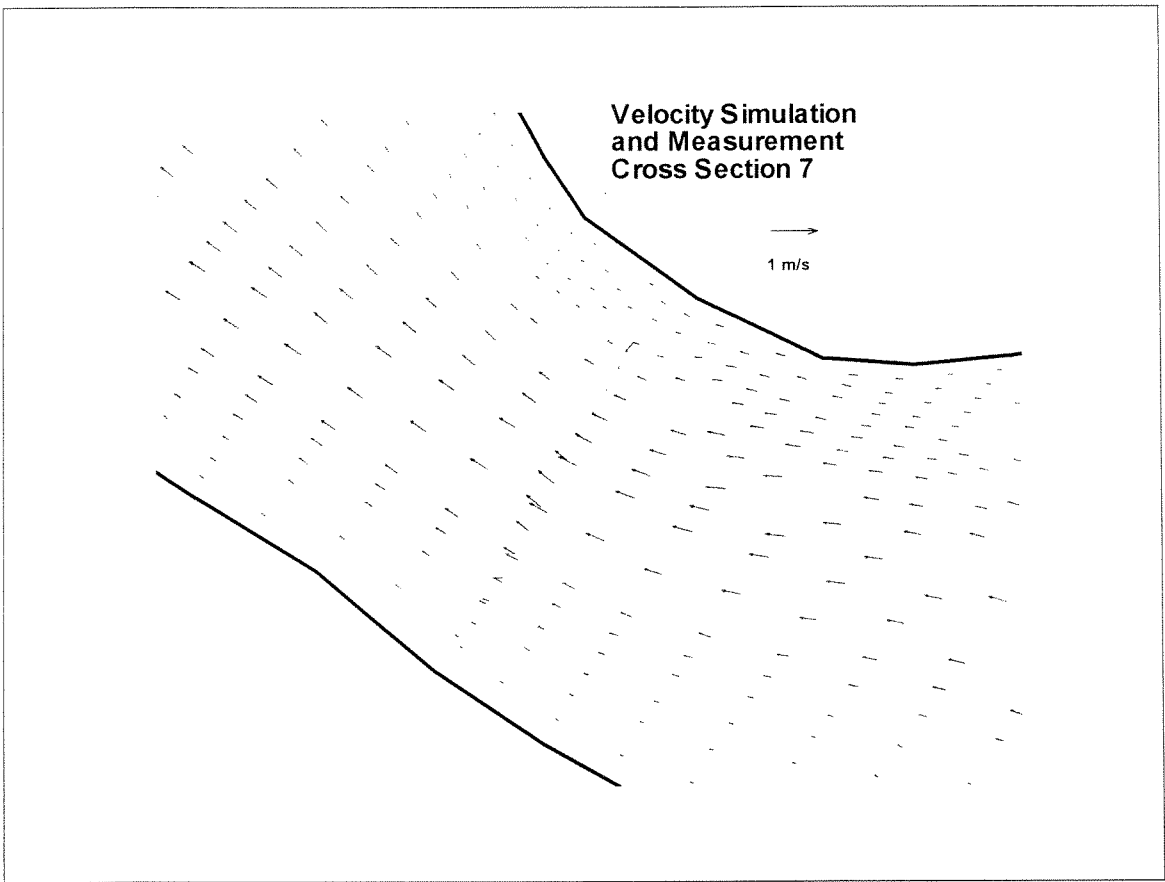
Velocity Simulation
and Measurement
Cross Section 3, 4 & 6
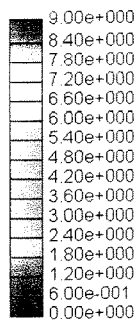
1 m/s

Velocity Simulation
and Measurement
Cross Section 7

1 m/s

Velocity Simulation
and Measurement
Cross Section 8

1 m/s

Velocity Simulation
and Measurement
Cross Section 9

1 m/s
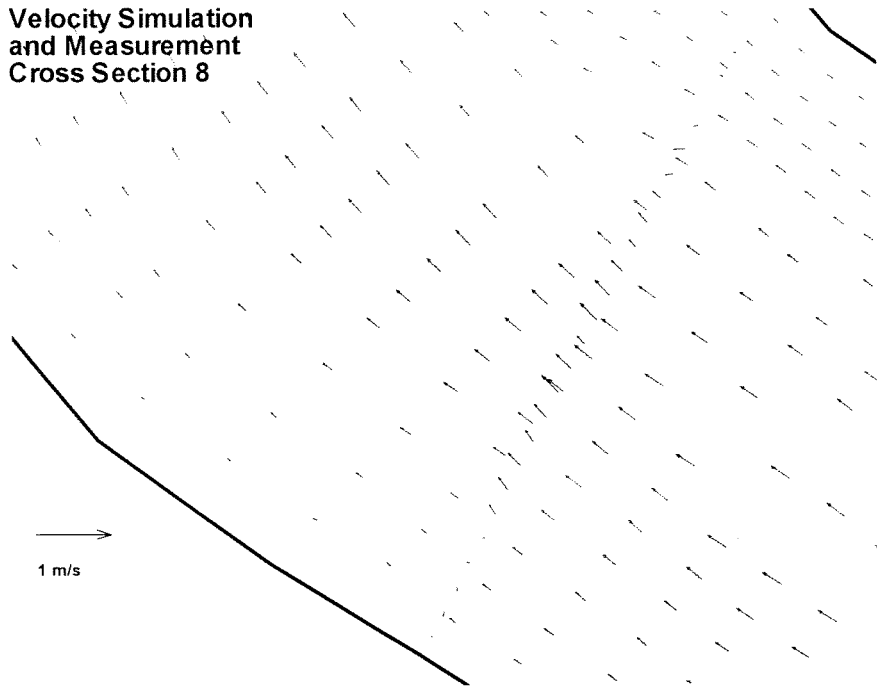
Velocity Simulation
and Measurement
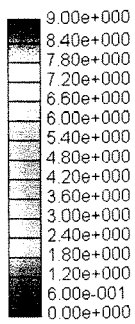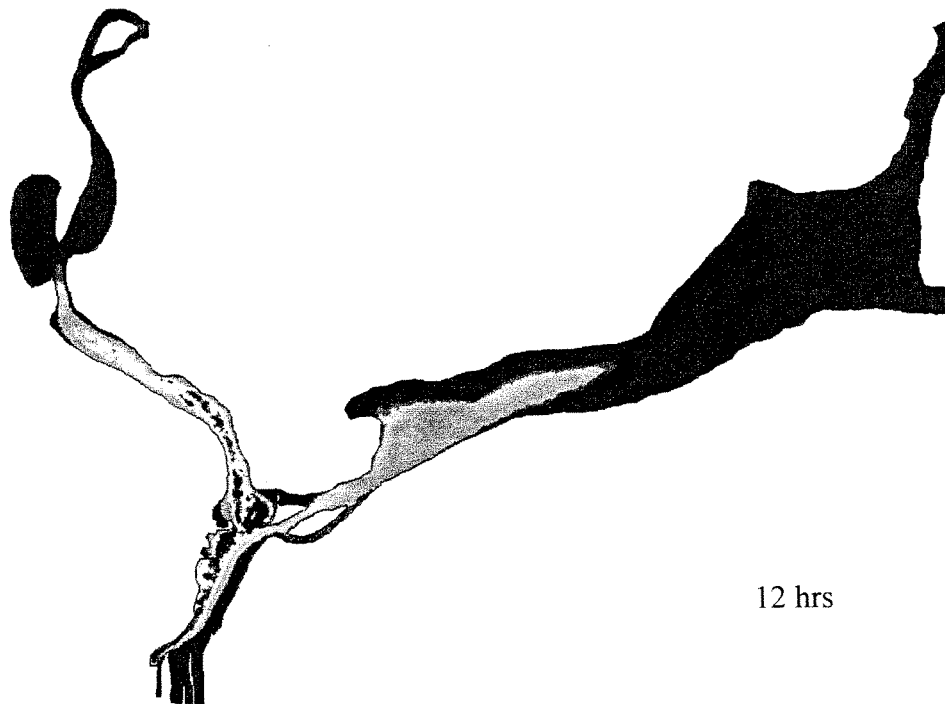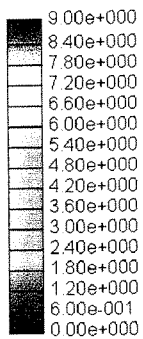Cross Section 10

1 m/s
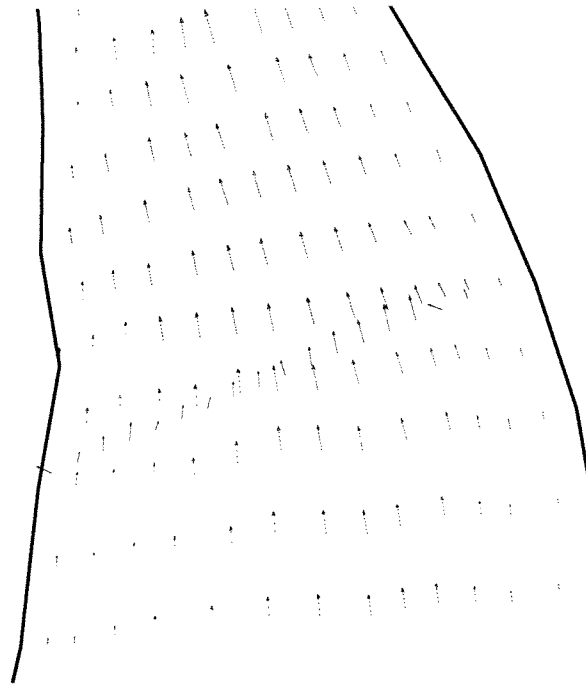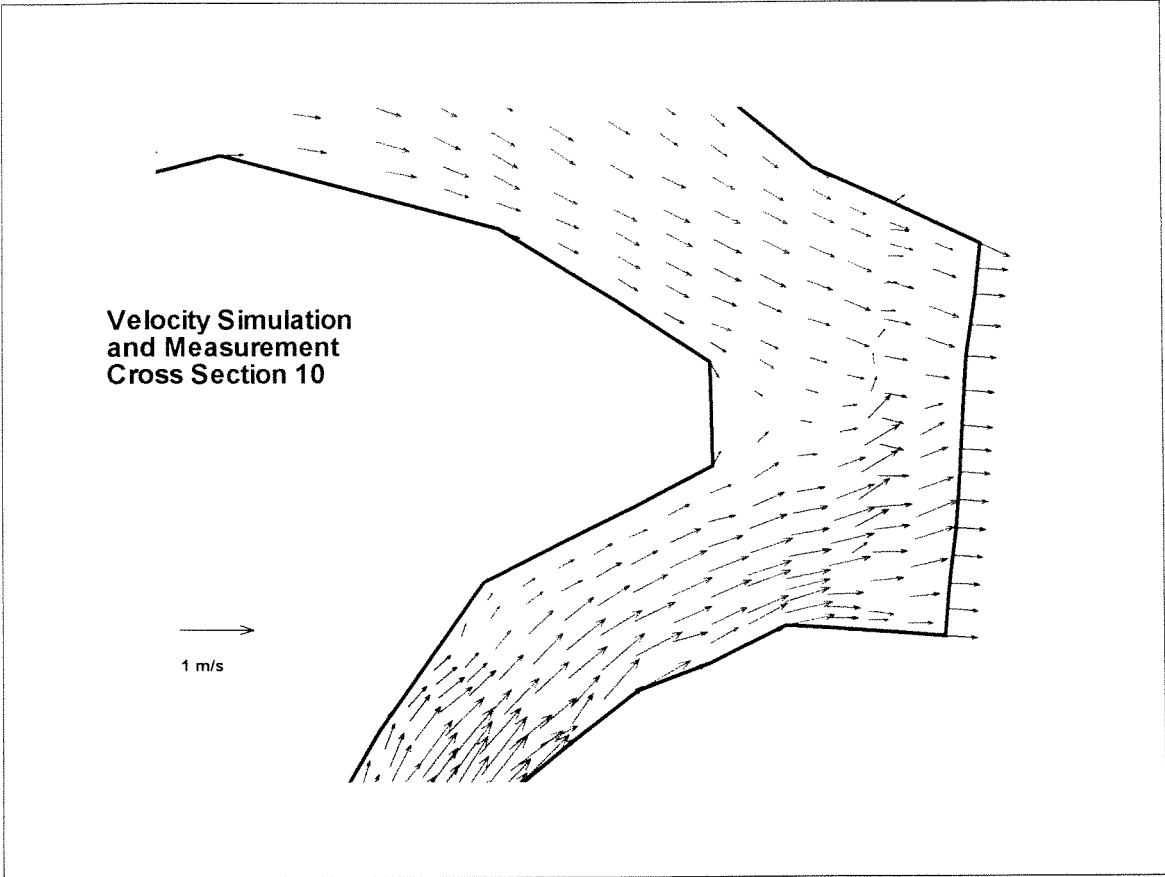
Appendix B Hourly Concentration for Calibration Case: Dye Study 2

1 hrs

3 hrs

7 hrs

12 hrs

9.00e+000
8.40e+000
7.80e+000
7.20e+000
6.60e+000
6.00e+000
5.40e+000
4.80e+000
4.20e+000
3.60e+000
3.00e+000
2.40e+000
1.80e+000
1.20e+000
6.00e-001
0.00e+000

18 hrs

9.00e+000
8.40e+000
7.80e+000
7.20e+000
6.60e+000
6.00e+000
5.40e+000
4.80e+000
4.20e+000
3.60e+000
3.00e+000
2.40e+000
1.80e+000
1.20e+000
6.00e-001
0.00e+000
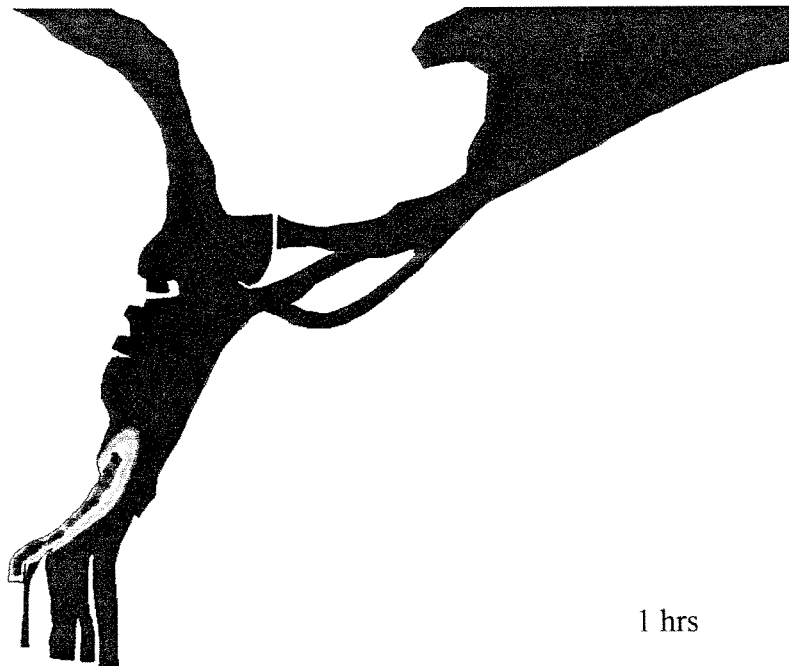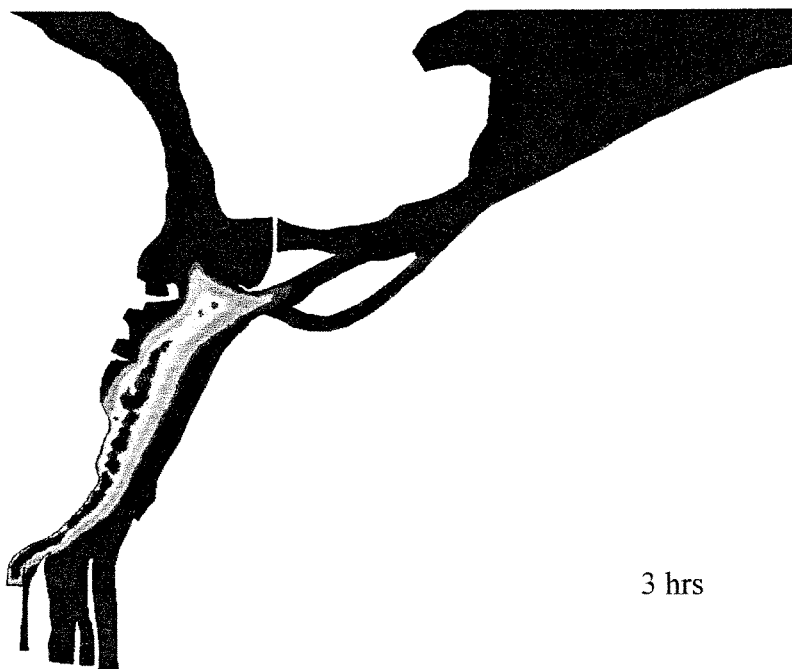
24 hrs
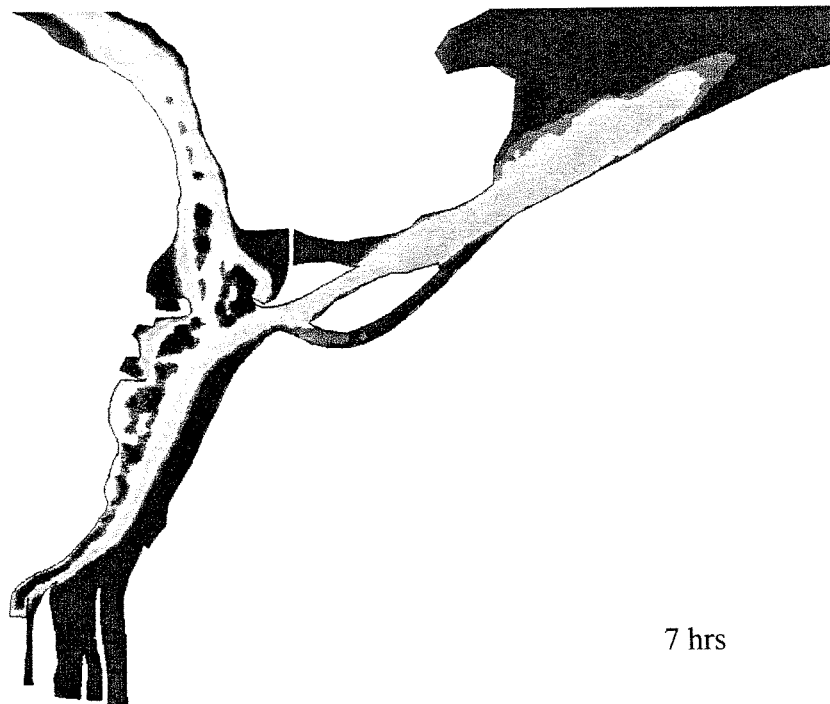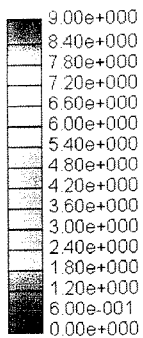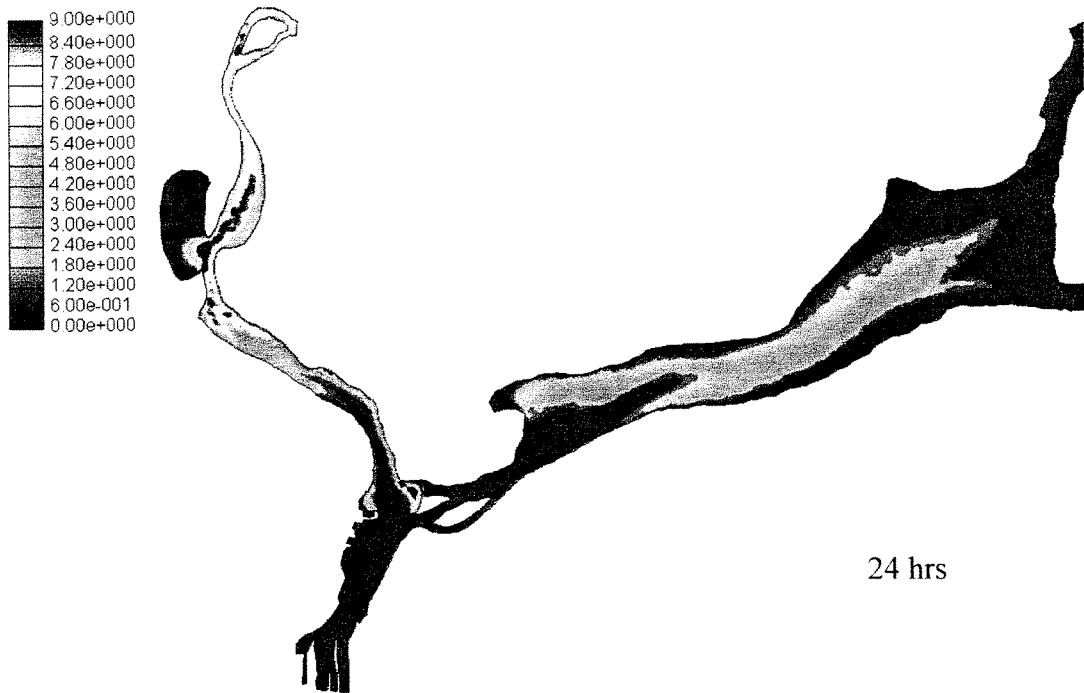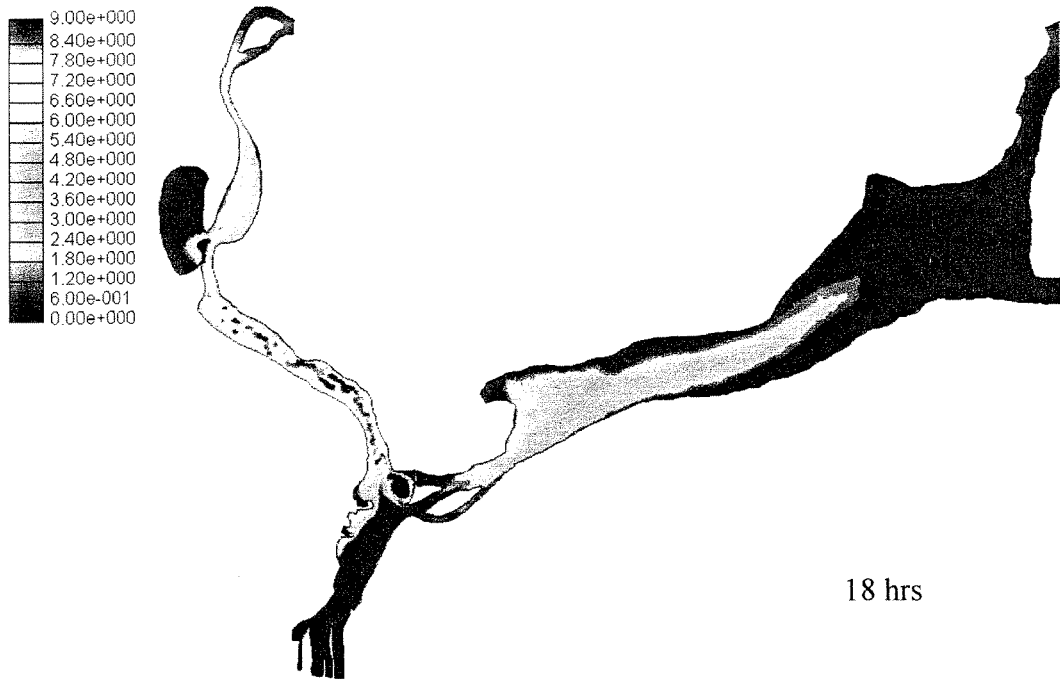
Appendix C. Simulation Result of Single Site Input Case

2.50e+000	
2.20e+000	
2.00e+000	
1.80e+000	
1.60e+000	
1.40e+000	
1.20e+000	
1.00e+000	
8.00e-001	
6.00e-001	
4.00e-001	
2.00e-001	
0.00e+000	

GLP: 22 kcfs
Compensating Works: 3.5 kcfs
COE Power: 9 kcfs
Input duration: 16 hours

Maximum concentration - Scenario 1A

9.00e+000	
8.40e+000	
7.80e+000	
7.20e+000	
6.60e+000	
6.00e+000	
5.40e+000	
4.80e+000	
4.20e+000	
3.60e+000	
3.00e+000	
2.40e+000	
1.80e+000	
1.20e+000	
6.00e-001	
0.00e+000	

GLP: 22 kcfs
Compensating Works: 3.5 kcfs
COE Power: 9 kcfs
Input duration: 16 hours

Areas where the lampricide exceeds the lethal level - Scenario 1A

70

2.50e+000	
2.20e+000	
2.00e+000	GLP: 22 kcfs
1.80e+000	Compensating Works: 3.5 kcfs
1.60e+000	COE Power: 9 kcfs
1.40e+000	Input duration: 20 hours
1.20e+000	
1.00e+000	
8.00e-001	
6.00e-001	
4.00e-001	
2.00e-001	
0.00e+000	

Maximum concentration - Scenario 1B

9.00e+000	
8.40e+000	
7.80e+000	GLP: 22 kcfs
7.20e+000	Compensating Works: 3.5 kcfs
6.60e+000	COE Power: 9 kcfs
6.00e+000	Input duration: 20 hours
5.40e+000	
4.80e+000	
4.20e+000	
3.60e+000	
3.00e+000	
2.40e+000	
1.80e+000	
1.20e+000	
6.00e-001	
0.00e+000	

Areas where the lampricide exceeds the lethal level - Scenario 1B

Legend values (top plot):
2.50e+000
2.20e+000
2.00e+000
1.80e+000
1.60e+000
1.40e+000
1.20e+000
1.00e+000
8.00e-001
6.00e-001
4.00e-001
2.00e-001
0.00e+000

GLP: 24 kcfs
Compensating Works: 3.5 kcfs
COE Power: 7 kcfs
Input duration: 16 hours

Maximum Concentration - Scenario 2A

Legend values (bottom plot):
9.00e+000
8.40e+000
7.80e+000
7.20e+000
6.60e+000
6.00e+000
5.40e+000
4.80e+000
4.20e+000
3.60e+000
3.00e+000
2.40e+000
1.80e+000
1.20e+000
6.00e-001
0.00e+000

GLP: 24 kcfs
Compensating Works: 3.5 kcfs
COE Power: 7 kcfs
Input duration: 16 hours

Areas where the lampricide exceeds the lethal level - Scenario 2A

Maximum Concentration - Scenario 2B

GLP: 24 kcfs
Compensating Works: 3.5 kcfs
COE Power: 7 kcfs
Input duration: 20 hours

Areas where the lampricide exceeds the lethal level - Scenario 2B

GLP: 24 kcfs
Compensating Works: 3.5 kcfs
COE Power: 7 kcfs
Input duration: 20 hours

GLP: 26 kcfs
Compensating Works: 1.5 kcfs
COE Power: 7 kcfs
Input duration: 16 hours

Maximum concentration - Scenario 3A

GLP: 26 kcfs
Compensating Works: 1.5 kcfs
COE Power: 7 kcfs
Input duration: 16 hours

Areas where the lampricide exceeds the lethal level - Scenario 3A

Legend values (top figure):
2.50e+000
2.20e+000
2.00e+000
1.80e+000
1.60e+000
1.40e+000
1.20e+000
1.00e+000
8.00e-001
6.00e-001
4.00e-001
2.00e-001
0.00e+000

GLP: 26 kcfs
Compensating Works: 1.5 kcfs
COE Power: 7 kcfs
Input duration: 20 hours

Maximum concentration - Scenario 3B

Legend values (bottom figure):
9.00e+000
8.40e+000
7.80e+000
7.20e+000
6.60e+000
6.00e+000
5.40e+000
4.80e+000
4.20e+000
3.60e+000
3.00e+000
2.40e+000
1.80e+000
1.20e+000
6.00e-001
0.00e+000

GLP: 26 kcfs
Compensating Works: 1.5 kcfs
COE Power: 7 kcfs
Input duration: 20 hours

Areas where the lampricide exceeds the lethal level - Scenario 3B

GLP: 28 kcfs
Compensating Works: 1.5 kcfs
COE Power: 5 kcfs
Input duration: 16 hours

Maximum Concentration. - Scenario 4A

GLP: 28 kcfs
Compensating Works: 1.5 kcfs
COE Power: 5 kcfs
Input duration: 16 hours

Areas where the lampricide exceeds the lethal level - Scenario 4A

GLP: 28 kcfs
Compensating Works: 1.5 kcfs
COE Power: 5 kcfs
Input duration: 20 hours

Maximum Concentration. - Scenario 4B

GLP: 28 kcfs
Compensating Works: 1.5 kcfs
COE Power: 5 kcfs
Input duration: 20 hours

Areas where the lampricide exceeds the lethal level - Scenario 4B

GLP: 30 kcfs
Compensating Works: 1.5 kcfs
COE Power: 3 kcfs
Input duration: 16 hours

Maximum Concentration - Scenario 5A

GLP: 30 kcfs
Compensating Works: 1.5 kcfs
COE Power: 3 kcfs
Input duration: 16 hours

Areas where the lampricide exceeds the lethal level - Scenario 5A

GLP: 30 kcfs
Compensating Works: 1.5 kcfs
COE Power: 3 kcfs
Input duration: 20 hours

Maximum concentration - Scenario 5B

GLP: 30 kcfs
Compensating Works: 1.5 kcfs
COE Power: 3 kcfs
Input duration: 20 hours

Areas where the lampricide exceeds the lethal level - Scenario 5B

Appendix D User's Mannual

Lampricide Transport Simulation Model

User's Manual

Department of Civil Engineering and Environment
Clarkson University

February, 1998

1. Introduction

This document contains the information about running the Lampricide Transport Simulation Model.

Lampricide Transportation Simulation Model is developed for the Lampricide transport study in the St. Marys River. The model is based on depth-averaged two-dimensional dispersion equation. The particle tracking method is used in the model to simulate the movement of chemical parcels in the river channel. The triangular mesh system of finite element method used to solve two-dimensional hydrodynamic model is directly used in the lampricide transport simulation model. The smoothed particle hydrodynamics is used in calculating the concentration distribution. The information of model detail and its application can be found in the main report.

This manual presents the necessary steps to run the model. Section 2 discusses model installation and the hardware and software requirement to install and run the model. Section 3 gives a brief information about how to run the two-dimensional hydrodynamic model of river channel. Section 4 is dedicated to the running of the lampricide transportation model: configuring the model, preparing the input data file, running the model, and understanding the output files. The list of files used in model is given at the end of the manual.
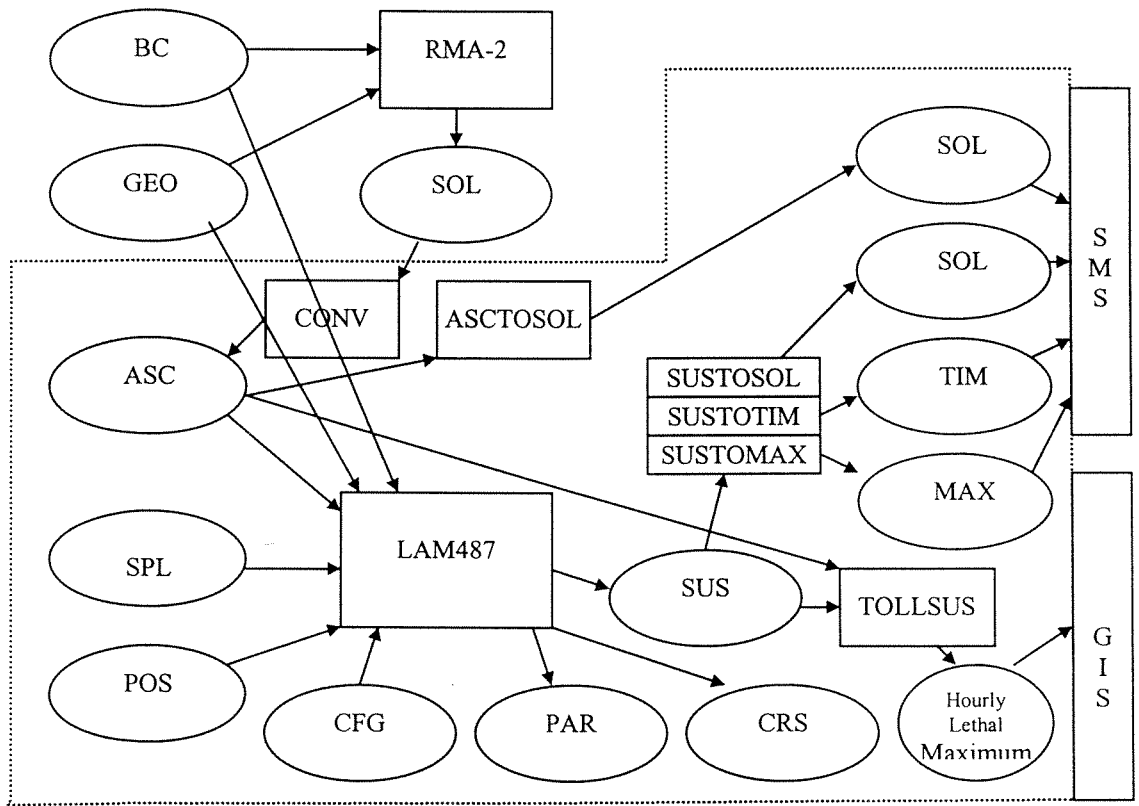
Figure 1. Program and Data Files in the Model

2. Installation

Before the model can be run, the necessary files have to be copied to the hard disk driver of a computer. The hardware and software requirement to install and run the model is described in this chapter.

A hydraulic model has to be run to get the flow velocity and water depth data before the lampricide transport simulation model can be run. The installation must contain a hydraulic model. Although any hydraulic model based on triangular finite element mesh system can be used, but the RMA2 is recommended.

2.1 Hardware and Software Requirement

The model is primary implemented for running on PC, but it can be recompiled on any workstation or mainframe computer which has the 32bit Fortran77 and C compiler.

To run the model on PC,

1. Windows 95 or Windows NT is required;
2. 100MB or more free hard disk space is required to run RMA2, and 50MB or more free hard disk space is required to run the lampricide model;
3. 16M memory and 486DX66 are the minimum requirement and larger memory and Pentium processor or better are highly recommended.

2.2 Installation

The installation process is simply to copy all the necessary files to a sub-directory on the hard disk driver.

1. Create a directory on the hard disk driver:

```
C:
md stm
```

2. Copy the self-extracting file stm2.exe to the directory:

```
cd atm
copy a:atm.exe .
```

3. Run the self-extracting file stm2.exe to extract all the files:

```
stm2.exe
```

Now, the model is ready to run.

3. Running Hydraulic Model

The water current affects advection, spreading and other movements of lampricide. A hydraulic model has to be run to supply the flow velocity and water depth data to the lampricide transport simulation model. A two-dimensional finite element model RMA2 is used to simulate the current velocity and depth in the river channel. Any two dimensional hydraulic model can be used to replace the RMA2 model but additional data conversion program is required. This section only discusses how to run the RMA2 model.

To run RMA2 model, two data files must be prepared: Geo file and BC file.

3.1 Prepare Geo File

A Geo file is the geometric data file which contains the triangular finite element mesh information and boundary definition information.

A typical Geo file is shown as following:

```
T1
T2      St. Marys River Hydraulic Simulation
T3
SI   1
$L        3 0 6 0
GO   1       1    9    8    15    14    18    17
GO    -1
GE       1       5      4      3      2      1     6      0      0      6     0.0
GE       2       1      9      8      7      5     6      0      0      6     0.0
GE       3       5      7      8     12     11    10      0      0      6     0.0
GE       4       8     15     14     13     11    12      0      0      6     0.0
.......
GE    8973   19073  19090  19089  19088  19071  19072    0      0      1     0.0
GE    8974   19073  19093  19092  19091  19089  19090    0      0      1     0.0
GE    8975   19073  19076  19077  19094  19092  19093    0      0      1     0.0
```

```
GNN     1 5.0140000e+003
GNN     3 5.0160000e+003    6.5920000e+000    4.9660000e+000
GNN     5 5.1076000e+003    1.0613000e+002    4.9660000e+000
......                      9.2196000e+001    4.9660000e+000
GNN 19084 3.5987000e+004
GNN 19089 3.5915000e+004    2.0314000e+004    1.2063000e+001
GNN 19092 3.6008000e+004    2.0860000e+004    1.2670000e+001
                            2.0819000e+004    1.2062000e+001
```

This is a geo file of finite element mesh which represents the St. Marys River by 8975 triangular elements and 19092 nodes.

The first three lines of a geo file are the identification cards which begin with T1, T2, and T3. Any legal ASCII character can be put in these three lines and act as the title of the geo file.

Following the T1, T2 and T3 cards is the SI card which indicate the unit system used in the simulation. 0 represents English Units, and 1 represents SI Units.

$L card and GO card are used for RMA2 program and is not used in chemical simulation program. Without special reason, these lines are not supposed to change.

GE cards list the element information. The first integer is the element ID. The next eight integers define the nodes of the element. 6 node triangular elements are used, so the first 6 integer represents the node number and rest two integers must be 0. The next integer follow the nodal numbers is the material code of the elements. The Manning's coefficients and eddy viscosities of elements of these material codes will be given in the BC file (boundary file). The last item in the GE card is not used and usually set to 0.

GNN cards give the nodal data. The first number in the line is the node ID. Following node ID is the x, y, and z co-ordinates of the node.

Manually editing the geo file is just too difficult, so graphic interface program is suggested to be used, for an example, SMS.

The detail description of geo file can be found in the reference manual of RMA2.

Geo file is also used in Lampricide model to define the geometry of the domain.

3.2 Prepare BC File

A BC file is the boundary data file which includes the data for the boundaries and materiel data for each element type.

A typical BC file is listed as following:

```
T1
T2      St. Marys River Hydraulic Simulation
T3
SI  1
$L  0   62   60   64   0   0   0
$M  1
TR  1   1   1   0   0
G1  0.000000   1.000000   1.000000   0
GC   16    18752    18690    18607    18494    18490    18487
GC   18603    18598    18594    18591    18686    18742
GC   18738    18665    18661    18657
.  .  .  .  .  .
GC   4    1    8    14    17
GC   4    893    1015    1145    1266
TZ  0.000000   0.000000   0   0   0
TI  20   0   0.000010   0.000000
FT  17.000000
IC  14.32   0.000000   0.250000
EV   1       1500.00     1500.00     1500.00     1500.00     0.045000
.  .  .  .  .  .
EV  45       1500.00     1500.00     1500.00     1500.00     0.035000
EV  46       1500.00     1500.00     1500.00     1500.00     0.035000
.  .  .  .  .  .
EV  60       1500.00     1500.00     1500.00     1500.00     0.060000
BCN   797   11000       0.00        0.00        0.00
```

7

```
  .    .    .    .    .    .
BCN   8944   11000              0.00          0.00          0.00
BQL    4     690.00    6.20
BQL    5    1018.80    1.54
BQL    6      28.00    1.57
BQL    7     110.96    1.46
BQL    8     316.88    1.52
BQL    9      16.33    1.50
BQL   10     739.84    2.46
BHL    2      14.32
BHL    3      14.34
BHL    1      14.28
END   simulation at time = 0.0
STOP
```

Like the geo file, the first three lines of BC files are the title lines. SI should be set

1 if SI Unit is used or set to 0 if English Unit is used. TR and G1 cards are usually not

changed.

$L card gives the input and output data file I/O units. Set the second integer to no

zero if the hot start file is asked. Set the first integer to no zero if the model is running

from hot start file.

GC cards contain data describing strings of nodes called GC string or continuity

check lines. These are used to define BHL/BQL lines as well as to check for mass

continuity in the analysis. The first field of a GC card should contain the number of

corner nodes in the string. Following the first field, the ID numbers of the nodes

contained in the string are listed. The data on a GC card should not extend more than 80

spaces. Therefore, if a GC string contains more than 80 spaces, the remaining nodes

should be placed on additional GC cards immediately following the first card. Multiple

GC strings may be input by following these directions. The GC cards are also used in

Lampricide Simulation Model to identify the free boundaries.

TZ card defines the computation time lengths, the number of time-steps, and the time-step length for a dynamic analysis.

TI card controls the number of iterations used in both steady state and dynamic analyses.

FT card is used to input the water temperature. Usually it is set to 17.0.

IC card is used to define the initial water surface elevation.

EV card contains material data used in a computation. Material data must be assigned before an analysis is made. Each element references the materials defined by the EV cards. Each material is assigned a material ID, eddy viscosities, and a Manning's n value.

BCN cards define the nodal boundary conditions.

BQL lines are used in conjunction with GC strings to define flow rate boundary conditions. The first field on the line is an integer corresponding to a GC string. For example, if there were three GC strings at the top of the BC file, they could be referenced with an index 1,2, or 3 by a BQL card. The second field of a BQL card is a flow rate. The flow rate is assumed to be constant along the boundary defined by the GC string. The third and final field of the BQL card is the angle of flow direction. The angle is measured in radians, counter-clockwise from the positive X-axis.

BHL cards are used in conjunction with GC strings to define head or water surface elevation boundary conditions. The first field on the card is an integer

corresponding to a GC string as described above for BQL cards. The second field is the head or water surface elevation that is assumed to be constant along the GC string.

END card signifies the end of the boundary condition input for a particular time step. Every time step should be concluded with an END card. Since steady state analysis does not involve time steps, only on end card is required.

STOP card signifies the end of an analysis.

BC file is also used in Lampricide model to supply the boundary information and Manning's n for each element.

3.3 Running RMA2

RMA2 consists of two separate programs: GFGEN and RMA2.

GFGEN is the pre-processor of RMA2. It converts geo file into binary file. RMA2 reads the binary geometric file generated by GFGEN and the BC file and output binary result file.

To run GFGEN, type

GFGEN

at a DOS prompt windows of Windows95 or Windows NT.

It will ask for the ASCII geo file name and output binary geo filename.

Figure 2. Running GFGEN in a DOS Prompt windows

After successfully running GFGEN, type

RMA2

at a DOS prompt windows of Windows95 or Windows NT. It will ask for BC file

name, program running status file, and binary geo file name. Depending on the $L card

of the BC file, it will also ask for the output hot start file name or input hot start file name

if the second field of the $L card or the first field of the $L card is non zero. Then, RMA2

will ask for the output binary result file name.

Figure 3. Running RMA2 in a DOS Prompt windows

If RMA2 finished successfully, check the convergence of the program from the status file. If it is not converged, modify the TZ or TI card in BC file and rerun the RMA2 program.

3.4 Convert Output File

The output file of RMA2 is a binary data file which can be read by the graphic interface program SMS to display the velocity and depth fields. However, the binary solution file of RMA2 has to be converted into ASCII data file before the lampricide transport simulation model can read it.

To convert the binary solution file into ASCII file, type

CONV

at a DOS Prompt windows of Windows 95 or Windows NT. The CONV program
will ask for the binary geo file name, binary solution file name (input file), and ASCII
data file name (output file).
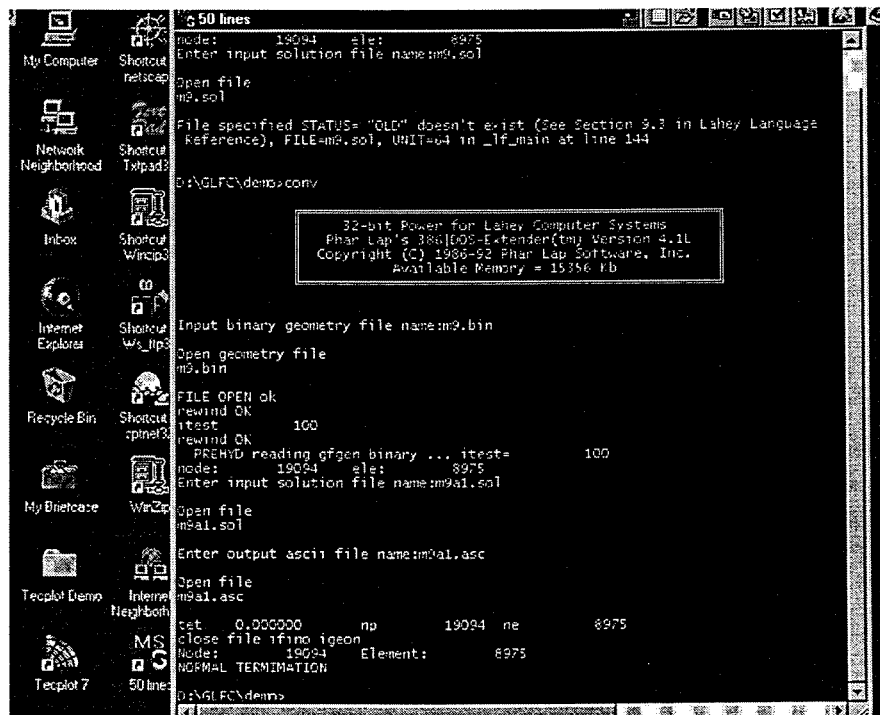
Figure 4. Running CONV in a DOS Prompt windows

The data format of the output ASCII data file is show in Figure 5.

Figure 5. ASC file

The first line of the ASCII data file is the number nodes and number of elements.

The rest lines of the file are the x and y coordinates, velocity vector, depth, and elevation

of each node.

4. Running Lampricide Transport Simulation Model

This section discuss how to run the lampricide transportation simulation program LAM487.EXE.

LAM487.EXE required four or five input files:

- lampricide input data file (.spl);
- geo file (.geo);
- boundary file (.bc);
- hydraulic solution file (.asc);

If crsflag in the configuration file is set to 1,

- cross section definition file (.pos);

LAM487.EXE has a configuration file named as lam487.cfg which contains the parameters useful to change the behaviour of LAM487.EXE.

LAM487.EXE will generate several output file:

- concentration data file (.sus);
- particle position file (.par), if parflag of the configuration file is set to 1;
- cross section concentration file (.crs), if crsflag of the configuration file is set to 1;

LAM487.EXE will also generate several intermediate data files.

4.1 Configure the Model

Before running LAM487.EXE, check the configuration first. Following is the typical configuration file:

```
40.0
70.0
0.0
70.0
1
1
-0.5
1
0
0
```

```
diffud  (<0 calculated in the program
        >0 calculated in the program and write to a file,
           then read from the file,

           factor to be multiplied to diffu coef.)
hsmth       initital smooth length
difact      enlarge coef.
hsmthmax    maximum smooth length
qudflag     =0 quadratic element (6 nodes)
            other linear element (3 nodes)
hodflag     =0 high order method (second derivative)
            other linear method
lucky       factor to scale down the effect of additional drift
            due to variation of depth and diff. coef.
            if luck<0 then no lucky file will be read,
            otherwise, read .luk file
crsflag     =1 output cross section data
parflag     =1 output particle position file
cctflag     other using all paricles to calculate concentration
            =1  only particles in the element
```

Usually, the parameter in the configuration don't need change.

If cross section concentration data file is expected, set the crsflag to 1. If particle position file is desired, set the parflag to 1. Otherwise, set them to 0.

Setting qudflag to 0 will force the LAM487.EXE to use quadratic element (6 nodes for each element). Comparing with linear element (3 node element), quadratic element can achieve higher accuracy and required more computing resource.

Setting hodflag to 0 will force the LAM487.EXE program to use high order method (second order) to interpolate the velocity and depth of particles in triangular

elements. Comparing with linear interpolation, high order method is more accurate and need more computing time.

By changing the initial smooth length, maximum smooth length, and growth rate of smooth length, lam487.exe program can be run with relative small number of particles.

4.2 Prepare Input File

First, generate the geo file, bc file, and asc solution file by running RMA2 model.

Then, prepare the lampricide input data file (spl file). A typical spl file is shown in following figure:

```
48     450  8
1
200000  0  461.76  0     50400  5  1250.0 -3800  1250.0 -3990.00
===========================================================
totime spildt ievery
nns
ntotal iapp splvol spilstrt  ns  xstart ystart xend yend

totime:  total simulation time, in hour
spildt:  time step, in second
ievery:  output concentration for every 'ievery' time steps
nns:   total number of spill lines
ntotal:     total particle number for each line
iapp:       iapp=1,  splvol is concentration for each line
            iapp=0,  splvol is spill volume for each line
splvol:     see above
spilstrt:   start time for each line
ns:         number of points for each line
xstart:     start point coordinate
ystart:
xend:       end point coordinate
yend
```

It is possible to define several input locations. In this example, only one input location is defined, so nns is set to 1.

If cross sectional concentration is desired, set the crsflag in the configuration file to 1 and prepare the cross section position file (pos file). A typical pos file is shown in following figure:

```
3883          1475
3896.666667 1460
3943.333333 1430
3967          1415
 .   .   .   .   .
17648.57143 9614.285714
17681.42857 9385.714286
17714.28571 9157.142857
17747.14286 8928.571429
17780          8700
-1
```

Each line in the pos file give the x and y coordinates of each points in all cross section lines. The last line of the pos file must be -1 which indicates the end of the file.

4.3 Running LAM487.EXE

To run LAM487.EXE program, type

LAM487.EXE

in a DOS Prompt windows of Windows 95 or Windows NT.

Enter asc, geo, bc file names when prompted. Then, enter the spl file name but don't enter the extension name. For example, if the spl file name is TEST.SPL, just enter TEST. The program will automatically look for the TEST.POS if crsflag in cfg file is set to 1 and the output fileS, sus file and crs file, will be named as TEST.SUS and TEST.CRS.

Figure 6. Running LAM487.EXE in a DOS Prompt Windows.
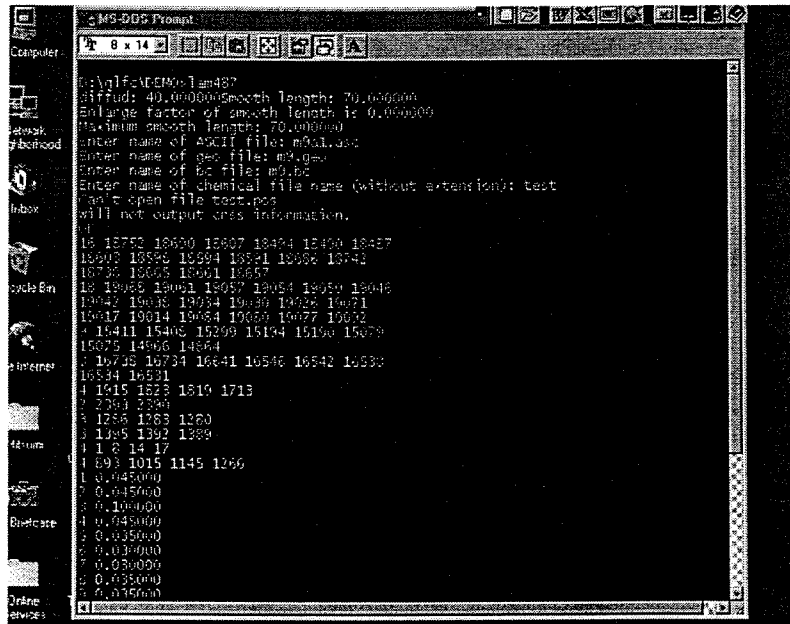
4.4 Understand Output File

The major output file of LAM487.EXE is the concentration file (sus file). The sus file contains the concentration data of each node of the triangular mesh system for each time step. Following list shows the format of the sus file:

```
N_STEPS N_NODES N_ELEMENTS
TIME_STEP1 N_NONZERO_NODES
NODE_ID CONCENTRATION
......
TIME_STEP2 N_NONZERO_NODES
NODE_ID CONCENTRATION
......

......

......

TIME_STEPN N_NONZERO_NODES
NODE_ID CONCENTRATION
......
```

The first line gives the total number time steps, number of nodes, and number elements. If the total number of time steps is N, there will be N blocks of data after the

first line. Each block of data begins with a line of time of this time step (in hour) and number of non-zero concentration nodes at this time step. Each line of the data block except the first line gives a node ID and the concentration of this node. Only non-zero concentration nodes are listed in the block. Figure shows an example of the sus file.

```
48 19094 8975
1.000000 851
502 0.006550
523 0.018797
524 0.076470
526 0.022807
531 0.018329
532 0.055775
533 0.005237
534 0.020189
535 0.005728
539 0.010783
540 0.019981
... ...
619 0.073060
620 0.314874
621 0.257167
622 0.130598
623 0.058048
624 0.088922
625 0.313654
626 0.393641
627 0.116992
... ...
```

In this example, the total number of time steps is 48. The number of elements is 8975. The number of nodes is 19094. The total number of non-zero concentration nodes at time step 1.0 (hour) is 851. At time step 1.0, the concentration of node 502 is 0.00655.

SMS can be used to display the concentration distribution on computer screen. SUSTOSOL.EXE will convert the sus file to the binary sol file which can be accepted by SMS. Run SUSTOSOL.EXE in a DOS Prompt windows of Windows 95 or Windows NT and type the file name of sus file which is to be converted and the file name of sol file which will be generated.
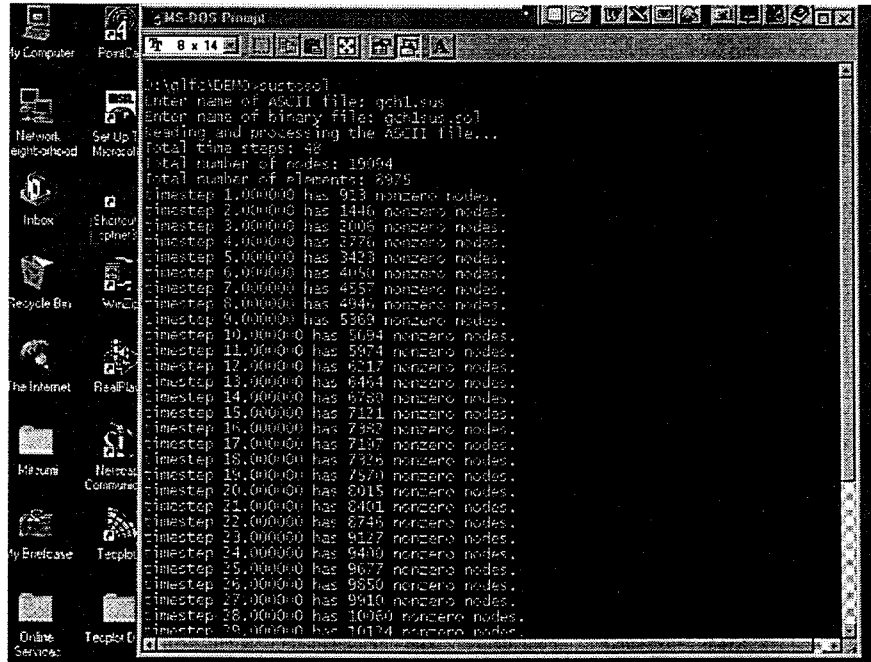
Figure 7. Convert SUS File Into Hourly Concentration File
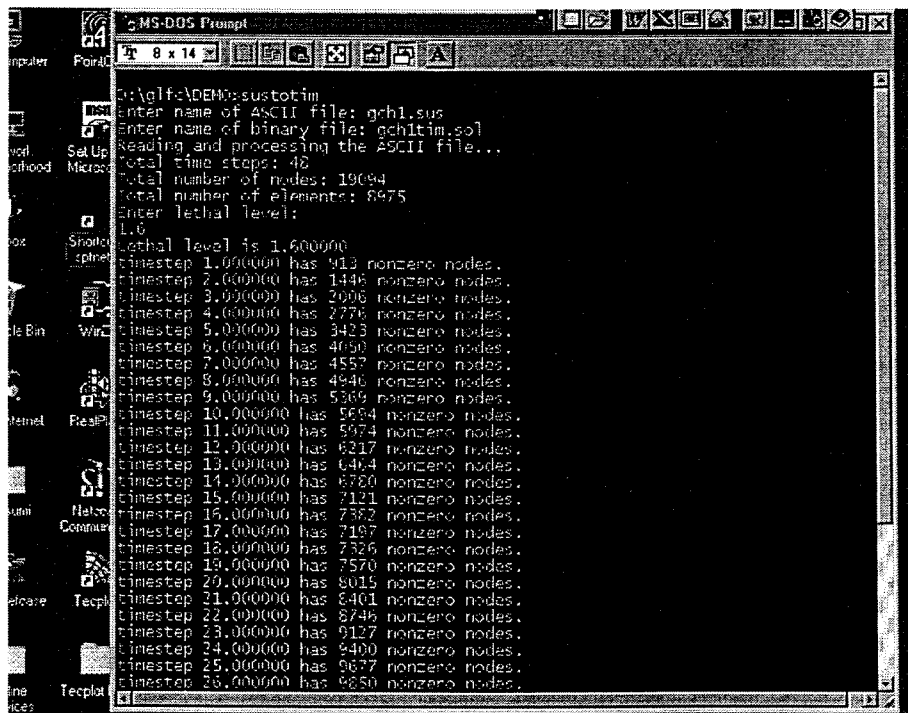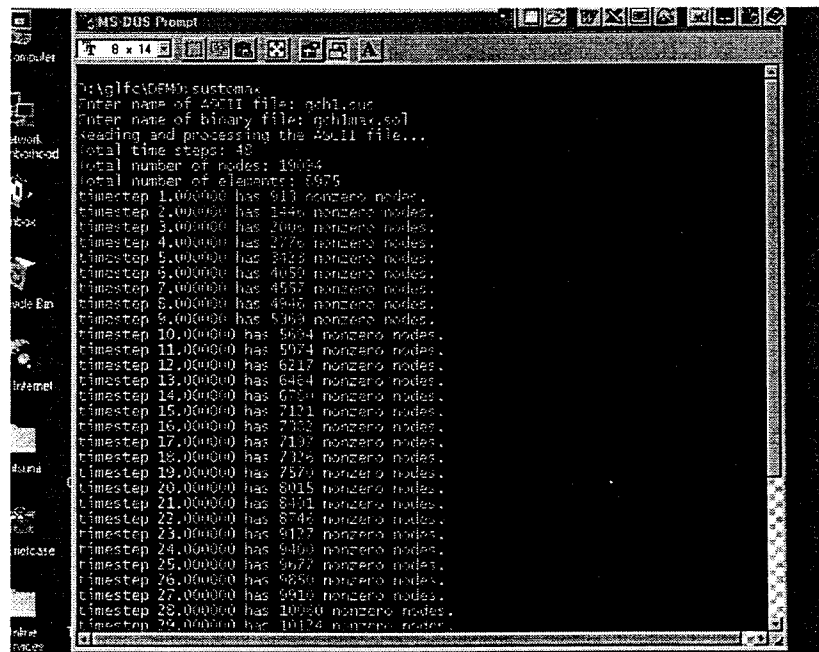
Figure 8. Convert SUS File into Lethal Level File

To convert the sus file into a lethal level file, type SUSTOTIM in a DOS Prompt

windows.

SUSTOTIM

Enter the sus file name, output file name, and the lethal level when SUSTOTIM

program prompts.

When the lethal level file is read and displayed by SMS, the contour displayed by

SMS represents the hours exceeding the lethal level.

Figure 9. Convert SUS File into Maximum Concentration File

To convert the SUS file into a maximum concentration file which can be read and

displayed by SMS, run SUSTOMAX program in a DOS Prompt windows. Enter the sus

file name and the output file name when prompted.

The converted binary file can be displayed by SMS.

1. Start the SMS as shown in Figure 10.
2. Click the menu command RMA2/Open Geometry as shown in Figure 11 and enter the geo file name.
3. In the same way, open the bc file.
4. Change the display option to turn off the display of finite element mesh. Only turn the boundary display on, as shown in Figure 12 and Figure 13.
5. Open binary solution file as shown in Figure 14. It can be hourly concentration file, lethal level file, or maximum concentration file.
6. If hourly concentration file is to be displayed, select the time steps when open the hour concentration file, as shown in Figure 15.
7. The contour lines is displayed as the default. Change the display option to show the contour in different colour as shown in Figure 16 and Figure 17.
8. Use other tools of SMS to show the contour in the best way.
9. Display other plots in the same way.

The sus file can also be converted into GIS data format using TOLLSUS.EXE program. TOLLSUS.EXE takes two input file: ASC file from CONV.EXE, and SUS file from LAM487.EXE. It can generate hourly concentration file, lethal (kill or no kill) file, or maximum concentration file depending on the user input after running TOLLSUS.EXE. TOLLSUS.EXE will ask for co-ordinate transformation coefficient. To transform the coordinates into polyconic co-ordinates, use following coefficients:

42550.0,	0.0,	-1.0
18900.0,	1.0,	0.0

The output file of TOLLSUS.EXE can be further transformed into other co-ordinate system using GIS utility program.
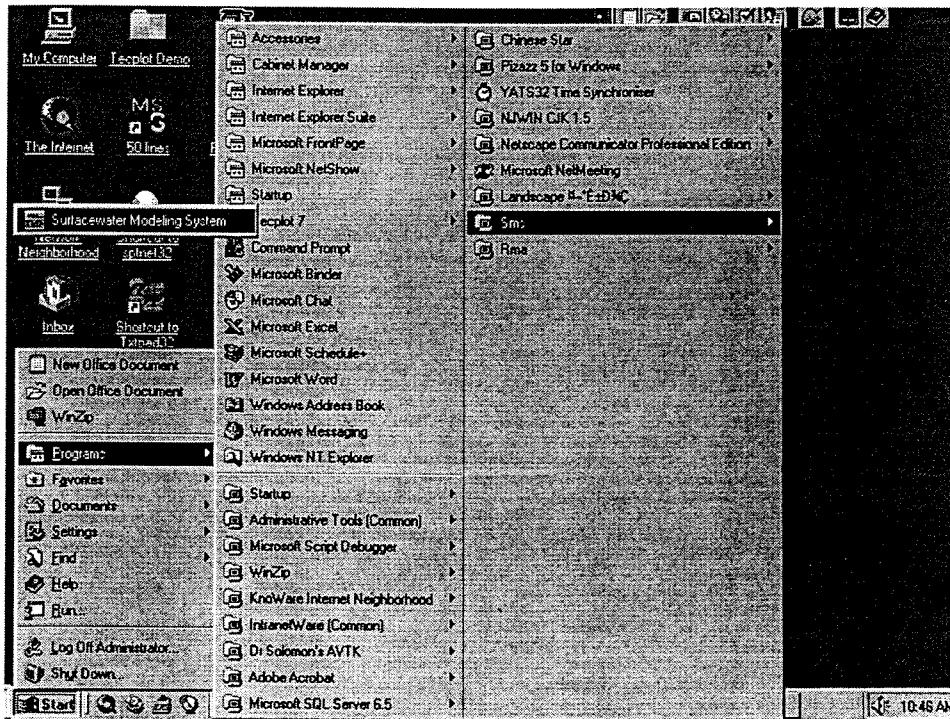
Figure 10. Start SMS in Windows 95.
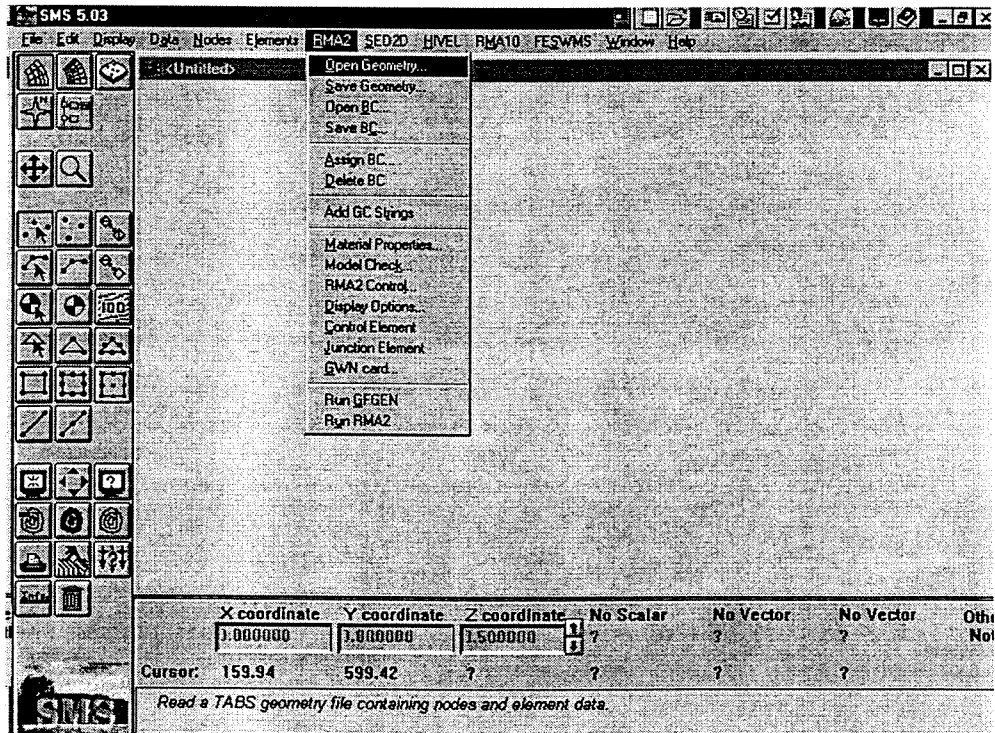
Figure 11. Open geo file
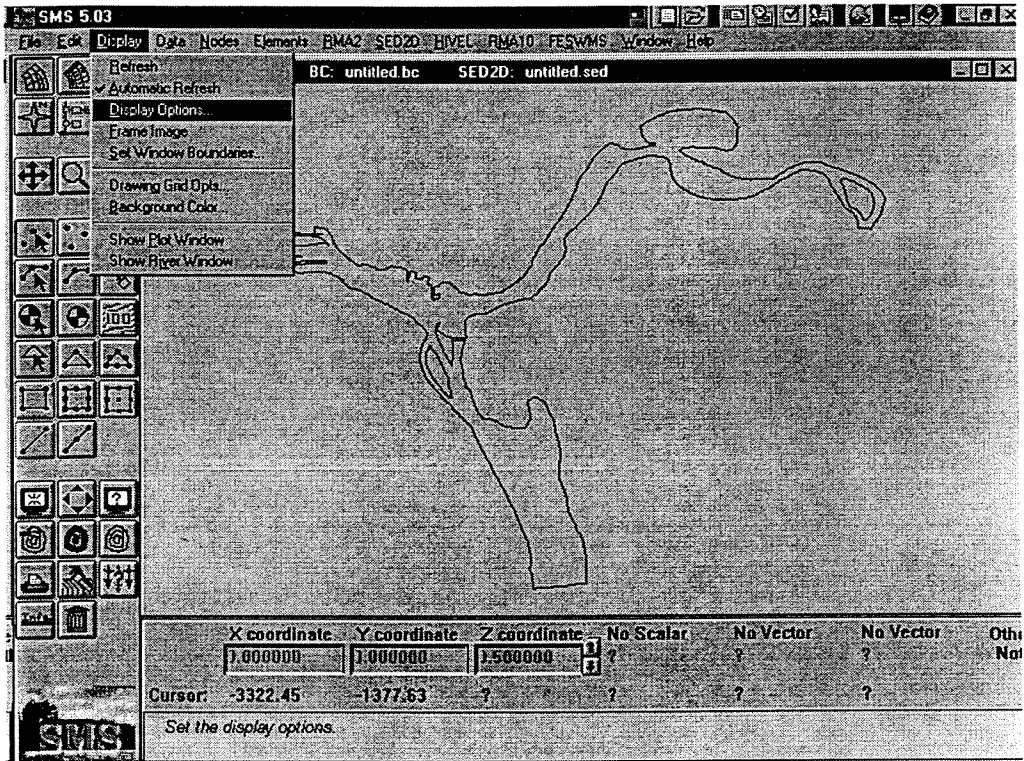
Figure 12. Change Display Options
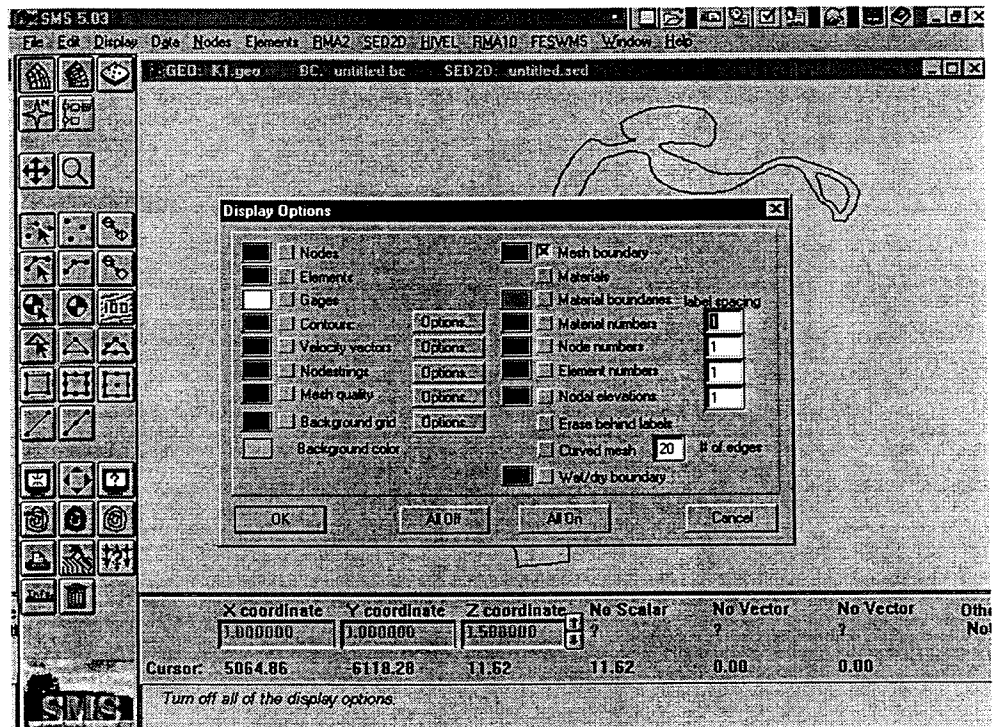
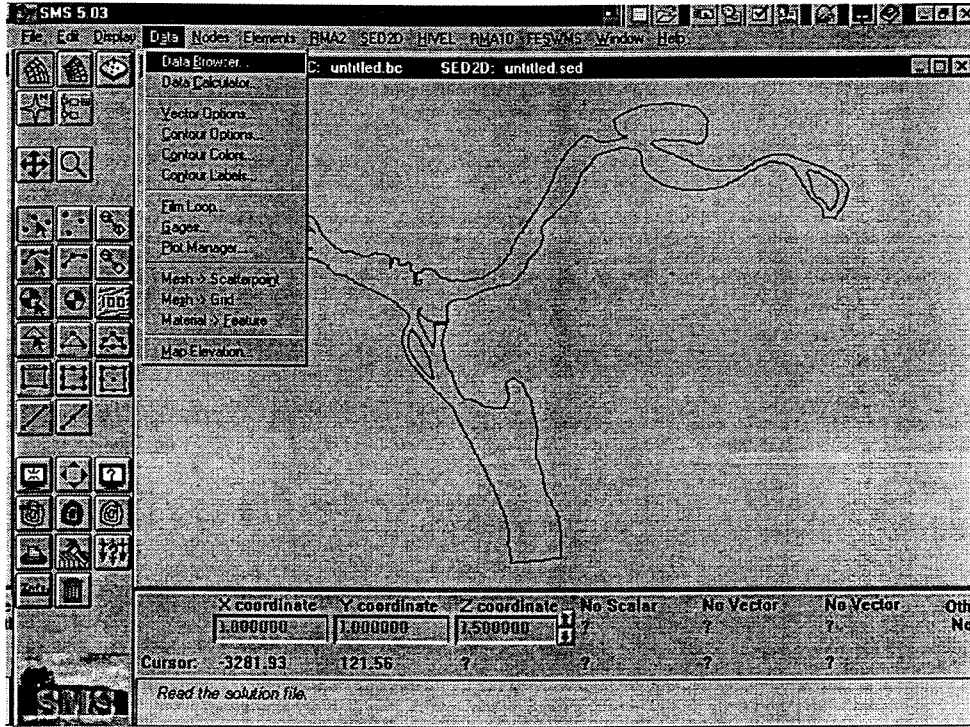

Figure 13. Shows only Mesh Boundary

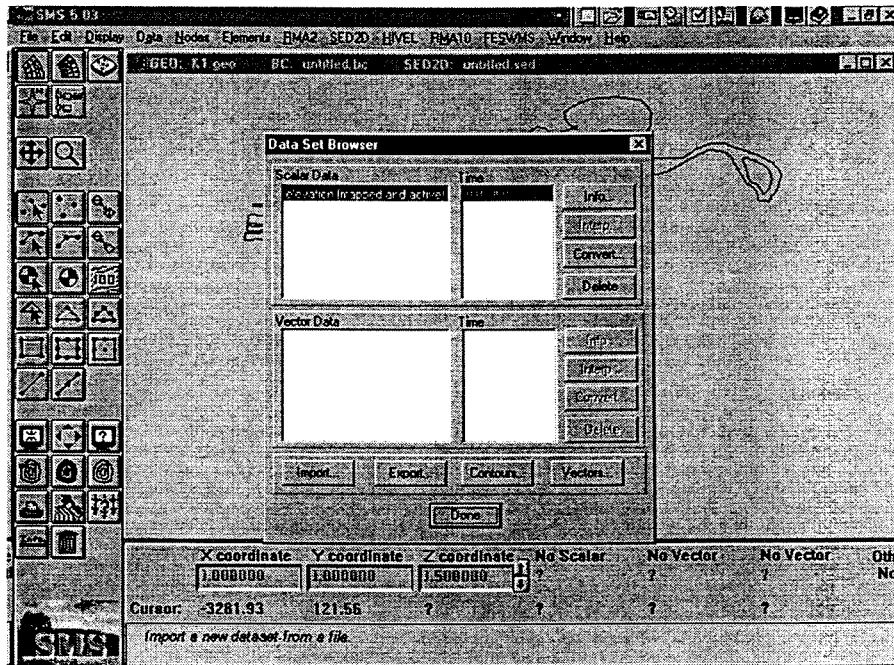**Figure 14. Read concentration file, lethal file, or maximum concentration file**
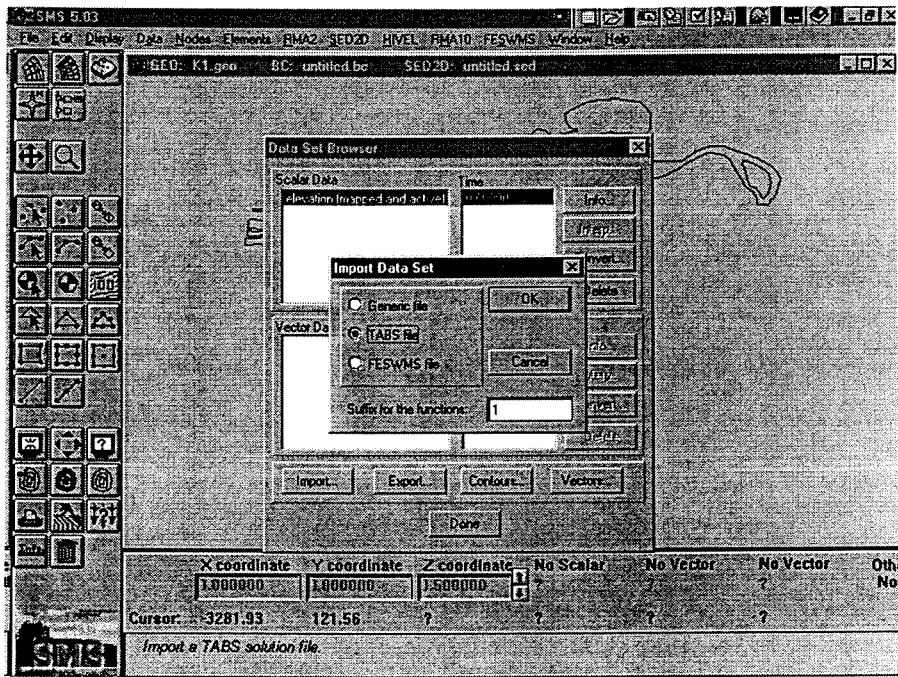

Figure 15a. Import solution file
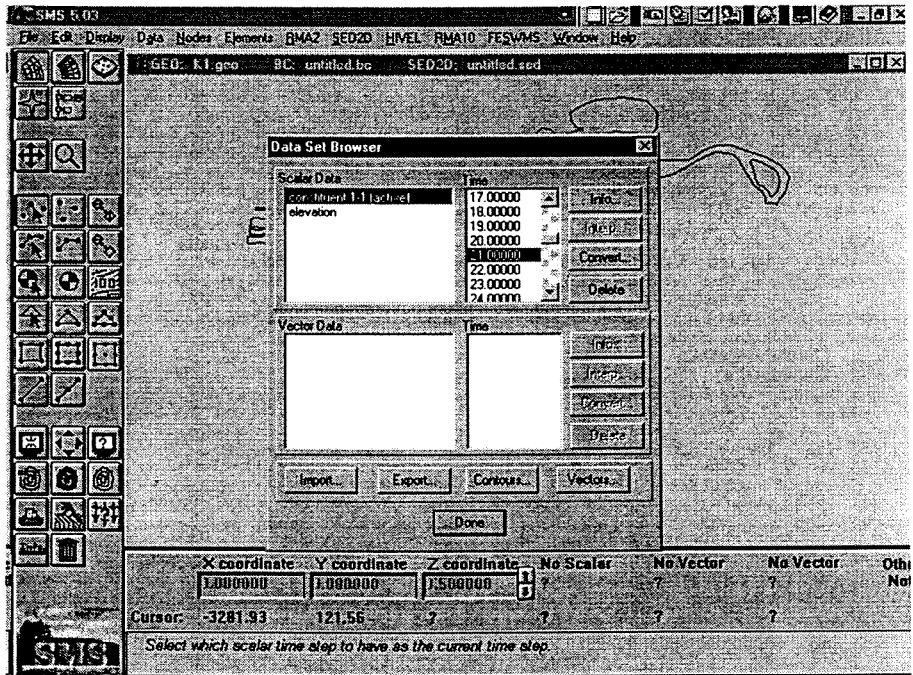
Figure 15b. Read solution file

Figure 15c. Select a time step when to display hourly concentration.

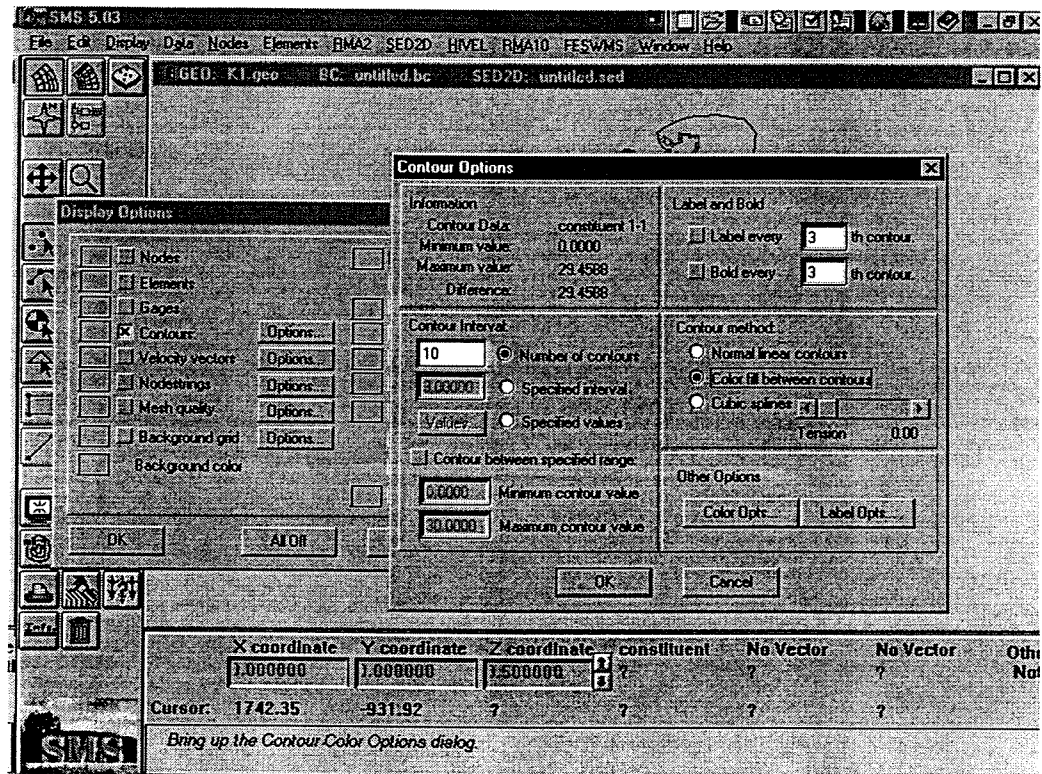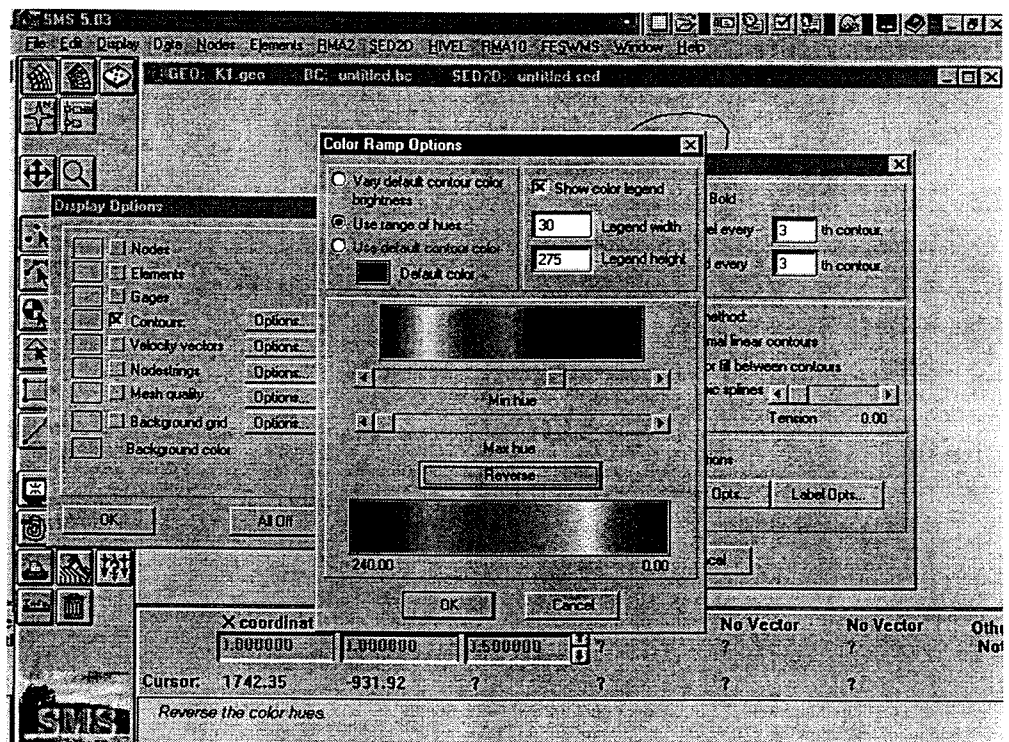**Figure 16. Change Display Option**

Figure 17. Select "Color fill between contours" and reverse the "Range of hues"

4.5 Calculate kill number

The SUSTOKIL.EXE program is implemented to calculate number of lamprey killed in the application of lampricide. To calculate how many lamprey killed, lamprey population density file should be prepared. The format of the file should be like:

```
DATASET
OBJTYPE "mesh2d"
BEGSCL
ACTTS 0.00000000e+000
ND  19094
NC   8975
NAME "lampop (mapped and active)"
TS 0 0.00000000e+000
0.00000000e+000
0.00000000e+000
0.00000000e+000
0.00000000e+000
0.00000000e+000
......
......
2.43499313e+002
2.41098862e+002
2.43361694e+002
0.00000000e+000
2.41904144e+002
2.42198624e+002
0.00000000e+000
2.42847702e+002
2.77319244e+002
2.43078415e+002
2.56314301e+002
2.40828674e+002
2.43479355e+002
2.43528336e+002
......
......
0.00000000e+000
0.00000000e+000
ENDDS
```

This file records the lamprey population density on each node of the finite element mesh. NC card records the number of elements and ND card represents the number of nodes. The order of the data set should be consistent with the node number, i.e.

first line represents density on node 1 and line 1000 represents node 1000. If lamprey density file is in other data format, SMS can be used to process the data and transform then into above format. Please see the user manual of SMS for the detail.

The SUSTOKIL.EXE program will prompt to input the geo file name, sus file name, and lamprey population density file name. Then, it will ask for the lethal level and lethal duration. The program will output the kill number on the screen and output the result into the file named as SUSTOKIL.OUT.

For an example, suppose we like to calculate the kill number of from the geo file, "m9.geo", sus file, "gcd1.sus", and the lamprey density file, "lampop.dat". The lethal level is 1.6ppm and the lethal duration is 9 hours.

Figure 18. Running SUSTOKIL.EXE to calculate kill number

Figure 18 shows the steps to run SUSTOKIL.EXE and Figure 19 shows the output result of SUSTOKILL.EXE.

Figure 19. Output of SUSTOKIL.EXE

List of Files Used in the Model

Data files:

- geo file: Geometry file of the domain
- bc file: Boundary file of the domain
- sol file: Binary output file of RMA2.EXE
- asc file: Ascii file converted from sol file of RMA2
- spl file: Chemical input information file
- pos file: Cross section definitaion file
- cfg file: Configuration file of LAM487.EXE
- sus file: Ascii output file of LAM487.EXE
- crs file: Cross section concentration file.
- par file: Particle position file.
- sol file: Binary solution file converted from sus file
- tim file: Binary lethal level file converted from sus file
- max file: Binary maximum concentration file converted from sus file

Program files:

- GFGV427.EXE: Convert the ascii geo file into binary geo file.
- RMA2.EXE: Hydraulic model program file.
- SOLTOASC.EXE: Convert the binary solution file of RMA into ascii file.
- LAM487.EXE: Lampericide simulation program file.
- SUSTOSOL.EXE: Convert ascii output file of LAM487.EXE into binary hourly concentration file.
- SUSTOTIM.EXE: Convert ascii output file of LAM487.EXE into binary lethal level file.
- SUSTOMAX.EXE: Convert ascii output file of LAM487.EXE into binary maximum concentration file.
- SUSTOKIL.EXE   Calculate kill-number from sus file and lamprey population density file
- TOLLSUS.EXE: Convert ascii output file of LAM487.EXE into ascii hourly concentration file, lethal level file, or maximum concentration file. Co-ordinate transformation can be used.