DESIGN AND IMPLEMENTATION OF AN ADVANCED SPILL MANAGEMENT INFORMATION SYSTEM FOR SURFACE WATERS

By

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To my dear husband, Clint, and our future,

may it be extensive and full of joy

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LIST OF ABBREVIATIONS

COSIM	Chemical and Oil Spill Impact Model
EPA	Environmental Protection Agency
EMSI	Environmental Modeling Systems Incorporated
ESRI	Environmental Systems Research Institute
ERM	Environmental Resources Management
GEMSS	Generalized Environmental Modeling System
GIS	Geographic Information Systems
GLLVHT	Generalized, Longitudinal-Lateral-Vertical Hydrodynamics Transport Model
GNOME	General NOAA Operational Modeling Environment
OPA	Oil Pollution Act
NOAA	National Oceanic and Atmospheric Administration
RM	River Mile
RMA	Resource Management Associates
SMIS	Spill Management Information System
SMS	Surface Water Modeling System
TMDL	Total Maximum Daily Load
TVA	Tennessee Valley Authority
USCG	United States Coast Guard
USGS	United States Geologic Society
WMS	Watershed Modeling System

CHAPTER I

INTRODUCTION

Background

Comprising approximately three percent of the world's water inventory, fresh water is considered a highly valuable and scarce resource (Serageldin 1995). Given the necessity to protect and maintain this resource, effective management of fresh water, including inland waterways, is essential. Inland waterways provide drinking water and hydropower for communities, recreational activities for many, habitats for aquatic species, and navigational pathways for freight transport. Beneficiaries of these waterways desire that their needs be met in terms of adequate water supply and quality. The 1972 *Clean Water Act* provided additional credence to water quality, mandating that both the public and private sectors "develop comprehensive programs for preventing, reducing or eliminating pollution" (USC 1972). More recently, the *2006-2011 EPA Strategic Plan* calls for improved standards, protection of source waters, security of water infrastructure, and improved quality of rivers, lakes, and streams (EPA 2006). These regulations alone create a burden on water resource managers independent of consideration of additional threats to our nation's surface waters.

One threat to water quality occurs when chemicals are accidentally or intentionally spilled. Thousands of inland waterway incidents, including oil spills, which pose risks to water supplies and public health, continue to be reported in the United States each year (NRC 2005). Freshwater oil and chemical spills are more frequent than marine oil spills (Owens and Michel 2002). However, most of the available information associated with oil spill modeling and response is focused on marine environments (Spaulding, Eric L. Anderson et al. 1993; Elliot and Jones 2000; Diaz, Pavon et al. 2008). Fortunately, since implementation of the *Oil Pollution Act* (USC 1990), the number and severity of oil spills in the U.S. have been reduced, in part due to planning and mitigation efforts by the United States Coast Guard (USCG) and other agencies (Burns, Pond et al. 2002). The new law, however, imposed additional regulations on waterbodies for water resource managers, calling for improvements in oil spill prevention, preparedness, and response capabilities (Burns, Pond et al. 2002; Ketkar 2002). The challenges faced by water resource mangers and spill response personnel have been made even more difficult by the current economic climate in which scarce resources are available to invest in such problem solving. This underscores the need for improved spill response technology to help managers prepare and respond to emergency accidental or intentional chemical releases in addition to daily operations on inland waterways.

Research Objectives

This research seeks to improve upon today's tools for inland waterway spill response through development of a new, easy-to-use decision-support system that utilizes the latest technologies in hydrodynamic and spill modeling. To ensure that the system contains relevant functionality while utilizing state-of-the-art information technology, a literature review was performed to understand the strengths and weaknesses of existing decision-support tools. In addition, a representative sample of personnel responsible for management of inland waterways and spill response were surveyed to ascertain their most important decision-support needs. The result of these activities assisted in the identification of areas where current systems are lacking, with the noted deficiencies serving as guidance in development of an enhanced system.

This resulted in the development of Spill Management Information System, version 2 (SMIS 2.0). The new system combines advanced hydrodynamic modeling, chemical spill modeling, and a geographic information system (GIS) to provide simple tools for spill response assistance.

SMIS 2.0 is intended to provide visual display of plume locations within minutes after a spill event without extensive modeling expertise required of the response personnel. The system provides vital information for spill response and decision support in a simple format unlike any other system currently used on inland waterways.

Spill model results can be utilized in ArcMap (ESRI 2006) to perform spatial queries to identify (i) local emergency response personnel such as hospitals, fire departments, and police within a specified distance of the spill event location; (ii) schools or other sensitive populations (e.g., nursing homes) that may need to be evacuated; (iii) sensitive species that may be impacted within or along the waterway; and (iv) spill response resources such as location of spill response contractors, stores of boom, sources of spill response materials such as home improvement stores, and grocery stores, restaurants, and lodging to support spill response personnel. In addition, maps can be produced for printing or electronic dissemination to assist in response and recovery efforts. SMIS 2.0 can also be used for training and planning of response strategies through development of reasonably foreseeable scenarios.

Organization of Dissertation

This dissertation is composed of seven chapters including this introduction. Chapter II provides a review of literature related to water quality modeling, including a discussion of techniques used in model selection, an evaluation of leading water quality models for inland waterways, an introduction to geographic information systems and their use in emergency response, and an analysis of current spill response systems for inland waterways. Chapters III, V, and VI represent planned manuscripts resulting from the research. Chapter III provides further investigation into current spill response efforts through conduct of a survey of water quality managers and spill response personnel to gain understanding of the demands faced, and critical needs for improved management and decision support. Chapter IV describes the process in developing the GLLVHT hydrodynamic model for use as part of the new spill response system that is the focus of this study. A description of the components and development of SMIS 2.0 is provided in Chapter V. Here, the tools created and their functionality are discussed in detail. In Chapter VI, the SMIS 2.0 system is applied to Kentucky Lake for a specific set of spill scenarios and the impacts of these scenarios are evaluated. Chapter VII provides a summary of the research with suggestions for future work.

CHAPTER II

LITERATURE REVIEW

Introduction

This chapter is a compilation of literature related to development of Spill Management Information System (SMIS 2.0). Included is information on hydrodynamic and spill modeling today, model selection techniques, geographic information systems (GIS), a short discussion of each hydrodynamic and water quality model/modeling system considered, and existing spill modeling systems that combine these technologies.

Water Quality Modeling Today

In water resources management, decision makers and engineers often rely upon models to forecast flow and water quality conditions. The trend today is to rely more heavily on modeling in the decision making process than in the past (Refsgaard and Henriksen 2004). Models are being employed to assist in decision support (Reda and Beck 1999; Cheng, Yang et al. 2003; Wool, Davie et al. 2003), for daily planning (Lord, Imberger et al. 1994; Chau, Chuntian et al. 2002; Cho, Sung et al. 2004; McIntyre and Wheater 2004), and as tools in emergency response (Martin, LeBoeuf et al. 2004; Samuels, Bahadur et al. Accessed September 2006). Modeling efforts are employed not only in attempts to meet regulatory requirements, but are used in establishing those standards. The Total Maximum Daily Load (TMDL) Modeling Toolbox is one example of such an application. The Toolbox is used by regulators and governments in establishing TMDL limits to be met by local municipalities and others discharging to surface waters (Wool, Davie et al. 2003; EPA 2008).

Currently available water quality models range from simplified 1-D flow and transport models such as FORTRAN-based, CE-QUAL-RIV1 (WES 1990) and the proprietary MIKE11 (DHI 2006), to more advanced 3-D models including the Environmental Fluid Dynamics Code (EFDC) (Hamrick 1992), Water Quality Analysis Simulation Program (WASP) (EPA 2006) and MIKE 3 (DHI 2006). Many other water quality models exist with a wide range of capabilities for modeling various scenarios, constituents, and water body types.

Water quality and hydrodynamics can be simulated using either analytical or numerical methods. Analytical modeling involves obtaining exact solutions to complex equations describing the processes involved. Numerical modeling involves simulating the behavior of a water body by solving intermediate equations in a step-wise process, often stepping through time. Analytical models are limited in applicability because they represent idealized situations assuming constant and/or steady values for variables such as flow rate and boundaries. With today's computing abilities, numerical models are used to provide solutions to complex systems which account for "real world," non-constant variables (Chapra 1997; Martin and McCutcheon 1999).

Several models have been linked with GIS to provide enhanced water resources and quality management through visualization of model output in spatial format (Foster and McDonald 2000; Sugumaran, Meyer et al. 2004; Martin, LeBoeuf et al. 2005). Spill Management Information System (SMIS), developed at Vanderbilt University as a spill response tool, links CE-QUAL-W2 with ArcView (Martin, LeBoeuf et al. 2004). The

Surface Water Modeling System (SMS) from Brigham Young University utilizes the TABS-MD (GFGEN, RMA2, RMA4, SED2D-WES), ADCIRC, CGWAVE, STWAVE, M2D, HIVEL2D, and HEC-RAS models. These are used with GIS for modeling scenarios in coastal environments or inland river systems (EMSI 2006).

The Modeling Process

A good explanation of the modeling process has been documented by Scott et al. (2000) who defined five main stages which are followed in most modeling applications today. First, the problem statement is defined. For this research, the objective is to identify a model that will not only represent the hydrodynamics and model several water quality parameters, but it must also be compatible with GIS. The model must be capable of capturing the complex hydrodynamics of the Tennessee River and the reservoir-like conditions near dams. Additional criteria for model selection are discussed later.

After identifying the problem to be addressed, a conceptual model is developed for the project of interest, which can include an initial selection of an existing model that is able to represent processes of interest. Next, model parameters are developed and the model is calibrated to existing data. This can be a time intensive activity. The model is then evaluated for accuracy through comparison with empirical observations. Finally, an analysis of the results is performed. Flow charts outlining the process can be found throughout the literature; see for example, *Good Modeling Practice Handbook* (Waveren, Groot et al. 2000) and *Surface Water-Quality Modeling* (Chapra 1997).

Model Selection Techniques

The primary goal in the model selection process is to determine the model which will best represent the hydrologic, hydrodynamic, and water quality processes associated with the natural system (Saloranta, Kamari et al. 2003). Specific considerations include the amount of detail attainable with a given model, data availability for calibration and validation, and, to a lesser extent today, simulation computational requirements. Additional factors to be considered in model selection include: (i) parameters of interest; (ii) data availability; (iii) model complexity; (iv) hydrodynamic and water quality processes involved; (v) model performance; (vi) familiarity with the model; (vii) available time for development and application; and (viii) the amount of accuracy desired (McCutcheon 1989; Marshall, Nott et al. 2005). Beyond selection of an appropriate model, it must be properly applied, calibrated, validated, and analyzed for the specific situation (Reckhow 1994). Appropriate information is also needed to perform these actions.

With so many factors to consider, how does one select the most appropriate model from the many options available? Saloranta and his colleagues previously developed "benchmark" criteria for selection of models in water management (Saloranta, Kamari et al. 2003). These criteria were posed as 14 questions as outlined below.

- How well does the model's output relate to the management task?
- How well does the model's span and resolution in time and space compare with the requirements of the management task?
- How well has the model been tested?
- How complicated is the model in relation to the management task?

- How is the balance between the model's input data requirements and data availability?
- How is identifiable are the model parameters?
- How easily are the model results understood and interpreted?
- How is the peer acceptance for the model and the model's consistency with scientific theory?
- How well is the model suited for sensitivity and uncertainty analyses and how well have these analyses been performed and documented?
- How is the model's version control?
- How are the model's user manual and tutorial?
- How is the model's technical documentation?
- How are the model's interactiveness, user-friendliness, and suitability for end-user participation?
- How is the model's flexibility for adaptation and improvements?

For each question, the user has three possible answers, with point values associated for each; good = 2, adequate = 1, and inadequate = 0. This scoring is then used to discard models under consideration that fail to meet the project requirements by receiving a score of 0 on any question. The remaining models are then deemed as candidate models and further analysis to identify the best candidate can be performed by selecting a model with the highest number of "2"s selected and considering other factors such as costs (Saloranta, Kamari et al. 2003). This technique helps narrow the number of models under consideration in a formalized process.

Select Hydrodynamic and Water Quality Models

This section contains a synthesis of current modeling uses and the specific models considered for the current project. It is by no means an all-inclusive summary of currently available hydrodynamic and water quality models.

EFDC

Developed by Hammrick and others at the Virginia Institute of Marine Science, Environmental Fluid Dynamics Code (EFDC), a Fortran77-based hydrologic model, has the ability to compute "3-D, vertically hydrostatic, free surface, turbulent averaged equations of motion for a variable density fluid (Hamrick 1996; Wool, Davie et al. 2003)." As a primarily hydrodynamic model, EFDC possesses some water quality modeling capabilities, including temperature and contaminant transport with sources and sinks. It currently possesses capabilities for using boundary-fitted, curvilinear-orthogonal coordinates in the horizontal plane, or sigma-stretched coordinates in the vertical direction to define the modeling mesh. This allows the vertical layer thicknesses to vary spatially, allowing one to maintain the number of layers present across varying waterbody depths during times of low (or high) flow. The textural format of the 3-D mesh for input and output within EFDC lend itself to possibilities for linkage with a GIS system (Smith and Friedmean 2004).

Presently, no grid generation package has been linked with EFDC, but a project is underway at the EPA. The project includes use of MapWindows, a generic, open source-code GIS application, and is expected to be completed late in 2007 (Wool 2006). MapWindows does not possess the querying or analytical capabilities of ArcView, the

GIS package to be used in this research. The EPA Better Assessment Science Integrating Point and Non-point Sources (BASINS) software utilizes MapWindows (EPA 2007).

Hydrologic modeling of EFDC is performed using a time-domain, finite-difference approach. Equations of motion for turbulent flow are solved in all three dimensions using an internal-external mode splitting procedure (Limno-Tech 2002). The Smogarinsky formula, commonly used for eddy diffusivity, is used for horizontal diffusion calculations. A second-moment turbulent closure technique is used to solve for eddy viscosity in the vertical direction. This involves solving for a variable of the Reynolds-averaged Navier Stokes equations using two independent equations. In EFDC, the "Mellor & Yamada" 2.5 equation is used for turbulence closure (Hamrick 1996; Imhoff, Stoddard et al. 2003). Given theses modeling capabilities, EFDC could be used to model flow around hydraulic structures such as bridge piers.

EFDC water quality capabilities include modeling transport of sediments and metals. These are enhanced through linkages with a water quality model such as the Water Quality Analysis Simulation Program (WASP) (Hamrick 1992; Hamrick 1996; EPA 2006). EFDC has the ability to report results in three dimensions in a format that can be read by computer aided design (CAD) programs. EFDC is in the public domain.

To date, EFDC has been applied to modeling (i) saltwater intrusion in estuaries, (ii) simulation of power plant cooling water discharges, (iii) oyster and crab larvae transport, and (iv) pollution transport from both point and non-point sources (Hamrick 1996; Ji, Morton et al. 2001; Park, Jung et al. 2005). Other uses include modeling of sediments and metals with capabilities for modeling estuaries, coastal oceans, reservoirs, lakes, and rivers.

One of the initial applications of EFDC was performed by Hamrick (Hamrick 1992) in performing environmental impact assessments on the James River and York River, both in Virginia. The James River study focused on identifying the impact on tidal flow in the adjoining estuary due to expansion of Craney Island by dumping of dredge soil. EFDC was calibrated using 5 years of data with only minor adjustment to the bottom roughness required to obtain agreement with measurements. Ultimately, dumping of the dredge soil was found to have little impact on the estuary as was previously observed by dye release analysis. Dilution and mixing of an industrial discharge were considered in the York River study. The grid used to represent the river area included approximately 1600 horizontal cells and eight layers. Hamrick assumed low flow for a conservative analysis of contaminant concentrations. Again, the model agreed with dye study results (Hamrick 1992). The ability to accurately model sedimentation, complex velocities, and pollutant discharges in large riverine systems is of great importance to the current project. Ji and colleagues (Ji, Hamrick et al. 2002) investigated the transport of metals and sediment during three storm events for the Blackstone River, Massachusetts. Calibration was performed under normal conditions using data from the Blackstone River Initiative, a "multi-year and multimillion dollar project" (Ji, Hamrick et al. 2002). Given that the Blackstone is a shallow, narrow river, EFDC was used in 1-D and was found to represent the hydrodynamic sediment and metals processes reasonably well. In a more complex situation, EFDC was used to simulate vertical mixing in Lake Okeechobee, Florida, in winter (Jin, Ji et al. 2002). Part of the investigation was on identifying circulation patterns and the causes of these patterns. Wind was found to be the leading force in circulation patterns. It was also suggested that horizontal dispersion was affected by diurnal thermal stratification (cooling of surface waters at night creating turn-over due to density differences) (Jin, Ji et al. 2002). These are just a few examples of the capabilities of EFDC.

Water Quality Analysis Simulation Program (WASP)

EPA's WASP 7.2 possesses 1-, 2-, and 3-D water quality modeling capabilities. WASP can predict dissolved oxygen, sediment loads, organic pollutants, and nutrients (EPA 2006). This publicly available model can be combined with EFDC for enhanced analysis including flows, temperatures, and depth velocities (Hamrick 1996; Virginia Institute of Marine Science 2002).

Employing dynamic compartment modeling, finite volumes (or compartments) are identified and mass balances are performed across boundaries allowing components to flow from one compartment to the next. WASP utilizes equations for time varying advection, dispersion, point and diffuse mass loading along with boundary exchanges to model water quality constituents. Processes modeled include eutrophication, phosphorous loading, and pollution (e.g., heavy metals, volatile organic compounds (VOCs), and polychlorinated biphenyls (PCBs) (EPA 2006).

A preprocessor packaged with WASP allows users to import hydrodynamic information from spreadsheets or text files. The postprocessor, MOVEM, enables display of model results as either a spatial grid or X/Y plots. These output types could be transferred into spatial information for display in GIS.

WASP has been used for modeling of eutrophication, pollution and water quality of Lake Okeechobee, the Potomac Estuary, the James River, and several other rivers, estuaries, and bays (Ji, Morton et al. 2001; Wool, Davie et al. 2003; EPA 2006). Tufford and colleagues (Tufford and McKellar 1999) used WASP to evaluate both hydrodynamic and water quality in Lake Marion, South Carolina. In this, the model represented phytoplankton and nutrient processes well, but the researchers suggested that the model did not fully accommodate the ecological variability in the lake due to model constraints on rate constants. Yet, they concluded that the model was highly versatile and useful as a predictive tool. Sensitivity analysis and a validation goodness of fit with $P < 0.05$ suggested the model was representing the "real-world" situation sufficiently (Tufford and McKellar 1999). An example of pairing of EFDC and WASP was performed by Watson and colleagues (Watson, Penne et al. 2003). In this, both models were used to evaluate TMDL guidelines for the Los Angeles River during low-flow conditions. The models were said to accurately represent the key processes and provided useful tools for TMDL regulatory decisions (Watson, Penne et al. 2003).

CE-QUAL-W2 (Quasi-3D)

Developed by the U.S. Army Corps of Engineers, CE-QUAL-W2 has the ability to perform both 1-D and 2-D finite-difference water quality and hydrologic modeling of rivers, estuaries, lakes, reservoirs, and river basin systems. Model simulations are run using a FORTRAN-77 code with lateral averaging of constituents. The model can be used for both stratified and non-stratified systems. The main assumption (and limitation) of CE-QUAL-W2 is that the waterbody is well-mixed in the lateral direction. However, using additional model branches/layers, one can create a quasi-3-D simulation. Grid-generation is performed using GRIDGEN, a tool developed by J.E. Edinger and Associates (Cole and Buchak 1995; Cole 2008).

Hydrodynamic modeling capabilities include flow around submerged hydraulic structures and two-way flow over submerged hydraulic structures including, but not limited to, dam piers, spillways, and weirs. Manning's or Chezy's friction factor, commonly used in open channel flow considerations, is used along with a dynamic shading algorithm, which estimates the amount of solar radiation reaching the waterbody based upon time of day and azimuth, to simulate topography or vegetative cover. Shading due to vegetative cover or local topography reduces the amount of solar radiation contributing to temperature increases. The current version, Version 3.5, provides improved hydrodynamic modeling for areas where riverine systems enter reservoirs by taking into account the velocities parallel to the channel slope (Hammoud 2006)

Water quality capabilities include modeling of biochemical oxygen demand, nitrogen, phosphorous, dissolved oxygen, sediments, and others. Inputs such as decay coefficients, temperature, and dissolved oxygen drive the water quality side of the model and contaminant degradation.

CE-QUAL-W2 has been applied to over 200 reservoirs and river systems worldwide (Bartholow, Hanna et al. 2001; Boegman, Loewen et al. 2001; Deliman and Gerald 2002; Bowen and Hieronymus 2003; Ha, Bae et al. 2003; Kuo, Liu et al. 2003; Martin, LeBoeuf et al. 2004; Cole 2008). The Tennessee Valley Authority, U.S. EPA, U.S. Army Corps of Engineers (USACE), and U.S. Geological Survey (USGS) are among those currently using CE-QUAL-W2 (Cole and Buchak 1995). CE-QUAL-W2 was tested for modeling accuracy of vertical-longitudinal thermal structure across seasons of Lake Erie. The model was able to accurately predict water levels, but required adjustments to eddy turbulence techniques to obtain acceptable longitudinal values (Boegman, Loewen et al. 2001). Martin and colleagues (2004) applied the model to the Cheatham Reach, a portion of the Cumberland River near Nashville, Tennessee, with a focus on contaminant migration during spill events. CE-QUAL-W2 was applied to the waterbody using 400-m long river segments that were assumed to be laterally averaged (Martin, LeBoeuf et al. 2004). While this work provides a foundation for this research, the Tennessee River represents a significantly wider water body relative to the Cumberland River and the Cheatham Reach. Thus, lateral averaging across the Tennessee River is not optimal for spill response analysis.

MIKE 3

The Danish Hydraulic Institute (DHI) developed MIKE3, which possesses capabilities to simulate 3-D free surface flows for rivers, estuaries, and lakes. The modeling suite, while boasting GIS integration and multiple grid generation capabilities (single grid, multiple grid, and flexible mesh), is proprietary; therefore, information from independent sources is limited. The package consists of a modular structure with three main components; estuarine and coastal hydraulics and oceanography, environmental hydraulics, and sediment processes. MIKE3 is capable of modeling flow simulations, cohesive sediments, water quality, and ecological processes.

Hydrologic modeling is performed using Reynolds-averaged Navier-Stokes (RANS) equations in three dimensions. Finite-difference algorithms are used to solve the

RANS equations. The water quality module, ECO Lab, is an ecological modeling solver used for chemical and biological processes in addition to physical sedimentation processes. MIKE3 models unsteady flow, taking into account density variations, bathymetry and external forcing such as meteorology, tidal elevations, currents and other hydrographic conditions (DHI 2006).

MIKE3 utilizes continuity, momentum, temperature, salinity, and density equations. It also employs the Boussinesq eddy viscosity concept and incorporates five turbulent closure techniques including constant eddy viscosity, Smagorinsky subgrid scale model, k-model, k-ε model, and mixed Smagorinsky/k-ε model. In the mixed Smagorinsky/k-ε model, horizontal turbulence is considered by the Smagorinsky formula in both directions and closed using a turbulence closure scheme. Vertical mixing is accounted for using the k-ε model to accomplish 3-D simulations (DHI 2006).

Within the environmental hydraulics module, sub-modules include advection-dispersion, water quality, and eutrophication. The system is capable of modeling dissolved oxygen, biochemical oxygen demand (BOD), and nutrients. In the advection-dispersion (AD) and transport (TR) module, linear decay is used to model chemical processes. The model possesses capabilities to simulate transport, dispersion, and decay of dissolved or suspended substances. This is carried further in the spill analysis module where spreading and weathering of suspended substances such as oil spills is performed. The developers state that this component is only for forecasting and scenario evaluation (DHI 2006).

MIKE3 has been used by the City of Toronto to evaluate shoreline water quality improvements in Lake Ontario. The model is used to simulate present day effects of pollution considering rainfall events and dry periods. Furthermore, MIKE3 is used to estimate the effectiveness of pollution prevention measures being employed by the City of Toronto's Water Pollution Solution program (Toronto 1998-2006). It has also been applied to sediment transport studies in estuarine (Stoschek and Zimmermann 2006) and riverine environments (Edelvang, Lund-Hansen et al. 2002). Stoschek and Zimmermann's (2006) work was used to evaluate the influence of geometry, tidal condition, and salinity on deposition of sediment in harbors. The model outputs agreed well with measured data during validation. The researchers found that density currents played a significant part in the amount of sediment deposited (Stoschek and Zimmermann 2006). Edelvang and colleagues (Edelvang, Lund-Hansen et al. 2002) evaluated the transport of suspended sediment transport in the Oder River using fully 3-D simulation of a one-year period. Model results were similar to *in situ* measurements with a slight underestimation of peak values of current speeds. This was considered to be the result of the difference between a single point measurement and the value obtained from the model representing a grid cell of much larger scale, which could be expected of any modeling effort (Edelvang, Lund-Hansen et al. 2002).

GEMSS

The Generalized Environmental Modeling System for Surface Waters (GEMSS) was developed by J.E. Edinger and Associates, now known as Environmental Resources Management, Inc. (ERM). The system consists of hydrodynamic, water quality, and constituent modules, and a graphical user interface (GUI) which assists in grid generation, pre- and post-processing of data, and visualization of results. GEMSS is applicable to rivers, lakes, reservoirs, estuaries and coastal waterbodies (Kolluru and Fichera ; Edinger and Buchak 1995; Edinger, Buchak et al. 1998; Wu, Buchak et al. 2001; Edinger, Dierks et al. 2003; Kolluru, Buchak et al. 2003). The model is free to the public, but only after having the intended project approved by the developers.

Much like MIKE3, GEMSS is an integrated system of hydrodynamic and transport models presented in modular format. The hydrodynamic modules include the 3-D Generalized, Longitudinal-Lateral-Vertical Hydrodynamic and Transport (GLLVHT), CE-QUAL-W2 (2-D), 1-D Generalized-Longitudinal Hydrodynamic and Transport (GLHT), and zero-dimensional real-time control (Dortch) model. Water quality modules have capabilities of modeling sediment transport, water quality, temperatures, chemical and oil spills, and bacterial processes (Edinger 2001; Edinger 2001) among others. The system uses finite-difference methods and process solutions similarly to CE-QUAL-W2. EFDC, the Princeton Ocean Model (POM), and the Estuarine and Coastal Model Sediments (ECOMSED) are also run using the graphical user interface independent of GEMSS with intentions being that these provide comparative analysis.

The majority of the applications for GEMSS have been in modeling cooling-water discharges in riverine and coastal systems (Wu, Buchak et al. 2001; Kolluru, Buchak et al. 2003). Kolluru and colleagues (Kolluru, Buchak et al. 2003) used the Thermal Analysis Module (TAM) within GEMSS to evaluate the mixing zone for a thermal plume emanating from a natural gas liquefaction facility in seawater near the Arabia Gulf. The study was performed to identify the impact of thermal releases on a proposed facility expansion. Results from GEMSS indicated that the thermal plume was vertically stratified with large surface and small bottom areas, which was desired. Among comments from the researchers were that the grid generation tool allowed for fast generation and revisions of the grid. Breakwaters and a pier were included in the grid and model set up without trouble (Kolluru, Buchak et al. 2003). Additional work has been performed in applications to TMDL studies (Wu, Buchak et al. 2001). The USEPA, the Bureau of Reclamation, and state agencies have also accepted use of the system (Edinger 2001).

Delft3D

A proprietary system developed by WL|Delft Hydraulics, Delft3D combines hydrodynamic, ecological, and morphologic modules for 2-D (depth-averaged) and 3-D hydrodynamic and sediment transport simulations in coastal, riverine, and estuarine systems. The system consists of six modules: hydrodynamics (Delft3D-FLOW), waves (Delft3D-WAVE), water quality (Delft3D-WAQ), morphology (Delft3D-MOR), sediment transport (Delft3D-SED), and ecology (Deflt3D-ECO) (WL/Delft 2007).

Flow and transport calculations are performed using finite volumes using the unsteady shallow water equations. When used in 2-D mode, wind-driven and tidal flow is simulated by assuming vertical accelerations are small reducing the vertical momentum equation to a simplified hydrostatic pressure relation (Luijendijk 2001). Curvilinear grid generation is performed using RGFGRID. Delft3D can model thermal stratification and transport of dissolved pollutants. Bottom shear/friction is determined using the Chezy (or Manning's) equation. An advection-diffusion solver is used to account for density gradients. Water quality constituents that are modeled by Delft 3D include oxygen, BOD, COD, salinity, coliform, and conservative and first-order decaying substances (WL/Delft 2007).

The FLOW module has been used independent of the package to assess the effects of tidal- and wind-driven flow in a coastal environment. Delft3D results were compared to measurements made by ferry to define sediment transport into the Marsdiep Basin. Validation and evaluation of Delft3D Flow indicated that the model results corresponded well to the measured values (Luijendijk 2001). Bleninger and Jirka (2007) used Delft3D to investigate mixing and dispersion of wastewater discharges in coastal waters. They coupled CORMIX, a near-field model that focuses on physical mixing processes with conservative decay reactions, with Delft3D (used as a far-field model) to create a "more complete" representation of the contaminant transport from submerged wastewater discharges. Near-field modeling is focused on the mixing zone while far-field modeling looks at the processes taking place over long time scales and long distances away from the mixing zone. Due to the ability of Delft3D to accommodate direct coupling of hydrodynamic results from other models, the researchers were able to more accurately predict the concentrations of discharges (Bleninger and Jirka 2007). Hibma and collegues evaluated the system's ability to model shoal and channel formation patterns for several estuaries, finding that the results of the model matched closely to field observations. A simulation of 120 years was performed (Hibma, Vriend et al. 2003). In some cells, the water depths reached unrealistic heights above "high-water" levels which was attributed to an artifact of the model during the wetting-drying sequence. The researchers found that decreasing the time steps prevented this occurrence (Hibma, Vriend et al. 2003).

Most applications of Delft3D are focused on coastal systems. However, scheduling of dam releases on the Tennessee River can create slight fluctuations in the direction of flow. Overall, the system incorporates many of the basic modeling components of interest to this project. However, the system is proprietary and information on some model qualities is limited.

RMA2/RMA4

RMA2 is a two-dimensional, depth-averaged, finite-element hydrodynamic model from Resource Management Associates (RMA). It is designed to model free-surface and sub-critical flows where vertical stratification is disregarded. Often, the model is used in combination with RMA4, its water quality counterpart (USGS 2006). The model is part of the USACE TABS-MD System (Donnel, Letter et al. 2001), and is thus also a component of the Surface Water Modeling System (SMS) (EMSI 2006).

As with RMA 2, RMA4 is a 2-D finite element model and another component of the TABS-MD System. RMA4 utilizes the hydrodynamics of RMA2 as basis for its modeling simulations (USGS 2006). Similarly, RMA4 is a component of SMS (EMSI 2006). The model can evaluate concentrations for up to six chemical constituents, while applying linear decay processes to each (Donnel, Letter et al. 2001).

RMA2 has been applied to several bays including Newport Bay, San Pablo Bay, and South San Francisco Bay, all in California (RMA 2006; USGS 2006). It has also been used for modeling flooding scenarios on the Santa Cruz River, taking into consideration the highly vegetated channel (Ghung, Lansley et al. 2004). Applications for RMA4 include projects for both San Francisco Bay and San Pablo Bay in California

(RMA 2006; USGS 2006). Stewart and colleagues investigated the suitability of both the Colorado and Yampa Rivers for two native fish species using RMA2 within SMS (Stewart, Anderson et al. 2005). In this effort, the focus was on temperature, velocities, and biomass (modeled separately) that would be compatible with sustaining the fish populations during low-flow periods. The modeling efforts resulted in relationships between suitable habitats and discharge quantities. In addition, one portion of this project considered threats to sensitive species during spill events using habitat requirements such as dissolved oxygen (DO) and temperature as criteria for protection zones. Unfortunately, nothing was mentioned concerning the calibration or validation of the model (Stewart, Anderson et al. 2005).

Geographical Information Systems (GIS)

At the forefront of monitoring and preparedness training for both intentional and accidental chemical releases, GIS have become a necessity. These systems allow users to gather, store, manipulate, and visualize spatial data. Individuals or agencies can create maps of areas of concern, locate specific entities within the maps and have access to vital information about these items. Government agencies and others have invested in establishing data sets/clearinghouses that are publicly available at little or no cost (Johnson 2000; Waveren, Groot et al. 2000; Martin, Brush et al. 2005). As an example, the U.S. Census Bureau has created Topologically Integrated Geographic Encoding and Referencing (TIGER®), which is a digital geodatabase containing both census data and general topography, including census blocks, roads, water bodies, railroads, landmarks and county boundaries (USCB 2005).

Currently, GIS uses include water resource management, accident risk assessment and management (Contini, Bellezza et al. 2000; Foster and McDonald 2000; Martin 2003; Jenks and Malecki 2004; Martin, LeBoeuf et al. 2004; Barnes 2005), environmental management (Mattikalli and Engman 1996; Tian and Nimmer 2000; Matejicek, Benesova et al. 2003), public health analysis (Jenks and Malecki 2004), weather forecasting, and hazardous materials tracking (Dobbins and Abkowitz 2002; Dobbins and Abkowitz 2003). A recent trend is to employ GIS in the decision making process (Sugumaran, Meyer et al. 204; Tian and Nimmer 2000; Barnes 2005) and as a tool for communication (Contini, Bellezza et al. 2000; Batty 2004). Contini and Bellezza et al. (2000) demonstrate the usefulness of GIS as tool to assist in solving risk-related problems by providing a transparent platform for interested parties. Within GIS, emergency plans are drawn up and displayed, safety reports are managed, and model data and results are presented for all to see and be equally informed, thus improving communication (Contini, Bellezza et al. 2000).

Recent advancements to GIS have led to the possibility of representing data as three-dimensional (3-D) objects. Not only does this provide for a more realistic view of spatial data, but users can manipulate the GIS outputs to obtain even more information. Employing the 3-D Analyst along with 3-D topographic maps, a triangulated irregular network (TIN), or a digital terrain model (DTM), the water body can be broken into small individual cells for modeling. ArcScene is a component of the 3-D Analyst Extension and contains tools for fly-over migration through the GIS layers, creation of animations, and rotation similar to that of computer-aided design (CAD) systems. 3-D GIS are already being used for utilities, mining and nuclear waste repository analysis (Elroi

1999). The 3-D data/scenes created using ArcView 3-D Analyst can be exported into virtual reality modeling files which would allow further manipulation and analysis of the data (Elroi 1999).

Water Quality Models Linked to GIS

Given the growing popularity of GIS in emergency response and risk assessment (Contini, Bellezza et al. 2000; Barnes 2005), it is only natural to incorporate these systems in response and recovery activities along our nation's waterways (Dobbins and Abkowitz 2003; Martin 2003; Martinez-Alegria, Ordonez et al. 2003; Martin, LeBoeuf et al. 2004). Several individual projects have linked models to GIS systems through pre- and post-processor graphical user interfaces (GUI) (Martin, LeBoeuf et al. 2005). Previous attempts to model contaminant releases for emergency response have resulted in systems such as RiverSpill, a 1-D water quality modeling system focused on water intakes developed by Science Applications International Corporation (Samuels, Bahadur et al. Accessed September 2006), and the Spill Management Information System (SMIS) 1.0 which links CE-QUAL-W2 (Cole and Buchak 1995) and CAMEO (NOAA/EPA 2002) with ArcView (ESRI 2006) for prediction/response of an inland waterway contaminant release (Martin, LeBoeuf et al. 2004).

Spill Management Information System (SMIS)

Martin et al. (2004) developed Spill Information Management System, Version 1.0 (SMIS 1.0) specifically for modeling contaminants along inland water bodies.

Development of an inland waterway traffic monitoring system provided the groundwork for SMIS (Dobbins and Abkowitz 2002; Dobbins and Abkowitz 2003). With support from US Army Corps of Engineers (USACE), the system was applied to Cheatham Reach, Nashville, Tennessee. SMIS 1.0 included CE-QUAL-W2 Version 3.0, a 2-D water quality model (Cole and Buchak 1995), and CAMEO, the 2-D air quality dispersion model (NOAA/EPA 2002). CE-QUAL-W2 requires rivers to be broken into segments and provides 2-D modeling averaged over each segment for output into GIS (Martin, LeBoeuf et al. 2004). For the Cheatham Reach area, the river was divided into 400-m segments. The concentration of the contaminant is averaged over the entire segment. While this presents a worst-case-scenario to first response crews, analysis of when to turn off water intakes or which bank of the river requires remediation cannot be accurately determined.

The system is linked to the U.S. Coast Guard's Chemical Hazard Response Information System (CHRIS) database which contains 1,300 chemicals typically found in waterway transport with properties and hazmat information for each (USCG 2000). Through the GIS-interface, users have the ability to provide spill input information such as spill location, duration, chemical name, and spill amount through a GIS interface. The input is then converted into acceptable format for input into CE-QUAL-W2. The model output is then displayed within the GIS framework. An example output from SMIS 1.0 illustrating a contaminant plume along the Cheatham Reach is shown in Figure 1.

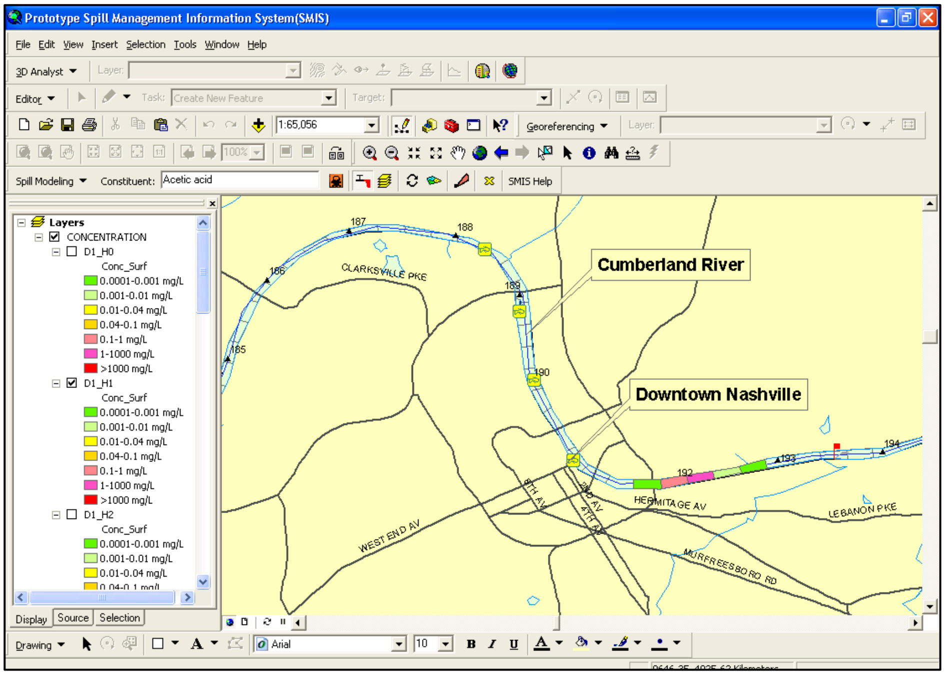

Figure 1: Example of the output from SMIS 1.0 for a chemical spill on the Cumberland River, Nashville, TN.

Surface Water Modeling System (SMS)

The Surface Water Modeling System (SMS) comes integrated within a GIS environment. In fact, ArcView, one of the many GIS software packages available today, is required to execute SMS. SMS includes capabilities for 1-D, 2-D, and 3-D hydrologic and environmental modeling. The model has the ability to perform 2-D finite element, 2-D finite difference, 3-D finite element and 1-D backwater modeling. SMS operates as a collection of environmental models including the USACE-ERDC supported TABS-MD (GFGEN, RMA2, RMA4, SED2D-WES), ADCIRC, CGWAVE, STWAVE, M2D, HIVEL2D, and HEC-RAS models). Flexibility within SMS enables users to add other water-quality models specific to their project to the module. A single user interface allows users to input data for the modeling system and the system then runs the appropriate model simulation. SMS can be applied to coastal environments or inland river systems (EMSI 2006).

While SMS is among initial efforts to link water quality models with GIS, it possesses several limitations. The GIS interface is only for creation of model grids and input to the suite of models. All output is independent of the GIS framework. Therefore, spatial relationships are not available contrary to the output in SMIS (Martin, LeBoeuf et al. 2004). In addition, extensive modeling understanding is required to use the system. SMS was created for use by highly knowledgeable water quality/hydrologic modelers. SMS is limited in modeling capabilities to those models included in the system and a "generic" modeling option which allows users to create model inputs and perform extensive formatting for exportation of the inputs to an exterior water quality model of the user's choice. Little information on how to actually perform such actions is provided in the User's Guide (EMSI 2006).

RiverSpill/ICWater

The 1-D, GIS-based system, RiverSpill, provides real-time leading edge calculations for contaminant transport for surface waters. Primary application of the software is protection of drinking water intakes, but it can be used as an emergency response tool (Samuels, Amstutz et al. 2006; Samuels, Bahadur et al. Accessed September 2006). While RiverSpill provides similar, but rudimentary worst-case scenario results relative to SMIS, more advanced modeling is needed to assist response crews in evaluating the most appropriate locations for boom placement and mitigation strategies such as closing off drinking water intakes. In addition, RiverSpill fails to operate if no water intake is identified downstream of the modeling focus area. Samuels' group expanded upon their work developing RiverSpill to create ICWater, which incorporates the NHD mean flow and velocity data and works as an extension to ArcGIS (Samuels, Amstutz et al. 2006). It is designed for use by emergency response teams for chemical, biological, and radiological incidents in river systems. It incorporates real-time flow information from nearby stream gages. However, the modeling behind the tool is still one-dimensional using a control volume approach for each segment of river (Samuels, Amstutz et al. 2006).

General NOAA Oil Modeling Environment (GNOME)

Another system of interest is GNOME, the General NOAA Oil Modeling Environment (GNOME). It is focused on modeling oil spills for multiple waterways, including rivers and provides trajectory movies show the predicted oil spill progression (NOAA 2007). GNOME, however, is not designed to model spills for contaminants other than oil.

Summary

In preparation for development of the next generation spill response tool, a review of current trends in water modeling was performed. Hydrodynamic and water quality modeling is used to assist in regulatory efforts and decision support. Modeling efforts are becoming more complex with a movement toward 3-D modeling of waterbodies. Selection of the most appropriate model for a given project include considering the ease of use, availability, computational limits, accuracy, applicability to the system of interest, and the ability to provide the information desired. A select group of models were evaluated for their possible use as part of the system under development.

Modeling today often utilizes GIS technologies for data management and improved visualization of results. GIS has been shown to be a leading technology in emergency response, decision support, and now spill response efforts. GIS provides a vast amount of information in a visual framework that can be understood by many.

Spill response technology for inland waterways is currently limited to a handful of 1-D and 2-D modeling systems. The amount of information provided on the location of the spill plume and the constituents being modeled is minimal with these systems. RiverSpill and ICWater provide only 1-D modeling information which leads to an approximation of the leading-edge of the plume. SMIS 1.0 utilizes the CE-QUAL-W2 water quality model and the results are somewhat better by approximating the average concentration of a 400-m segment of the river. With this, the response personnel have a general idea of the quantity and location of the plume. However, CE-QUAL-W2 does not easily model oil slicks and is laterally averaged. A spatially referenced spill response tool is needed that provides advanced modeling capabilities for multiple waterbody types and multiple chemical constituents.

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CHAPTER III

INLAND WATERWAY RESOURCE AND SPILL MANAGEMENT NEEDS OF SOUTHEASTERN U.S.

Introduction

Inland waterways provide drinking water and hydropower for communities, recreational activities for many, habitats for aquatic species, and navigational pathways for freight transport. Beneficiaries of these waterways desire that their needs be met in terms of adequate water supply and quality. The 1972 Clean Water Act provided additional credence to water quality, mandating that both the public and private sectors "develop comprehensive programs for preventing, reducing or eliminating pollution, and improving the sanitary condition of surface and underground waters" (USC 1972). More recently, the *2006-2011 EPA Strategic Plan* calls for improved standards, protection of source waters, security of water infrastructure, and improved quality of rivers, lakes, and streams (EPA 2006).

Water resource managers are faced daily with the task of trying to meet these sometimes competing expectations, often making for difficult management decisions while attempting to balance the demands of many. In addition, managers must be prepared to protect these valuable resources in the likelihood of a contamination event such as a chemical spill. Thousands of inland waterway incidents, including oil spills which threaten water supplies and public health, continue to be reported in the United States each year (NRC 2005). A classic example is the Ashland oil spill of 1988, where approximately 750,000 gallons of diesel fuel was spilled into the Monongahela River near Pittsburgh, PA, when a storage tank collapsed (USEPA 2006). Efforts to mitigate the damages were impaired by emulsification, the location of locks on the river, and adverse weather conditions. Once cleanup efforts were completed, the spill had impacted approximately 130 miles of river area, several communities and their water supplies, and thousands of animals (USEPA 2006). Incidents such as this underscore the importance for managers to be prepared for emergency accidental or intentional chemical releases in addition to daily operations. These challenges have been made even more difficult by the current economic climate in which scarce resources are available to invest in such problem solving.

In an effort to assist with these considerations, the authors initiated the development of a decision-support system to be used both for water quality management and spill response. The resulting first generation spill management information system (SMIS) combines geographic information with hydrodynamic and water quality modeling to show contaminant plume migration in a riverine system (Martin, LeBoeuf et al. 2004). To maximize the usefulness of such a system, however, it is important to confirm that the key decision-support needs of water resource management and spill response activities are included in the functionality built into SMIS. To accomplish this objective, a survey was administered to evaluate the views of relevant stakeholders. There is considerable precedent for utilizing this approach to elicit such opinion (Borsuk, Clemen et al. 2001; Hermans, Erickson et al. 2007). However, no such study has been documented with a focus on the demands and prioritizations of water quality managers and spill response personnel prior to the current study.

Background and Motivation

Water Quality Management

Comprising only about three percent of the world's water and a smaller portion contained in our lakes and rivers, fresh water is considered a highly valuable and scarce resource (Serageldin 1995). Given the necessity to protect and maintain this resource, effective management of fresh water, including inland waterways, is essential. Biswas (Biswas 2004) defines the main objectives of water quality management as including improvement of the lifestyle for people and providing environmental conservation.

Problems facing water quality managers consist of greater demands on available resources due to population growth, a higher standard of living, and contamination of current sources (Bouwer 2000). Effective water quality management can include reconciling conflicting interests of conservation, irrigation, drainage, supply, flood control, hydropower, waste, and recreation (Grigg 1996). One area receiving attention is the provision of acceptable drinking water. Pollard et al. (2004) suggest that consumer expectations are rising concerning the safety, acceptability, and reliability of drinking water. They also note that water resources management is further complicated because it involves pleasing multiple stakeholders within both an institutional and business framework. Other demands on water resources include maintaining storage behind dams for times of drought while trying to meet municipality, ecological, and recreational needs downstream (Bouwer 2000). Furthermore, the focus on environmental concerns such as aquatic habitats and protection of wildlife refuges are competing with the increased demands for growing communities. Community growth presents additional potential for contamination of these vital resources from non-point sources, including agricultural and urban area runoff.

Today, water quality is more interconnected with social, economic, environmental, and political factors, and cannot necessarily be solved by water professionals alone (Biswas 2004). Some researchers believe that a paradigm shift from that of sustainability to a broader decision making network focused on ecosystem management and collaborative decision making is needed to meet current demands (Pollard, Strutt et al. 2004). Involving stakeholders in the decision making process has many benefits. One of these is the acceptance of policies and regulations established by government agencies by giving stakeholders a voice, thus developing greater trust in the process. In addition, participation by stakeholders can bring awareness to the importance of specific issues. Furthermore, invested interest can lead to greater awareness of the consequences of actions taken by stakeholders. For example, persons involved in decision support to protect local recreational fishing areas may be more cautious about water usage and personal choices that may lead to pollution of water supplies.

Carson and Mitchell (1993) conducted a survey of households to evaluate the value placed by the general public on water quality by estimating the benefits of strict water quality standards of riverine systems versus the costs associated with meeting the standards set forth by the Clean Water Act. They found that permitting some water bodies or stretches of rivers to be "un-swimmable" would allow for resources to be used elsewhere with greater benefits. In another study, rural property owners were polled to assess their perceptions on maintaining the natural qualities of a river corridor. Individuals living most closely to the river were more concerned about water quality and flooding than those living away from the river who valued the visual quality (for possible recreational purposes) (Ryan 1998). Competition exists between farmers cultivating fertile lands on river flood plains with individuals seeking riverfront property for housing. Such examples illustrate the challenges faced by governments in maintaining water quality while accommodating competing demands from a variety of stakeholders.

Spill response activities

In 1991, Westermeyer examined the response to the *Exxon Valdez* spill and called for improvements in response technologies and organization in responding to large spills. Over the last several years, the number and severity of oil spills in the U.S. have been reduced, in part due to planning and mitigation efforts by the United States Coast Guard (USCG) and other agencies (Burns, Pond et al. 2002). For example, when the *M/T Westchester* spilled 1,925 tons of crude oil into the Mississippi River on November 28, 2000, response crews recovered nearly 50% of the lost material (Michel, Henry et al. 2002). The spill was contained with booms and diverted into sheltered recovery areas where skimmers recovered much of the oil. This action prevented the oil from migrating through the Empire Lock, located downstream of the incident site.

In the event of an inland waterway spill, an Environmental Protection Agency (EPA) on-scene coordinator (OSC) assumes control of the incident (Stoschek and Zimmermann 2006). The OSC assesses the size and nature of the spill, along with potential hazards and the necessary resources for containment and clean-up operations. If the incident warrants federal involvement, the appropriate regional response team may be activated to assist in response activities. Additional support from the EPA's

Environmental Response Team can be obtained if necessary. Most spill response efforts are managed by local authorities and emergency response personnel.

As with water resource management, stakeholder participation can also play an important role in spill response management activities. An example of how multiple agencies/stakeholders may interact and weigh different values during a spill event is illustrated in the spill response and cleanup operations in 2000 on the East Walker River, California, during extreme winter conditions (McCleneghan, Reiter et al. 2002). The spill resulted from an oil tank truck accident releasing approximately 3608 gallons of oil into the nearby river. The Unified Command, which included USCG, US Fish and Wildlife Service (USFWS), EPA, Nevada Division of Wildlife, and the Walker River Irrigation District (WRID), had to weigh the options of asking the local irrigation district to reduce the flow in the river to assist in spill response and clean up while considering the impacts of lower flows on potential fish kills downstream due to freezing of the surface in winter temperatures. Due to irrigation contracts with the local farming community, cleanup efforts had to be expedited to allow for scheduled increased river flows within the next few days. In addition, urgency to contain and clean up the spill was hampered by weather conditions and concerns for worker safety during icy conditions (McCleneghan, Reiter et al. 2002).

Furthermore, a recent meeting of the Region 4 Regional Response Team identified the need for "early coordination of stakeholders and clear definitions of roles, responsibilities and needs [in emergency response activities]" (RRT4 2006). In this instance, the stakeholders not only include the general public but those involved in making management decisions, including response personnel and local authorities that may be impacted. Thus, action items from a subsequent meeting included increasing involvement of state and federal agencies in meetings and activities. On a larger scale, USCG has gathered stakeholder input on oil spill prevention and response through workshops and conferences (Burns, Pond et al. 2002). The aforementioned examples represent just a few the focused efforts to organize individual agencies and persons to identify the responsibilities, needs, and values in spill response efforts.

Current Technologies for Inland Waterway Spill Response Assistance

Efforts by the authors and others to assist agencies in responding to inland waterway incidents include development of both an inland marine transportation risk management system and an inland marine hazardous materials response database (Dobbins and Abkowitz 2002; Dobbins and Abkowitz 2003), in addition to the aforementioned SMIS (Martin, LeBoeuf et al. 2004). As a first generation, 2-D spill response tool that provides valuable information in a spatial framework, SMIS is limited due to its ability to only provide estimates of average concentrations for 400-meter river segments along the waterway. In addition, SMIS is laterally-averaged, so it is unable to take into consideration wind effects that may force a plume to one side of a river.

A second software tool, RiverSpill, represents a 1-D, GIS-based system that provides real-time leading edge calculations for contaminant transport of surface waters (Samuels, Amstutz et al. 2006; Samuels, Bahadur et al. Accessed September 2006). Primary application of the software is for protection of drinking water intakes, but it can be used as an emergency response tool. While RiverSpill provides similar, but rudimentary worst-case scenario results relative to SMIS, more advanced modeling is needed to assist response crews in evaluating the most appropriate locations for boom placement and mitigation strategies such as closing off drinking water intakes and isolating sensitive ecological areas. In addition, RiverSpill fails to operate if no water intake is identified downstream of the modeling focus area.

Samuels et al. (2006) expanded upon their earlier work with RiverSpill to create ICWater, which incorporates National Hydrography Data Set (NHD) mean flow and velocity data and works as an extension to ArcGIS. It is designed for use by emergency response teams for chemical, biological, and radiological incidents in river systems. ICWater incorporates real-time flow information from nearby stream gauges. The modeling behind the tool is still one-dimensional, however, using a control volume approach for each segment of river (Samuels, Amstutz et al. 2006).

A third system of interest is the General NOAA Oil Modeling Environment (GNOME). It is focused on modeling oil spills for multiple waterways, including rivers, and provides trajectory movies showing the predicted oil spill progression (NOAA 2007). GNOME, however, is not designed to model spills for contaminants other than oil.

Review of the current technology and assessment of needs for improved spill response and communication capabilities during a spill event suggests great value in development of a spatially referenced spill response tool that provides advanced modeling capabilities for multiple water body types and multiple chemical constituents. However, in striving to meet this objective, it is important that the functionality contained therein is responsive to decision-maker needs. A survey study was thus undertaken to assess the demands and values of water resource managers and spill response personnel.

Methodology

Bryant and Abkowitz (2007) utilized a modified Delphi survey to poll 95 experts on their views of the risks to soil, surface water, human health, etc. due to terrestrial chemical spills. In a similar manner, an online survey was employed in this study to assess "expert" opinions on demands and difficulties faced in water quality management and spill response activities for inland waterways. The survey was developed and administered to water quality and spill response personnel in the southeastern United States. Direct involvement in governmental water quality management, spill response activities or management, and directors of local water utilities or environmental agencies was deemed as "expert" opinion and all were considered stakeholders in management of our nation's waterways. Three hundred eight surveys were distributed to persons involved in the management of inland water bodies in the region. In an attempt to maximize distribution of the survey to appropriate individuals, survey recipients were requested to disseminate the survey to others in their organization that may be best suited to participate.

The survey participants were targeted to be evenly distributed between roles in spill response and water quality management. This included representatives of the Tennessee Valley Authority (TVA), U.S. Army Corps of Engineers (USACE), Environmental Protection Agency (EPA) regional offices, U.S. Fish and Wildlife (USFWS), local utilities, and local governments. Individuals representing agencies responsible for training activities, exercises, or responding to releases of hazardous materials and oil spills, were also asked to participate. In addition, a focus group was formed to identify other appropriate survey participants as well as to review survey contents.

The survey consisted of two parts, one focused on water quality management and the other on spill response. A mixture of rating and multiple choice questions were used. Free response options were also made available for some questions to allow for additional feedback from participants. Surveys were furnished to participants via an initial email containing introductory information, instructions, and both a link to the online survey and an Adobe Acrobat portable document format (PDF) file attachment of the printable version. The survey is provided in Appendix A.

Answers were assigned numeric values for questions where participants were asked to rate their agreement to the phrase presented (Ferreira, Nobre et al. 2006). These ranged between strongly agree (= 5) and strongly disagree (= 2). No response or a response of "no opinion" was disregarded in all data analyses. Response values were averaged for each question, with a value of 4.0 or higher considered to indicate significant agreement with, or a high level of importance associated with, the corresponding statement. Additional analyses were performed to evaluate differences in responses. Single factor analysis of variance (ANOVA) was used to identify significance of survey results. Statistically significant (α = 0.05) differences in responses were evaluated for the following factors (Schiff and D'Agostino 1996): (i) survey focus areas (i.e., water quality management and spill response); (ii) respondent roles (i.e., environmental steward, human health and safety officer, water resources manager, utility provider); and (iii) levels of authority (i.e., local, state, regional or federal).

Results

Of the 308 surveys administered, 92 completed surveys were returned. This corresponds to a 30% response rate, which was evenly distributed between spill response and water quality management personnel. The response rate is low; however, for email surveys, a response rate of 25-30% is common (Kittleson 1995; Cook, Heath et al. 2000). The sample was deemed representative because the distribution of respondents was proportional to the distribution of persons invited to participate in the survey, but on a lesser scale. One-third of those participating indicated that they hold positions in both categories. Respondents included public utilities, conservation groups, regulatory agencies and water resource managers (see Figure 2). Overall, participation appeared to be representative of persons involved in protection of our inland surface waters. Participants were geographically distributed across the southeastern U.S., located at ports, near significant waterways, or in largely populated areas that house governmental offices, and at all levels of authority. The largest group of responders was affiliated with state agencies (45%), with the remainder distributed evenly among local, regional, and federal representation. The increased involvement of state-level personnel may be attributable to efforts by both the Environmental Protection Agency (EPA) and many states to move management of environmental compliance, clean energy, and other programs to the state level through partnerships, reasoning that state representatives are "closer" to the situation and possibly better informed. Table 1 summarizes many of the survey responses.

Table 1: Summary of Survey Responses

	Percentage of Responses		
Statement	*Agree*	*Disagree*	*No Opinion*
Management			
Best management practices (BMPs) exist	81	11	7
Costs outweigh benefits of regulations	2	85	13
Models are useful for improved communication between agencies	86	8	6
Communication			
Communication is very important across agency boundaries	100	0	0
Improvements in coordination between agencies is needed	96	2	2
Intra-agency communication needs improvement	82	2	8
Public Involvement			
Public is one of most important stakeholders	90	8	2
Public involvement is necessary for successful management of our water resources	90	8	2
Public should be notified immediately of spill occurrence	76	14	10
Public should be notified only if their participation is necessary during a spill	76	14	10
Spill Response			
My agency is prepared to respond to a spill today	78	22	0
I am personally prepared to respond to a spill today	61	30	9
Agency boundaries are eliminated for common good during spill response activities	51	33	16
Drinking water source protection is first priority after safety	86	11	2
Knowing the location of contaminant plumes is very important	75	16	9
Knowing the location of sensitive species is very important	74	23	2

Virtually all respondents agree that water quality management could be improved. They also believe that improved communication and coordination between agencies is necessary for better management of water resources. Individuals representing utilities rated interagency communication as the highest level of priority. There was also strong agreement that individual agencies would benefit from the existence of a guidebook or established protocols to aid in making water quality management decisions.

Specific questions were asked concerning the values placed on inland waterway use and the threats to these natural resources. As shown in Figure 3, public water supplies and habitat for aquatic species were the most highly valued uses for our waterways, a finding consistent with previous work reported by Borsuk et al. (2001).

Activities seen as being most critical in impairing and threatening the viability of waterways included agricultural activities and combined sanitary sewer, storm water bypasses and overflows (see Figure 4). A possible explanation for the larger perceived criticality of these activities relative to chemical spills, terrorist activities, and household chemical use (e.g., pesticides and fertilizers) may be the difficulty in enforcing regulations and controlling these activities (Mitchell 2005; EPA 2008). In addition, much has already been done to regulate end-of-pipe discharges into surface waters (USC 1972), so the next step for maintaining/improving water quality is to focus on other sources.

Another area of interest included respondent familiarity and comfort level in using water quality models as tools for supporting management decisions. Nearly three-quarters of the respondents believe that their agency could benefit from improved modeling capabilities and training on the use of models for decision support. Use of models as tools for assistance in water resource management decision support was also found to be of value by Borowski and Hare (2007). They suggest improved communication between the model development community and water managers of modeling capabilities, limitations, and intended uses to improve utilization in management decisions (Borowski and Hare 2007). Visual information such as that obtained from modeling outputs was highly valued as a means to improve understanding. Better knowledge of the capabilities and underlying assumptions involved in the modeling process to assist in decision support was also indicated as a current need by survey respondents in this study, a finding consistent with that reported by Olsson and Anderson (2007).

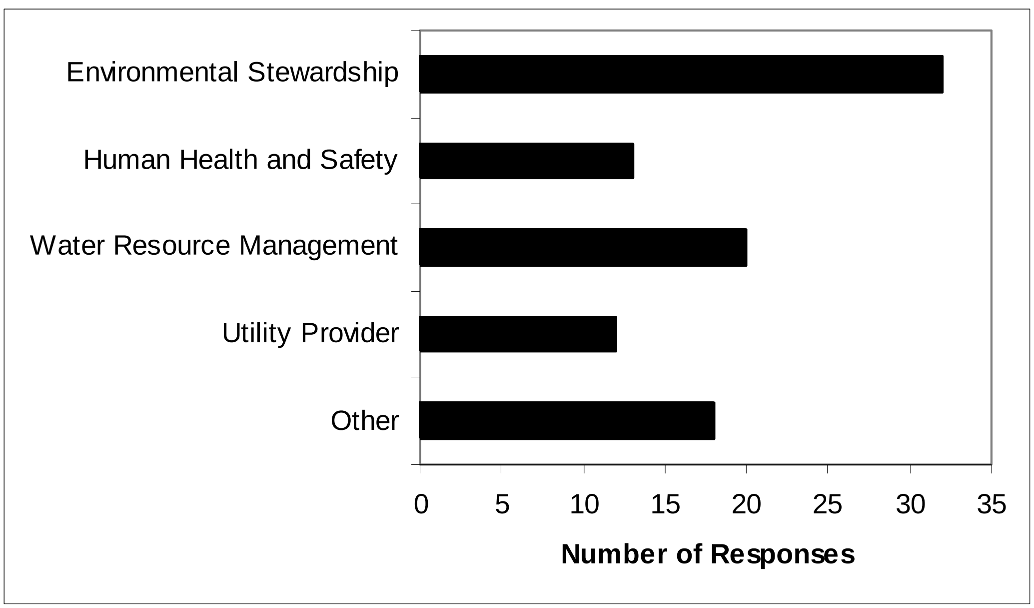

Figure 2: Distribution of survey participant roles.

Another area of inquiry focused on factors influencing the decision-making process itself. Figure 5 summarizes the survey responses concerning primary factors in the decision process for managing both water quality and spill response. Water quality personnel indicated that they were driven by established guidelines and permit requirements, while spill responders focused on the immediate safety of response personnel, closely followed by protection of water intakes. Similarly, during spill response activities, managers used established protocol and personal experience to guide their decisions.

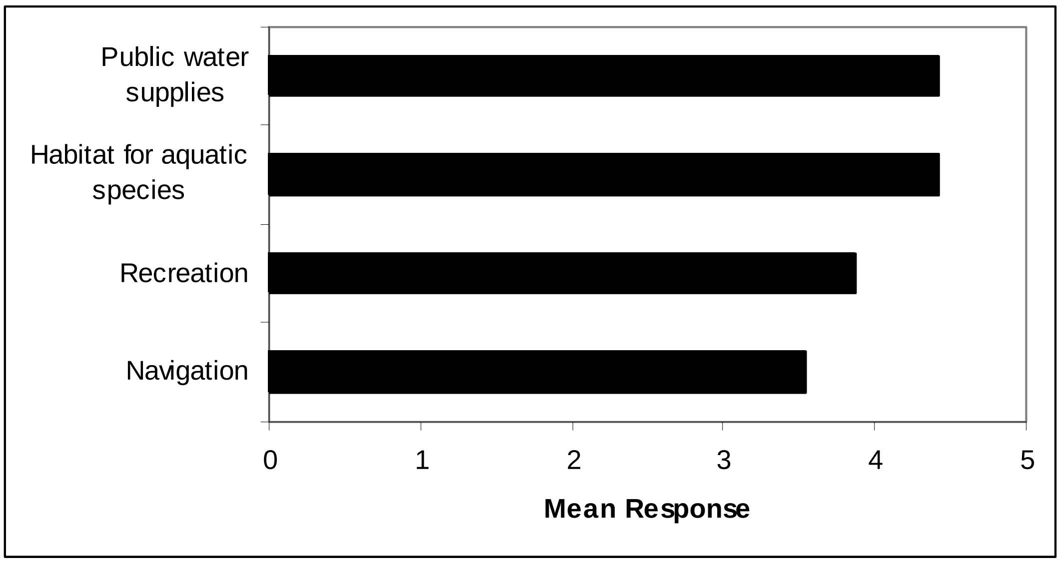

Figure 3: Suggested uses for water bodies.

Among those surveyed that participate in spill response, the most frequently cited areas of responsibility are to provide technical support and to manage on-site-command during a spill event. The majority of spill respondents believe their agency is well prepared to deal with a chemical spill. Notification of all parties involved in waterway management in the event of a spill was viewed unanimously as being highly important. Protection of drinking water supplies was also highly valued during spill response after first ensuring the safety of responding personnel.

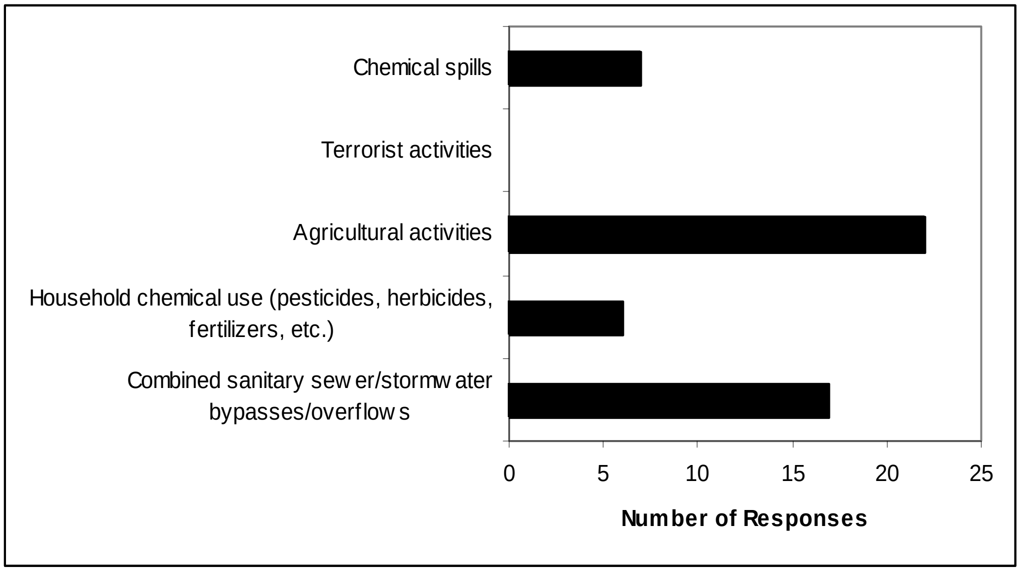

Figure 4: Perceived threats to water quality.

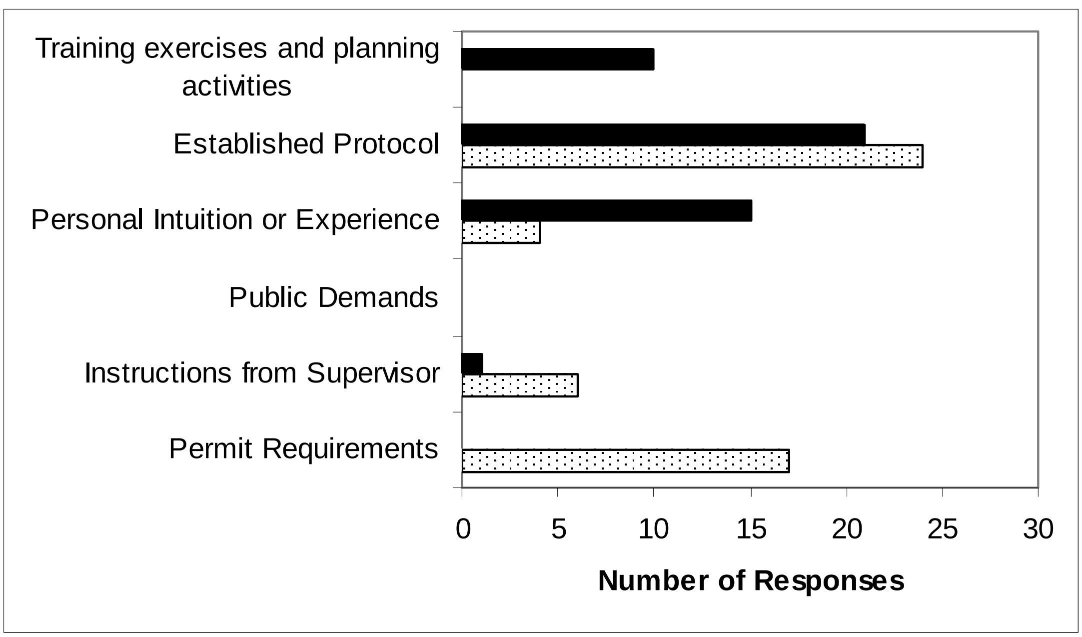

Figure 5: Driving forces in decision making. (Responses for water management are solid bars and responses for spill response are patterned.)

Participants were also asked to indicate the prioritization of efforts that could be used to improve spill response preparation within their agencies. Among these, the following were cited: (i) identify water intakes and ecologically sensitive areas for protection; (ii) avoid or reduce the frequency and severity of hazardous material releases; and (iii) improve responder safety procedures. It is interesting to note, given today's tumultuous world, that the threat of terrorist activities was not highly-rated.

A group of questions inquired about information needs when responding to an inland waterway spill. Knowledge of the location of the following items are highly valued: sensitive or endangered species, water intakes, schools, hospitals, sensitive populations, source water protection zones, and routes of travel to boom deployment locations. Similarly, in an assessment of response capabilities in the United States, it was noted that leading variables affecting oil spill clean up included the response time, weather, and the location of the spill which affects the timeliness of launching of response equipment (Westermeyer 1991). Regarding what would be most effective in enhancing spill response activities (see Figure 6), improved communication was most often cited, with additional training and experience also noted.

Figure 6: Activities for improving spill response.

Based upon interest expressed by the focus group, specific questions relating to communication needs and effectiveness of existing techniques/equipment were included in the survey. There was strong agreement with the position that communication is the key to improving water quality management between agencies as well as within an individual organization. As shown in Figure 7, the majority of the respondents cited periodic contact between different agencies as the most important consideration to bridge gaps in interagency communication, with face-to-face contact as the preferred mechanism (see Table 2). Pathways seen as most useful in communication during spill events included phones, visual aids such as display boards, GIS, and personal communication. Interestingly, email was excluded from the list of effective forms of communication during emergency response activities.

The vast majority of respondents agreed that the public is one of the most important stakeholders in water quality management, a result consistent with findings reported by McDaniels et al. (1999) and Borsuk et al. (2001). Furthermore, public involvement in water preservation programs is considered essential through assistance in pollution prevention activities. Regarding spill response, a significant majority of respondents believe that the public should be notified immediately when a spill occurs to gain assistance and understanding. This view is held more strongly by local and federal officials than by state authorities.

Table 2: Effectiveness of Communication Pathways.

	Percentage of Responses				
Communication Pathway	*Very Effective*	*Effective*	*Somewhat Effective*	*Not Effective*	*No Opinion*
Phones	30	56	9	0	5
Radios	21	44	23	5	7
Face-to-face	601	30	2	2	5
Email	2	16	40	28	14
GPS	30	37	26	0	7
Visual aids	12	54	21	5	9
Paper documents	9	47	33	7	5
Internet/internal network	7	54	28	5	7
GIS	28	56	9	0	7

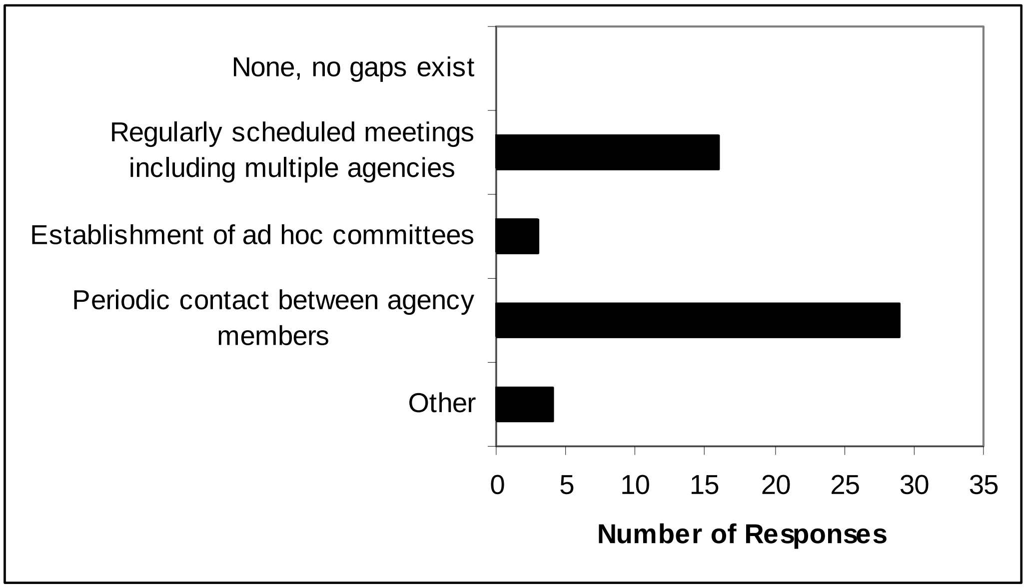

Figure 7: Techniques used to promote interagency communication.

Conclusions

Management of inland waterways both in daily operations and emergency situations requires the cooperation of many parties. Each individual or agency operates with a specific mission that has impacts on others and requires coordination with many. Through conduct of an online survey, the current views and decision-support priorities of water quality and spill response personnel located across the southeastern United States was elicited. Survey results can be used to guide future efforts in improving water quality management and spill response activities, including the development of advanced decision-support tools.

Across agency boundaries, geographic regions and participant roles, common values emerged regarding priority concerns. Human safety and protection of natural resources are considered central to decision making and both are valued highly. Increased involvement and communication among management agencies and with the public are viewed as essential to successful management of water resources. The greatest concerns include control of contaminant sources, preparation for spill events, accuracy and timeliness of information exchange, and meeting multiple demands. A majority of participants believe that agricultural activities and overflow of sanitary sewer systems are the most critical threats to inland water quality.

Preparation for spill response activities through increased training and use of spill response exercises are favored by all respondents. Providing visual information or direct communication appears to be the most effective form of communication within and between agencies. Furthermore, survey results recognize the role of modeling as a helpful tool for providing improved spill response information exchange in a timely manner. Responders indicated that visualization of modeling output of contaminant locations and scenario analysis would allow them to more effectively make decisions on necessary actions.

While the survey results did not reveal any unusual findings, it has served to validate the important decisions and means of conveying information that influence the design of water quality and spill response decision-support tools so as to maximize their effectiveness. Moreover, the valuation scheme used in interpreting the survey results has established a metric for establishing management priorities, an important consideration in these times of such limited resource availability.

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CHAPTER IV

HYDRODYNAMIC MODELING OF KENTUCKY LAKE USING GEMSS

Introduction

A vital part of the Spill Management Information System (SMIS) 2.0 system is the advanced hydrodynamic modeling using the Generalized Environmental Modeling System for Surface Waters (GEMSS), which serves as the basis for advective flow forces in the Chemical/Oil Spill Impact Module (COSIM) spill model. Accurate representation of chemical spill fate and transport processes is first and foremost dependent on the accuracy of the employed hydrodynamic model. The 3-D modeling capability of the Generalized, Longitudinal-Lateral-Vertical Hydrodynamic and Transport (GLLVHT) model within GEMSS is used in order to effectively capture resolution of spill migration behaviors necessary to support first responder actions.

This chapter describes the use of GEMSS and the GLLVHT model for hydrodynamic modeling of Kentucky Lake. Included are discussions on selection of GEMSS (and GLLVHT) for modeling efforts, preparation of model input files, data resources, calibration and sensitivity analysis of the model, and results of these efforts. For purposes of this research, the year 2006 was used as the time period of interest.

Background Information

Hydrodynamic modeling involves representation of the movement of water for a waterbody of interest. First, one must represent the waterbody as a grided entity of cells with appropriate sizes to accurately represent the system bathymetry, but limited data availability requires interpolation and estimation of the region. In addition, the grid refinement can be a limiting factor in computational time and is itself limited by data availability. Furthermore, boundary conditions are required to account for flows into and out of the system and the storage within the system. The following sections describe the project area of interest for this research, the processes involved in selecting GEMSS as the most appropriate hydrodynamic model/modeling system for use in SMIS 2.0, and a detailed discussion on the GEMSS modeling system.

Project Area

The project area consists of a 180-mile portion of the Tennessee River bound on the upstream end by Pickwick Dam at River Mile (RM) 202.3 and the downstream end by Kentucky Lake (RM 22.4), both managed by the Tennessee Valley Authority (TVA) (Figure 8). The river is narrow and sinuous leaving Pickwick Dam (0.3 km wide) and becomes a wide and deep reservoir referenced as Kentucky Lake before reaching Kentucky Dam (3.3 km wide). The depth of the river ranges from 8.3 meters (elevation 353.4 ft) at the tail waters of Pickwick Dam to 25.6 meters (elevation of 296.6 ft) in Kentucky Lake (TVA 2006). The total drainage area for Kentucky Lake is approximately 2.57×10^{7} acres (4.02×10^{4} square miles) (Lubbers 2007; TVA 2007-2009). Average winter pool elevation is 107.9 meters (354 ft) above mean sea level (AMSL) and summer pool elevation is 109.4 meters (359 ft) AMSL (TVA 2007-2009; KLProductions 2009). The average flow in 2006 was 1,033 m^3/s for Pickwick Dam and 1,074 m^3/s for Kentucky Dam (TVA 2006).

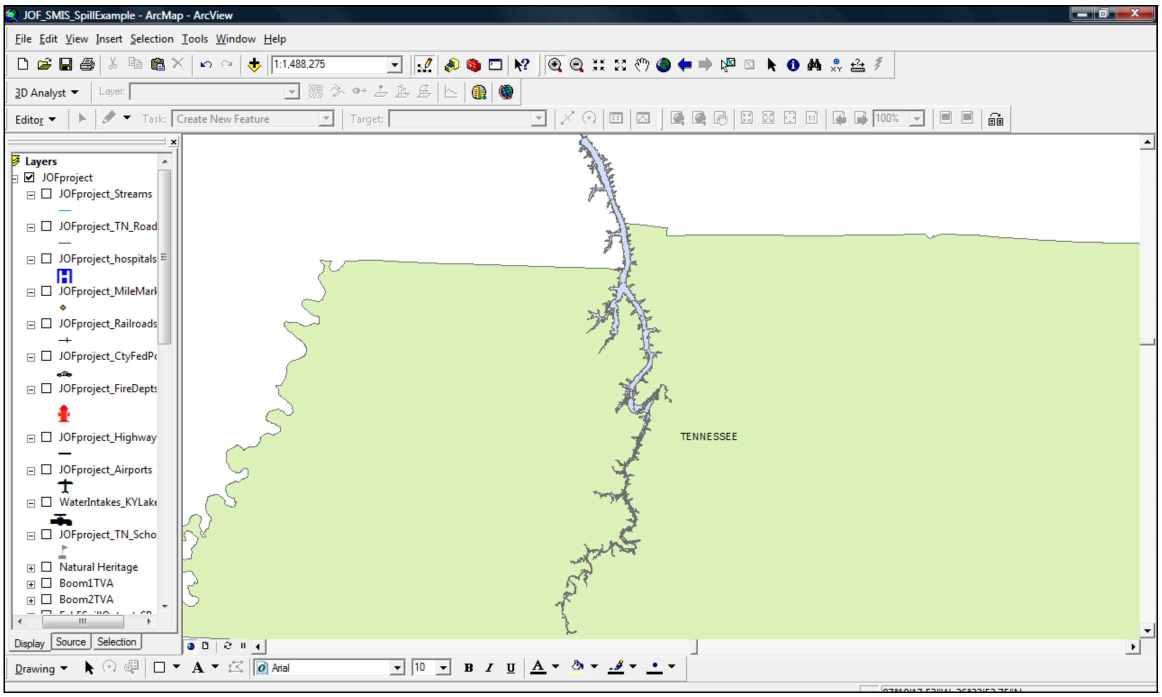

Figure 8: Kentucky Lake project area.

Model Selection

Given the vast size and varying characteristics of the project area (narrow, winding river to very large reservoir), the desired model must meet several objectives. The following sections describe the processes involved and the criteria used to select the best modeling option from currently available modeling systems.

The first criterion for selecting an appropriate model required that it be publicly available to reduce costs for the end user and peer-reviewed as a testament for acceptance by experts in this area. In addition, the model (or suite of models) would, ideally, possess the ability to (i) accurately capture the physics of diverse hydrologic and hydraulic settings including lacustrine, riverine, and estuarine environments; (ii) capture the fluid dynamics associated with flow around and through structures such as buoys and/or booms; and (iii) represent the chemistry of water quality constituents. The model(s) should also be capable of minimally 2-D and preferably 3-D modeling for both hydrodynamics and additional capabilities for modeling typical water quality parameters, which may be of interest in the future. To better evaluate the appropriateness of the models under consideration, each criterion was assigned a priority level 1 (higher) or level 2 (lower).

The resulting models selected for evaluation were those identified as most likely to be used in this research and among those commonly used today by water quality mangers. By applying the initial screening criteria, the list of candidate models/model couplings was reduced to the following (see Table 3):

- EFDC/WASP (Virginia Institute of Marine Science and U.S. Environmental Protection Agency)
- CE-QUAL-W2 (U.S. Army Corps of Engineers)
- MIKE 3 (Danish Hydraulic Institute (DHI))
- GEMSS (J.E. Edinger and Associates, now Environmental Resources Management, Inc.)
- DELFT3D (WL|Delft Hydraulics)
- RMA2/RMA4 (Resource Management Associates (RMA))

Since each of these models satisfies many of the initial criteria, a set of secondary criteria was established to facilitate the most desirable selection. For this project, the secondary criteria of interest were hydrodynamic and water quality modeling capabilities.

Hydrodynamics

To accurately represent the waterbody, the model chosen for the project must be able to closely represent the hydrodynamics, especially the surface and near surface velocities, of Kentucky Lake to serve as the basis for constituent transport, more specifically chemical spill events including fuel oil spills. Criteria include flow around hydraulic structures, wetting and drying capabilities for flooding/overbank considerations, and flows from tributary streams entering the water body of interest. General hydrologic processes of interest include stratification, water surface elevation, vertical and horizontal turbulent mixing, temperature (for density gradients), wind shear, and bottom friction. These capabilities are required since the project area covers a vast region with multiple tributaries and varies from a narrow meandering river with shallow island areas upstream, which may be turbulent, to a large reservoir area downstream that experiences stratification. Typically, models employ Navier-Stokes equations of motion to define fluid flow. The basis is often the same, but assumptions and analytical or numerical techniques employed to solve these equations differ among models (Martin and McCutcheon 1999; Imhoff, Stoddard et al. 2003). Table 4 shows the ability of each candidate model to meet the hydrodynamic criteria.

Water Quality

The primary objective of SMIS is to assist in spill planning and response activities, including spill exercises. The models under consideration must therefore be able to simulate various water quality components such as organic compounds that are common spill constituents (e.g. oil, fuel, etc.). Reaction processes, including biotic and abiotic degradation of these compounds, are of interest. Advection-dispersion processes are also essential in predicting the migration of a contaminant in a waterbody. At a minimum, a conservative (worst-case) first-order reaction or linear decay to predict water quality parameters is desired. Table 5 provides a summary of the models and their ability to meet water quality component criteria.

Model Evaluation

MIKE3 and Delft3D are not likely candidates due to the costs associated with acquiring each model, which would ultimately have to be passed on to SMIS users. RMA2/RMA4 lack in 3-D capabilities and in having an open source code for manipulation and creation of user interfaces within GIS. It also assumes that the waterbody of interest is well-mixed and provides limited water quality analysis. This leaves EFDC/WASP, GEMSS and CE-QUAL-W2 as the most suitable candidates.

CE-QUAL-W2 does not possess the 3-D modeling capabilities that EFDC/WASP and GEMSS possess. In addition, it is limited in hydrologic and water quality modeling abilities in that it is laterally averaged, which assumes concentrations for constituents of interest are constant across the waterbody. For this application, assuming a water body such as the Tennessee River as laterally averaged would be highly unrealistic. Therefore, the only possibilities for using CE-QUAL-W2 would involve creating multiple layers to account for mixing or attempt to model the river as being vertically averaged (i.e., turning the waterbody on its side for modeling purposes) CE-QUAL-W2 can be operated in quasi-3-D mode by essential.

Both EFDC and GEMSS meet many of the desired criteria. Presently, EFDC does not possess a grid generation package or a user interface, but this is a project underway at the US EPA (TetraTech 2007-2008). The lack of a graphical user interface (GUI), manuals for users, and documentation on preparing the grid and input files and options for viewing output limit the ease of use of the model. Dynamic Solutions developed EFDC Explorer which has a user interface for EFDC and a grid generation tool. However, it is limited in accuracy in that the grid input files are used differently and may leave gaps between cells. It also lacks in transparency to underlying processes involved in generating the grid, which was found to be different from EFDC grid generation processes (TetraTech 2007-2008). GEMSS combines the core modeling capabilities of both EFDC and CE-QUAL-W2 as sub-modules within the package in addition to the Generalized, Longitudinal-Lateral-Vertical Hydrodynamic and Transport (GLLVHT) model, which provides 3-D numeric solutions for both hydrodynamic and transport computations. Use of GEMSS allows for complex hydrodynamic and water quality modeling at 3-D and lower levels. GEMSS also has a GIS-like user interface for grid development and viewing hydrodynamic and water quality modeling results. Additionally, GEMSS has several tools/modules built in to assist with preparing input files, viewing output, and setting up the control file.

Table 3: General criteria for model selection (X indicates the model possesses the specific attribute.)

PRIORITY	CRITERIA	EFDC/WASP	RMA2/RMA4	CE-QUAL-W2	MIKE3	DELFT3D	GEMSS
1	Peer-reviewed	X	X	X	X	X	X
1	Non-proprietary	X	X	X			X
1	Open source code	X		X			X
1	Comma or space delimited text input files	X	X	X			X
1	Comma or space delimited text output files	X	X	X			X
2	Uses or has grid generation package		X	X	X	X	X
2	Animation/visualization of output		X	X	X	X	X
2	Linkage established with GIS		X	X			X
2	Graphical User Interface		X	X	X	X	X

Table 4: Hydrodynamic Modeling Criteria (X indicates the model possesses the specific quality.)

PRIORITY	CRITERIA	EFDC/WASP	RMA2/RMA4	CE-QUAL-W2	MIKE3	DELFT3D	GEMSS
1	Large riverine areas	X	X	X	X	X	X
1	Lacustrine areas	X	X	X	X	X	X
1	Stratification	X		X			X
1	Around or through structures (e.g., piers)	X	X	X		X	X
1	2D hydrodynamics	X	X	X	X	X	X
2	3D hydrodynamics	X		X (quasi)	X	X	X
2	Utilizes meteorological data	X	X	X	X		X
2	Wetting and drying of flood plains	X	X	X	X	X	X

Table 5: Water Quality Criteria (X indicates the model possesses the specific quality.)

PRIORITY	CRITERIA	EFDC/WASP	RMA2/RMA4	CE-QUAL-W2	MIKE3	DELFT3D	GEMSS
1	Eutrophication	X					
1	pH	X		X			X
1	Temperature	X		X	X	X	X
1	DO	X	X	X	X	X	X
1	Organic constituents	X	X	X		X	X
1	Generic unknown compounds	X	X		X		X
2	Sediment	X		X	X	X	X
2	BOD/COD	X	X	X	X	X	X
2	Nitrogen	X		X	X		X
2	Phosphorous	X		X	X		X

For SMIS 2.0, GEMSS provides additional benefits in that it contains the Chemical and Oil Spill Impact Module (COSIM), which provides specific capabilities for modeling oil and other floating contaminant plumes in a spill event. This sets it apart from the other modeling systems because it is a module specifically focused on spill modeling. Spill modeling using EFDC requires use of particle tracking as the best estimate for migration of an oil spill plume. Output from GEMSS and COSIM consists of both text (*.txt) and database (*.mdb) files, which are favorable for use with GIS. The model is free to the public, but only after having the intended project approved by the developers. Therefore, GEMSS was selected to be used for the current research. GEMSS and GLLVHT are discussed further in the next section. COSIM will be discussed in more detail in the following chapters.

GEMSS

GEMSS was developed by J.E. Edinger and Associates, now known as Environmental Resources Management, Inc. (ERM). The system consists of hydrodynamic, water quality, and constituent modules. GEMSS utilizes a graphical user interface (GUI) which assists in grid generation, pre- and post-processing of data, and visualization of results. GEMSS is applicable to rivers and lakes (Edinger 2001; Na and Park 2006; Prakash and Kolluru 2006), estuaries, and coastal waterbodies (Wu, Buchak et al. 2001; Geotchius and Salmun 2002; Kolluru, Buchak et al. 2003). The hydrodynamic modules include the 3-D Generalized, Longitudinal-Lateral-Vertical Hydrodynamic and Transport (GLLVHT), CE-QUAL-W2 (2-D), 1-D Generalized-Longitudinal Hydrodynamic and Transport (GLHT), and zero-dimensional real-time control (Dortch) models. Water quality modules possess capabilities of modeling sediment transport, water quality, temperatures, chemical and oil spills, and bacterial processes (Edinger 2001; Edinger 2001).

GLLVHT Model

The GLLVHT model uses time-varying, finite-difference methods and processes solutions that formed the basis for CE-QUAL-W2 (Edinger 2001; ERM 2006; ERM 2006). The hydrodynamic equations are semi-implicit. Both x-, and y-faces of each cell are solved simultaneously for each time step. Hydrodynamic computations are based upon common relationships such as the horizontal momentum balance (Equation 1 shows the equation for the x-direction) and the local continuity equation in the vertical direction (Equation 2).

$$\frac{\partial u}{\partial t} = g\frac{\partial z'}{\partial x} - \frac{g}{p}\int_{dz'}^{z}\left(\frac{\partial p}{\partial x}\right)\partial z + fv - \frac{\partial uu}{\partial x} - \frac{\partial vu}{\partial y} - \frac{\partial wu}{\partial z} + SM_x + \frac{\partial A_x}{\partial x}\left(\frac{\partial u}{\partial x}\right) + \frac{\partial A_y}{\partial y}\left(\frac{\partial u}{\partial y}\right) + \frac{\partial A_z}{\partial z}\left(\frac{\partial u}{\partial z}\right) \qquad (1)$$

where *du/dt* is the change in velocity in the x-direction with respect to time, *g (dz'/dx)* is the water surface slope with respect to the x-direction, and the second term on the right is the slope caused by density or gravity and *z'* is the surface elevation. In the Coriolis acceleration equation, *f* is typically 10^{-4} s^{-1} and *v* is the velocity. The following terms represent the advection momentum in the x-, y-, and z-direction, respectively. SMx is the specific momentum which would be included during a high velocity discharge. It is computed by multiplying the velocity and flow rate flowing through a specific cell divided by that cell's volume (Edinger 2001; ERM 2006). The final group of terms represents the momentum dispersion in each direction.

$$\frac{\partial w}{\partial z} = -\frac{\partial u}{\partial x} - \frac{\partial v}{\partial y} \qquad (2)$$

where u, v, and w define velocity components in the x-, y-, and z-directions, respectively. The term *dw/dz* is the vertical velocity, and *du/dx* and *dv/dy* are the velocity components in the x-, and y-directions.

. Velocities, U, V, and z' (the vertical velocity of the surface elevation), are integrated simultaneously and projected forward in time. The other terms are lumped into forcing functions, F. When GLLVHT is performing computations, the forcing functions are first determined from U, V, and z' of the previous time step and then used to solve for U, V, and z' of the next time step. The vertical momentum dispersion coefficient and vertical shear are computed using the Von Karman constant (Edinger 2001; ERM 2006; Prakash and Kolluru 2006). Wind surface stresses are calculated using quadratic relationships with appropriate friction coefficients (ERM 2006). Bottom friction is considered through use of the Chezy equation which is discussed in more detail later.

GEMSS Applications

The majority of the applications for GEMSS have been in modeling cooling-water discharges in riverine and coastal systems (Wu, Buchak et al. 2001; Kolluru, Buchak et al. 2003). Kolluru and colleagues (2003) used the Thermal Analysis Module (TAM) within GEMSS to evaluate the mixing zone for a thermal plume emanating from a natural gas liquefaction facility in seawater near the Gulf of Arabia. The study was performed to identify the impact of thermal releases on a proposed facility expansion. Results indicated that the thermal plume was vertically stratified with large surface and small bottom areas. Among comments from the researchers was that the grid generation tool allowed for fast generation and revisions of the grid. Breakwaters and a pier were included in the grid and modeled without trouble (Kolluru, Buchak et al. 2003). Additional work has been performed in applications to TMDL studies (Wu, Buchak et al. 2001). The USEPA, the Bureau of Reclamation, and state agencies have also accepted use of the system (Edinger 2001).

GEMSS System Components

As mentioned previously GEMSS is a system that combines many models, modules and tools for increased user ease in modeling. Figure 9 illustrates how these items work together as the complete system. The components used in the current research are discussed in the following sections.

Methodology

The following sections describe the resources and files used in developing the hydrodynamic model for Kentucky Lake. In addition, the GEMSS tools used in formatting the input files and boundary conditions as well as use of GridGen for development of the hydrodynamic grid are discussed. Examples of the settings used for the hydrodynamic model are presented. Plots of the data used for the input files are presented in Appendix C.

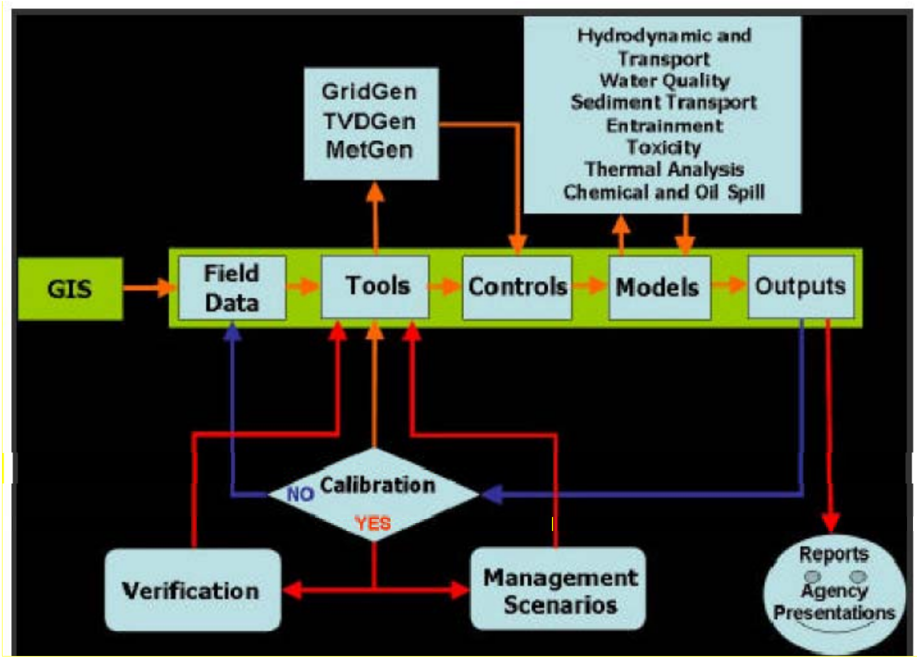

Figure 9: GEMSS System Diagram (ERM 2006).

Data Sources

This section describes the sources of data for use in modeling of Kentucky Lake. Unless otherwise noted, the year of focus for all data files is 2006.

Bathymetric Data

Hydrodynamic modeling requires accurate representation of bottom topography of the waterbody to account for the volume of water stored and moving through the system. Bathymetry is the term used for the topographic map of the bottom depths of a waterbody (Chapra 1997). The bottom depths are measured at specified intervals using various techniques such as LiDar, the Laser Airborne Depth Sounder (LADS) (Hilldale and Raff 2008), and acoustic Doppler current pfofilers (ADCP) (Adler and Nicodemus 2001; Dinehart and Burau 2005). Bathymetric data for use in this research was obtained from both the Tennessee Valley Authority (TVA) and the US Army Corps of Engineers (USACE). The data from USACE was obtained in the mid 1990's using an electronic echo-depth sounding device, Ratheon Model DE-1719B Fathometer Depth Sounder (Gregory 2008-2009). The specific techniques used to gather the data the TVA bathymetric data are unknown to the researchers. The data was used in GEMSS's grid generation tool (GridGEN) for creation of the hydrodynamic grid. Here, the bathymetric information from both sources is presented as a series of points or cross-sections crossing the river perpendicular to the flow of water with depth values as well as either distance from shore or x-, y-locations expressed as latitude and longitude.

The cross-sectional data from TVA (see Appendix B) was not spatially referenced, thus limiting the accuracy in which it could be used in a GIS-based grid generation package. However, each cross-section was identified by river mile and this was used as an estimate of the location. Using this information and navigation charts (AM 2006a; AM 2006b) to identify approximate placement of the navigation channel (identified as maximum depths in the cross-section data set), the data was converted to a GIS layer. The x-distance from the left bank of the Tennessee River was used as an initial guideline for placement of points within a shapefile using the Editor tool within GIS. Once each data point was placed along a cross-section at the appropriate river mile, corresponding depths were assigned from the data to the attribute table. The attribute table in a GIS shapefile contains the properties associated with each feature. For the bathymetric data, each point feature possesses latitude, longitude, and elevation/depth fields. This led to spatially referenced bathymetric data in a GIS shapefile format that could easily be used by GEMSS for grid generation.

Additional data obtained from USACE consisted of spatially referenced point values in the main navigation channel from a 2005 survey. This data was highly refined with cross sections approximately every five meters, but lacked the final 20 miles of the study area and was focused mainly within the navigation channel. Since the USACE data was already spatially referenced, but in the form of a comma-delimited text file, conversion to a GIS layer for use in GEMSS was only a matter of adding the data to GIS and then using a common GIS tool to convert it to a shapefile of points. Each point in the shapefile possesses latitude, longitude, and depth information.

Both TVA and USACE data were used for determination of grid cell depths (discussed in the Grid Generation section below). Figure 10 shows a portion of the waterbody with a sampling of both TVA and USACE bathymetric data. As shown in the figure, the USACE data possesses greater density relative to the TVA data, but does not cover the entire waterbody area.

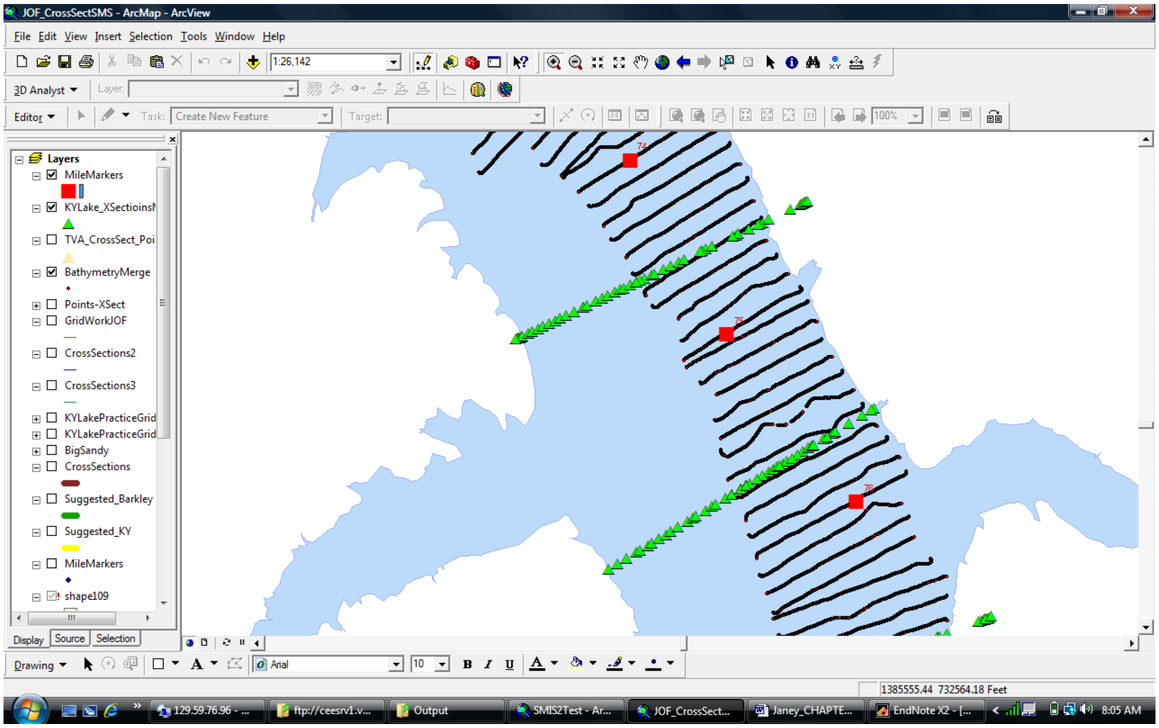

Figure 10: Bathymetry Data within GIS. Small black dots represent the USACE bathymetry data. Green triangles that span across the entire waterbody, but are less frequent along the river, are TVA cross-sections that have been assigned spatial reference. Red squares are river mile markers.

Meteorological Data

GLLVHT, as with many other models, takes into consideration the meteorological impacts on the waterbody. Factors such as wind shear, temperature, evaporation, solar radiation, and precipitation are all part of the modeling calculations for GEMSS. Meteorological information for the area was thus required. The meteorological input data was obtained from the US Climatic Data Center records for the Nashville, Tennessee Airport (BNA) (NCDC 2008). Nashville is the largest city near the project area with a large airport that monitors and records vast amounts of meteorological information on a frequent basis.

Flow, Temperature and Elevation Data

TVA provided many of the data inputs for the GLVHT model. Supplied data sets included flows, temperatures, and the tailwater elevations of Pickwick Dam and the headwater elevation with temperatures and flows from Kentucky Dam, as well as data for Barkley Canal and the Johnsonville Fossil Fuel Plant (JOF). The Barkley Canal links Lake Barkley on the Cumberland River with Kentucky Lake. The canal is located near RM 25.0 just upstream of Kentucky Dam. Depending on the elevation difference between the two lakes, the water exchange between Kentucky Lake and Barkley Canal may be flowing to or from the canal at a given time. The flow data for the canal was also provided by TVA. JOF is located at approximately RM 99 on Kentucky Lake. The plant, which is operated by TVA, withdraws water for cooling and then discharges it back into Kentucky Lake. Flows and water temperatures for the intake and discharge for JOF were provided by TVA and included intake and discharge boundary conditions.

Since the project area covers such a large region, many tributaries existing as either small streams or rivers flow into the Tennessee River between Pickwick Dam and Kentucky Lake. Obviously, not all of these tributaries represent significant contributions to the flow in the river and flow data is not monitored for each one. Given these limits, efforts were made to identify tributaries that had significant flows into Kentucky Lake and available flow data. The Watershed Modeling System (WMS 8.1) developed by Environmental Modeling Systems, Inc., Salt Lake City, Utah, was used to assist in identifying tributaries for consideration in the modeling process by evaluating the associated drainage area of each tributary. The drainage area was used as representative of the amount of flow coming from the tributary. Figure 11 illustrates an example of the delineation of select tributary drainage areas using WMS. A summary of all tributaries considered and their respective drainage area is provided in Table 6. Two tributaries were considered significant based on drainage area compared to the total drainage area for Kentucky Lake. Those considered significant represented >1% of the total drainage area for Kentucky Lake, and consisted of the Duck River (RM 110.0) and Big Sandy River (RM 67.0).

Flow data for Big Sandy River and Duck River was obtained from US Geological Survey (USGS) records (USGS 2008a; USGS 2008b). The data record available for Big Sandy River ended on September 30, 2006, after which the gauging station was closed. Big Sandy River is still monitored by USGS and data for the entire year of 2006 was available.

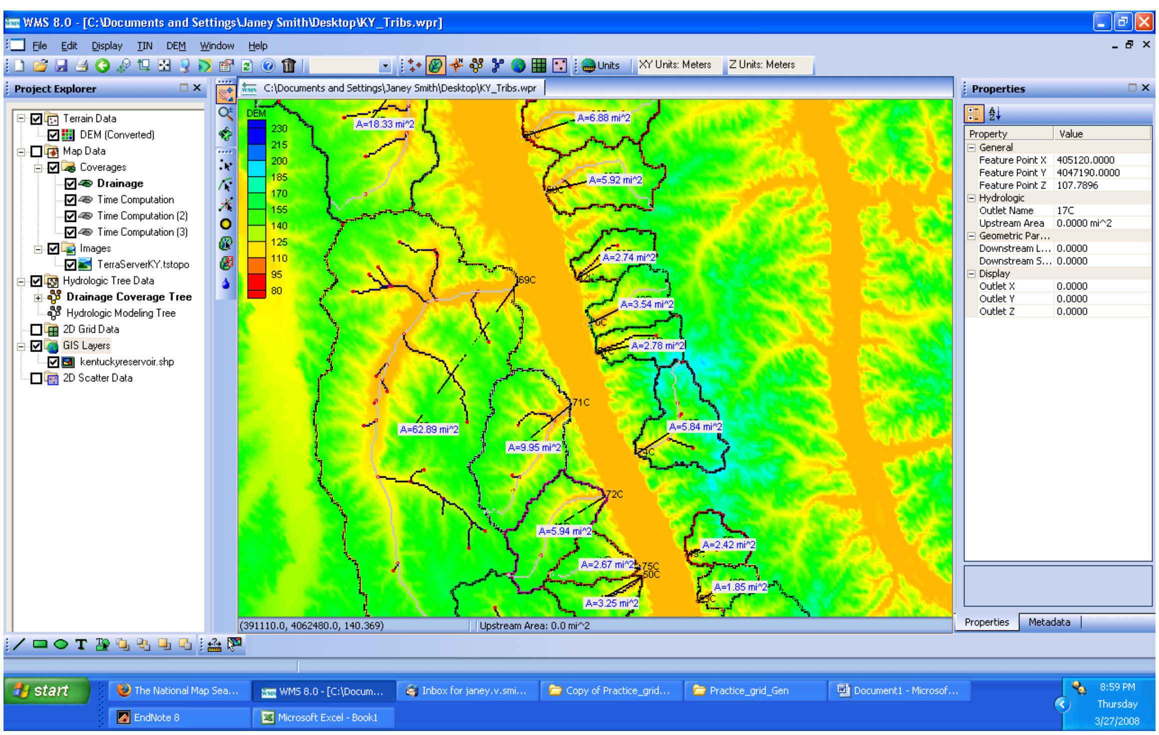

Figure 11: Delineation of contributing drainage areas for tributariess using WMS.

Table 6: Kentucky Lake Tributaries Summary

River Mile	Waterbody	Area (mi^2)	% of KY Lake	River Mile	Waterbody	Area (mi^2)	% of KY Lake
25.5	Sledd Creek	4.91	0.012	67	Big Sandy River	423.89	1.054
26.5	Little Bear Creek	7.1	0.018	79	Cane Creek	105.9	0.263
30	Malcoln Creek/Bear Creek	18.33	0.046	82.5	White Oak Creek	186.16	0.463
30.5	Pisgah Bay	7.22	0.018	100	Cypress Creek	41.59	0.103
32.5	Smith Creek	5.72	0.014	103.2	Birdsong Creek	90.9	0.226
34	Duncan Creek	6.88	0.017	110.9	Duck River	1542.03	3.836
36	Sugar Creek	5.92	0.015	112.5	Eagle Creek	27.7	0.069
38	Johnathan Creek	62.89	0.156	115.5	Blue Creek/ Cuba Landing	17.96	0.045
39	Rhodes Creek	2.74	0.007	119	Morgan Creek	19.5	0.049
40	Vickers Bay	3.54	0.009	121.5	Crooked Creek	16.89	0.042
41	Barnett Creek	2.78	0.007	123	Roan Creek	15.14	0.038
42.5	Ledbetter Creek	9.95	0.025	124.3	Tom's Creek	28.7	0.071
45	Anderson Creek	5.94	0.015	129.5	Cub Creek	86.3	0.215
45	Turkey Creek/Bay	5.84	0.015	131	Lick Creek	33	0.082
48	Blockhouse Creek	2.42	0.006	135.5	Beech River	302.22	0.752
48	Minnow Rd (no name on creek)	2.67	0.007	136.5	Cypress Creek	18.58	0.046
48	Snipe Creek	3.25	0.008	138	Marsh Creek	17.34	0.043
49.5	Jones Creek	1.85	0.005	141.3	Cedar Creek	30.48	0.076
51	Blood River	81.04	0.202	144.5	Whites Creek	24.16	0.060
51	Rushing Creek	6.06	0.015	155	Beech Creek	58.04	0.144
53	Ginger Creek	4.33	0.011	165	Hardin Creek	98.07	0.244
54	Boyds Branch	2.82	0.007	165.5	Turnbo Creek	20.19	0.050
54.2	Clay Creek	2.61	0.006	165.5	Turnbo Creek	21.02	0.052
57	Byrd Creek	6.63	0.016	168.5	Indian Creek	227.6	0.566
58	Hughes Creek	3.77	0.009	172	Doe Creek	32.28	0.080
60	Dry Fork Bay/Panther Creek	10.37	0.026	173.5	Whie Oak Creek	186.79	0.465
60	Shannon Creek	3.46	0.009	178.3	Horse Creek	175.58	0.437
60	Yellow Spring Branch	1.74	0.004	197.4	Snake Creek	127.84	0.318
67	Eagle Creek by Big Sandy	23.55	0.059				

Grid Development

The grid generation module (GridGen) represents a toolbar within GEMSS that allows for use of GIS layers as guidelines and data sources for grid generation. This promotes accurate representation of the shape and area of the waterbody through visualization of where grid points are located with respect to the waterbody perimeter. Some grid generation techniques, such as those used with EFDC do not allow the user to easily visualize whether or not the grid covers the waterbody or if areas of interest (such as island areas or tributaries) are properly captured. For GEMSS, the GIS shapefiles for both the waterbody outline and bathymetric data must be in the State Plane coordinate system. A tool within GEMSS is available to convert from other coordinate systems to State Plane.

A shapefile from TVA outlining the Kentucky Lake region between Pickwick Dam and Kentucky Dam along with select tributaries was used as the basis for the grid. GEMSS allows users to choose between a rectilinear (uniform, rectangular cells which intersect at right angles), curvilinear grid (cells are non-rectangular and may curve, are not always uniform, and do not always intersect at right angles), and a curvilinear orthogonal grid which combines features of both (cells are non-uniform and may curve, but intersect at right angles) (Edinger 2001). For this research, the curvilinear orthogonal grid was chosen due to the ability to represent the waterbody with grid cells of multiple sizes and represent the curvature of specific regions most efficiently.

Use of the GridGen tool allows the user to place control points deemed most appropriate to represent the waterbody; GEMSS then connects the points and develops the grid between them. The user specifies the i- and j- cell index on the control points which in turn defines the number of cells that are generated between them. For this research, exterior control points were placed ~ ¼ mile along both the east and west banks of the river. Both the Big Sandy River and Duck River were included in the system grid because of their size and use as significant contributing waterbodies along with select smaller tributaries to account for storage in those areas. On the upstream end, several islands exist that displace much of the surface area. These islands were accounted for by treating them as inactive grid cells.

Once the basic surface grid is complete, bathymetric data can be used to develop the subsurface layers and waterbody bottom cells. This is done by adding bathymetry shapefiles to GEMSS and scanning the bathymetry. Nearest neighbor interpolation is performed by averaging the depths of either four or eight adjacent cells to obtain the depth of cells with no bathymetric data available. Both TVA and USACE bathymetric data were scanned and interpolated to develop the grid for this research. Cells missing bathymetric data were assigned depths using interpolation of the eight surrounding cell depths. Bathymetric smoothing was used to find and correct solitary deep cells. Finally, the grid was manually inspected and cell depths edited based upon surrounding cells, the original TVA cross-section data, and navigation charts to ensure proper representation of the waterbody.

Additional inspection of the grid was performed using ArcScene (Component of ArcView GIS, ESRI, Redlands, CA). ArcScene is an Environmenal Systems Research Institute, Inc. (ESRI) ArcGIS product that allows for 3-D visualization of spatial data. The grid was exported as a shapefile using the export tool in GEMSS and imported into ArcScene. The grid cells were extruded to their depths for viewing as water blocks. This provided a 3-D view of the bottom surface of the waterbody and allowed for identification of cells that were extremely shallow or deep compared to other cells. It was also beneficial in viewing the navigation channel for comparison to navigation charts to ensure that it was properly aligned. Once erroneous cells were identified, they were edited appropriately in GEMSS. A screenshot of the grid within ArcScene is shown in Figure 12.

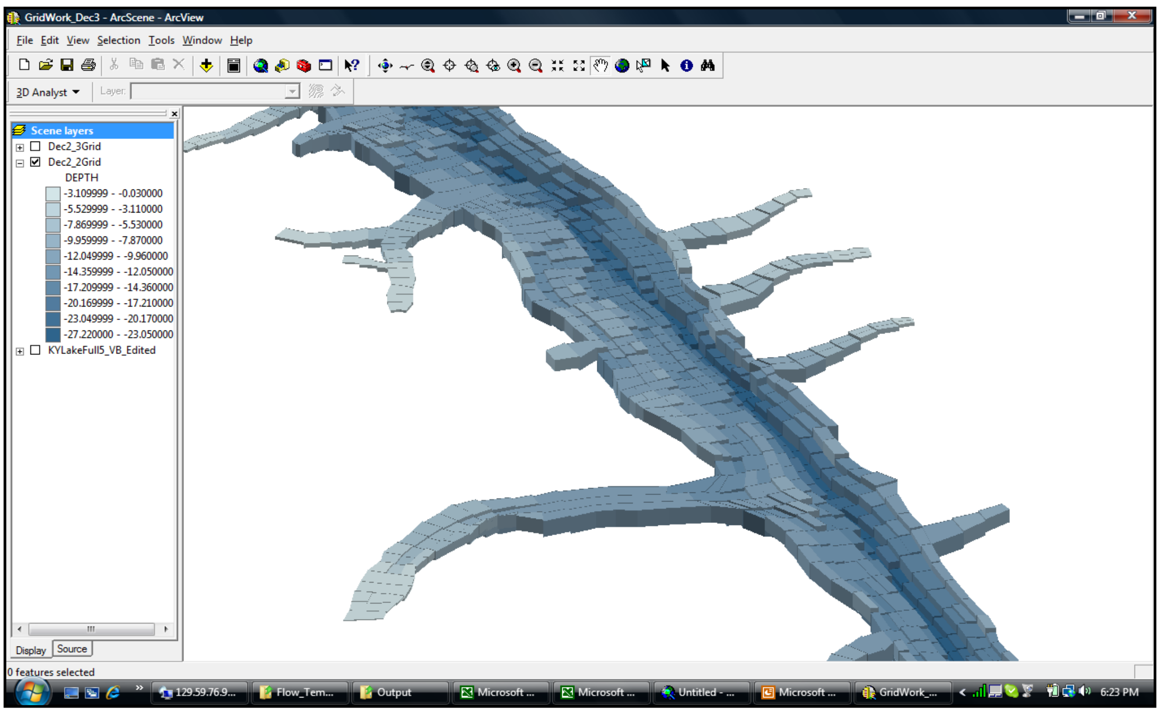

Figure 12: View of grid in 3-D using ArcScene.

The final grid is shown in Figure 13. It consists of 5,768 cells on the surface, with layers four-meters deep. It has a total of 33,023 cells for the entire grid. This layer depth was not considered optimal for modeling purposes, but was required to account for the difference in elevation between the tailwater of Pickwick Dam and the headwater at Kentucky Dam; the GLLVHT hydrodynamic model requires that the surface elevation throughout the project area be within the same grid layer. A layer depth of one meter would have been preferred for improved model accuracy, but this increase in accuracy would have increased computation time (minimal computation time is desired for spill modeling).

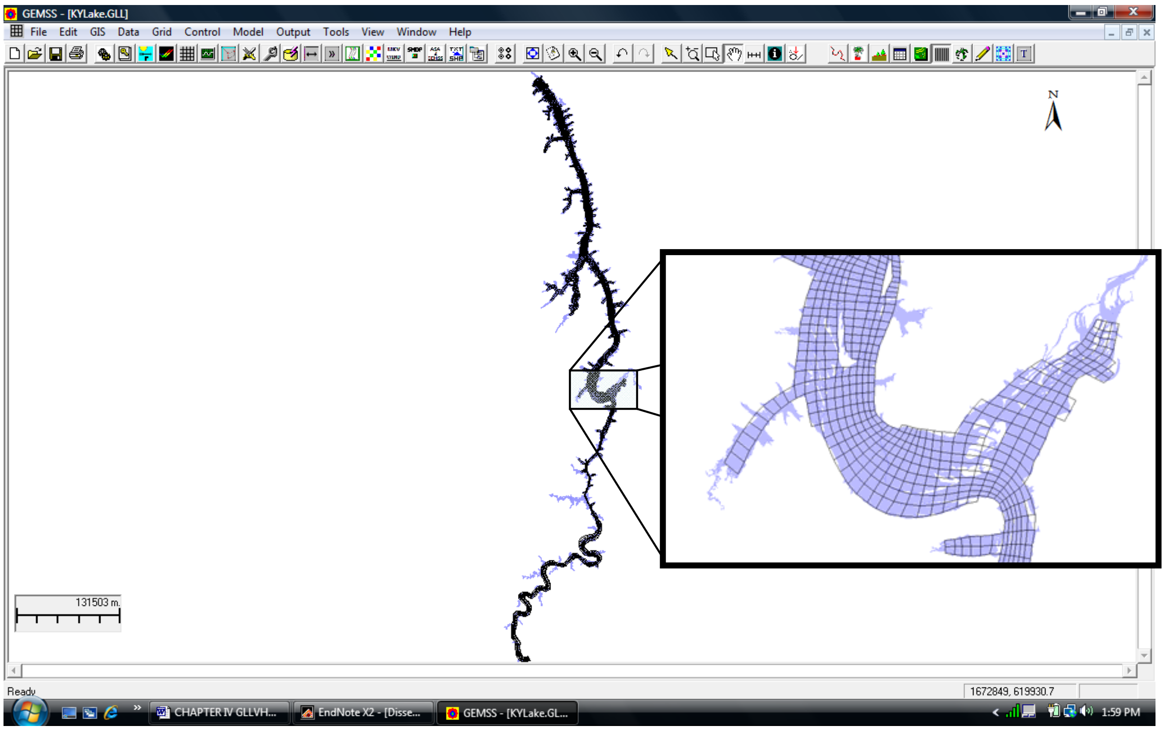

Figure 13: Final grid for Kentucky Lake project area.

Boundary Conditions

GEMSS provides tools called TVDGen (Time Varied Data Generator) and MetGen (Meteorological Data Generator) to assist in formatting the input files/boundary conditions for the model. TVDGen was used to create the boundary conditions for flow and elevation. Within the TVDGen tool, one specifies the beginning and ending time for the data set, the frequency of the individual data points, the constituent type (discharge, intake, precipitation, elevation, etc.), and units. Each data file is given a name and data can be pasted directly from a spreadsheet. An example of the setup of the TVD file for Duck River Flow is shown in Figure 14. The flow for Big Sandy River was split between two headwater regions, with 1/3 going to the smaller region and 2/3 of the flow going to the larger region. This was done because the cells in the smaller region would have had no water/flow from the other input. In a similar manner, meteorological data files were created using MetGen. Meteorological data files include dew point temperature, wind speed and direction, and solar radiation. Table 7 lists each boundary condition file, a description, the type of boundary condition, and the location of the cells where the boundary condition is applied on the hydrodynamic grid.

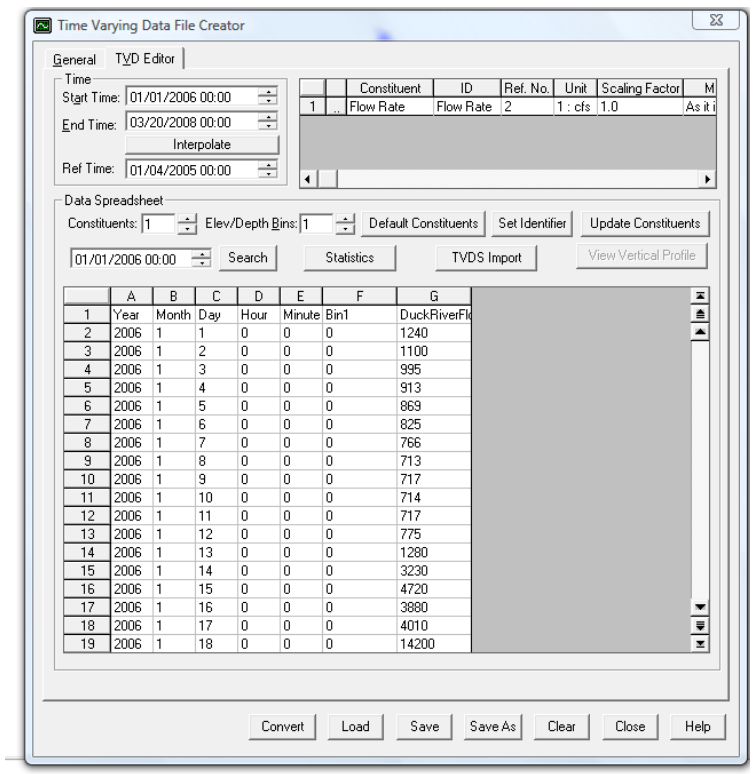

Figure 14: TVD file generator for Duck River flow.

Table 7: Boundary Conditions used for Kentucky Lake Model

Boundary Condition	Location: I start	I end	J start	J end	Type	Description	TVD Files
Pickwick	91	93	1	1	Discharge	Pickwick Dam flow for 2006	Pick_Flow06_Version1.hdg
Precipitation	1	139	1	899	Precipitation	Precipitation for 2006	Precip2006.hdg
BigSandy_Main	26	26	482	483	Discharge	Big Sandy River Discharge (large branch)	BigSandyFlow05_06_Main_aVersion1.hdg
DuckRiverFlow	112	112	352	353	Discharge	Duck River Flow	DuckRiverFlow06-08_Version1.hdg
PickwickHead	91	93	1	1	Elevation	Pickwick Tailwaters Elevation	Pick_TailElev06_116Version1.hdg
JOF_Intake	94	94	381	381	Intake and Withdrawl	JOF Plant Intake	JOF_PlantIntakeFlow06_Version1.hdg
JOF_Discharge	94	94	393	393	Discharge	JOF Plant Discharge	JOF_PlantFlow06_Version1.hdg
KY Dam Withdrawl	94	96	632	632	Intake and Withdrawl	Kentucky Dam Flow	KY_Flow06.hdg
CanalFlow06	100	100	618	618	Intake and Withdrawl	Barkley Canal Flow	CanalFlow06_2Version1.hdg
BigSandySmall	59	59	511	511	Discharge	Big Sandy River Discharge (small branch)	BigSandyFlow05_06_small_bVersion1.hdg
FCBC Using Specific Region	94	96	632	632	Flow Correction Using Elevation Data	Flow Correction	KY_Head06_116.hdg
Flow from HCBC	86	86	500	633	Distributed Flow	First Zone for Distributed Flow	N/A
Flow from HCBC	96	96	500	633	Distributed Flow	Second Zone for Distributed Flow	N/A

Control File

GEMSS provides a simple to use interface for editing/creating the text control file (Figure 15). The model possesses several tabs with options for editing simulation time and timesteps, setting up the boundary conditions by identifying the TVD and Met files to use, specifying the grid to be used, and the initial layer elevation for start up. A button at the bottom of the form allows the user to establish time periods of interest, layers to include in the results, specific cells for profile results (e.g. temperature profiles), and locations for time series data results. Within the results, the OS Velocity Field is used to define the desired output time periods and frequency for generation of the currents file which is used as the basis for transport in COSIM.

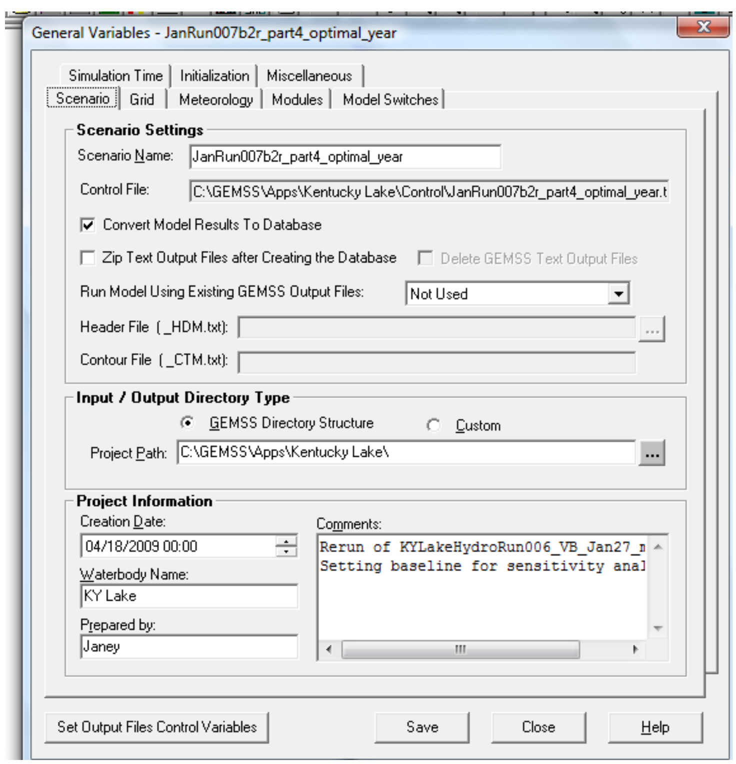

Figure 15: Example Control File

For the current research, the boundary conditions previously discussed were included in the model for simulation of the year 2006. The time step was limited to a minimum of 0.2 seconds and maximum of 20 seconds. Using a forward-time, backward space control-volume approach, the time step must be less than the cell in the y-direction divided by the velocity in the y-direction for stability (Chapra 1997). With grid cells of approximately 1,500 m long and an average velocity in the waterway of 0.2 m/s (TVA 2006), the maximum stable time step would be 7,500 seconds. However, time steps greater than 20 seconds resulted in instability errors. Pickwick tailwater elevation data was used as the initial layer elevation for simulations. Data for most boundary conditions was available at hourly time increments. Since the maximum time step was less than the data frequency, the model was set up to interpolate between times in each data set for all boundary conditions. Initially, the Chezy coefficient was set to 60. An upwind, first-order transport scheme was used. Wetting and drying of layers was included with a limited thickness factor of 0.8 for both. The water body was considered to have variable density to account for stratification in the reservoir behind Kentucky Dam.

An additional feature with GEMSS is the Miscellaneous tab in the control file. Collaboration with one of GEMSS's developers, Venkat Kolluru, led to additional functionality with this tab (Figure 16). Used primarily to assist in accurately representing the waterbody storage in grid development and provide closure on stability issues, the Miscellaneous tab contains a series of spreadsheet-like cells that allow the user to identify a range of cells and adjust the volume of those cells using a scaling factor. The limited bathymetric data available for this research led to difficulties in accounting for the storage at certain depths. The Miscellaneous tab was used to adjust cell volumes and provide a good representation of the storage of Kentucky Lake at all levels. An additional set of cells in the Miscellaneous tab are used to identify the region of cells where distributed flow should be applied to account for groundwater flow, un-gauged tributary flow, and overland flow during rain events that was not included in the boundary conditions. This feature is used with the Head Correction option for calibration, which is discussed further in the Results section.

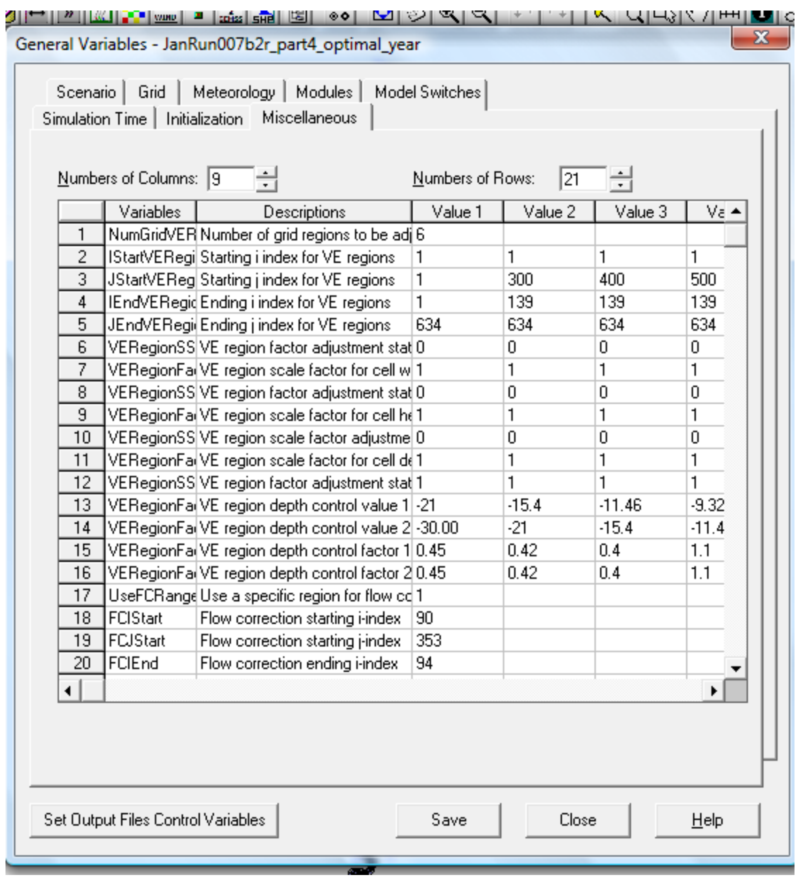

Figure 16: Example of Head Correction settings.

Results and Discussion

Kentucky Lake represents a very large waterbody comprising over 180 river miles. The modeled region consists of islands, multiple tributaries, and a fossil fuel plant using the river water for cooling. Further, the waterbody is bound on each end by controlled hydrologic features (Pickwick Dam and Kentucky Dam). This physical complexity, coupled with multiple natural and manmade features, renders it difficult to model such an extensive river area.

The modeling effort required use of bathymetric data from multiple sources in creation of the curvilinear orthogonal grid. Input files included flows from Pickwick Dam, Big Sandy River, Duck River, and the Barkley Canal between Kentucky Lake and Lake Barkley. In addition, temperature and flow data for the intake and discharge for the Johnsonville Fossil Plant (JOF) were also used. To ensure accuracy and enhance confidence in the modeling effort, calibration of the model was performed using the surface elevation at Kentucky Dam through use of the Head Correction tool. Sensitivity analysis was performed on the Chezy coefficient, which impacts the surface elevation, the region of cells to which the distributed flow was applied and the frequency to which the distributed flow was applied to account for differences in the elevation at Kentucky Dam using the Head Correction. Similar to Schladow and Hamilton's work with the DYRESM water quality model (Schladow and Hamilton 1997), sensitivity analysis was performed by varying the values of one parameter while holding all others constant to determine the impact of that parameter on the system. Differences in surface elevation at Kentucky Dam between the measured data (provided by TVA) and model results at cell i = 93 and j = 632 was used as the basis for calibration and sensitivity analysis.

Simulations were performed for the time period between March 10 and May 20, 2006, which included both a low flow and high flow period. This allowed for the most efficient evaluation of model results in a timely manner.

A simulation period of 14 days was used to evaluate the processing time of the GLLVHT model on two different computers. The first evaluation was performed on a Dell Dimension (DIM9100) with an Intel® Pentium® processor with 1.00GB of random access memory (RAM) using Microsoft Windows XP Professional 2002 with Service Pack 3. A two-week simulation required 5.16 hours of processing time. This was reduced by nearly half (2.66 hours processing time) using a Dell XPS (XPS710) with an Intel® Core™2 2.66GHZ with 2.00GB of RAM and using the same Microsoft Windows operating system.

Water Balance

A good estimate of whether a model is representative of the "real-world" system can be determined through evaluation of the water balance. The water balance can be defined as (Chapra 1997):

Accumulation = loadings (inputs – outputs) +/- transport +/- reactions. (3)

Often, as was the case for Kentucky Lake, the data on flows coming into and out of the waterbody are limited to the largest tributaries and do not account for groundwater flow, overland flow, or flow from small streams/tributaries. One technique commonly used to account for this difference is to add/subtract distributed flow as needed to close the water balance or compare model results to a known relationship between elevation and volume called the stage-storage curve. The stage-storage data for Kentucky Lake was provided by TVA.

Since both the bathymetric data and boundary conditions were limited, it was likely that the model and measured (TVA) stage-storage curves would not match initially. The Miscellaneous tool was used to adjust the volume of cells in certain regions within GEMSS to obtain a good match for the stage-storage curve. Below is the stage-storage curve for Kentucky Lake illustrating both the model simulation and data from TVA (Figure 17). Normal operating pool range is identified on the plot.

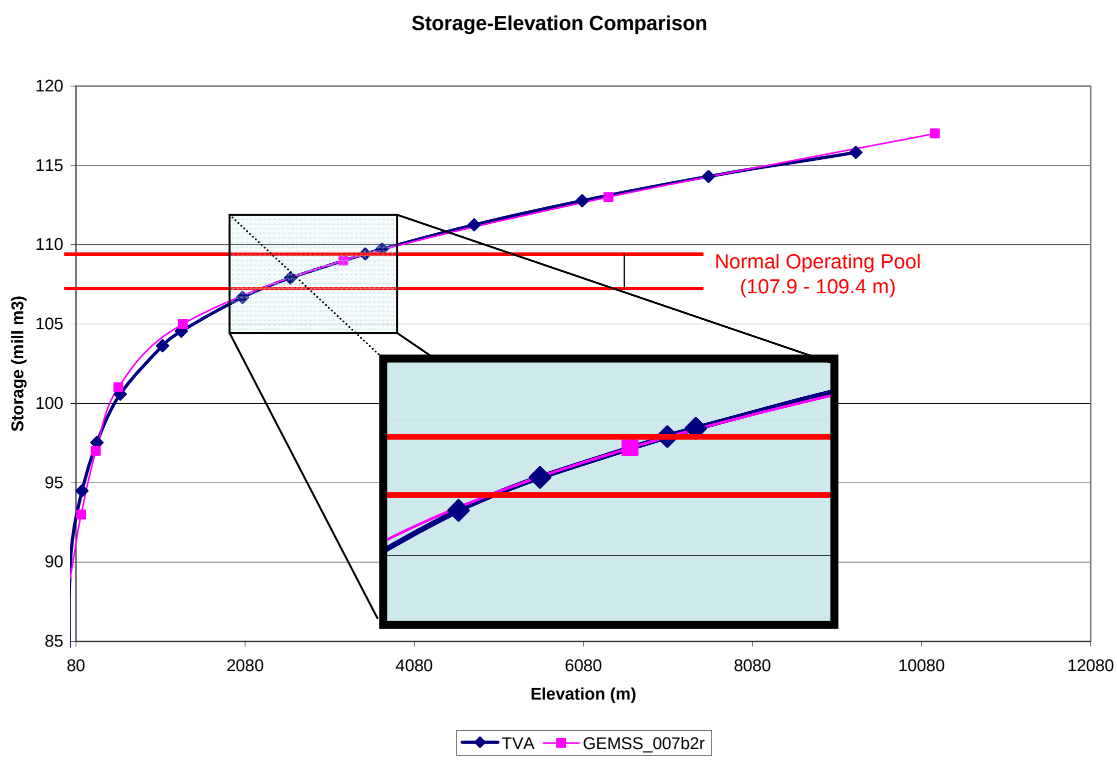

Figure 17: Stage-storage curve for Kentucky Lake and GEMSS Model. Normal operating pool ranges between 354 ft (107.9 m) and 359 ft (109.4 m).

Model Calibration and Sensitivity Analysis

The GLLVHT Model was calibrated through use of the Head Correction tool within GEMSS. This tool calculates the difference in flow required to match the head elevation of the model with the measured elevation. The measured surface elevation at Kentucky Dam (cell i=93, j=632) was used for calibration. Differential flow to make up the difference in elevation is added to the model at a designated frequency as distributed flow for a specified region of cells. A good match between the elevation at Kentucky Dam and the model-generated surface elevation near the dam was achieved through use of Head Correction (Figure 18). Within the head correction tool, two parameters must be optimized to achieve the best possible fit with the real system. These are the frequency of the calculation of distributed flow and the region of cells to which the distributed flow is applied. In addition, sensitivity analysis of the Chezy coefficient was performed. Each of these are discussed in further detail below. For each parameter under consideration for sensitivity analysis, all other parameters and model settings were held constant while the constituent of interest was varied for model simulations to evaluate the impact of changes on model results. The results for the sensitivity analysis were expressed as percent difference (Equation 4) between the model results and measured system:

$$\% \; Difference = 100\% * (Model - TVA) / [(TVA + Model)/2] \quad (4)$$

Here, Model represents the model results and TVA represents the measured data from TVA. Minimal percent differences for a model run were considered optimal.

Head Correction Frequency

The frequency in which the distributed flow was calculated and applied was evaluated for 5 different times. Following discussions with Venkat Kolluru, 12 hours was used as a base frequency. This resulted in a fairly good match with the surface elevation at Kentucky Dam. Additional trials were performed for frequency times of 6, 4, 3, and 2 hours. For 4 and 3 hour results, very good matches were obtained with the measured data. One hour was not evaluated since the 2 hour frequency data fluctuated greatly compared to the measured results. This was considered the point of diminishing returns. Sensitivity analysis for the Head Correction frequency is presented as percent differences in Table 8. A Head Correction frequency of 3 hours was determined to be the optimal setting.

Table 8: Head Correction Frequency Sensitivity Analysis (Reported Items are %Differences)

	BASE	HC1	HC2	HC3	HC4
	Freq = 12hrs	Freq = 6hrs	Freq = 4hrs	Freq = 3hrs	Freq = 2hrs
Average	0.4619	0.254	0.202	0.175	0.218
Max	3.146	2.771	2.078	2.601	5.742
Min	-2.157	-1.859	-1.503	-2.328	-4.824
StdDev	0.674	0.532	0.470	0.473	2.111

Distributed Flow Region

Originally, the region considered for application of distributed flow was bound by the cells i82 to i105 and j475 to j632 (RM 71 to 22.4). This was considered the "original" region. Distributed flow was added or removed to the cell region depending on the amount required to close the difference in elevation at Kentucky Lake as computed by the Head Correction. Upon further inspection of the drainage area of tributaries for the study area, a "new" group of cells were identified as a more likely distributed flow region to represent additional flow from some larger tributaries the area. The "new" distributed flow region included the cell range from i90 to i94 and j353 to j632 (RM 110.5 to 22.4). Simulations were conducted for both regions to evaluate the impacts of the distributed flow region on the elevation differences at Kentucky Lake. Table 9 provides the percent difference results of these two simulations. The "new" region possesses a lower average percent difference and lower maximum difference. Therefore, the new cell range was chosen as the best option for the Kentucky Lake model. Figure 19 shows the elevation comparison for the different flow regions.

Table 9: Analysis of model sensitivity to the distributed flow region expressed as percent differences.

	New Region	Original Region
Average	0.013	0.462
Maximum	2.467	3.146
Minimum	-2.348	-2.157
Std. Dev.	0.807	0.674

Chezy Coefficient

A simplified version of the Chezy equation (Equation 5) is used to account for the impacts of channel roughness on flow and thus elevation independent of flow and channel slope (Kreith and Goswami 2004).

$$Cz = (1/n)*(Rh)^{1/6} \quad (5)$$

where Cz is the Chezy coefficient, n is Manning's roughness coefficient, and Rh is the hydraulic radius of the channel. Increased roughness impedes flow through the channel and thus increases the elevation. Sensitivity analysis was performed by conducting simulations for Chezy coefficients of 40, 50, 60, 70, and 80. The Chezy equation was rearranged to solve for n. This was used as a test for reasonableness of the Cz values. Due to the variation in river morphology for the project area, the hydraulic radius was calculated at three locations on the waterbody for use in the Manning's coefficient calculations: near Pickwick Dam (RM 202.33), mid-way between dams (RM 112.04), and at Kentucky Dam (RM 22.4). The resulting Manning's n values for each location and Chezy coefficient evaluated are presented in Table 10. For natural channels, Manning's roughness coefficients range from 0.3 for clean straight channels to 0.5 for winding channels with weeds and pool areas (Chow 1959). With the exception of a Chezy coefficient of 40 at Pickwick Dam, all of the Chezy coefficients considered fall within this range and can be considered acceptable. As shown in Table 11, little difference in surface elevation at Kentucky Dam was obtained by changing the Chezy factor. All of the results had an average percent difference between the modeled and measured elevations of less than 0.07 percent. The Chezy coefficient of 70 provided the smallest percent difference and was selected as the best option.

Table 10: Manning's n values for three different locations in Kentucky Lake. Rh is the respective hydraulic radius for each location.

	RM 202.33	RM 112.04	RM 22.4
Rh	*116.6929*	*54.97494*	*41.51215*
Cz (40)	0.055265	0.048749	0.04652
Cz (50)	0.044212	0.038999	0.037216
Cz (60)	0.044212	0.032499	0.031013
Cz (70)	0.03158	0.027857	0.026583
Cz (80)	0.027632	0.024375	0.02326

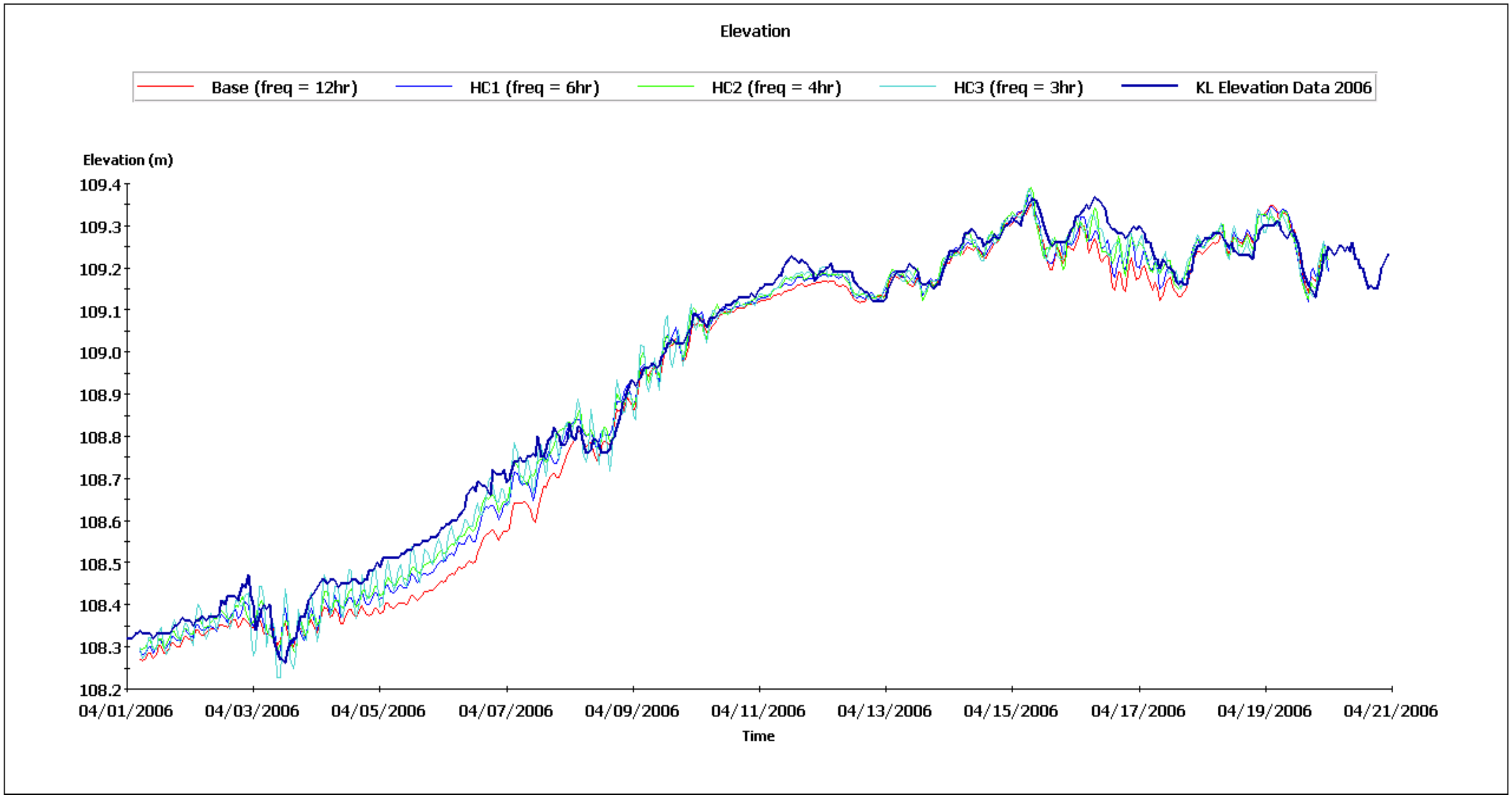

Figure 18: Surface elevation differences at Kentucky Dam for each Head Correction frequency evaluated.

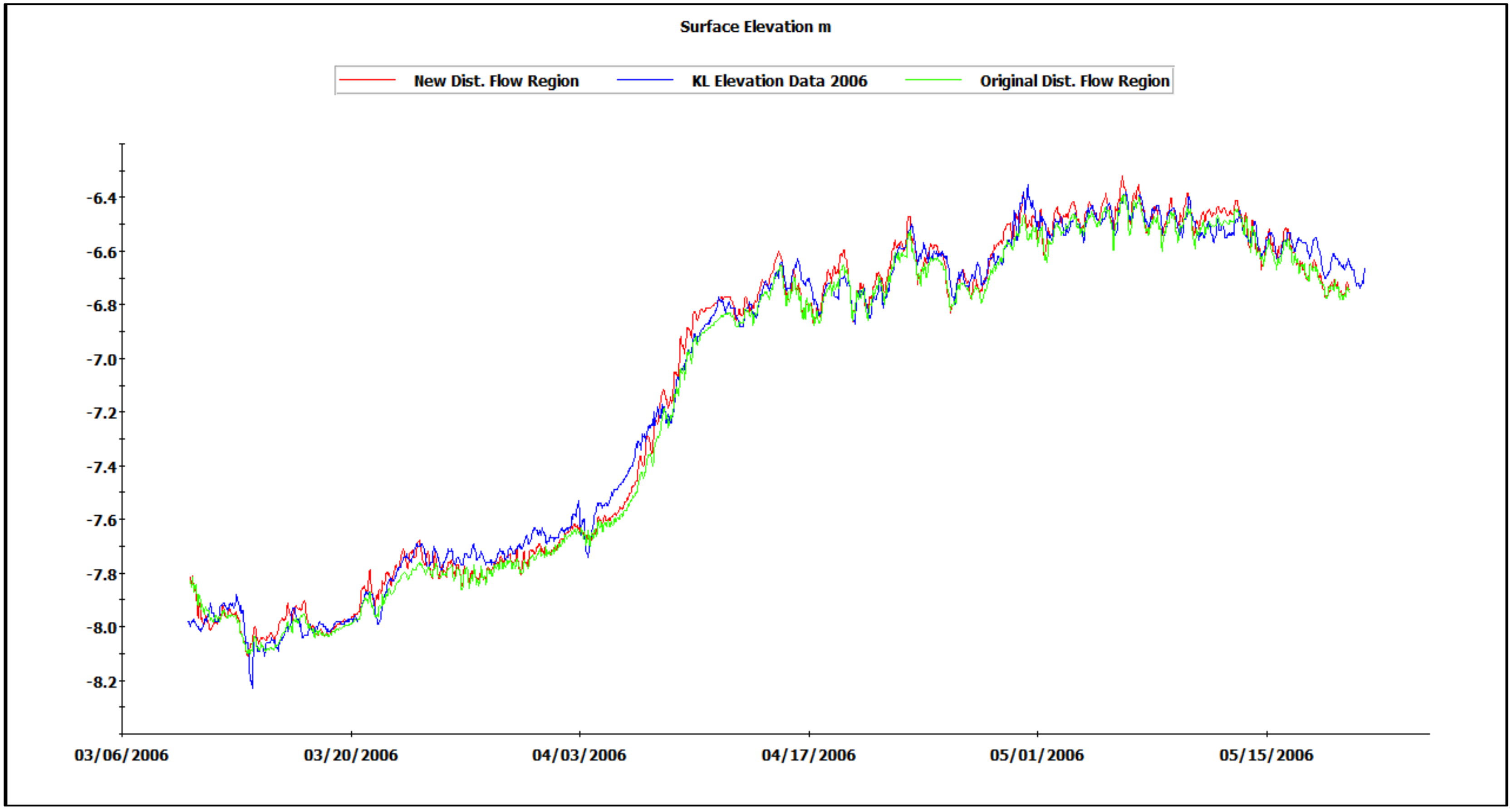

Figure 19: Surface elevation differences between the two regions identified for application of distributed flow.

Table 11: Sensitivity analysis results for Chezy coeffieient (all values are reported as percent differences).

	Cz = 40	Cz = 50	Cz = 60	Cz = 70	Cz = 80
Avg.	-0.0629	-0.02148	-0.03015	0.006656	-0.01729
Max.	0.155037	0.164855	0.157958	0.175053	0.15928
Min.	-0.22578	-0.17048	-0.18527	-0.13895	-0.17207
Std. Dev.	0.041794	0.046272	0.044215	0.055239	0.048142

Summary

The GEMSS modeling environment provides users with the capability of performing advanced, 3-D hydrodynamic modeling with tools to make setting up the model an ease. Development of the hydrodynamic model is an essential step that provides input information to the COSIM spill model. Both the hydrodynamic and spill model are essential components of SMIS 2.0.

It was found that optimal settings for Kentucky Lake included use of a three-hour frequency for head correction, use of the new region of cells (i90 to i94 and j353 to j632) for application of the distributed flow, and a Chezy coefficient of 70. Using these settings, a simulation was performed for an entire year. A good match between model results and measured data was obtained for Kentucky Lake (Figure 20). The percent differences were again calculated and are presented in Table 12. The hydrodynamic model has been calibrated and undergone sensitivity analysis. It now presents a good fit for both storage and elevation properties of Kentucky Lake with an average percent differences between the model and the true system of less than one percent. Relative mean errors in a range of 5 to 10% is often considered justification for the model to be representative of the system (Kolluru, Buchak et al. 2003). Here, we exceed that and thus can ascertain that the model is adequate for use as the basis for spill modeling with COSIM.

Table 12: The percent differences between the model and measured data for the surface elevation at Kentucky Dam for the full year simulation with optimal settings.

	% Difference Full Year
Average	-0.0113
Maximum	0.1776
Minimum	-0.3567
Standard Deviation	0.0535

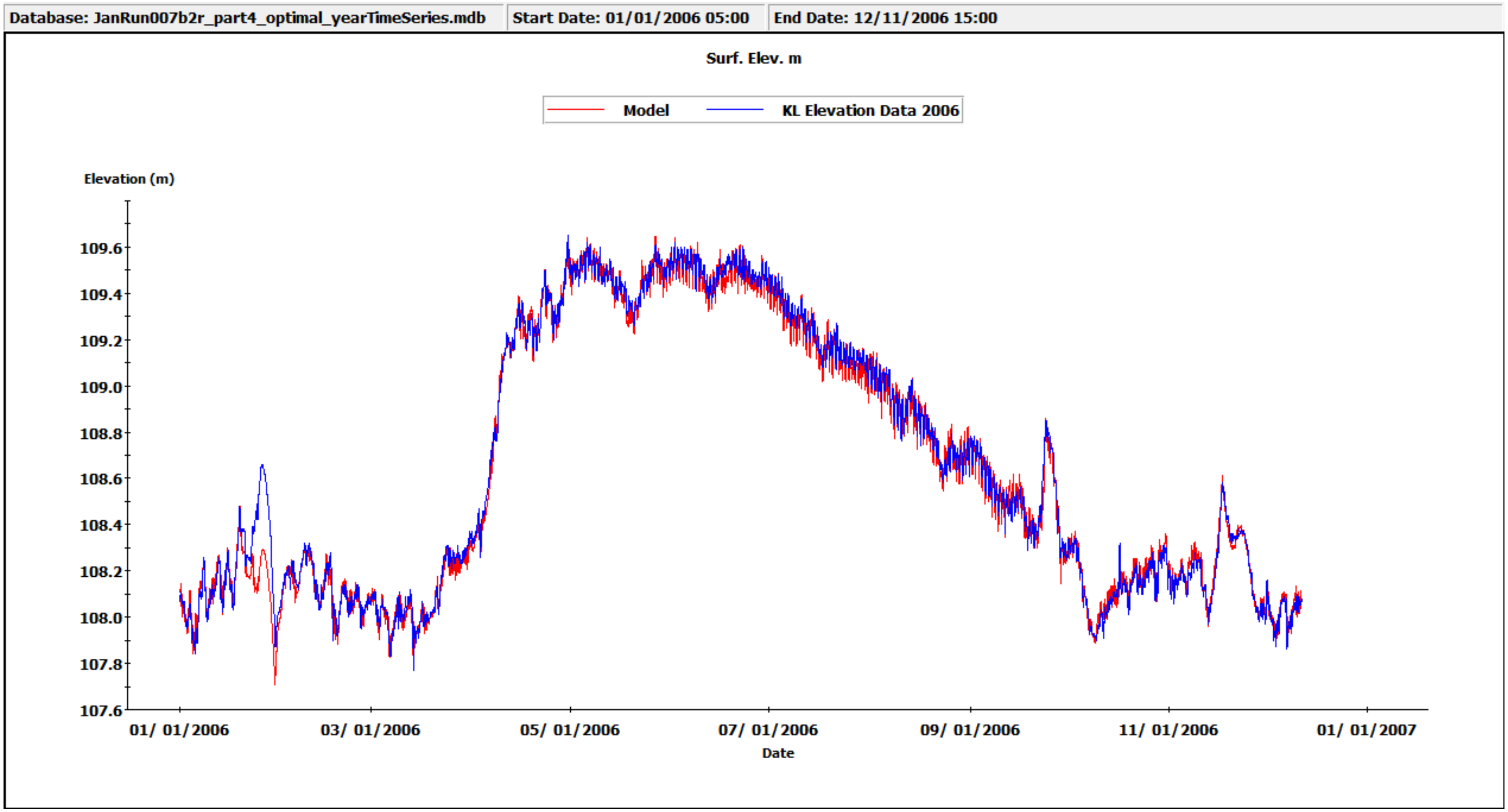

Figure 20: Surface elevation for year's simulation with optimal parameter settings.

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CHAPTER V

SMIS 2.0 SYSTEM DEVELOPMENT

Introduction

As water quality regulations become more stringent and with increased concerns over homeland security, chemical spills along our inland waterways, whether intentional or not, are presenting unique challenges. Although freshwater oil and chemical spills have been more frequent than marine oil spills (Owens and Michel 2002), most of the available information associated with spill modeling and response is focused on marine environments. In addition, spill modeling efforts are often focused on retrospective studies to determine the source of the spill (Elliot and Jones 2000), instead of predicting the migration of the plume for spill response.

To assist in management of inland waterway spills, primarily resulting from barge allisions or refueling accidents, researchers at Vanderbilt University developed Spill Management Information System (SMIS 1.0). The system combines 2-D modeling through CE-QUAL-W2 with geographical information systems (GIS) and air dispersion modeling through the US Coast Guard's CAMEO and ALOHA models (Martin, LeBoeuf et al. 2004). Given the growing popularity of GIS in emergency response and risk assessment (Contini, Bellezza et al. 2000; Barnes 2005), a logical next step is to integrate these systems with spill response and recovery activities (Dobbins and Abkowitz 2003; Martin 2003; Martinez-Alegria, Ordonez et al. 2003; Martin, LeBoeuf et al. 2004).

This paper describes the development of an enhanced version of SMIS, SMIS 2.0, designed to combine the visual capabilities of GIS with advanced hydrodynamic and spill modeling to allow response teams to better visualize the migration of an oil spill while providing the ability to identify possible resources for assistance. Elliot and Jones (2000) call for improved grid resolution in spill modeling and improved access to real-time meteorological data such as wind velocities that may significantly impact migration of a spill plume. In development of SMIS 2.0, these issues were considered in hydrodynamic and chemical fate and transport model selection. By selecting the Generalized Environmental Modeling System for Surfacewaters (GEMSS) for this purpose, the system provides advanced hydrodynamic modeling using GLLVHT, which is then used as the basis for contaminant transport modeling through the Chemical/Oil Spill Impact Model (COSIM) (Edinger 2006). Through a user interface structured within ArcMap (ESRI 2006), SMIS 2.0 allows a user to edit the COSIM control file, run the spill model, and load and format the output for viewing within GIS.

One benefit of SMIS 2.0 is that the end user only needs to be experienced in basic GIS skills to employ the model's full capabilities. After loading the spill model results, simple queries in GIS can lead to identification of: (i) local emergency response personnel such as hospitals, fire departments, and police within a specified distance of the spill event location; (ii) schools or other sensitive populations (e.g., nursing homes) that may need to be evacuated; and (iii) sensitive species that may be impacted within or along the waterway; and (iv) spill response resources such as location of spill response contractors, stores of boom, sources of spill response materials such as home improvement stores, and grocery stores, restaurants, and lodging to support spill response personnel. In addition, using a pre-set template, maps can be produced for printing or other distribution.

This tool provides a useful link between advanced modeling information and simplified visualization for decision support when time is of essence. SMIS 2.0 can also be used for training and strategic planning through development of reasonably foreseeable scenarios. Spill scenario output files can be saved in a common directory and added to ArcMap (ESRI 2006) at any future time.

The discussion to follow contains a description of SMIS 2.0 development, including the components that interact through the spill response tool, information on the techniques/programming that were used to bring these components together, and a sample SMIS 2.0 application.

Inland Waterway Spill Modeling

The *Spill Science and Technology Bulletin* dedicated an issue in 2002 to freshwater spills because of the lack of information and increased interest in spills in freshwater environments (Owens and Michel 2002). Due to the limited amount of modeling research and development in this area, current systems often utilize organic transport modeling or particle tracking features of water quality models for "best guesses" at the migration of a spill plume.

Inland waterway spills possess unique characteristics. Due to the impacts of shoreline and bottom friction processes, the flow in a river is most often moving in one direction, but are doing so at different velocities in a river cross-section (e.g., near shore flow will be reduced due to friction versus larger mid-river flows). Moreover, dams, bridges, and other structures may impact the trajectory of the spill plume.

Several individual projects have linked water quality models to GIS systems for the purpose of spill modeling on inland waterways through the pre- and post-processor graphical user interface (GUI) (Martin, LeBoeuf et al. 2005). These include RiverSpill, (Samuels, Amstutz et al. 2006), SMIS 1.0 (Martin, LeBoeuf et al. 2004), and General NOAA Oil Modeling Environment (GNOME) (NOAA 2007). These systems are described below.

RiverSpill/ICWater

The 1-D, GIS-based system, RiverSpill, provides real-time leading edge calculations for contaminant transport of surface waters. Primary application of the software is for protection of drinking water intakes, but it can also be used as an emergency response tool (Samuels, Amstutz et al. 2006; Samuels, Bahadur et al. Accessed September 2006). While RiverSpill provides rudimentary worst-case scenario results, more advanced modeling is needed to assist response crews in evaluating the most appropriate locations for boom placement and mitigation strategies, such as closing off drinking water intakes. In addition, RiverSpill fails to operate if no water intake is identified downstream of the modeling focus area. Samuels' group expanded upon their work in creating ICWater, which incorporates the National Hydrologic Data Set (NHD) mean flow and velocity data, and works as an extension to ArcGIS (Samuels, Amstutz et al. 2006). It is designed for use by emergency response teams for chemical, biological, and radiological incidents in river systems. ICWater incorporates real-time flow information from nearby stream gages. However, the model is still 1-D, using a control volume approach for each segment of river (Samuels, Bahadur et al. Accessed September 2006).

Spill Management Information System (SMIS 1.0)

Martin, LeBoeuf et al. (2004) developed SMIS, Version 1.0 specifically for modeling contaminants along inland water bodies. With support from US Army Corps of Engineers (USACE), the system was applied to Cheatham Reach along the Cumberland River. SMIS 1.0 includes CE-QUAL-W2 Version 3.0, a 2-D water quality model (Cole and Buchak 1995), and CAMEO, the 2-D air quality dispersion model (NOAA/EPA 2002). CE-QUAL-W2 requires rivers to be separated into segments and provides 2-D modeling averaged over each segment for output into GIS (Martin, LeBoeuf et al. 2004). For the Cheatham Reach area, the river was divided into 400 meter segments, with the concentration of the contaminant laterally averaged over the entire segment. While representing a clear forward step in contaminant migration modeling on this section of the Cumberland River, the limitations of laterally averaging represents challenges for wider segments of the river or other wide water bodies such as the Tennessee River.

SMIS 1.0 is linked to the US Coast Guard's Chemical Hazard Response Information System (CHRIS) database, which contains the properties of 1,300 chemicals typically found in waterway transport (USCG 2000). Through the GIS-interface, users have the ability to provide spill information such as location, duration, chemical name, and quantity spilled through a GIS interface. These inputs are then converted into acceptable format for CE-QUAL-W2. The model output is then displayed within the GIS framework. An example output from SMIS 1.0 illustrating a contaminant plume along the Cheatham Reach is shown in Figure 21.

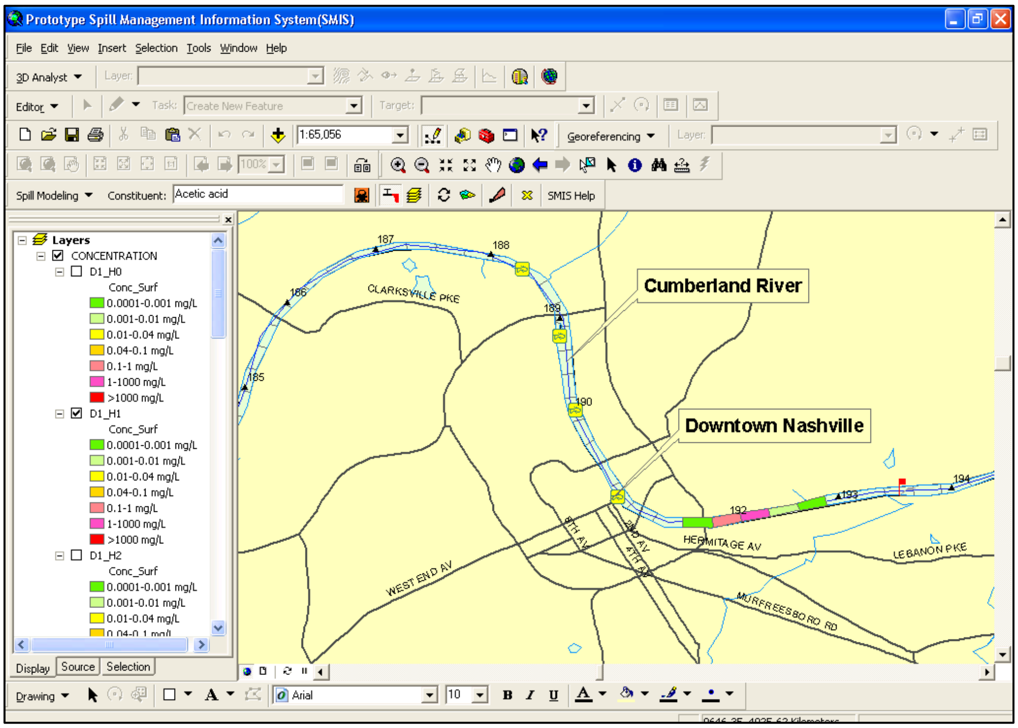

Figure 21: Sample of SMIS 1.0 Output for a Chemical Spill

General NOAA Oil Modeling Environment (GNOME)

GNOME was developed for use by both spill response personnel and others interested in tracking spill trajectories (Beegle-Krause 2001). It is focused on modeling oil spills for multiple waterways, including rivers, and provides trajectory that illustrates the predicted oil spill progression (NOAA 2007). GNOME includes modeling capabilities for gasoline, kerosene/jet fuels, diesel, fuel oil No. 4, medium crude, and fuel oil No. 6. There is an option to view GNOME output in GIS. GNOME, however, like SMIS 1.0, only provides 2-D modeling; future development is intended to model 3-D trajectories and currents (Beegle-Krause 2001).

SMIS 2.0 Methodology

Given the limited options for spill modeling on inland waterways, a spatially referenced spill response tool is needed that provides advanced modeling capabilities for multiple waterbody types and multiple chemical constituents. To respond to this need, an effort was undertaken to develop a system with these capabilities within a GIS framework. The system consists of customized tools that allow the user to perform spill analysis and view the results within ArcMap, which can then be used for decision support during spill response activities. Available tools allow for editing of the oil spill model control file with spill information, running the oil spill model, and then converting the results to proper format for viewing in GIS. By using ArcMap as a main component, users can perform queries utilizing standard GIS options to identify locations such as the nearest emergency response personnel facilities (e.g., hospitals and fire departments) and roadways to access the waterbody for deployment of booms.

Figure 22 provides a diagram of the SMIS 2.0 system components. Each element of the system is discussed further in the following sections.

GEMSS Hydrodynamic and Water Quality Modeling System

GEMSS consists of hydrodynamic, water quality and constituent modules, COSIM, and a graphical user interface (GUI) which assists in grid generation, pre- and post-processing of data, and visualization of results. GEMSS is applicable to rivers, lakes, reservoirs, estuaries, and coastal waterbodies (Wu, Buchak et al. 2001). GEMSS possesses a unique file directory structure that allows for archival of historical flow data that can be used for scenario analysis and planning, and in situations where time constraints or data availability limit users in running the hydrodynamic model to obtain immediate results. The model is free to the public, but only after having the intended project approved by the developers.

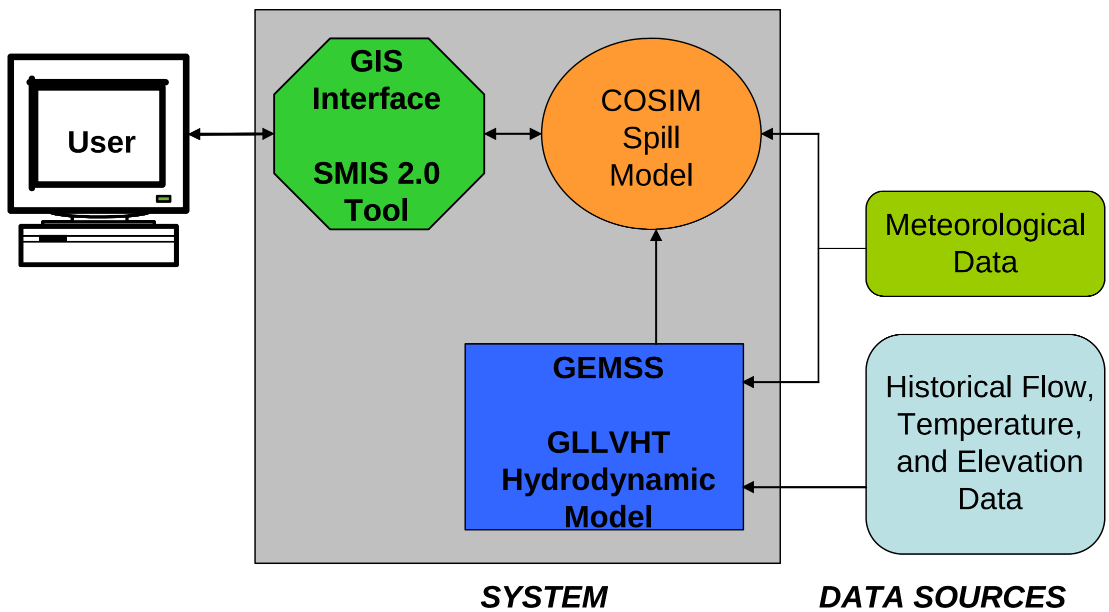

Figure 22: System Diagram

GEMSS is an integrated system of hydrodynamic and transport models presented in modular format. The hydrodynamic modules include the 3-D GLLVHT, 2-D CE-QUAL-W2, 1-D Generalized-Longitudinal Hydrodynamic and Transport (GLHT), and zero-dimensional real-time control (Dortch) model. Water quality module capabilities include modeling sediment transport, water quality, temperatures, chemical and oil spills, and bacterial processes (ERM 2006). GEMSS provides the overarching system for both hydrodynamic and oil spill modeling through COSIM.

Within GEMSS are tools to assist users in creating/formatting input files for both the hydrodynamic and spill models. The time varied data file generator (TVDGen) allows the user to create input files (*.tvd) representing boundary conditions for the hydrodynamic model, including discharges, elevation heads, and precipitation. The meteorological data file generator (METGen) provides a tool for inputting all meteorological data (*.met) for the model, including evaporation, solar radiation and dew point temperature. Both of these generators can readily accept data from Microsoft Excel (Microsoft Corporation, Redmond, Washington, USA). In addition, boundary conditions can be assigned spatial locations either through identification of the cells to which the boundary condition is to be applied in the model control file, or by assigning latitude and longitude coordinates in the .tvd or .met file.

GLLVHT

Due to its advanced 3-D hydrodynamic capabilities, GLLVHT was selected for use as the hydrodynamic basis for contaminant fate and transport modeling for this development effort (Wu, Buchak et al. 2001; Edinger 2006). GLLVHT uses time-varying, finite-difference methods and processes solutions that also serve as the basis for CE-QUAL-W2 (ERM 2006). Velocities are computed in x-, y-, and z-directions for each grid cell in the waterbody, allowing for more realistic representation of flow as opposed to lumping/averaging cell flow in one or more directions as is done in 1-D or 2-D modeling (Khangaonkar, Yang et al. 2005). GLLVHT can account for lake stratification due to its density computations, and takes into account wind surface stresses which can influence migration of surface contaminant plumes (Edinger 2006).

Chemical and Oil Spill Impact Module (COSIM)

COSIM fate and transport modeling provides an estimation of migration and environmental interactions of chemicals and oil over time and space. Physical processes modeled include dispersion, diffusion, advection, evaporation, entrainment and resurfacing, dissolution, emulsification, photooxidation, biodegradation, sorption, sinking and sedimentation, volatilization, and shoreline interactions. Shoreline interactions include portions of the spill adhering to shore materials such as rocks, sand or vegetation. Throughout the simulation, the model tracks the location, amount of chemical, sub-components of the chemical (e.g., for many oils: pentane, hexane, benzene, etc.), and physical phase (e.g., pure phase, dissolved phase, sorbed phase, volatilized phases) (Edinger 2006).

COSIM has the capabilities of modeling surface and/or subsurface chemical spills through utilization of GLLVHT hydrodynamic information, thus making COSIM a quasi-3-D spill model. This sets it apart from other spill models that have been applied to inland waterways. A mass balance accounting for all phases of the chemical (e.g., the amount of chemical spilled on the water's surface, adhered to the shoreline, contained in the subsurface layers, or lost due to evaporation) is available as an output option. Classification of the shoreline material properties (e.g., reflective, sorptive, or somewhere between) is taken into account during the modeling process (Edinger 2006). Chemical and physical properties of chemicals, crude oil, and oil products used in the model are commonly obtained from *A Catalogue of Crude Oil and Oil Product Properties* (Borbra and Callaghan 1990).

The COSIM control file is currently presented for editing and management as a Microsoft Excel spreadsheet (see Appendix D). The spill model can be run through the GEMSS interface or the command prompt as a batch (*.bat) file. Contaminant plumes can be viewed within GEMSS as time step animations through the GIS-like interface. However, the ability to perform spatial queries to locate sensitive populations or local authorities that may assist with response efforts in the area of a spill is not an easy task within GEMSS.

One example of COSIM application is the *Barge B120* oil spill in Buzzard's Bay, Massachusetts (GeoInsight 1994). COSIM was used after the spill event to identify the processes and pathways for fate of the oil spill. It was also used as a tool to determine areas where clean-up efforts may be required due to shoreline adhesion or subsurface impacts (GeoInsight 1994). While this is an example of application of COSIM for hindcasting, COSIM can be utilized as a forecasting model as intended for SMIS 2.0. This is done through predictive modeling using GLLVHT and incorporating forecasts of future hydrodynamic flow behaviors in COSIM (Kolluru 2008-2009).

VB.net Coding/Development of System Tools

SMIS 2.0 primarily consists of ArcMap (Environmental Systems Research Institute, Redlands, California, USA), GEMSS, COSIM, and the custom SMIS 2.0 toolbar (Figure 23) within ArcMap that brings these components together. The toolbar has buttons/tools that allow the user to input data into the COSIM model, identify file locations and output options, or run COSIM, and then provides options for the user to view the results as spill concentration contours within GIS. These contours can then be used to query the location of local emergency response personnel and sensitive populations along with providing spill response crews with visual information for decision support. Tracking plume migration over time allows field crews to identify locations for placement of booms if initial containment methods are ineffective.

Microsoft Visual Basic 2005 Express Edition (VB.net) (Microsoft Corporation, Redmond, Washington, USA), in conjunction with the ArcGIS Desktop Software Developer's Kit (SDK) (Environmental Systems Research Institute, Redlands, California, USA), were used to develop the tools for editing input and output of COSIM and running the model. The tools include Windows Forms (Microsoft Corporation, Redmond, Washington, USA) that are opened in ArcMap and interact with either the COSIM Microsoft Excel control file, RunCOSFates.bat file (i.e., COSIM Fate and Transport batch file) or output .mdb files. Each tool was compiled and packaged as a dynamic link library (.dll) which can be used as a stand alone tool within ArcMap through creation of a class library and inheriting ICommand and ITool in VB.net. Appendix E contains the VB.net coding for the tools created.

In addition to the VB.net form for input to the COSIM spreadsheet, tools were created to format the COSIM results into concentration contour layers within GIS. Within the toolbar, the first two tools, "Spill Output Prep" and "Output mdb to shp", and the last tool, "Zoom to Layer VBNet", were created in the same manner as "Spill Info Tool" and "RunCOSIM." The tool "Features to 3D" can be added to any ArcMap toolbar with the 3-D Analyst extension. It is recommended that the user be consistent with naming conventions for identification of scenarios and an output time frequency of one hour has been found to be most useful.

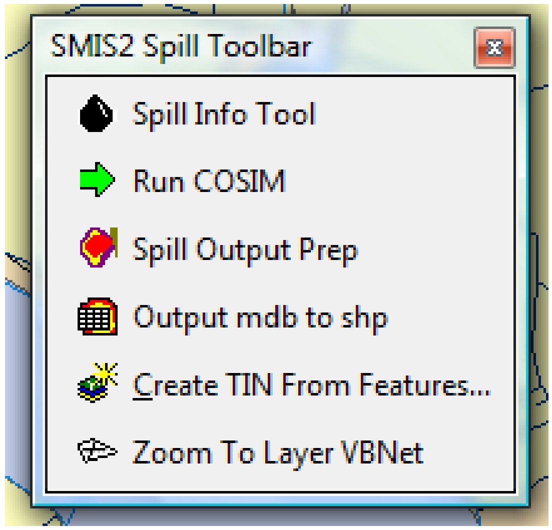

Figure 23: SMIS 2.0 System Toolbar

Spill Info Tool

The front-end GIS-to-COSIM interface tool, Spill Info Tool, was created as a Windows Form with tabs for file locations (including the COSIM control file, output files from GEMSS hydrodynamic modeling, meteorological data, shoreline type information, and the spill grid), spill release information (date, time, amount, depth, and location), and output options (time and frequency information for spill output files and modeling options). The user interface was developed to utilize the GEMSS project directory, where the control file is in the control folder for the project and the output files are in the output folder. Output file names created using this tool include the scenario name as part of the file path to assist in data management. During initial development of SMIS 2.0, assumptions were made that the spill only consists of one chemical (diesel fuel); however, COSIM can model additional chemicals. In addition, wind effects in the x- and y-directions are considered to be either all on or all off, and start times for all output file types are the same. Each tab of the form can be seen in Figures 24 - 26. A table listing the relationships between items in the “Spill Info Tool” and cells in the COSIM control file spreadsheet is provided in Appendix D.

When the “Spill Info Tool” is initiated from the SMIS 2.0 toolbar, a mouse down event requires the user to click on the map to identify the spill location. The location in state plane coordinates is automatically entered in the form for both the spill location and the default point for meteorological data. The Spill Information window (Figure 24) loads after the user clicks on the map. Alternatively, the user can manually enter different coordinates if desired. The scenario name entered by the user becomes the name for the tab on the spreadsheet in the control file. This scenario name must be used when using the “Run COSIM” tool. The control file to be edited is then selected. The user may choose the appropriate currents and snapshot output files from GLLVHT simulations to use as inputs into COSIM. The meteorological data file, spill grid file, and shoreline properties file are then selected. After all of the information is added to the form, the “Apply” button is pressed, generating a copy of the last active Microsoft Excel spreadsheet in the control file which is updated with input from the tool and named as the scenario.

The “Release Info” tab (Figure 25) contains specific information about the release date, time, amount and duration. All units must be specified using drop downs on the form or errors will result in the execution of the model. Typically, only one release is recommended for modeling.

“Output Options” (Figure 26) allows the user to specify the processes that will be addressed in the model (e.g., biodegradation, wind effects, spreading, emulsification). This is also where the user identifies the start time for output files to be generated and the frequency of data recording. An output frequency and simulation time step of 60 minutes is recommended. Having output at hourly intervals provides the necessary information for projected response efforts without unnecessary computation time or output storage space. Defaults for waterbody temperature and i- and j-cells for currents information are input here. It is recommended that a default i- and j-cell location near the spill, but away from the shore, be used to ensure sufficient flow for worst-case spill migration estimates. The default currents location is only used if current information is not available for a cell. Options for the shoreline process to be used can be selected. The options include 100% absorptive, 100% reflective, or use of Environmental Sensitivity Index (ESI) codes. Selection of the ESI codes results in the shoreline being modeled as sand (current default setting of COSIM), clay or some other material. These are commonly used in chemical spill response efforts or prevention planning (Jensen, Ramsey et al. 1990). The number of simulation days specifies the days that the model will run regardless of whether the chemical is of significant concentration.

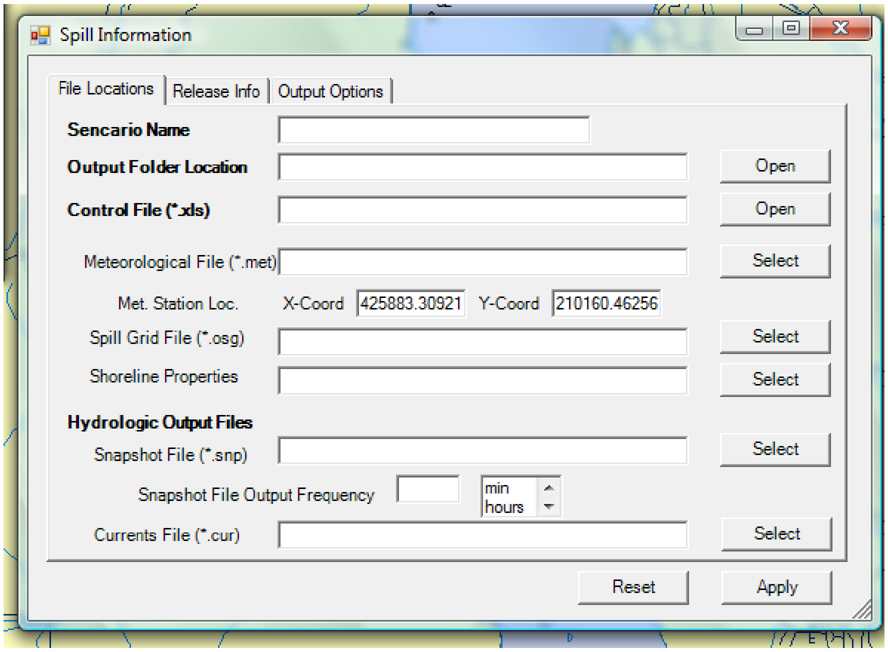

Figure 24: Spill Information Window: File Locations

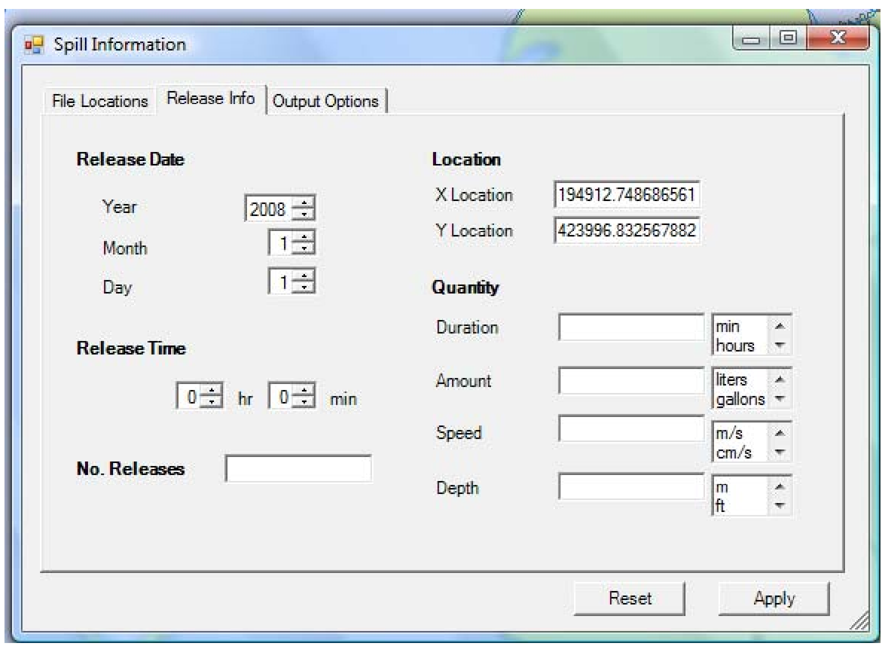

Figure 25: Spill Information Window: Release Scenario Inputs

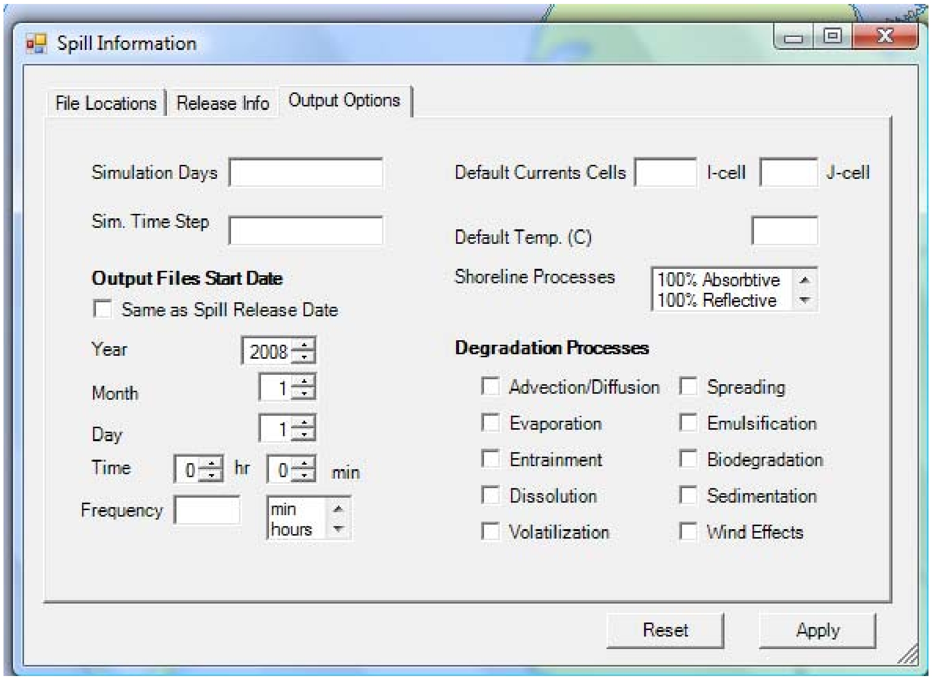

Figure 26: Spill Information Window: Processes and Output File Parameters

Run COSIM

The "RunCOSIM" tool is identified by a green arrow. The associated form (Figure 27) allows the user to select the COSIM control file spreadsheet and identify the scenario name (which should be the same as the worksheet tab name containing the scenario to be run). Clicking the "Update Model File" button generates a new *RunCOSFate.bat* file that contains the information needed to run COSIM in batch mode. After the batch file has been updated with the desired file and scenario name, the "Run" button can be used to run COSIM. A command prompt window will open and the user can view the model progress through the simulation. Any errors in running the model will be displayed in the command prompt window.

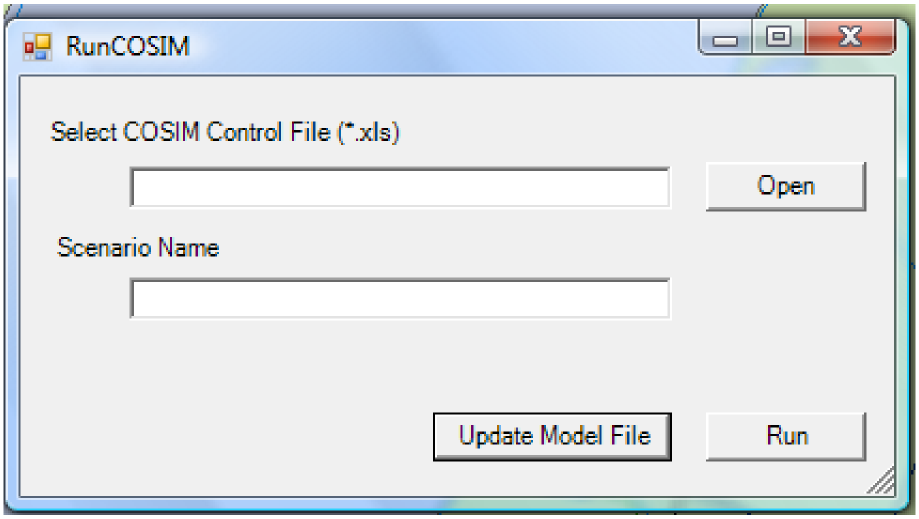

Figure 27: Run COSIM Tool

Spill Output Prep

The "Spill Output Prep" tool allows the user to manipulate the main output database file (*.mdb) produced by COSIM and separate the database into individual databases for each time step of the model simulation for the first 36 hours after a spill. Within the main output database, tables exist that contain information about the surface mass, subsurface concentrations (if this is modeled), mass balance results for the partitioning of the chemical between land, air, water, and the shoreline, and the table "tblAttribute" defining the field names/variables and the data contained within. For example, in the table "tblSurface," the field "C14" represents the mass of benzene in kilograms. Of interest for this research is field "C5" surface mass in kilograms.

This tool requires the user to select the desired .mdb output file, identify the folder location of this database (which also serves as the folder where the new database files for each time step will be stored), assign a scenario name with which to identify the new files (preferably the same as the output scenario name), and then click the "Go" button to perform the splitting procedure (see Figure 28). The listbox is populated with each available time step for selection of the output time step to add to ArcMap, first as an XYEvents layer and then as a points shapefile. Each point represents a discretized mass or concentration within cells above a pre-set threshold in the control file. Anything below that threshold is considered fully dissolved. Clicking on the "Select" button adds the XYEvents layer to the map. Clicking on the "Add shp file" converts the XYEvents layer to a points shapefile and adds it to the map. It is now available for viewing in ArcMap and further manipulation to create concentration contours (see Figure 29). With the form open, the user can select additional times to convert to XYEvents and then shapefiles.

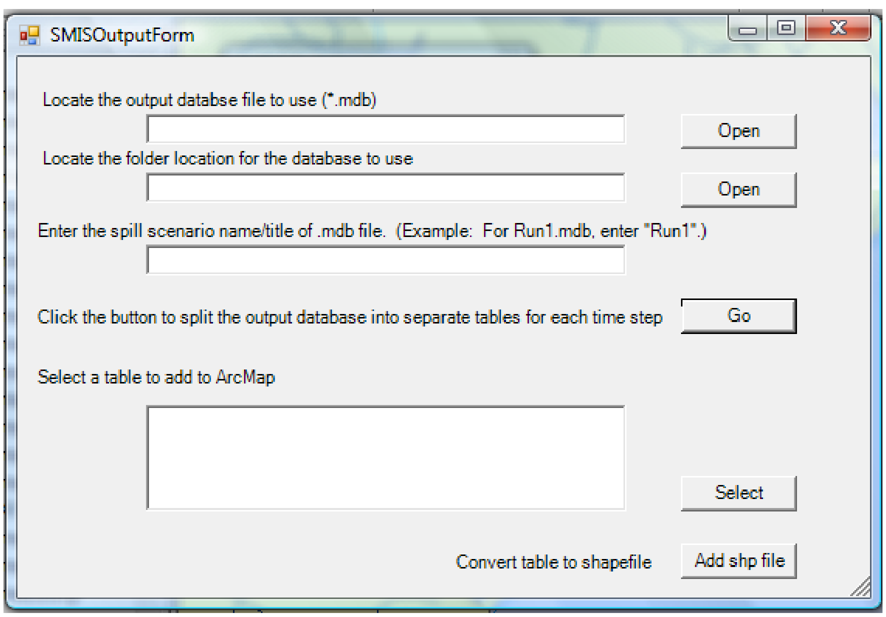

Figure 28: Spill Output Prep Form

Output mdb to shp

The "Output mdb to shp" tool serves as a complement to the "Spill Output Prep" tool. Once the main COSIM output database file has been split into database files for individual time steps, there is no need to repeat the process. In fact, if an individual time step database file exists, the tool will not replace it. Therefore, the "Output mdb to shp" tool can be used to select an individual time step database for conversion to a shapefile to be added to the map. The form used in this process is shown in Figure 30. The user must specify the name and folder location for the new shapefile to be saved. In the "Spill Output Prep" tool, the shapefile is automatically saved to the same folder as the .mdb files.

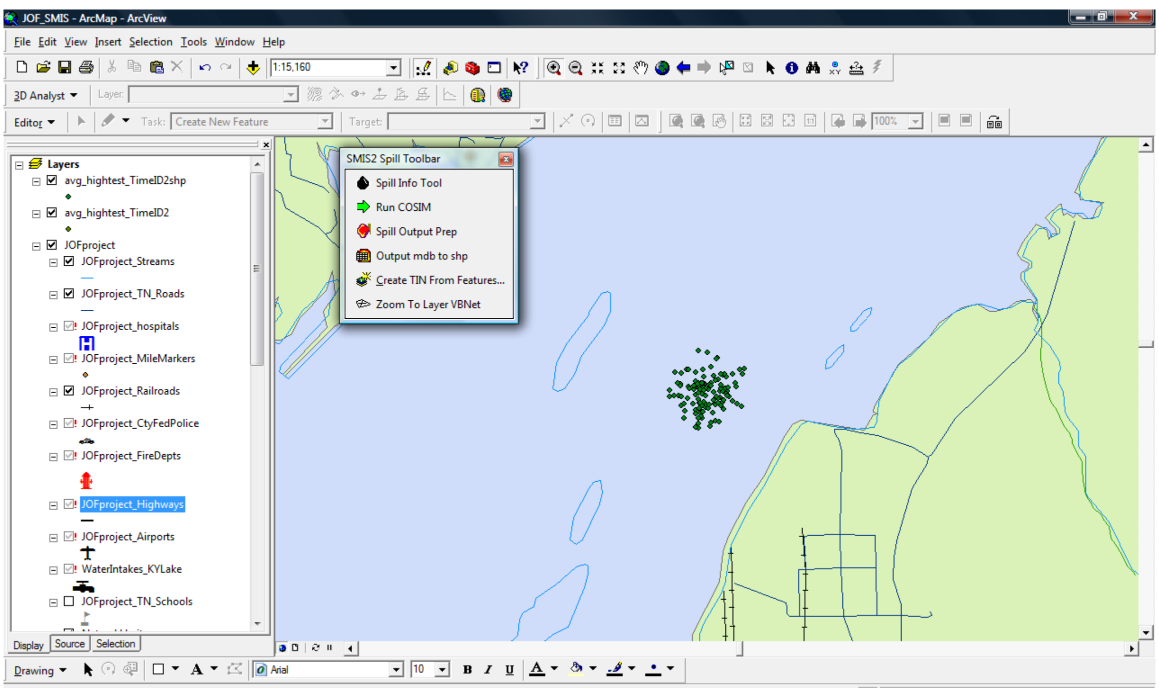

Figure 29: Sample Point Shapefile Resulting From Conversion of COSIM Output Database File

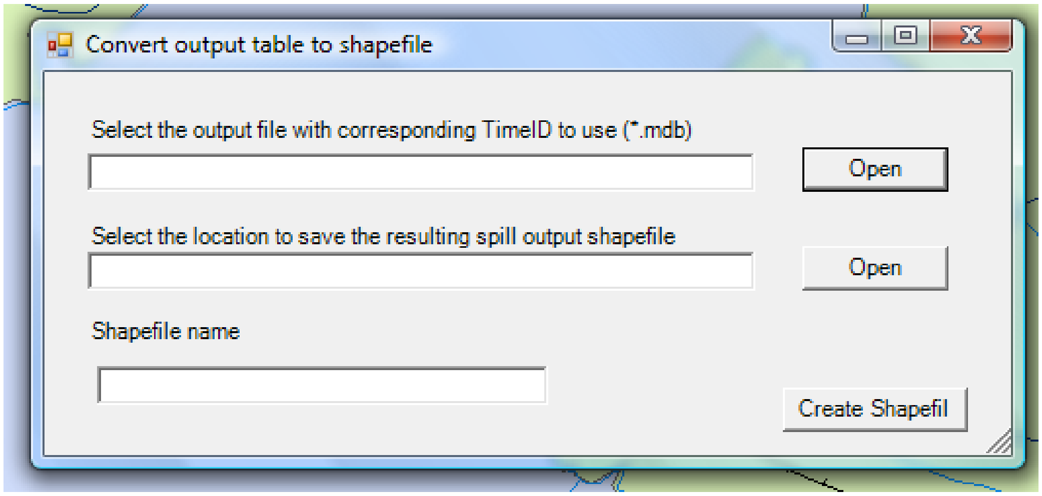

Figure 30: Output mdb to shp Tool Window

Create TIN from Features

The "Create TIN from Features" tool is used to generate contours for the surface concentration point shapefile (Figure 31). This tool is a built-in command for ArcMap when the 3-D Analyst Extension is activated. In this, the user will select the output shapefile of interest, using "C5" as the height source and triangulated as mass points. The variable "C5" in the output table represents the surface mass of all components of the diesel fuel oil. In emergency response situations, the mass and thickness of oil are of interest as opposed to concentration; therefore, mass is presented in the output for oil spill simulations. Within the main output .mdb is a table listing all of the constituents in the output file and their respective field codes. The waterbody shapefile is then selected and triangulated as a hard clip with both height source and tag value fields listed as "none." The resulting tin is given a file name and saved with the option to add it to the map. Triangulating points will cross land masses and thus a hard clip based upon the waterbody outline will remove the resulting polygons over land areas. After the tin is created, the user can right click on the layer and modify the symbology for optimal representation of the contours. The window used for this is shown in Figure 32. This action was not included in the coding due to variation in spill events and concentrations that may occur.

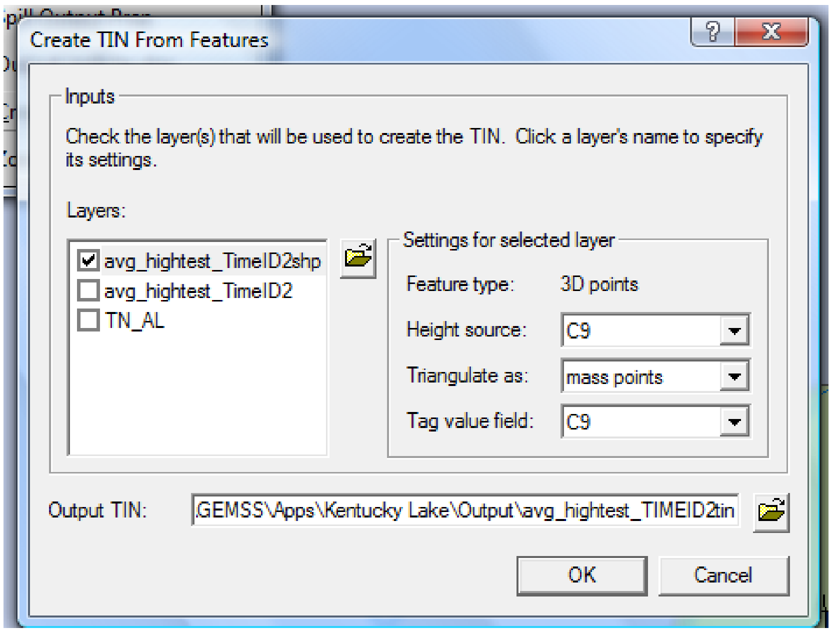

Figure 31: Create TIN from Features Tool

Zoom to Layer VB.Net

"Zoom to Layer" is a command constructed in VB.net. The tool allows the user to quickly zoom to the extent of the layer highlighted in the ArcMap table of contents. If the user wants to focus on the spill layer, then a single click on the spill layer activates it and then clicking on the "Zoom to Layer" tool will redefine the extent of the map. This is a useful feature for viewing a spill plume or response resources (e.g., area hospitals, fire departments, etc.).

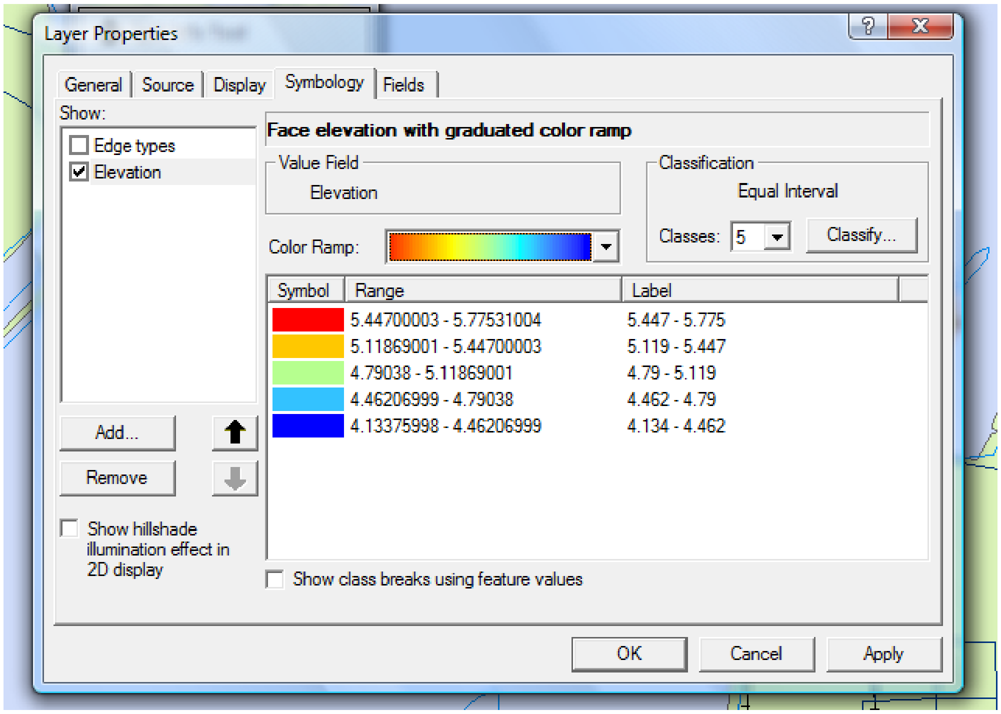

Figure 32: Sample Symbology

Results

For demonstration purposes, an example spill event is considered on Kentucky Lake, which represents a portion of the Tennessee River. The spill was assumed to occur near RM 98 (coordinates: 1380700, 630875.6) at midnight on May 28, 2006. Approximately 500 gallons of diesel fuel was released over 8 hours at a depth of 8.5 meters, which is the water surface as related to the datum of 116 m used in grid generation. SMIS 2.0 was used to input the information to the COSIM spreadsheet and run the model. A simulation time of two days was used to show how the plume would migrate with no response efforts taken. With a release at midnight, it is highly likely that no one would notice the spill prior to daylight (approximately six hours later). By that time, the oil is still being released and the plume may have migrated away from its source. Wind effects were neglected for this scenario.

The resulting tins for 4, 16, 24, and 36 hour time snapshots after the onset of the spill are shown in Figure 33. The initial, early hours would be the most critical times for response personnel to contain the spill. The spill remains in the vicinity of the release during the first 16 hours spreading in all directions, then begins to progress downstream and spread. The average flow in Kentucky Lake at this time is 726.6 m^3/s.

If, for example, a response crew member was injured during deployment of booms or other recovery efforts, locating the nearest hospital would be of interest. Using the spill plume four hours after the initial release as a base, a query in GIS was performed to locate hospitals within a 20-mile range of the spill. The built-in ArcMap tool "Select by Attributes" was used to select features from the hospital layer that were within 20 miles of the spill plume at t = 4. The query resulted in identification of two hospitals meeting this criterion: Benton Community Hospital and Waverly Hospital (see Figure 34). Upon the onset of a spill, the local police, fire departments, hospitals, and other resources can be located and notified. Among the attributes for the local resources in GIS are phone numbers, addresses and, in some cases, a point of contact that can be utilized once the nearby facilities are identified through queries.

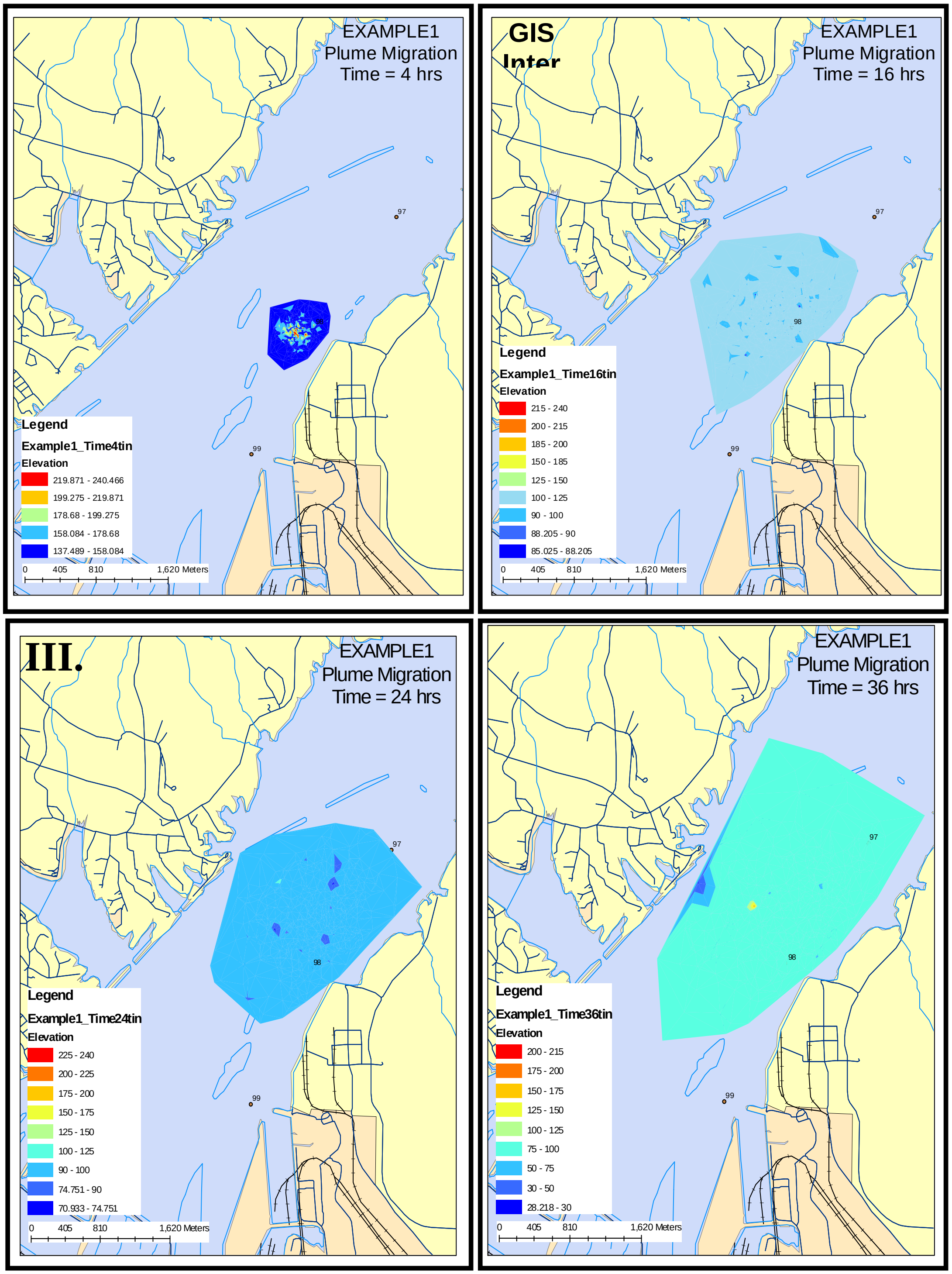

Figure 33: Sample Spill Plumes: Plot I. Time = 4 hours; Plot II. Time = 16 hours; Plot III. Time = 24 hours; Plot IV. Time = 36 hours.

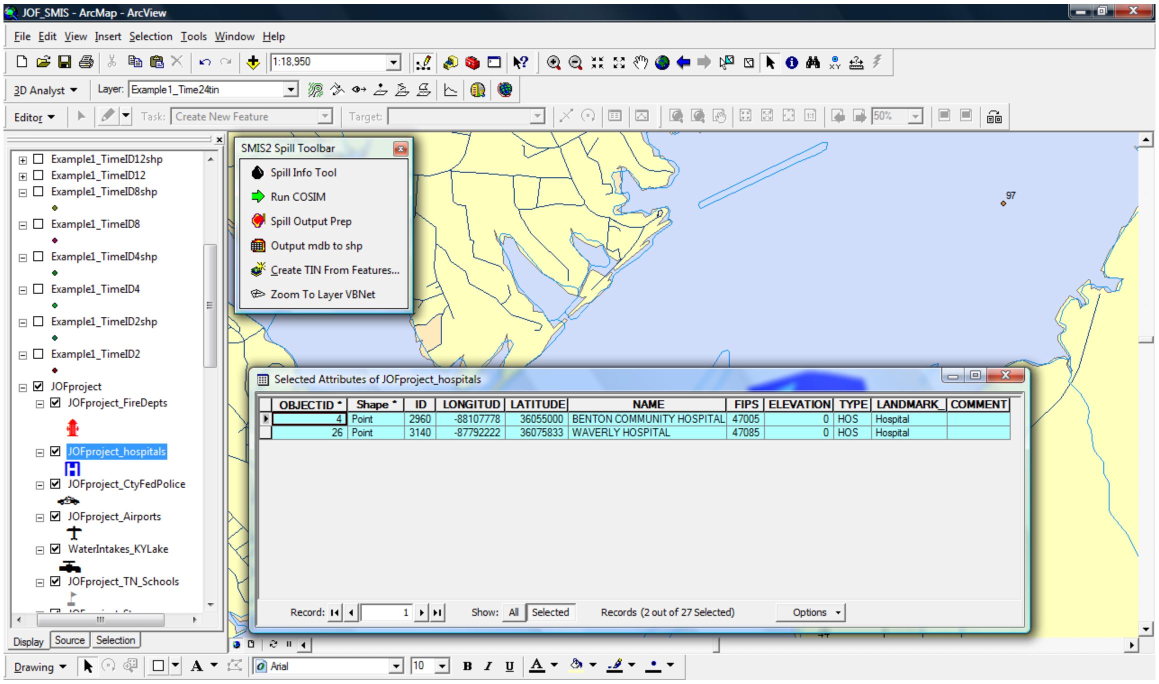

Figure 34: Hospitals within 20 miles of the spill event.

Conclusions

This chapter provided a discussion on development of the next generation technology for spill response assistance on inland waterways, SMIS 2.0. The system combines spatial information management through GIS, advanced hydrodynamic modeling through GLLVHT, and advanced spill modeling through COSIM. Use of this 3-D hydrodynamic model, combined with COSIM, provides more accurate representation of spill plumes when compared to the currently available spill modeling tools, which focus on 1-D or 2-D representations. SMIS 2.0 functionality was created using a combination of VB.net and the ArcGIS Desktop Software Developers Kit.

Through a simple user interface, spill response personnel can input chemical spill release information, identify the input files to be used, run the spill model, and load output in ArcMap for viewing and decision support. Once the output is in ArcMap, queries can be used to locate local emergency response resources for assistance. As a proof-of-concept, SMIS 2.0 was successfully applied to a simulated diesel spill on the Kentucky Lake portion of the Tennessee River, where 10,000 gallons of fuel were spilled.

SMIS 2.0 advances spill response technologies by utilizing 3-D hydrodynamic modeling and advanced spill modeling for more accurate representation of plume migration as opposed to other available inland waterway tools. However, the current system provides only basic, necessary procedures to provide spill response personnel with simple and quick representation of spill plume migration. Additional functionality in future SMIS developments could provide even more assistance, such as creation of tools that allow users to modify the hydrodynamic model inputs to create near real-time flow situations, develop scenarios during a spill event to evaluate the use of booms and response techniques, and creation of animations of spill progression over time.

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CHAPTER VI

A CASE STUDY APPLICATION OF THE ENHANCED SPILL MANAGEMENT INFORMATION SYSTEM (SMIS)

Introduction

Previous work (Chapter III) has shown that spill response and management personnel would benefit from creation of a decision support system that provides advanced modeling technology within a visual framework. Current technologies for spill response assistance include 1-D and 2-D modeling systems such as RiverSpill and ICWater (Samuels, Amstutz et al. 2006), GNOME (Beegle-Krause 2001), and SMIS 1.0 (Martin, LeBoeuf et al. 2004). Many of these models provide rough estimates of spill plume locations often in a geographic information system (GIS) visual environment. However, the representation of plume location is presented as leading edge (Samuels, Amstutz et al. 2006) or in bulk 400-m river segments (Martin, LeBoeuf et al. 2004). Efforts to improve these technologies and move toward a new generation of spill response technology have led to development of Spill Management Information System (SMIS), Version 2.0.

SMIS 2.0 represents a user-friendly, state-of-the-art 3-D hydrodynamic and chemical spill modeling system tool that provides for improved predictive spill fate and transport capability, combined with a geographic information systems (GIS) spatial environment in which to better inform and assist decision support for planning and response activities. Within SMIS 2.0, the 3-D Generalized, Longitudinal-Lateral-Vertical Hydrodynamic and Transport (GLLVHT) model provides hydrodynamic information for contaminant transport modeling through the Chemical/Oil Spill Impact Model (COSIM) (Edinger 2006). Through use of a graphical user interface within ArcMap (Component of ArcView GIS, ESRI, Redlands, CA), SMIS 2.0 enables users to edit the COSIM control file, execute the spill model, and load and format the output for viewing within GIS.

Employment of SMIS 2.0 requires only experience with use of basic GIS tools, thus aiding in more timely and effective spill response. Once the spill model results are placed in ArcMap, simple spatial queries can lead to identification of (i) local emergency response personnel such as hospitals, fire departments, and police within a specified distance of the spill event location; (ii) schools or other sensitive populations (e.g., nursing homes) that may need to be evacuated; (iii) sensitive species that may be impacted within or along the waterway; and (iv) spill response resources such as location of spill response contractors, stores of boom, sources of spill response materials such as home improvement stores, and grocery stores, restaurants, and lodging to support spill response personnel. In addition, using a pre-set template, maps can be produced for printing or display through other means such as screen projection within a spill response operations center, or distributed to spill response personnel in the field through email and/or website postings. SMIS 2.0 can also be used for training and planning of response strategies through development of reasonably foreseeable scenarios. Spill scenario output files can be saved in a common directory and added to ArcMap at any future time.

This chapter focuses on the use of SMIS 2.0 as a decision-support tool by describing its application in a case study of possible spill scenarios occurring near the

Johnsonville, Tennessee fossil fuel electrical generating facility on Kentucky Lake. Three different spill scenarios are considered: (i) an average probable spill, (ii) a maximum probable spill, and (iii) a worst case spill, as defined by the Tennessee Valley Authority (TVA) (Majiros 2007-2009), under varying flow conditions. SMIS 2.0 is used in creation of the scenarios and manipulation of the output for viewing in ArcMap 9.2 (Environmental Systems Research Institute, Redlands, CA). Presentation and comparison among simulation results for each scenario is provided, including a demonstration of querying capabilities within ArcMap to locate nearby schools. Placement of booms on the waterbody to assist with chemical spill recovery and protection measures is also evaluated. Boom interactions are of interest for: (i) developing pre-planned boom placement locations, (ii) evaluating containment and exclusion strategies, and (iii) determining resource needs for typical spill situations. Attributes of COSIM are then demonstrated through presentation and analysis of the effectiveness of boom placement on the waterbody.

SMIS 2.0

As outlined in the system development manuscript (Chapter IV), SMIS 2.0 combines ArcMap 9.2 (ESRI, Redlands, California, USA), with Generalized Environmental Modeling System for Surface Waters (GEMSS) and COSIM modeling for enhanced spill response support. GEMSS contains multiple hydrodynamic models that can be used to provide water velocity information for COSIM spill modeling. The 3-D GLLVHT model was selected for use in SMIS 2.0 to enable advanced (3-D) hydrodynamic modeling for more accurate representation of flow characteristics in a waterbody that may impact spill plume migration. A diagram of the components involved and the corresponding SMIS 2.0 toolbar are shown in Figures 35 and 36, respectively.

COSIM is capable of modeling numerous chemical constituents including BTEX hydrocarbons and its chemical components (ERM 1994; Edinger 2006). In this application, a diesel fuel spill is simulated. In addition, COSIM can simulate many physical and chemical interactions between the spilled chemical and the environment, including advection, dispersion, biodegradation, and evaporation (Edinger 2006). Wind effects in the x- and y-directions on the water body hydrodynamics and plume migration are considered to be either all on or all off.

Case Study Area

The Tennessee River represents a major navigation pathway for barge traffic, carrying steel, chemicals, petroleum products and ores, connecting the southeastern United States region with the Ohio and Mississippi rivers. Due to its size, location and amount of barge traffic, Kentucky Lake, which comprises 184 miles of the Tennessee River situated west of Nashville, Tennessee, was chosen as the focus area for this study. Furthermore, with its large navigation capacity, Kentucky Lake is highly susceptible to accidents which could result in chemical spillage.

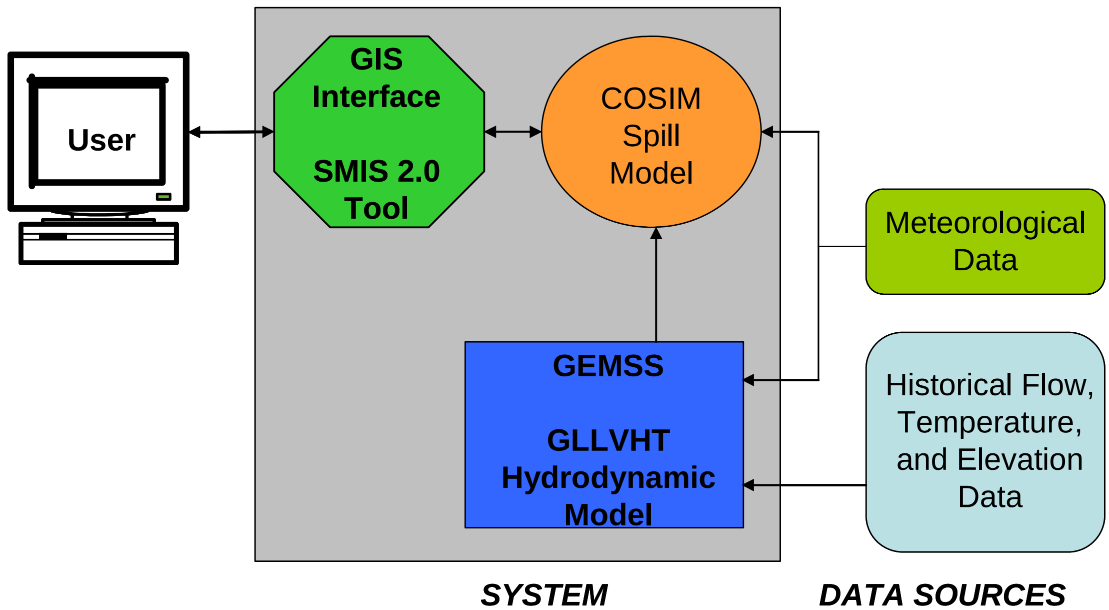

Figure 35: System diagram.

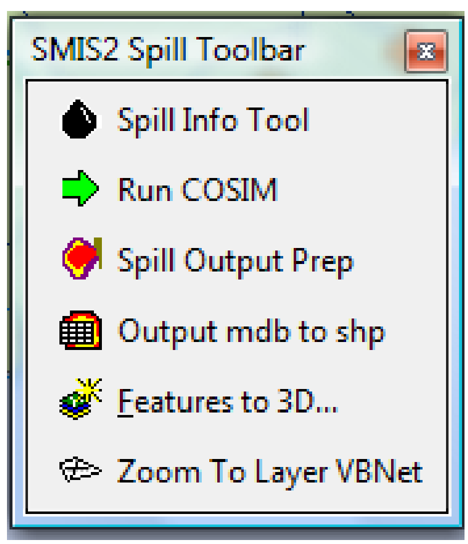

Figure 36: SMIS 2.0 system toolbar.

The lake area is bound on the upstream end by Pickwick Dam at River Mile (RM) 202.3 and downstream by Kentucky Lake (RM 22.4); both managed by the Tennessee Valley Authority (TVA) (see Figure 37). At normal operating level, the lake covers approximately 160,300 acres (Lubbers 2007; KLProductions 2009). This includes tributaries such as the Duck and Big Sandy rivers, and a man-made canal linking Kentucky Lake to the Cumberland River.

The river is narrow and sinuous downstream of Pickwick Dam before opening to a wide and deep reservoir behind Kentucky Dam, which serves as a sink for sediments, nutrients, and possible pollutants such as metals and organic compounds (Kingsbury, Hoos et al. 1999). The depth of the river ranges from 8.3 meters (elevation 353.4 ft) at the tail waters of Pickwick Dam to 25.6 meters (elevation of 296.6 ft) at Kentucky Dam. The average flow in 2006 was 1,033 m^3/s for Pickwick Dam and 1,074 m^3/s for Kentucky Dam (TVA 2006).

Study Approach

The project area boundary for GIS reference layers includes counties adjacent to the Tennessee River between the Pickwick and Kentucky dams. Base layers for counties, cities, and landmarks were obtained from U.S. Tiger Files (USCB 2005). The shapefiles for highways, streams, bridges, and other transportation features were obtained through the National Transportation Bureau data clearinghouse (BTS 2008). A national fire department shapefile was created using fire department addresses from the National Fire Department Census (USFA 2008) and address matching the locations. Both the layers for schools and police/sheriff departments were developed by using online Yellow Pages (Yellowpages.com LLC, AT&T, 2008) and local online searches for each county included in the study area. Sensitive species information and addresses of subcontractors who provide response and clean-up equipment were provided by TVA (TVA 2006;

Majiros 2007-2009). An example map view of the GIS reference layers is shown in Figure 38.

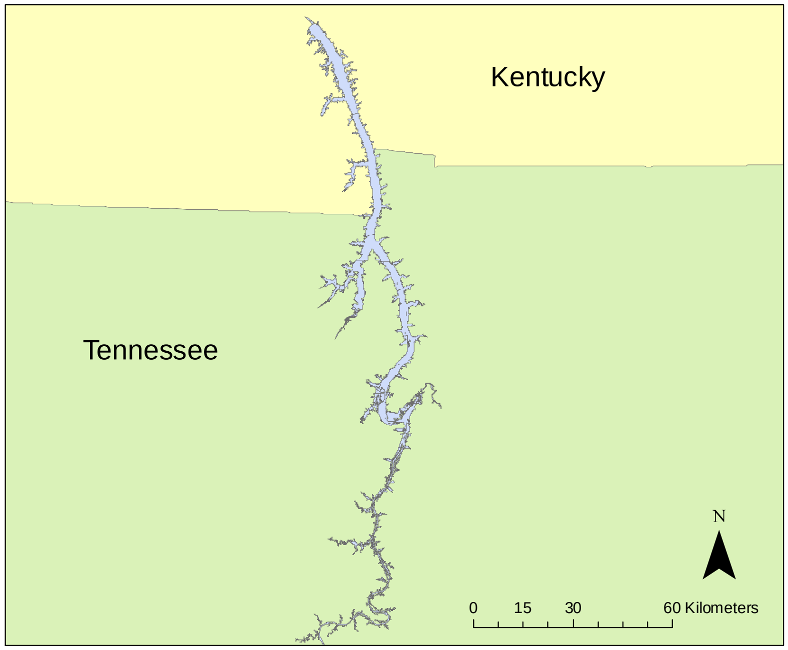

Figure 37: Kentucky lake project area.

Hydrodynamic Modeling with GLLVHT

River flow data for 2006 was employed as a base case since this annual data represented typical flow conditions for Kentucky Lake (Hadjerioua 2007-2009). Supplied data sets included flows, temperatures, and tailwater elevations of Pickwick Dam, headwater elevation with temperatures and flows from Kentucky Dam as well as data for Barkley Canal and the Johnsonville Fossil Fuel Plant (JOF), located at RM 99 on Kentucky Lake (TVA 2006). Barkley Canal, located near RM 25.0 just upstream of Kentucky Dam, links Lake Barkley on the Cumberland River with Kentucky Lake on the Tennessee River. Depending on the elevation difference between the two lakes, the water exchange between Kentucky Lake and Barkley Canal may be flowing to or from the canal at a given time. JOF, which is operated by TVA, withdraws water for cooling and then discharges it back into Kentucky Lake. Flows for Barkley Canal and flows and water temperatures for the intake and discharge for JOF were provided by TVA (TVA 2006). Spill scenarios were established for periods of high, low, and average flows during the year, which arre then used by GEMMS for spill forecasting. Bathymetric data was obtained from both the TVA and the U.S. Army Corps of Engineers (USACE). The data from USACE was collected in the mid 1990's using an electronic echo-depth sounding device(Gregory 2008-2009). GEMSS's grid generation tool (GridGEN) was employed to create the hydrodynamic grid (see Chapter IV). Meteorological data was obtained from the U.S. Climatic Data Center records for the Nashville, Tennessee Airport (BNA) (NCDC 2008). Additional details on how this information was prepared and employed as input files to GEMMS are provided in Chapter IV.

The Kentucky Lake watershed comprises a very large region that encompasses many tributaries to the Tennessee River existing as either small streams or rivers. Tributaries with significant watershed areas contributing to flow into Kentucky Lake were identified using the Watershed Modeling System (WMS 8.1) developed by Environmental Modeling Systems, Inc., (Salt Lake City, Utah). Two tributaries were considered significant based on drainage area compared to the total drainage area for Kentucky Lake. Both the Duck River (RM 110.0) and Big Sandy River (RM 67.0) were identified as such because each represented greater than 1% of the total drainage area for Kentucky Lake. Flow data for these rivers were obtained from US Geological Survey (USGS) records (USGS 2008; USGSa 2008).

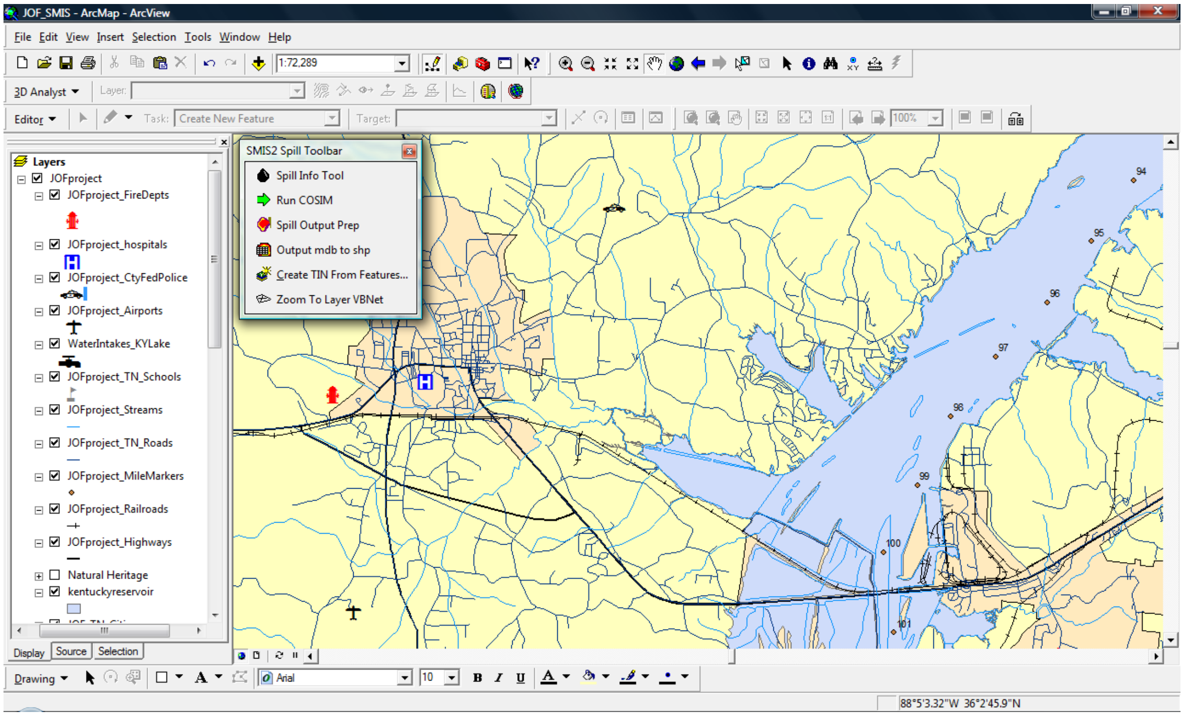

Figure 38: Sample of Kentucky Lake project GIS layers. Items shown include a fire department, police department, hospital, an airport, the Tennessee River, railroads and highways, and river mile markers.

The GLLVHT hydrodynamic model was calibrated for both high and low flow conditions through use of the model's Head Correction tool (see Chapter IV), which calculates the amount of distributed flow required to close the difference between the model's estimated elevation and the measured elevation at a specified point. The elevation at Kentucky Dam was used as the calibration point. Sensitivity analysis was performed on the Chezy coefficient, the location of cells to which the distributed flow was applied, and the frequency of the Head Correction calculations. Calibration and sensitivity analysis efforts resulted in modeled elevation at Kentucky Dam within 0.3% of the measured elevation for the entire year.

COSIM Set-Up

Among the activities required in setting up COSIM are creation of a rectilinear spill grid (*.osg) for use in the COSIM model and preparing the shoreline characteristics data (if used). This spill grid overlays the hydrodynamic grid created in GEMSS for use with GLLVHT. The following discussion describes the various spill scenarios considered in this study, and set up of COSIM inputs not included as part of the GLLVHT model.

Three spill scenarios were evaluated (as recommended by TVA), each involving leakage of diesel fuel on or adjacent to the waterway during a barge fuel unloading operation (see Table 13). Since each of the scenarios represents a different amount of diesel fuel spilled for a different release duration, a fourth scenario was considered for comparison. This included the same spill amount as the "Worst Case" scenario (68,200 gallons) and an eight-hour release duration similar to the "Average Probable" spill scenario, titled "Worst 8 Hour Spill."

Table 13: Spill Scenarios

Scenario	Amount (gallons)	Time to Discover (min)	Time to Stop (min)	Flow Rate (gpm)	Additional Spillage (gallons)
Average Probable	500	480	5	1	-
Maximum Probable	3,200	30	5	85	225
Worst Case	68,200	5	15	3400	225

Each of the three original scenarios were evaluated for three different flow conditions (low, average, and high flow), so that altogether nine different cases were evaluated. For the year 2006, a low flow period was determined to begin on 30 March with an average flow of 416 m^3/s over a three day period. The average flow simulation period began on 12 April with an average flow rate of 1,354 m^3/s over a three day period. The high flow period began on 18 November with a three-day average flow of 2,548 m^3/s. The "Worst 8 Hour Spill" was evaluated at average flow for comparative purposes.

Spill Grid

The spill grid was established in much the same manner as the grid for the hydrodynamic model in GEMSS. The main difference is that the grid is rectilinear instead of orthogonal, curvilinear, and must cover the entire area of interest (including shoreline), not just the waterbody region. Due to the size of Kentucky Lake and computational requirements of the spill model, it was deemed impractical to capture the entire region with a single grid without the use of very large grid cells with widths similar to the width of the river (an obviously undesirable condition for spill modeling). Smaller spill grids were thus employed, with defined areas for their use. The spill grid for the scenarios under consideration here ranged from river mile (RM) RM 112 to RM 65 and was 100 cells by 100 cells. Each cell covers 1,520 m x 1,980 m (see Figure 39).

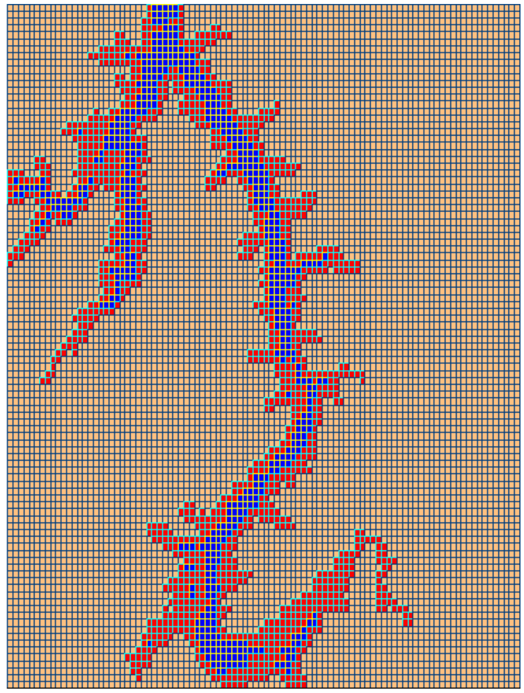

Figure 39: Spill Grid for Kentucky Lake RM 112 to RM 65.

Shoreline Classification

COSIM allows for modeling the amount of oil adhered to the shoreline of the waterbody; therefore, the bank area material type must be defined. This is done either by designating the shoreline as 100% reflective, 100% sorptive, or using ESI shoreline classification codes (Jensen, Ramsey et al. 1990). Selection of the shoreline classification is done in the “Spill Information Tool” within SMIS 2.0. If the ESI Code option is chosen, a spill classification file is required. For the case study, due to lack of soil classification information for the region, a shoreline classification code of four was used, representing sand.

SMIS 2.0 Application to Spill Scenarios

The front-end GIS-to-COSIM interface tool, known as the "Spill Info Tool", was used to edit the COSIM control file. The spill location was identified by clicking on the map. Here, the spill was assumed to occur at latitude 130700.00 and longitude 630875.60 (1983 NAD Tennessee State Plane Feet). Output file names created using this tool included the scenario name and flow level (e.g., avg_lowflow, worst_highflow) as part of the file path to assist in data management. Next, the "RunCOSIM" tool (green arrow) was used to run COSIM in batch mode for each scenario.

The "Spill Output Prep" tool was used to manipulate the main output database file (*.mdb) produced by COSIM and separate the information into individual databases for each time step of the model simulation for the first 36 hours after a spill. Times of 2, 4, 12, and 24 hours after the spill were selected for conversion, first to XYEvent layers and then to shapefiles for each scenario.

The "Create TIN from Features" tool was used to generate contours for the surface mass point shapefiles. This tool is a built-in command for ArcMap when the 3-D Analyst Extension is activated. In this, the field "C5", representing surface mass in kilograms, was used as the height source and triangulated as mass points. The resulting tin was assigned a file name, saved, and added to the map. The tin symbology was modified for optimal representation of the contours.

Spill Scenario Results

Results of the nine spill simulations representing the three scenarios at each of three flow levels are presented in Table 15, shown as the maximum surface mass in kilograms and maximum length of the plume at 24 hours. Plots representing 2, 4, 12, and 24 hours after the initial spill release for the three scenarios at average flow rates are also provided (see Figures 40 through 42). Additional plots for scenarios at low and high flows are presented in Appendix F.

The average probable spill represents the smallest quantity of oil released over the simulation period. For the average probable spill under average flow conditions, the mass on the surface ranges from 2.912 to 5.313 kilograms in the first 12 hours. As expected, the surface mass decreases as the plume spreads and degradation processes take place. Within 24 hours, the plume spreads approximately 4,054 m from its source. The area covered by the plume at 24 hours after the spill is 5.6 km^2. The plots for each time considered are shown in Figure 40.

Spill plots for the maximum probable spill scenario for the four selected times are shown in Figure 41. Compared to the average probable spill, the maximum probable spill represents six times the amount of diesel fuel released in a sixteenth of the time. Surprisingly, the plume is not much larger than the average probable spill or the worst case scenario for low flow conditions, but it exceeds both spill scenarios for average and high flow conditions. For all flow conditions, the maximum probable spill has a lower surface mass. The fuel oil on the surface drops from 2.60 kg to 1.27 kg in the first 24 hours after the spill began. With the short release time, there is no continued source to supply the plume and therefore the amount of oil on the surface is reduced by dispersion and possible volatilization effects.

The worst case scenario presents a spill of very large quantity (68,200 gallons) released over approximately 20 minutes (see Figure 42). As expected, the plume possesses very high masses compared to the other scenarios. While the spill amount is 20 times greater than for the maximum probable spill, the mass observed on the surface is only greater by a factor of 15. Similar to the maximum probable spill, the source does not sustain the spill, but the high mass takes longer to dissipate.

Oil reactions and spill plume spread have been found to be a function of the thickness of the oil, which is proportional to the surface mass (Reed, Johansen et al. 1999). The large quantity of oil spilled may in fact lead to reduced dispersion and evaporation effects. Thicker oil slicks are easier to skim off the surface with weir skimmers (Hammoud 2006). While it may seem counterintuitive, a larger spill may be easier to clean up in terms of percent of spill recovered due to the reduced spread and improved recovery with booms and skimmers.

As an additional consideration, the "Worst Case 8 Hour Spill" was evaluated at average flow, representing a spill of 68,200 gallons over an eight-hour period. The plume plots are provided in Figure 43. The continued release of approximately eight hours leads to much higher masses on the surface under these conditions than for any other scenario considered. The maximum plume length and area, however, are similar to that observed in both the average probable spill and worst case spill at average flow, but with a small increase. As expected, one could conclude that the spread of the oil is primarily a function of flow in the waterbody.

Table 14: Summary of spill scenario results.

	Flow Level		
Scenario	***Low***	***Average***	***High***
Average Probable (500 gal/485 min)			
Maximum surface mass (kg)	11.14	9.74	10.76
Maximum plume length (m)	2215	4013	6500
Plume area at 24 hours (km^2)	3.086	5.641	8.367
Maximum Probable (3,200 gal/35 min)			
Maximum surface mass (kg)	3.126	2.6	2.98
Maximum plume length (m)	2835	4297	7254
Plume area at 24 hours (km^2)	4.115	6.238	9.27
Worst Case (62,800 gal/20 min)			
Maximum surface mass (kg)	47.56	40.04	43.86
Maximum plume length (m)	3204	3710	6307
Plume area at 24 hours (km^2)	4.574	5.49	8.499
Worst Case 8 hr (62,800 gal/485 min)			
Maximum surface mass (kg)	-	1648	-
Maximum plume length (m)	-	4119	-
Plume area at 24 hours (km^2)	-	5.92	-

Querying Capabilities

As mentioned previously, one added benefit of using GIS as a fundamental component of SMIS 2.0 is the ability to perform spatial queries. The average probable scenario with average flow at hour two was used to demonstrate this functionality. In this instance, a query was made to identify the locations of schools within 25 miles of the spill plume. School gymnasiums may be used as command centers during a spill event if they are in relatively close proximity. Twelve schools are located within 25 miles of the average plume two hours after the release (see Figure 44). Among these are five elementary schools, three middle schools, three high schools and one K-12 school. The attributes for the GIS layer for schools include the school address, principal name, email (if available), and phone number. This information could be highly useful during a spill event, especially for highly volatile and hazardous chemical spills where schools may need to be locked down to minimize exposure to volatilized gases.

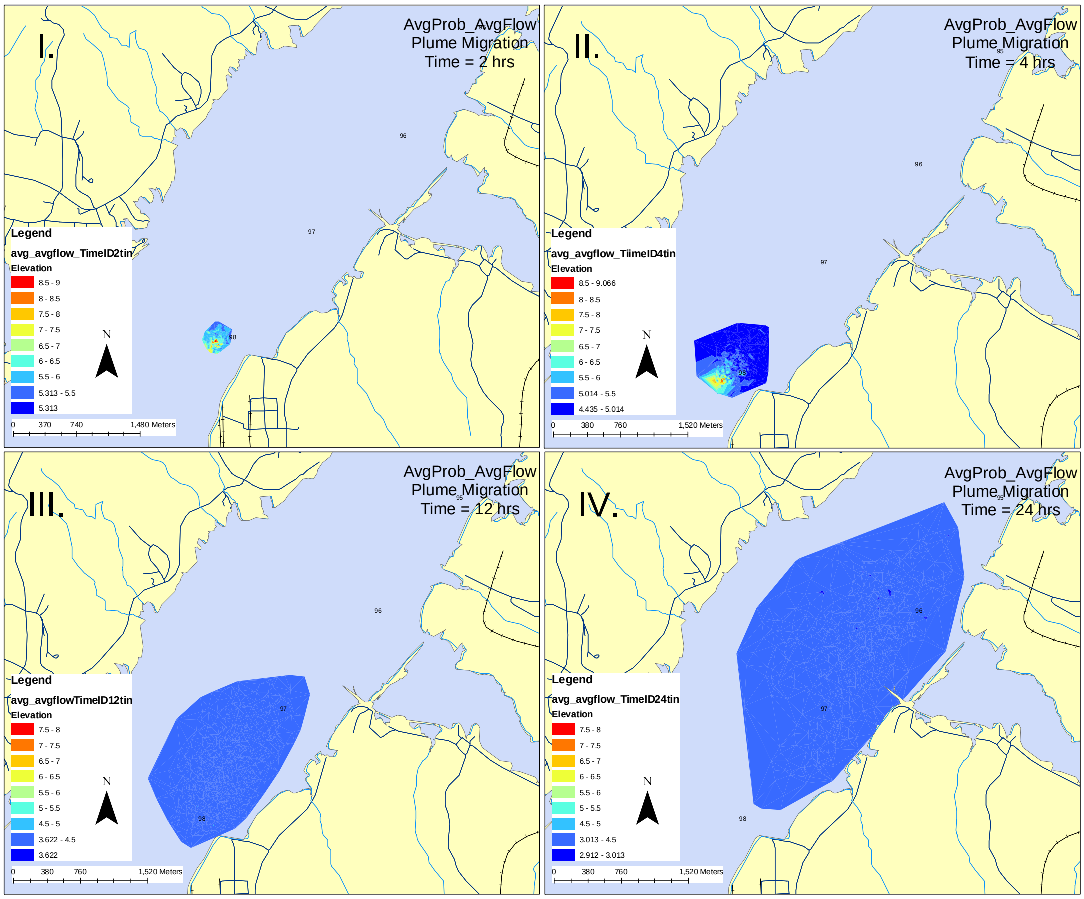

Figure 40: Average probability, average flow scenario plots at t = 2, 4, 12, and 24 hours after spill.

Similar queries can be performed to locate water intakes, fire departments, police stations, hospitals, sensitive species, and airports. The possibilities are limited only to the amount of available spatial information that can be represented as reference layers in GIS. Maintenance of the GIS reference layers with up-to-date information is important, however, to ensure accuracy and usefulness during a spill event.

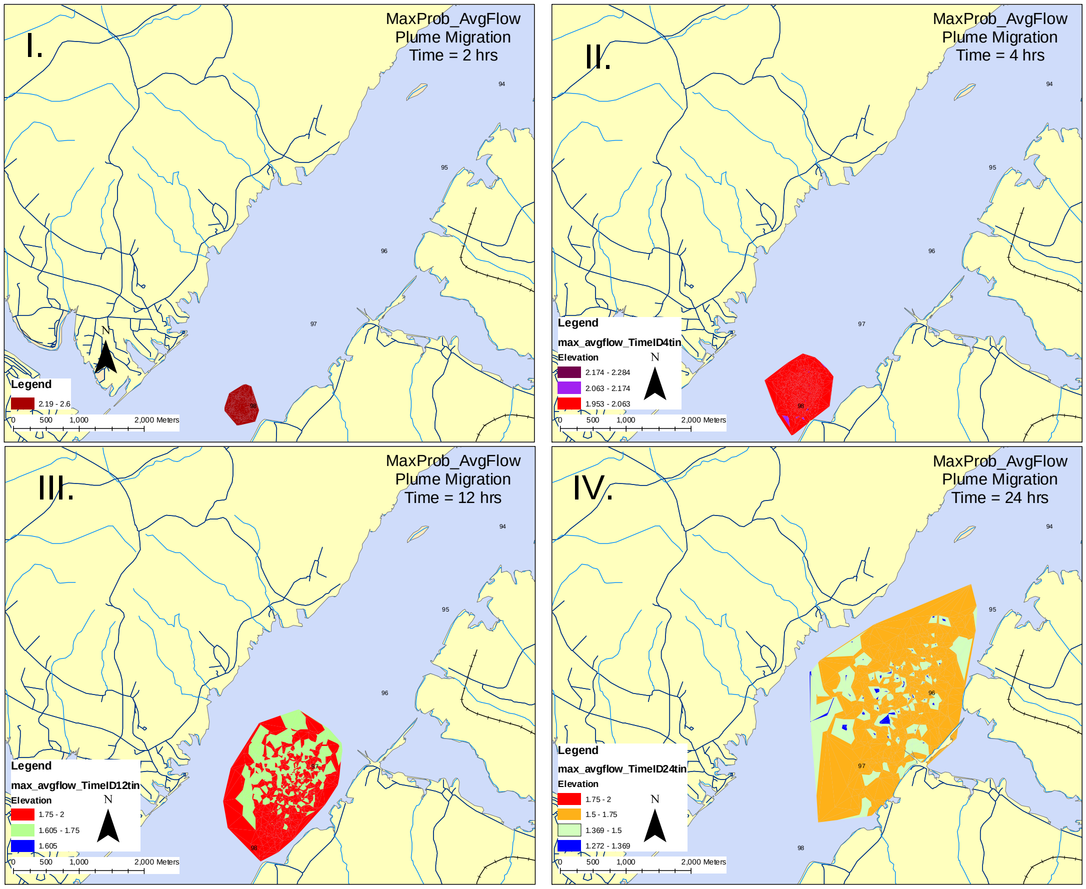

Figure 41: Maximum probable, average flow scenario plots for t = 2, 4, 12, and 24 hours after spill.

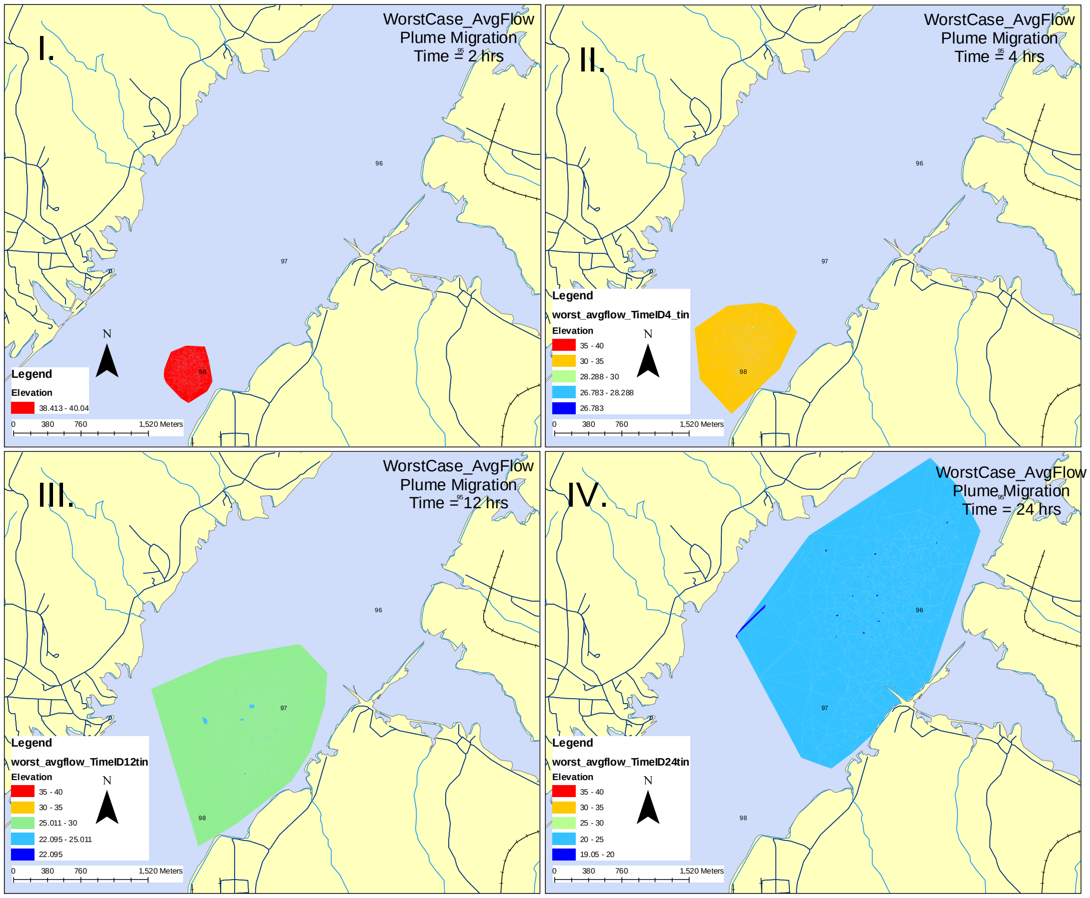

Figure 42: Worst case, average flow scenario plots at t = 2, 4, 12, 24 hours after spill.

Other Considerations

An additional feature of COSIM modeling, not presently included as an automated function in SMIS 2.0, is the ability to model the effects of remediation and recovery efforts. For demonstration purposes, the worst case scenario under high flow conditions was modeled with booms deployed at seemingly strategic locations in an attempt to contain a portion of the plume. Figure 45 shows the migration of the plume under normal conditions (Part I) and with a boom deployed (Part II) at 12 hours after the release. As shown, the boom contains a portion of the spill.

It is obvious that adding boom deployment functionality to SMIS 2.0 would be of great benefit during spill response efforts to gauge the effectiveness of containment and exclusion activities. Currently, the boom simulations require the user to create the boom in GIS and then convert points outlining the boom into a spatially-referenced, comma-delimited text file for use in COSIM.

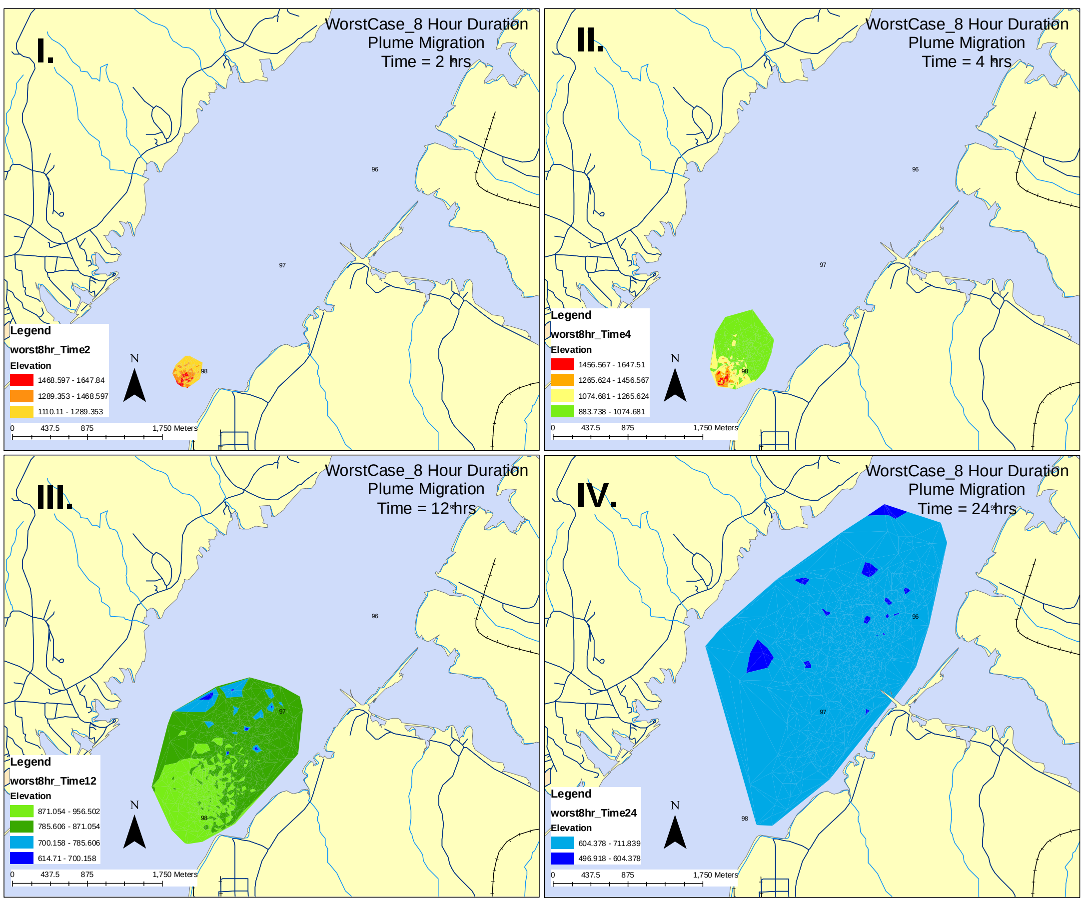

Figure 43: Worst case spill with an eight-hour duration at average flow conditions.

Selected Attributes of JOFproject_TN_Schools

F_STATE	F_TITLE	F_STATUS	F_ADDRESS	F_CITY	F_ZIPCODE	F_PHONE1
TN	Principal: Elaine Hewitt	A	6500 State Route 13 South	Erin	37061	(931) 289-3127
TN	Principal: Linda McDonough	A	2500 State Route 149	Erin	37061	(931) 289-5525
TN	Principal: David Bell	A	2500 State Route 149	Erin	37061	(931) 289-4447
TN	Principal: Sylvia Vinson	A	3460 West Main Street	Erin	37061	(931) 289-5591
TN	Principal: Eric Lomax	A	196 East Fourth Ave	Lobelville	37097	(931) 593-2354
TN	Principal: Jerry Honea	A	335 Melrose Street	McEwen	37101	(931) 582-6913
TN	Principal: Terry Coleman	A	365 Melrose Street	Mc Ewen	37101	(931) 582-8417
TN	Principal: Miss Vicki Spann	A	220 Swift Street East	Mc Ewen	37101	(931) 582-6913
TN	Principal: Judy Stephan	A	135 School ST	Tenn Ridge	37178	(931) 721-3780
TN	Principal: Mike Bell	A	13305 Highway 69 A	Big Sandy	38221	(731) 593-3221
TN	Principal: Marty Arnold	A	148 Stokes Road	Holladay	38341	(731) 584-6874
TN	Principal: Chris Villaflor	A	2740 Hwy 641 South	Parsons	38363	(731) 847-6510

Record: 12 Show: All Selected Records (12 out of 37 Selected) Options

Figure 44: Query results for schools within 25 miles of the spill.

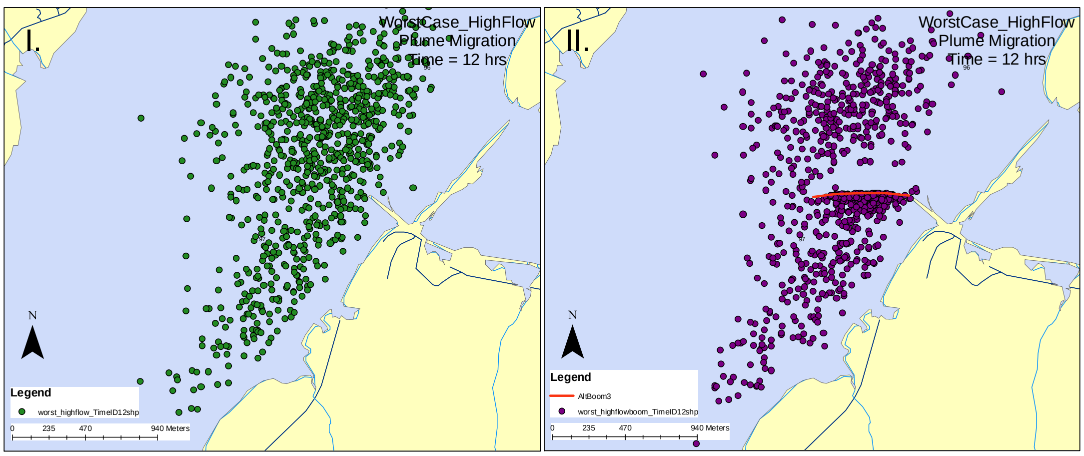

Figure 45: Comparison of worst case scenario with and without boom deployment at t = 12 hours.

Other features of COSIM include the ability to track the distribution of the released chemical in different phases and identify impacted shoreline areas. These are currently not options in SMIS 2.0. Figure 46 shows the output for both shoreline impact and a bar chart for the distribution of the diesel fuel into separate phases for the average probable spill at average flow twelve hours after the release. In the figure, darkened spill grid cells identify the shoreline areas where diesel fuel may be adsorbed. Using the output database table “tblMassBalance,” the distribution of diesel fuel for each of the three scenarios at 2, 12, and 24 hours after the release were obtained. The distribution of

TCE between phases 12 hours after the release was also evaluated. The resulting distributions for both substances are presented in Table 16. Figure 47 shows the distribution of diesel fuel for each of the three spill scenarios at average flow twelve hours after the initial release. For all scenarios, the majority of the fuel has been volatilized at this time and only a small amount has migrated into the subsurface/water column through dissolution. In all cases, at least 20% remains on the surface. Therefore, efforts to contain/recover the fuel at this time are limited because most of the fuel has been volatilized, adsorbed to the shoreline, or mixed in the water column.

The current version of SMIS only provides tools for evaluation of diesel fuel/oils on the surface. However, COSIM can be used to predict concentrations of other chemicals both on the surface and within the water column. To demonstrate this, two techniques were employed. First, a separate chemical spill simulation was performed to model the release of trichloroethylene (TCE) under average flow conditions (3,200 gallons released over 35 minutes). Due to its chemical properties, TCE is more likely to mix in the water column and be dispersed than to float on the surface. Therefore, the surface results only show the initial release and nothing exists after the first time step. Within the output database created by COSIM, the "tblSubSurface" contains information about the concentrations of chemicals within the water column. This is also available for oil/diesel fuel, but only the water soluble fractions of the fuel are available for analysis. The chemical concentrations can be used similar to the surface mass plots; however, the depth of the concentrations is not represented well in 2-D, which limits the ability to discern the true location of the contaminants (e.g., with respect to water intakes or sensitive species below the surface). Secondly, to provide better representation of the true location of the subsurface concentrations, ArcScene (ESRI, Redlands, CA) was used to plot the subsurface concentrations for hexane (as representative of the oil spill) (see Figure 48) and TCE (see Figure 49).

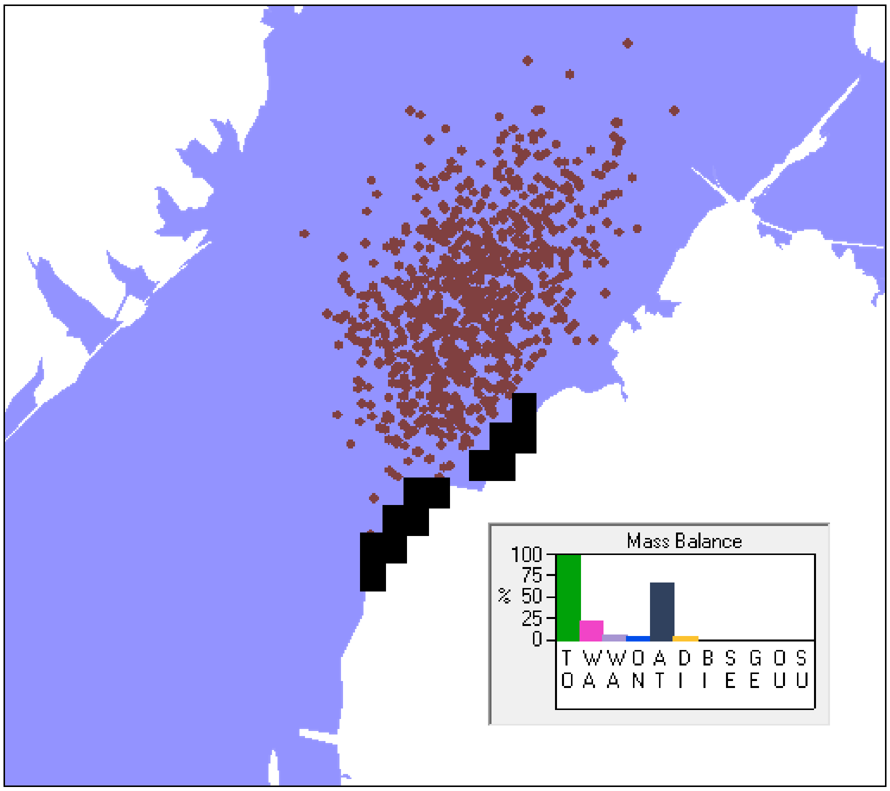

Figure 46: Example of mass balance and impacted shoreline display at t = 12 for average probable spill at average flow. Black rectangles indicate impacted shoreline. The bars in the mass balance chart represent from left to right: total amount, water surface, water column, on shore, atmosphere, dissolution, biodegradation, and sediments.

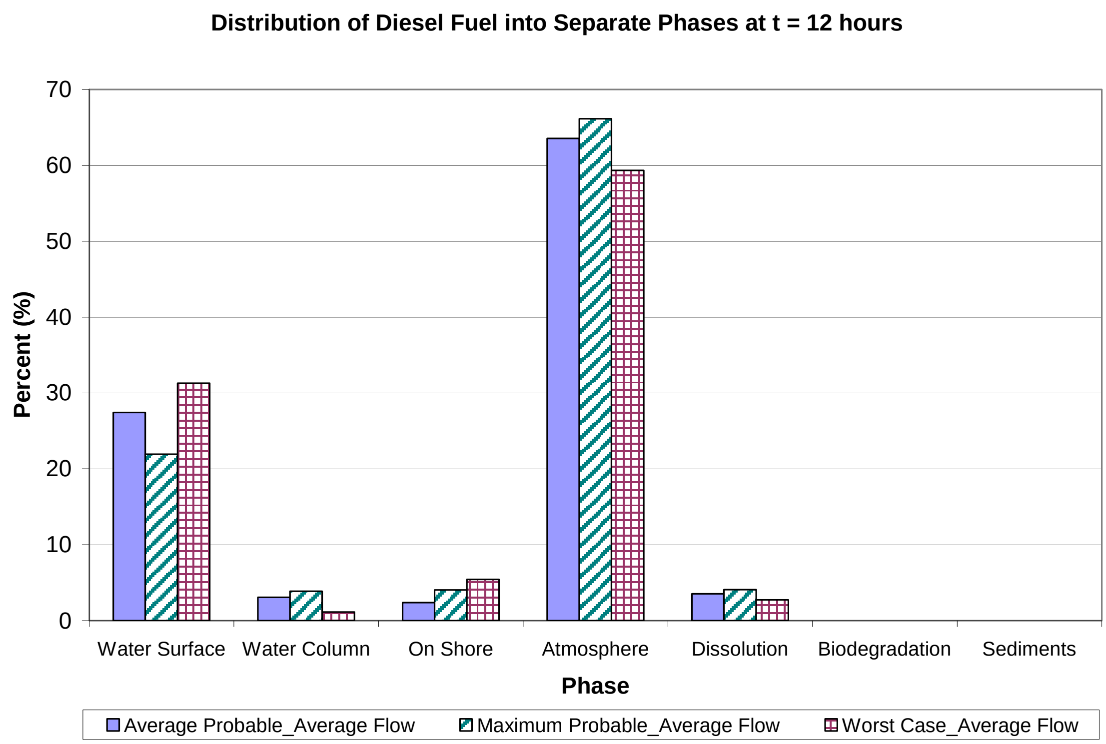

Figure 47: Comparison of diesel fuel distributions for the three spill scenarios at average flow 12 hours after the initial release.

Both chemicals are plotted at hour 12 after the spill release and a range of colors were used to indicate the concentration of model output points. A long narrow vertical tube represents a water intake to demonstrate decision support capabilities of SMIS 2.0. For the diesel fuel spill, hexane is located primarily near the surface and surrounds the water intake at t = 12 hours. The maximum concentration (percent by weight) presented as grams solute/100 grams solvent (gms) at this time is 1.31×10^{-2} gms. The maximum concentration of TCE is 19,791 gms after 12 hours. The area covered by TCE is only slightly larger, but the concentration is much higher.

Table 15: Mass balance distribution for diesel fuel for three spill scenarios at average flow (t = 2, 12, and 24 hours).

	Diesel Fuel		
Distribution as Percentages of Total Mass Released	**Average Probable - Average Flow**	**Maximum Probable - Average Flow**	**Worst Case - Average Flow**
At t = 2 hours			
Water Surface	50.439	41.884	56.96
Water Column	0	0.1676	0
On Shore	0	0	0
Atmosphere	48.619	55.866	42.69
Dissolution	0.939	2.075	0.338
Biodegradation	0	0	0
Sediments	0	0	0
At t = 12 hours			
Water Surface	27.433	21.948	31.283
Water Column	3.082	3.872	1.152
On Shore	2.361	4.028	5.451
Atmosphere	63.534	66.141	59.348
Dissolution	3.545	4.0945	2.724
Biodegradation	0	0	0
Sediments	0	0	0
At t = 24 hours			
Water Surface	18.66	15.332	20.8765
Water Column	2.136	2.493	0.933
On Shore	6.117	7.879	8.938
Atmosphere	68.238	69.188	65.8042
Dissolution	4.631	5.228	3.4028
Biodegradation	0	0	0
Sediments	0	0	0
	TCE		
At t = 12 hours			
Water Surface	-	3.89	-
Water Column	-	47.071	-
On Shore	-	0	-
Atmosphere	-	0.002	-
Dissolution	-	47.018	-
Biodegradation	-	0.0197	-
Sediments	-	0.002	-

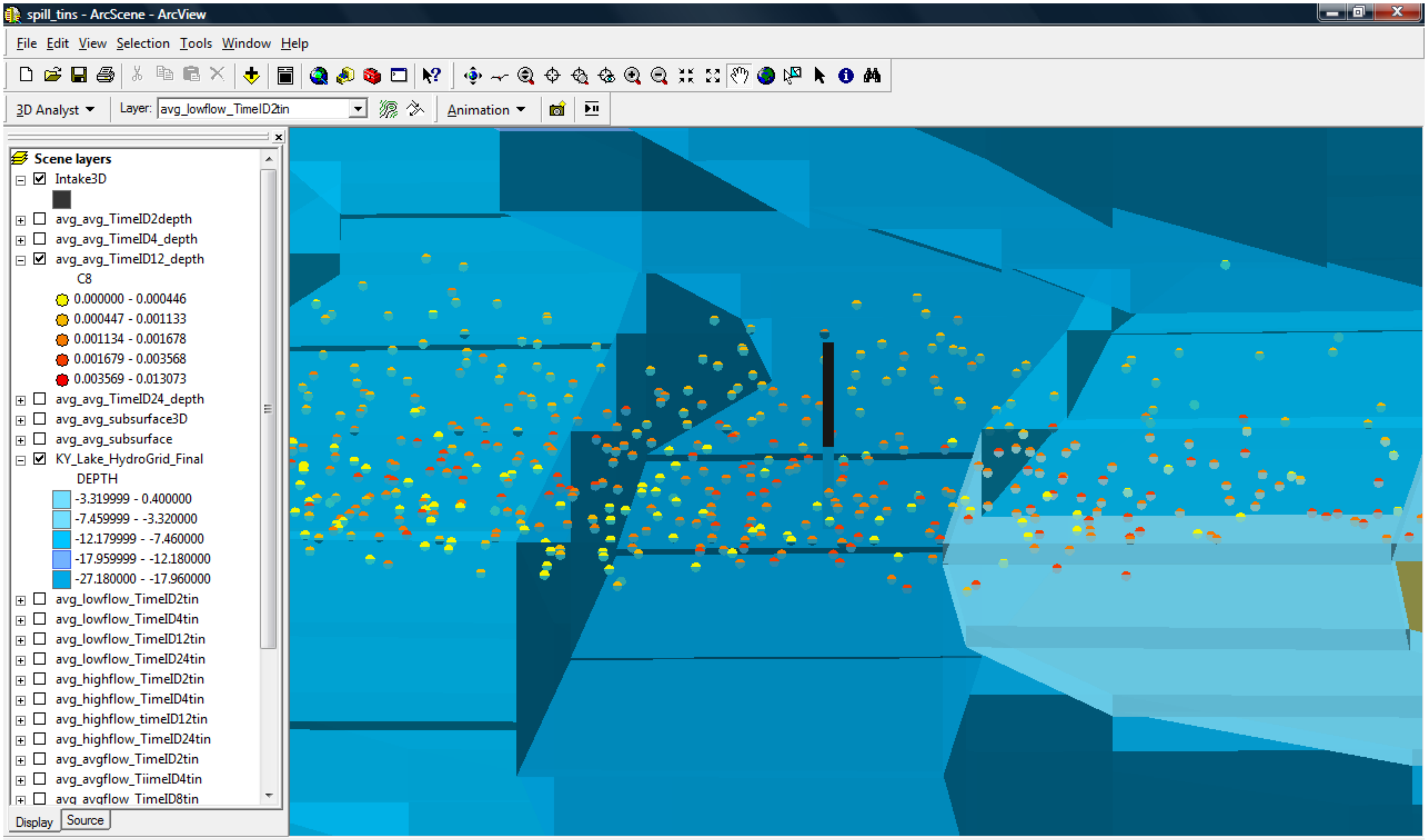

Figure 48: 3-D representation of hexane for the average probable spill at average flow, 12 hours after the release. The black rectangle in the center represents a water intake. Hexane is represented by dots with a color gradient representing the subsurface concentration (gms). Blue blocks are hydrodynamic grid cells.

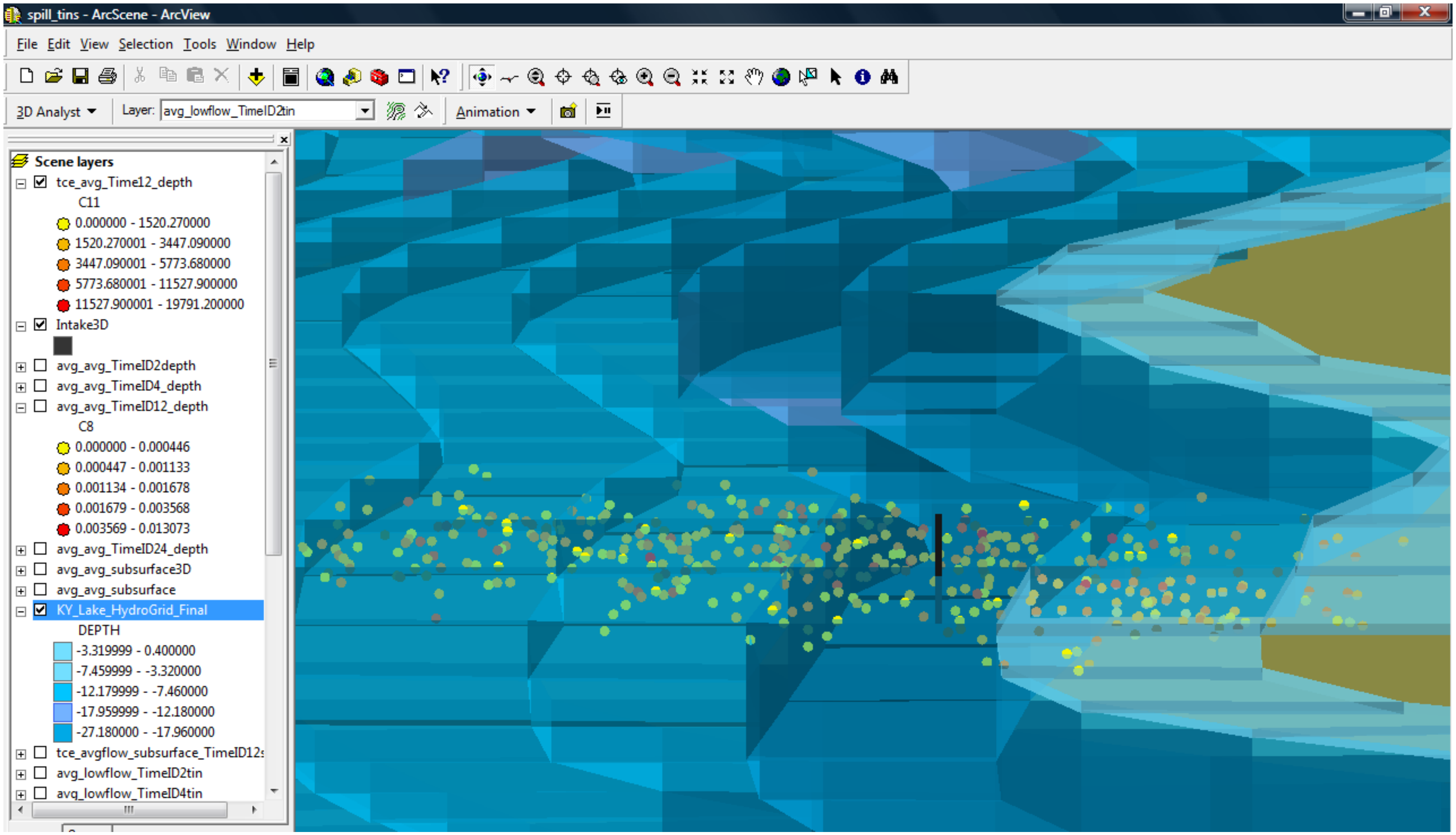

Figure 49: 3-D representation of TCE at average flow, 12 hours after the release. The black rectangle in the center represents a water intake. Hexane is represented by dots with a color gradient representing the subsurface concentration (gms). Blue blocks are hydrodynamic grid cells.

The same color scheme was used for both chemicals at the subsurface, but TCE points that are not near the water surface are darker because they appear within the blue grid cell blocks. Additional rotation, not shown due to difficulties in representation in 2-D, allow the user to view the concentration points below the surface in relation to depth. Display of subsurface COSIM outputs in 3-D allows spill response personnel to identify the proximity of the plume to water intakes, the depth at which the majority of the concentration occurs, and also the maximum concentration for comparison to water quality standards and sensitive species requirements. Additional work in SMIS development will be required to make this analysis an easy-to-use option for spill response personnel.

Conclusions

SMIS 2.0 was developed to assist in spill response efforts on inland waterways by providing timely visualization of spill propagation and identification of impact locations and response resources in proximity of the spill. To demonstrate its use, three spill scenarios were simulated on the Kentucky Lake portion of the Tennessee River, each analyzed at low, average, and high flow conditions. As expected, the worst case scenario resulted in the highest surface mass. However, due to the large amount of diesel fuel released, plume migration was limited and dispersed in a similar manner to an average spill scenario at average flow conditions.

The usefulness of performing spatial queries in ArcMap to locate resources for assistance in spill response was demonstrated by identifying schools within a 25-mile range of the spill site. The accessible information resulting from the spill plume-based query for local schools includes the address, principal name, email address, and phone number of each entity. Such information could be vital for immediate notification during a spill event. Other response resources can also be queried, limitations being the availability of the data in a spatial format.

The ability of SMIS 2.0 to convert spill output into shapefiles and tins for enhanced viewing and querying abilities was also shown. An extended application illustrating the ability of COSIM to simulate boom interactions with a plume was demonstrated, a functionality that is under consideration for future SMIS development. In addition, COSIM provides both surface and subsurface fate and transport modeling for oils and other chemicals along with determination of impacted shorelines and distribution of the chemical among various physical phases. While utilization of these outputs is currently not included in SMIS 2.0, future work could involve incorporating these options. In the interim, spill response personnel still have the information available for additional decision support.

Utilizing 3-D hydrodynamic modeling to provide underlying waterbody velocities and the advanced COSIM spill model within a GIS environment, SMIS 2.0 provides the highest level of spill modeling with simplified user involvement. This system provides advances in spill response technologies through superior visualization of predicted plume paths in comparison to other leading spill response systems which are limited by their rough estimates of the plume location such as leading edge or large river segments identified as being contaminated. SMIS 2.0 allows spill response personnel to determine appropriate locations for recovery efforts such as boom placement and better manage use of resources. Where responders may have previously deployed large booms in hopes of retaining a portion of the plume, they now have a simple tool to project true representations of the plume migration for improved decision support.

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CHAPTER VII

CONCLUSIONS

This research began with an evaluation of current decision-support tools used in spill response on inland waterways. Limitations on the functionality and output display associated with these systems led to a decision to develop an improved approach, Spill Management Information System, version 2.0.

As part of the development effort, water quality managers and spill response personnel were queried to identify their priority needs in managing routine and emergency situations, to ensure that these considerations would be included in SMIS 2.0. This prompted a search for the most appropriate hydrodynamic, water quality, and spill models to include in the system design, resulting in selection of GEMSS, with GLLVHT providing hydrodynamic modeling and COSIM providing the spill modeling components.

SMIS 2.0 combines advanced hydrodynamic modeling, spill modeling, and GIS data visualization within a simplified system to allow users to input spill information, run COSIM, and view contaminant plumes within GIS for assistance in spill response. The system user interface allows emergency response personnel, regardless of their modeling expertise, to edit and run the COSIM model. GLLVHT can be set up prior to a spill by someone with modeling expertise to provide hydrodynamic information to the COSIM model. As demonstrated, COSIM results can be utilized within GIS to perform queries and locate local resources such as hospitals, police, schools, and water intakes that may be of assistance or at risk due to the spill. It is important to recognize that the results of the query are only as good as the data used to create the base GIS reference layers. Therefore, these layers should be updated and maintained regularly to ensure that response crews have access to accurate phone numbers and contact information. Furthermore, advanced users with additional training on the use of GEMSS and COSIM can simulate boom interactions and perform analysis on their effectiveness in spill response efforts.

Use of this 3-D hydrodynamic model, combined with COSIM, provides a more accurate representation of spill plumes when compared to currently available spill modeling tools, which only provide 1-D or broad 2-D representation. The tools involved in SMIS 2.0 were created using a combination of VB.net and the ArcGIS Desktop Software Developers Kit. Once the model is run, the output can be easily loaded into ArcMap using customized GIS tools for viewing to assist with response efforts and decision support.

Although SMIS 2.0 has advanced the state-of-the-art in spill modeling, much more can be done. Currently, the system requires the GLLVHT hydrodynamic model to be developed and simulations conducted prior to use of SMIS 2.0. Preferably, the system would be run in real-time to account for changes in dam flows or weather conditions to more accurately represent plume migration. During spill events on managed waterways, bound on both ends by dams as in Kentucky Lake, operators possess the capability to terminate flow from one or both dams during a spill event to assist in recovery efforts. In some cases, with the right combinations of flows from dams, the currents in the river may flow upstream. This is not accounted for in SMIS 2.0. Operating the hydrodynamic model in quasi-real-time conditions would allow for consideration of these impacts on the spill. In addition, near real-time weather and flow data are available and could be used as inputs into the model. The limiting constraint for Kentucky Lake is the size, resulting in very large processing times. Efforts should be made to find alternatives for improving simulation times and developing an interface to the GLLVHT model for real-time simulations with tools to update the input files using TVDGen and MetGen quickly.

Not only was the grid size a limitation in simulation times for this research, but creation of the hydrodynamic grid proved to be an arduous task. For this study, the ability to scan in spatially referenced bathymetric data to define cell depths and the GIS-like interface for generating the grid were seen as an advantage over other grid generation programs, but GridGen, like many other grid generation packages for complex modeling systems, has limitations. Instructions for use of GridGen are limited and creation of a complex hydrodynamic grid requires additional assistance from a member of the ERM team. Floodplain areas and overbanks are generally ignored unless the user adds additional cells on the exterior of the grid with shallow depths to simulate these regions. Exclusion of the islands in the upstream reaches of the river required some complicated grid manipulation and instruction from a GEMSS developer. In addition, once the grid was created and the bathymetric information is applied, the interpolation created false depths in some areas due to curvature of the river and location of the navigation channel. For example, if the navigation channel (deepest portion) of the river meanders from one side to the other in a short distance, the low depths of the navigation channel may be interpolated with very shallow depths near a bank to give median depths for areas that would normally be shallow. This was a considerable problem for Kentucky Lake. In several areas, the exterior cell depths (those closest to the shore) were deeper than the navigation channel due to interpolation. Manual editing of the hydrodynamic grid was required using navigation charts to approximate true depths. Future research should include additional development with GridGen to improve the grid generation process.

Once the hydrodynamic grid is generated, the COSIM grid is generated using similar process. It too presents several challenges. For COSIM spill grids, the user is limited to only a rectilinear grid and unless one utilized a rectilinear grid for the hydrodynamic model, the two grids will not match. ERM uses point velocities from the hydrodynamic grid as inputs into COSIM, but similar grids would be preferred. Another drawback in creation of the spill grid occurs during classification of cells as water, land, or shoreline. For cells that the tool has difficulty in discerning whether it be land, shore, and water, the user has the option of further refining the grid and manually selecting which portions of the cell belong in which classification. This is time consuming for grids covering large areas. Additional work is needed to either expand the spill grid generation capabilities to include curvilinear, orthogonal grids similar to the hydrodynamic grid, or create a copy of the hydrodynamic grid cells for COSIM use. Furthermore, streamlining the cell classification (land, shore, water) process would be beneficial.

As mentioned previously, COSIM possesses capabilities for spill modeling that were not included in this version of SMIS. Additional features that would provide further benefit during spill response include automation of boom creation, placement, and use in simulations. Additions to the "SpillInfoTool" would allow one to turn on/off boom layers and locate the input boom .csv files. However, creation of the booms must be done in GIS and the data converted to the proper .csv file format for use in COSIM.

To assist in spill response efforts, it is recommended that several scenarios be developed for accident-prone locations and typical hydrodynamic flow conditions to use as a "play book" during spill events. This would serve as a back-up to SMIS 2.0 and provide assistance if power sources or other problems arise during an emergency event.

Finally, GIS layers must be created and maintained on a regular basis to ensure the usefulness of the system. Out-of-date records are problematic in emergency events. Layers can and should be developed for local restaurants, hotels, and hardware stores to improve management of spill events. Designation of a person or group to maintain these databases within the user's agency would ensure the most accurate information is available. Scheduled or automatic updates via linkages to data sources or use of a database management system would reduce the likelihood of having false or out-of-date information during a spill event. Additional efforts by government agencies and others to provide and maintain public databases of spatial information would be of benefit for users of systems such as SMIS 2.0. Many of the GIS reference layers used for this study were created by manually entering data from online sources. Time restrictions and opportunity for human error become limitations in data availability and accuracy; therefore, additional efforts to identify pre-established spatial data resources and perform regular updates are necessary. Future developments of SMIS should include locating additional sources of data and use of a database management system (DBMS).

The current design of SMIS 2.0 is focused on modeling oil spills. COSIM has capabilities to model other chemicals as was demonstrated in the Chapter VI. Additional tools or functionality within the current system tools should be developed to allow users to model these other chemicals and evaluate the model results. Currently, a Microsoft

Excel file serves as the database for approximately 500 chemical compounds that can be used by COSIM. Ideally, one component of SMIS would allow the user to select the chemical of interest from this database and update the COSIM control file with the necessary chemical property information.

GEMSS provides a mass balance bar chart to track the distribution of oil in each phase (i.e., water surface, water column, shore, etc.), but this is not an option in SMIS 2.0. Currently, a user must either use GEMSS or investigate the tblMassBalance in the output database to gain this information. In addition, the shoreline impacted by the spill can be shown as blackened spill grid cells within GEMSS. This is not yet an option in SMIS 2.0. Future work should include making both the mass balance and affected shoreline information more easily accessible in ArcMap.

While COSIM provides the highest level of spill modeling and use of GLLVHT enables the most accurate approximation of hydrodynamic information for use by the spill model, it is still only an estimate. To provide additional value and confidence in the system, calibration and validation of COSIM results must be performed. This is not a trivial task and would require either a dye trace or acoustic Doppler radar analysis on the Tennessee River which would be compared to model results. A validation study is recommended to provide the highest level of confidence in use of COSIM and GLLVHT for emergency response.

APPENDIX A

WATER QUALITY MANAGEMENT AND SPILL RESPONSE QUESTIONAIRRE

Water Quality Management Questionnaire

Introduction

Inland waterways provide sources for drinking water, hydropower generation, and recreational opportunities for communities, habitats for aquatic species, and navigational pathways for freight transport. Management of these water resources involves the balancing of many competing demands, including the need to provide adequate protection during an emergency spill event. Efforts to assist decision support capabilities of water resource managers include the development of a water quality and spill response system that combines geographic information systems (GIS) with hydrodynamic and water quality modeling. Creation of this system involves the identification of major information requirements for individuals and agencies involved in water resources management and spill response activities.

The purpose of this questionnaire is to identify effective management techniques, driving forces, and information needs to support the decision process by gathering input from multiple stakeholders representing different water management organizations. Since communication is vital for information transfer, communication practices and their effectiveness are also considered. Some participants will be asked to respond to additional questions focused on spill response activities. Based upon analysis of the results, we plan to develop a hierarchy of information needs in water quality management and spill response activities, management decision making techniques, and suggest improved management practices. The results will be published at a later date.

You have been selected based upon recommendations from colleagues or your position in water resources and/or spill response management to help identify these information needs. Your participation in the following survey would be greatly appreciated and is completely voluntary and confidential. The survey should take less than 20 minutes of your time.

Instructions

The following is a list of questions pertaining to water resource management activities for inland waterways. Part of the questionnaire intends to assess information and communication needs in this area. Please answer each question to the best of your ability. You have two options for completing the survey. The first, and preferred method, is an online version, accessed by clicking the link contained within the email message. The second method consists of a pdf file that you may print, mark your answers, and fax or mail back to me at the address below. When you have completed the online survey, click on the ***Finish*** button and the results will be placed in a database for analysis.

Estimated completion time is no more than **20 minutes**. Please complete the survey and return it by **Friday, May 18**. Your responses will remain completely confidential.

Your cooperation and assistance is very much appreciated!

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Please answer each of the following questions to the best of your ability. Again, your participation is greatly appreciated.

1. To which group do most closely associate yourself with?
    a. Environmental stewardship
    b. Human health and safety
    c. Water resources management
    d. Utility provider
    e. None of the above

2. On what scale is your organization responsible for water quality management?
    a. Local
    b. State
    c. Regional
    d. National

If you do not participate in water resources management, but do participate in spill response activities, please skip to Question 12. If you do not participate in either of these actions, please quit the survey now and submit your answers to the previous questions.

3. Please indicate the extent of your agreement or disagreement with each of the following statements regarding the need for improved water resource management.

Please mark one box for each statement.	Strongly Agree	Agree	Disagree	Strongly disagree	No opinion
Water quality management operations need to be improved in my region/community/state/organization.					
Improvements in water quality management will require more effective coordination by multiple agencies.					
Other water resource management agencies in my state/community have shown little interest in improving coordination with my agency.					
The field of water quality management needs consensus in how to best manage our resources.					
Best management practices exist for guiding water quality management decisions.					
Water quality management is driven by regulations and financial capabilities of the organization involved.					
The cost to manage and meet water quality standards exceeds the derived benefits of having them.					
Regulators that develop discharge limits do not understand the difficulties in meeting the imposed requirements.					
My agency would benefit from the existence of a guidebook or established protocols for making water quality management decisions.					

4. Please indicate the importance of the following uses of our inland waterways in your daily responsibilities and management activities. (Multiple items can be marked at the same level. For example, more than one item may be identified as "Most Important.")

Use	Very Important	Important	Somewhat Important	Not Important	No Opinion
Public water supplies					
Habitat for aquatic species					
Recreation					
Navigation					

5. What governance do you most often follow in prioritizing protection of water intakes, sensitive species, and human health in daily management decisions?
   a. Established protocol
   b. Personal intuition/experience
   c. Public demands
   d. Instructions from supervisor
   e. Permit requirements

6. Which of the following do you see as the greatest threat to surface water quality?
   a. Chemical spills
   b. Terrorist activities
   c. Agricultural activities
   d. Household chemical use (pesticides, herbicides, fertilizers)
   e. Combined sanitary sewer/stormwater bypasses/overflows

7. Please indicate the extent of your agreement or disagreement with each of the following statements regarding the need for information resources in water quality management.

Please mark one box for each statement.	Strongly agree	Agree	Disagree	Strongly disagree	No opinion
My organization uses hydrodynamic and/or water quality models as decision support tools.					
I understand how the modeling process works and feel comfortable with using models.					
My agency could benefit from improved modeling capabilities and training on the use of models as decision support tools.					
Visual information such as that obtained through modeling outputs is highly effective in creating understanding within and between agencies.					

8. Which of the following do you find most useful in making water resource management decisions?
    a. Current conditions
    b. Historical information
    c. Predictive information
    d. Other (please specify)________________________

9. Please indicate the extent of your agreement or disagreement with each of the following statements regarding the need for improved communication in water quality management.

Please mark one box for each statement.	Strongly Agree	Agree	Disagree	Strongly disagree	No opinion
Communication is key for improving water quality management across multiple agencies.					
Water resource management operations within my agency could be improved with better communication.					
My agency works to create effective communication relationships with other agencies in our area.					
Communication pathways between agencies are effective.					
I know the key players within my organization who are responsible for management of our inland waterways.					
Chain-of-command exists within my organization for management decisions.					

10. Which of the following techniques are currently being used to bridge gaps in interagency communications?

    a. None, no gaps exist
    b. Regularly scheduled meetings including multiple agencies
    c. Establishment of *ad hoc* committees
    d. Periodic contact between agency managers
    e. Other, please specify:__________________________

11. Please indicate the extent of your agreement or disagreement with each of the following statements regarding the need for public involvement in water quality and spill response management.

Please mark one box for each statement.	Strongly Agree	Agree	Disagree	Strongly disagree	No opinion
One of the most important stakeholders in water quality management is the public.					
The public should be involved in management decisions to ensure widespread acceptance and participation.					
An informed public can help with management of the water quality of inland water bodies.					
My organization can help to improve surface water quality through public education programs.					
Efforts should be made to notify the public immediately when a spill occurs to gain their assistance and understanding.					
The public should only be notified when and if their participation is necessary (e.g., mandatory evacuation) during a spill event.					

12. Do you participate in spill response activities?

a. Yes
b. No

If you answered "no" to Question 12, you are finished with the questionnaire. If you answered "yes," please answer the following questions related to spill response activities.

13. Are you one of the first alerted when an inland waterway spill occurs?

a. Yes
b. No

14. What is your role when responding to a spill event?

a. On-site command
b. Field crew (deploying booms, etc.)
c. Technical support
d. Logistics
e. Safety and/or security

15. In making decisions during a spill event, what do you rely on most for guidance?

    a. Personal experience
    b. Standard protocols
    c. Training exercises and planning activities
    d. Instructions passed down from supervisors

16. Please indicate the extent of your agreement or disagreement with each of the following statements regarding information and communication needs during spill response.

Please mark one box for each statement.	Strongly Agree	Agree	Disagree	Strongly disagree	No opinion
My agency is well prepared to respond to a chemical spill on a nearby waterway.					
My agency is usually the last to hear about or arrive on the scene of a spill event.					
I feel fully prepared to respond to a chemical spill on an inland waterway.					
During a spill event, we all have the same objectives, so agency barriers are eliminated for the common good.					
The first priority after ensuring safety of responding personnel is the protection of drinking water supplies during a spill event.					
Notification of a spill event should include all agencies responsible for the waterway in the vicinity of the spill (state environmental department, local utilities, etc.).					
Knowing the location of a contaminant plume at a given time is the most valuable piece of information during a spill event.					
Knowing the location of sensitive or endangered species in the vicinity of a spill event plays an important role in spill management decisions.					

17. What information do you feel is necessary for field crews (i.e., those deploying booms, etc.) during a spill event?

    a. Location of sensitive or endangered species
    b. Locations of water intakes
    c. Routes of travel to boom deployment locations
    d. Locations of schools, hospitals, and sensitive populations
    e. Locations of source water protection zones
    f. None of the above, these are for management only
    g. All of the above

18. During a spill event to which you responded, please rate the effectiveness of communication pathways/equipment used by marking the appropriate box.

Communication Pathway	No Opinion	Not Effective	Somewhat Effective	Effective	Very Effective
Phones (cellular or land-line)					
Radios (walkie-talkie)					
Face-to-face communications					
Email					
Global positioning system (GPS) devices					
Visual aides such as display boards					
Paper documentation					
Intranet/internal (possibly secure) network					
Geographic information systems (GIS)					

19. If you were asked to develop a plan for improved spill response preparation for your organization, how much importance would you assign to each of the following?

Action	Very Important	Important	Somewhat important	Not important	No opinion
Improve responder safety procedures					
Avoid or reduce the potential for terrorist attack					
Improve the accuracy and timeliness of information provided to the public					
Improve the accuracy and timeliness of information shared between responding organizations					
Avoid or reduce the frequency and severity of hazardous material releases					
Protect the environment (including sensitive species)					
Reduce the time required for investigations and reports					
Protect water intakes					
Reduce operating costs for the responding agencies					

20. What item do you feel would be most effective in improving spill response activities?

   a. Additional personnel training
   b. Additional spill exercise activities
   c. Spill response playbook that describes optimal boom deployment for several “most likely” spill scenarios
   d. Centralized real-time information displays
   e. Improved communications between responding agencies

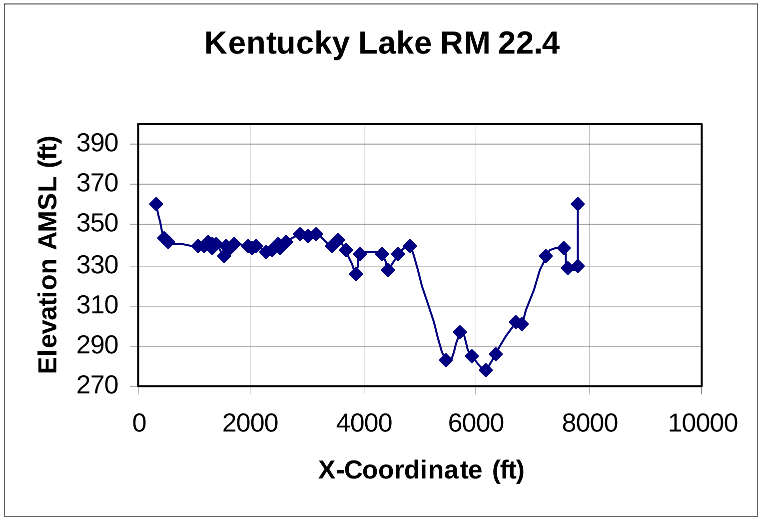
If you would like to receive a summary of the results from this questionnaire, please provide your contact information below.

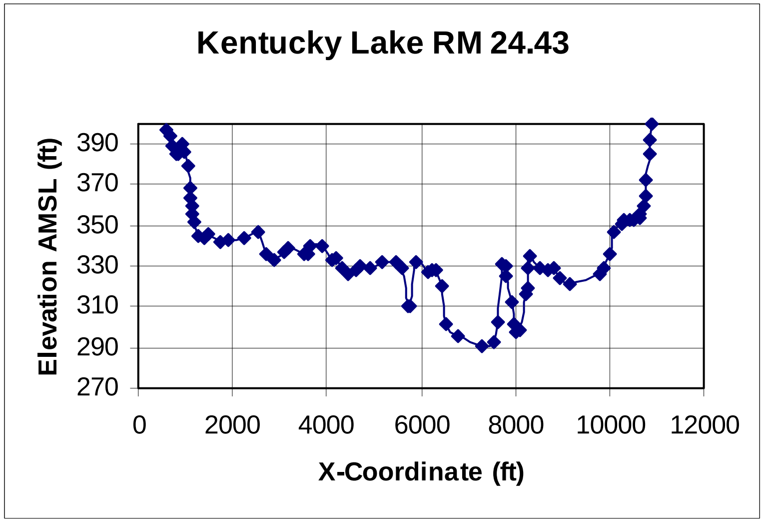
Name: ___________________________________
Email: ___________________________________
Organization: ____________________________
Address: _________________________________
____
Phone: ___________________________________

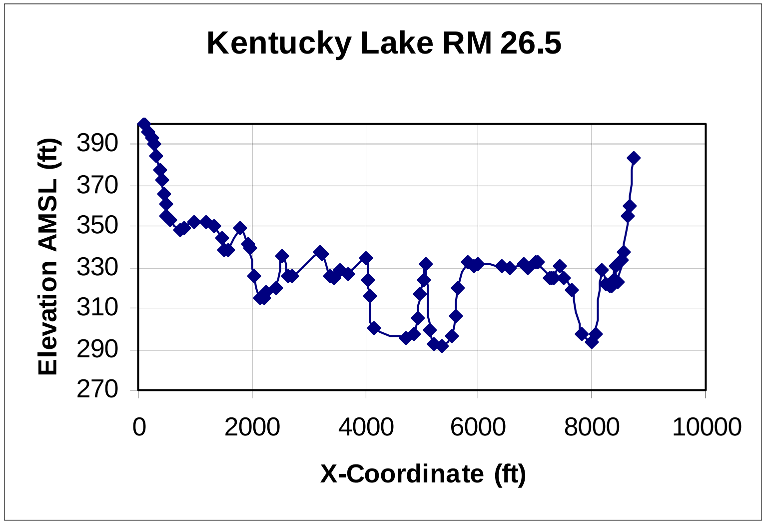
APPENDIX B

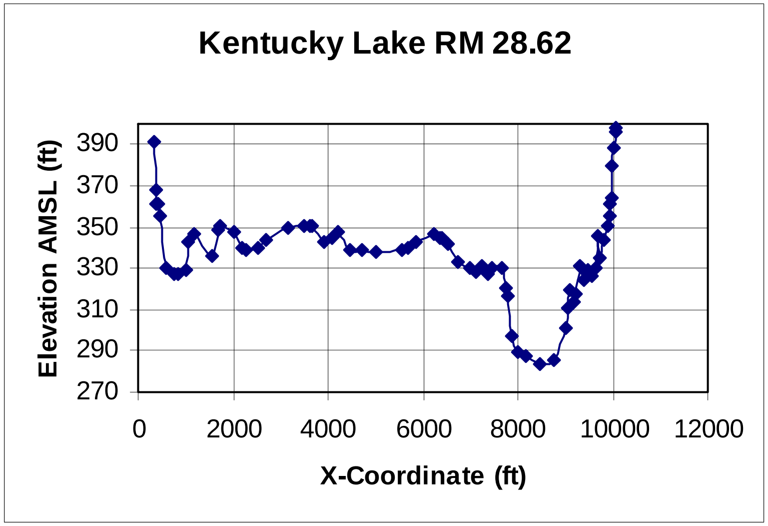
CROSS-SECTIONS FOR KENTUCKY LAKE

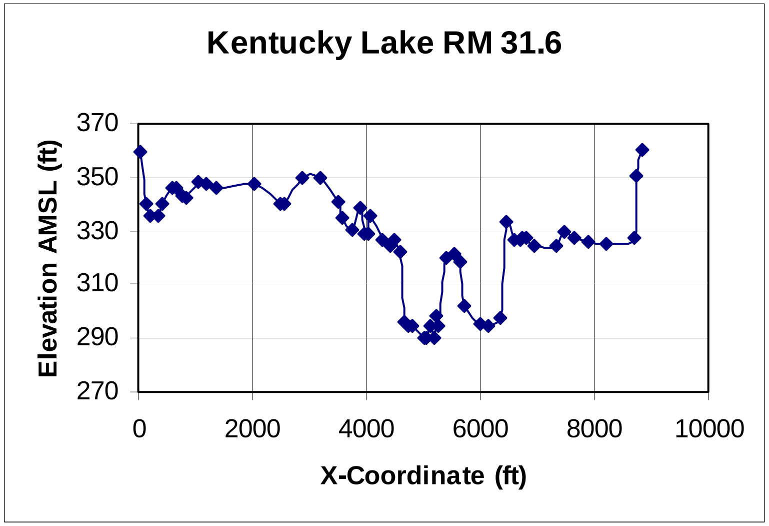
Cross-section Data for Kentucky Lake from TVA










Kentucky Lake RM 31.6
Elevation AMSL (ft)
370
350
330
310
290
270
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2000
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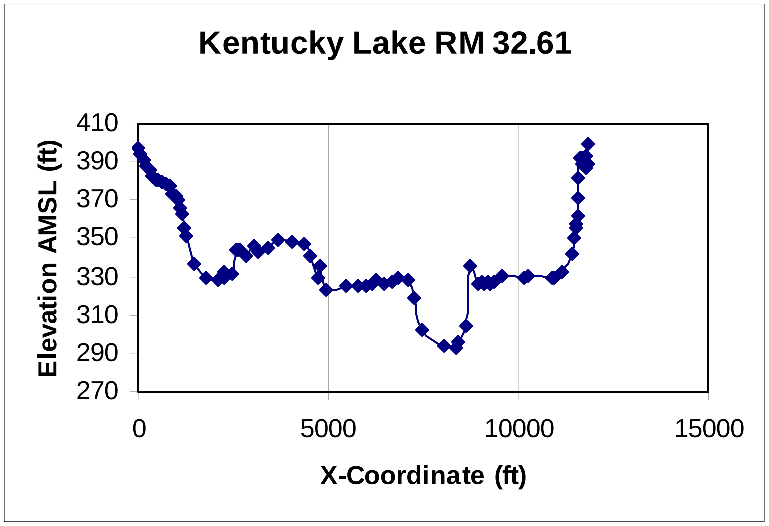
6000
8000
10000
X-Coordinate (ft)


Kentucky Lake RM 32.61
Elevation AMSL (ft)
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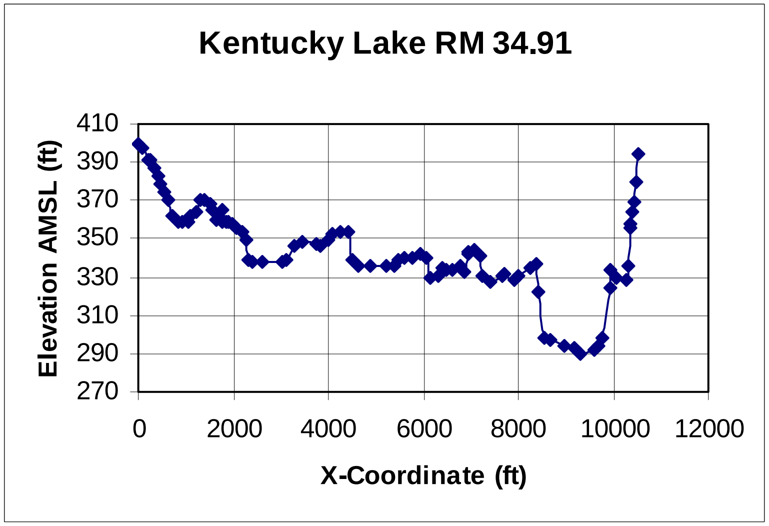
X-Coordinate (ft)


Kentucky Lake RM 34.91
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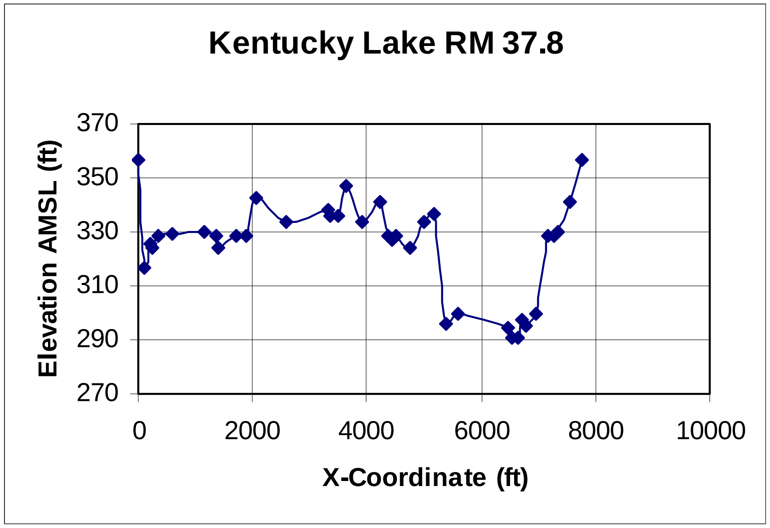
Kentucky Lake RM 37.8
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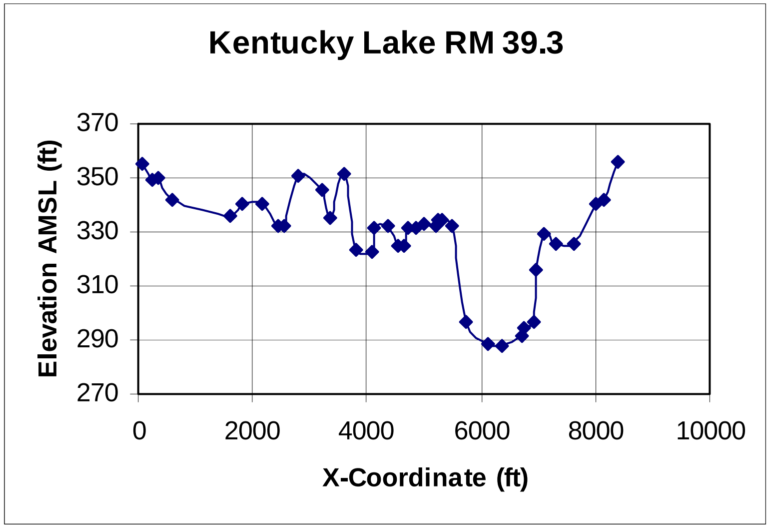
X-Coordinate (ft)


Kentucky Lake RM 39.3
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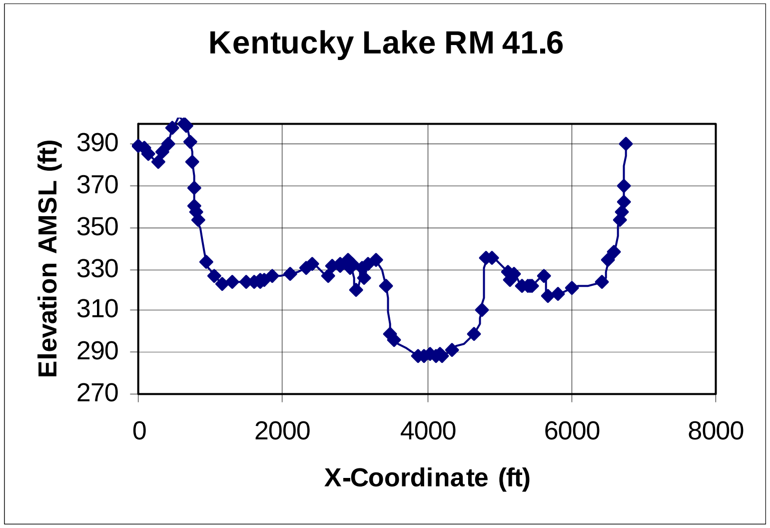
X-Coordinate (ft)


Kentucky Lake RM 41.6
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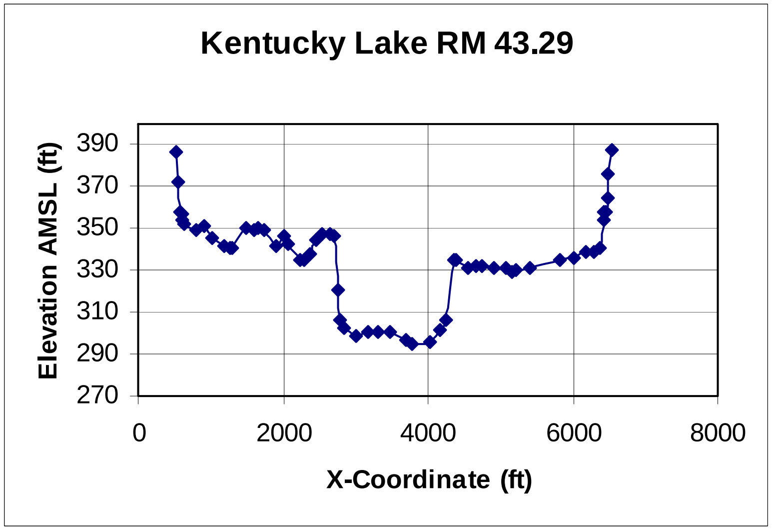
X-Coordinate (ft)


Kentucky Lake RM 43.29
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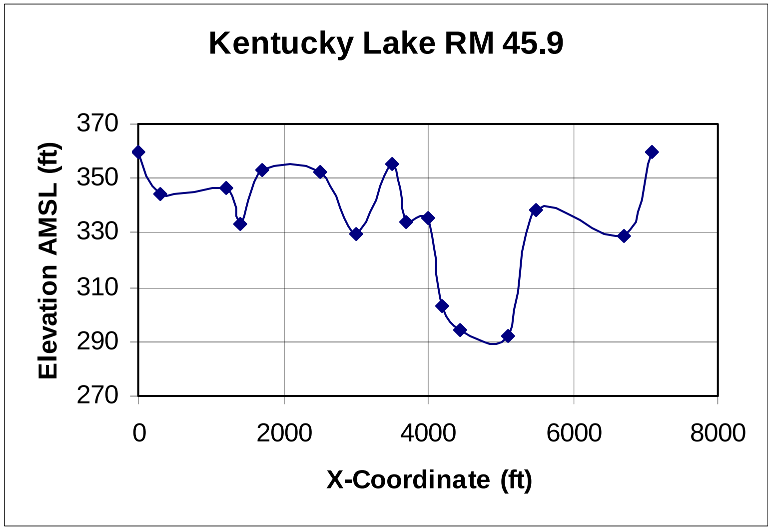
X-Coordinate (ft)


Kentucky Lake RM 45.9
Elevation AMSL (ft)
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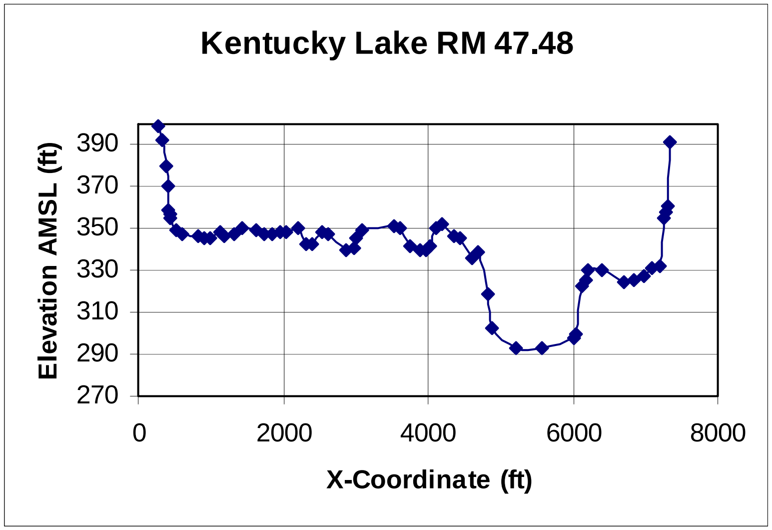
X-Coordinate (ft)


Kentucky Lake RM 47.48
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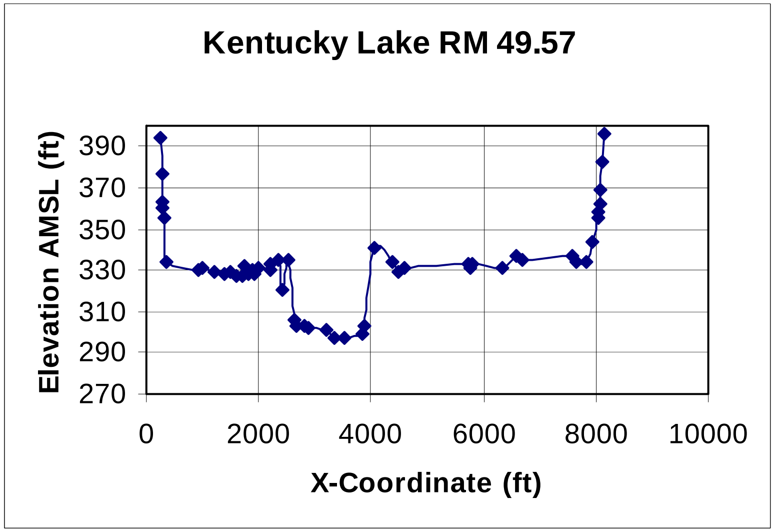
X-Coordinate (ft)


Kentucky Lake RM 49.57
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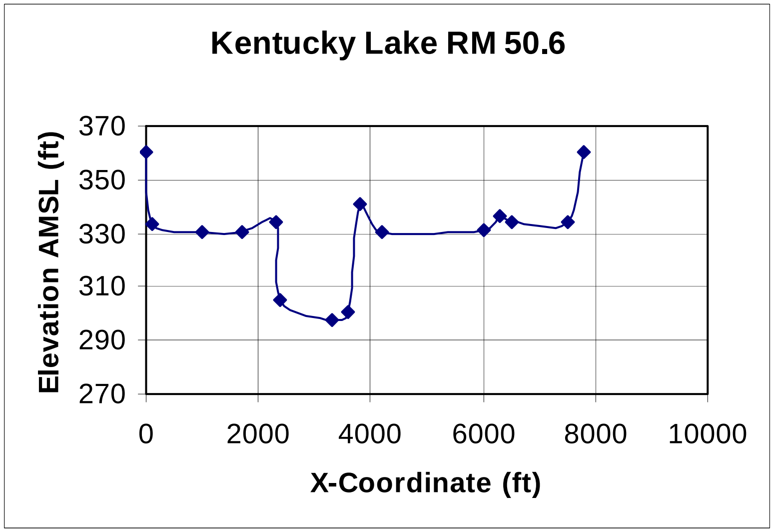
X-Coordinate (ft)


Kentucky Lake RM 50.6
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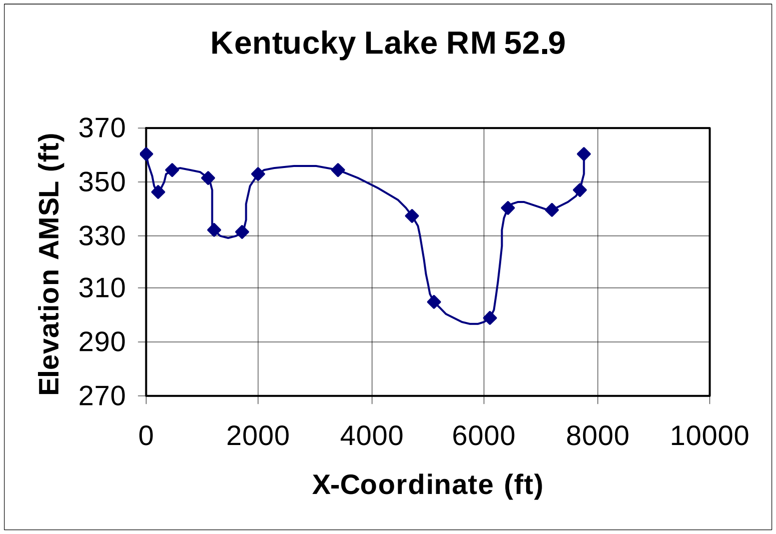
8000
10000
X-Coordinate (ft)


Kentucky Lake RM 52.9
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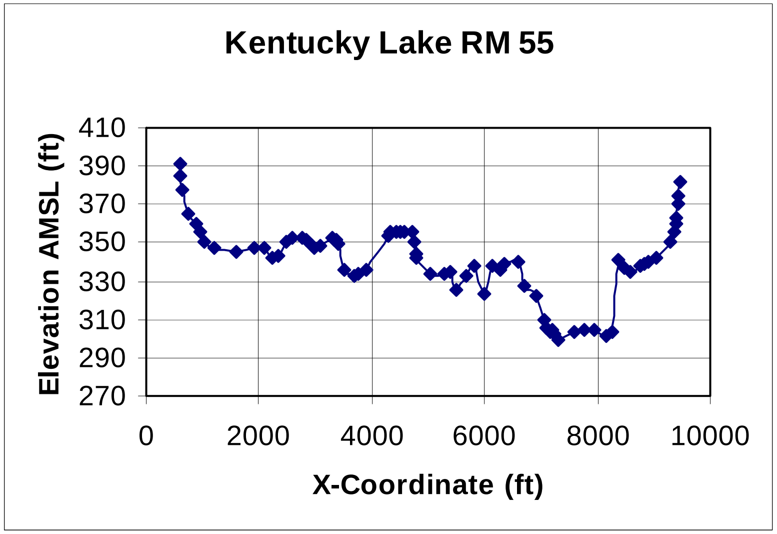
10000
X-Coordinate (ft)


Kentucky Lake RM 55
Elevation AMSL (ft)
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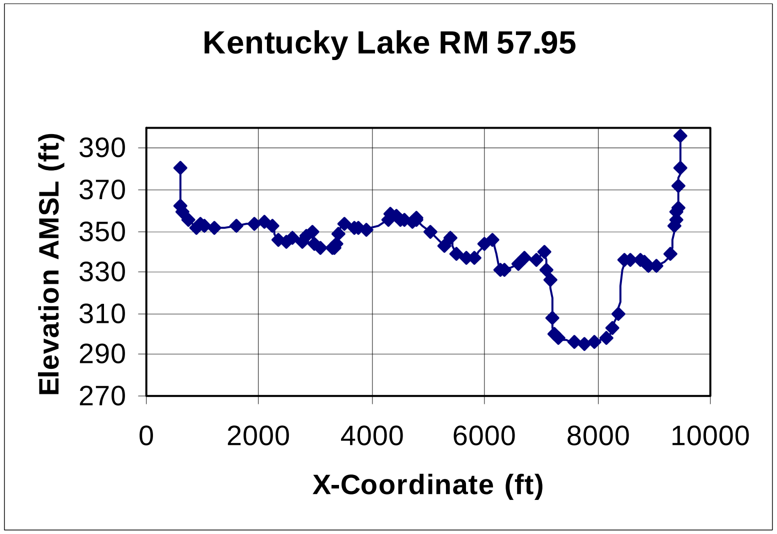
10000
X-Coordinate (ft)


Kentucky Lake RM 57.95
Elevation AMSL (ft)
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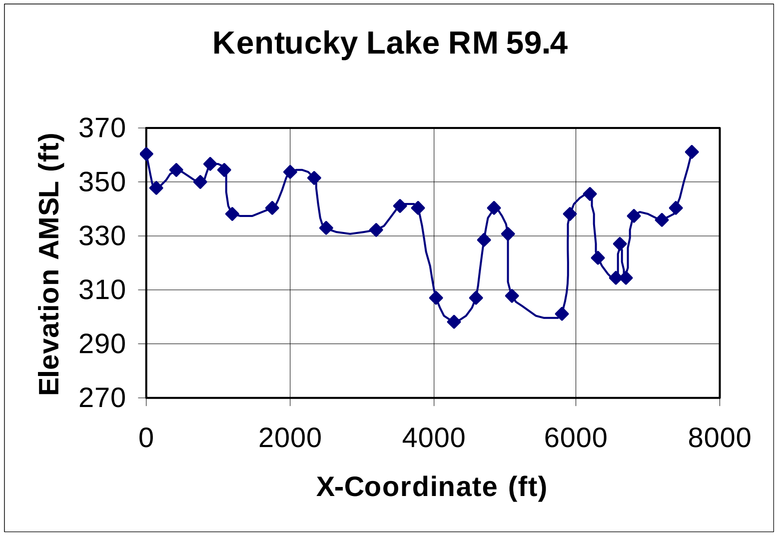
10000
X-Coordinate (ft)


Kentucky Lake RM 59.4
Elevation AMSL (ft)
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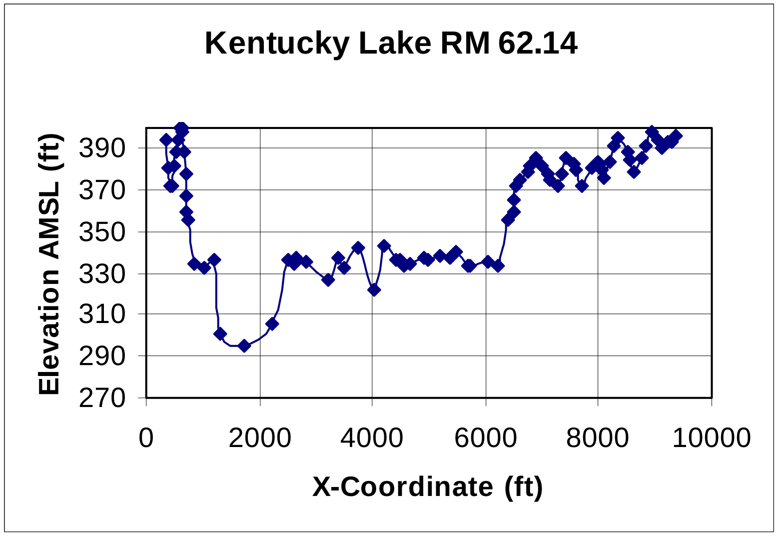
4000
6000
8000
X-Coordinate (ft)


Kentucky Lake RM 62.14
Elevation AMSL (ft)
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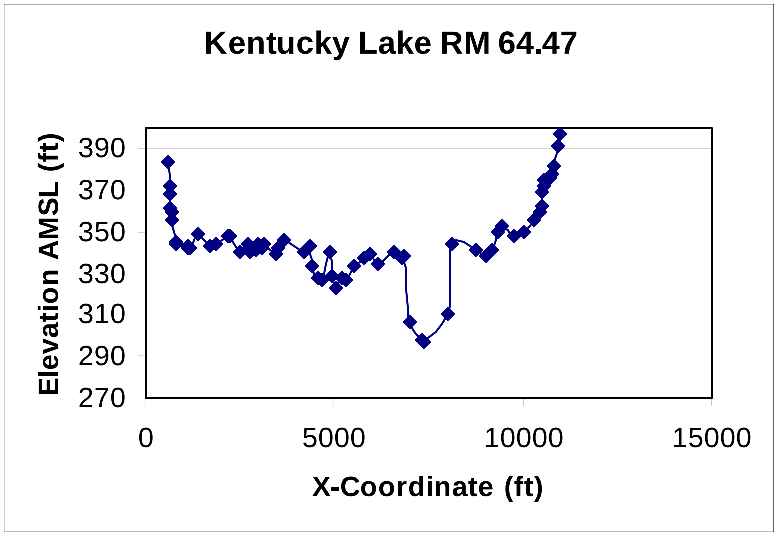
10000
X-Coordinate (ft)


Kentucky Lake RM 64.47
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290
270
0
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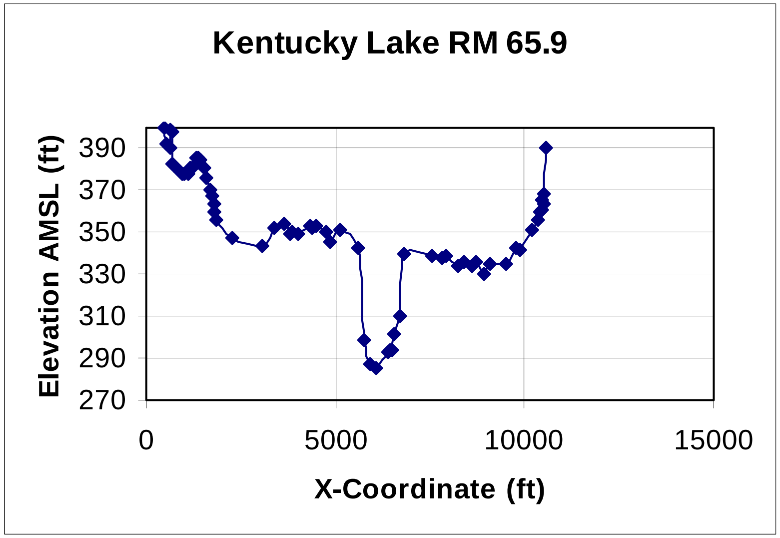
10000
15000
X-Coordinate (ft)


Kentucky Lake RM 65.9
Elevation AMSL (ft)
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370
350
330
310
290
270
0
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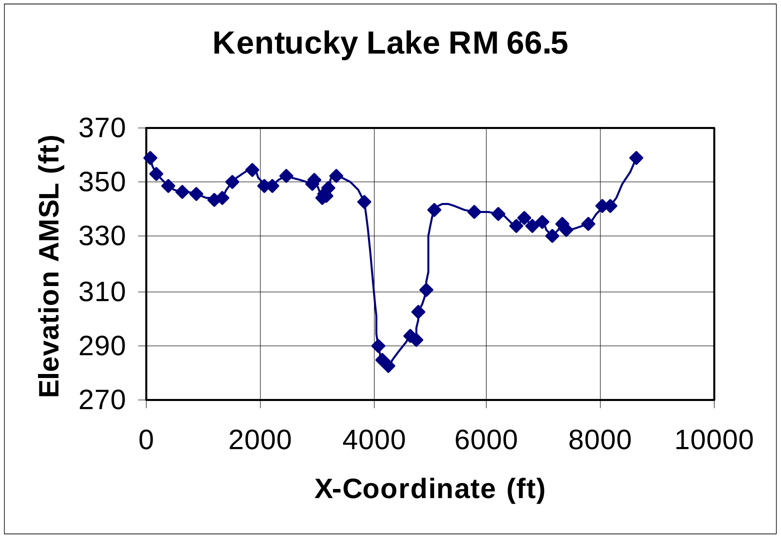
10000
15000
X-Coordinate (ft)


Kentucky Lake RM 66.5
Elevation AMSL (ft)
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350
330
310
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270
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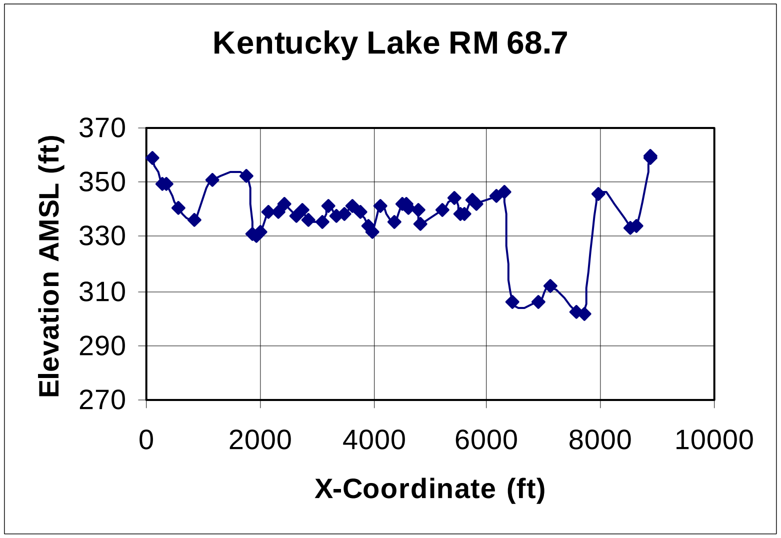
10000
X-Coordinate (ft)


Kentucky Lake RM 68.7
Elevation AMSL (ft)
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350
330
310
290
270
0
2000
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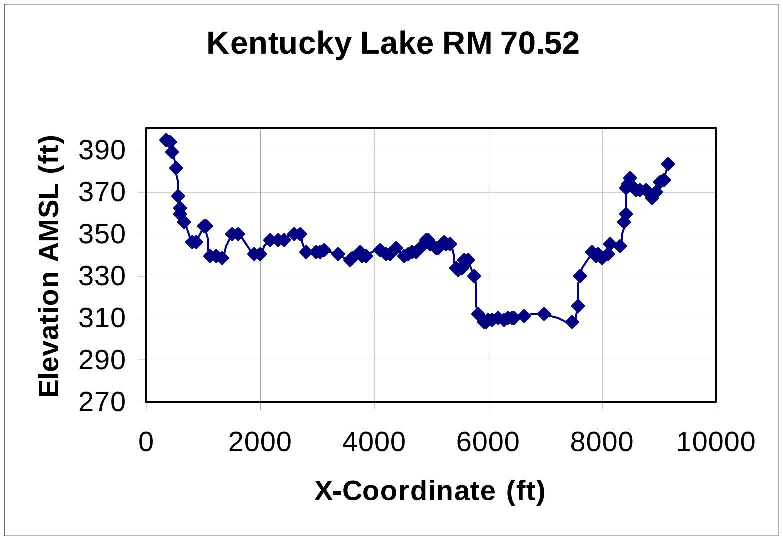
10000
X-Coordinate (ft)


Kentucky Lake RM 70.52
Elevation AMSL (ft)
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370
350
330
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270
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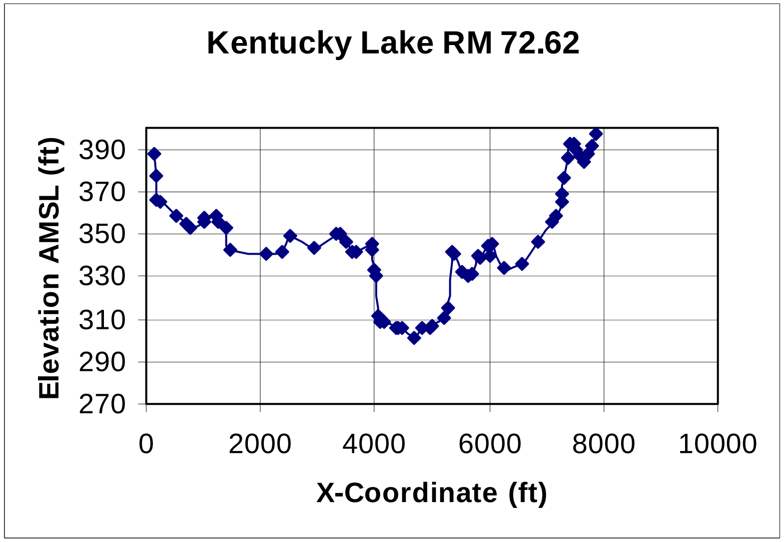
10000
X-Coordinate (ft)


Kentucky Lake RM 72.62
Elevation AMSL (ft)
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370
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330
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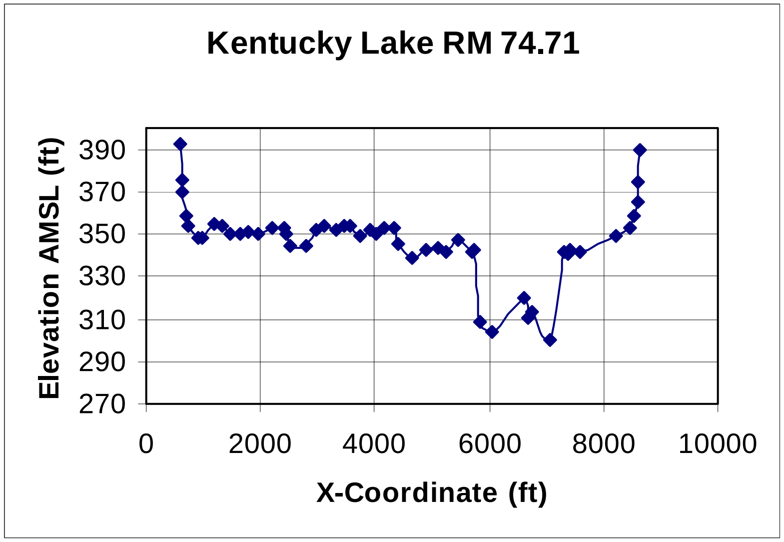
10000
X-Coordinate (ft)


Kentucky Lake RM 74.71
Elevation AMSL (ft)
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370
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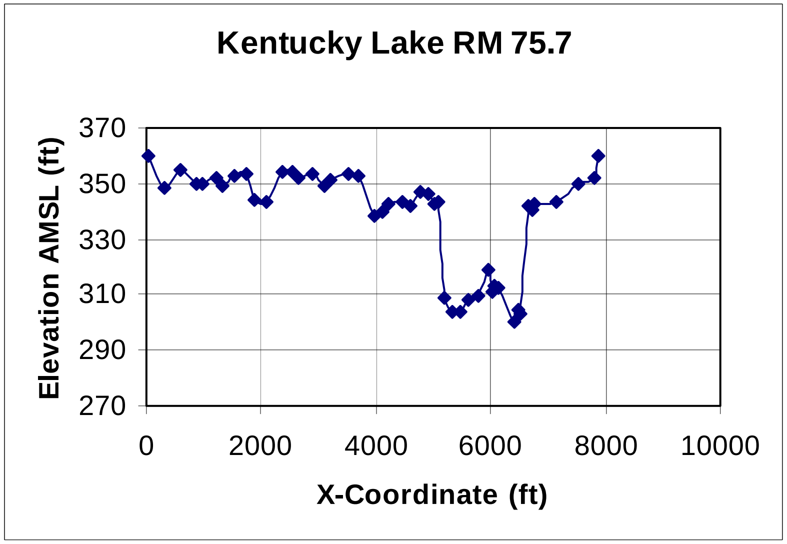
X-Coordinate (ft)


Kentucky Lake RM 75.7
Elevation AMSL (ft)
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270
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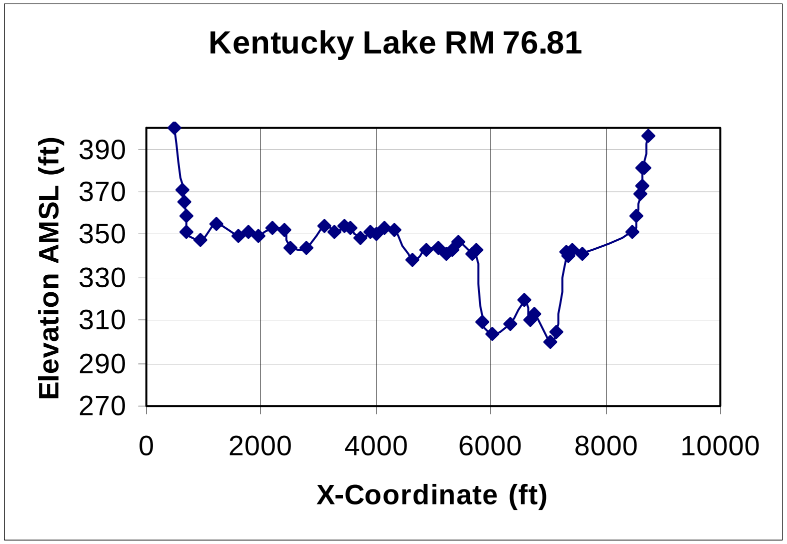
10000
X-Coordinate (ft)


Kentucky Lake RM 76.81
Elevation AMSL (ft)
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370
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330
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290
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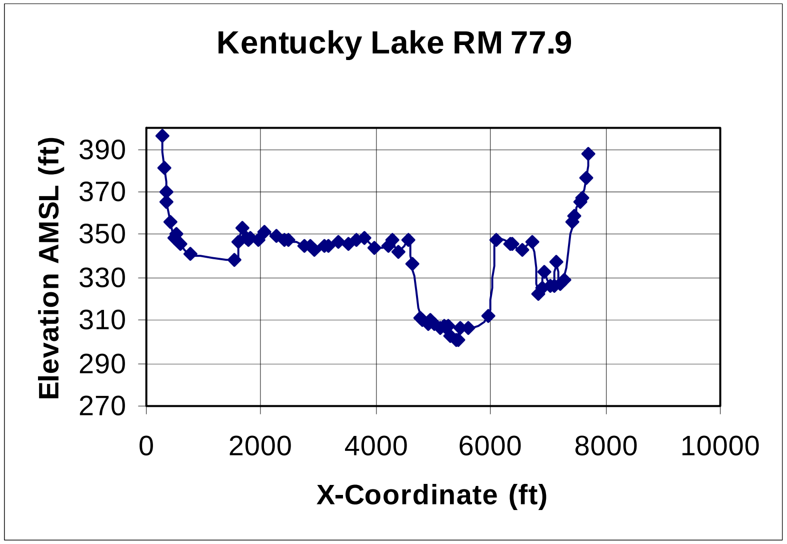
X-Coordinate (ft)


Kentucky Lake RM 77.9
Elevation AMSL (ft)
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370
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310
290
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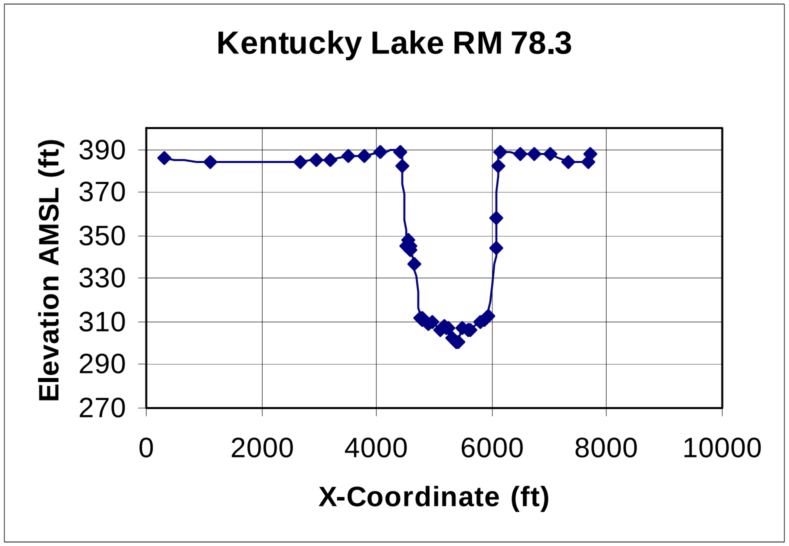
10000
X-Coordinate (ft)


Kentucky Lake RM 78.3
Elevation AMSL (ft)
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370
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330
310
290
270
0
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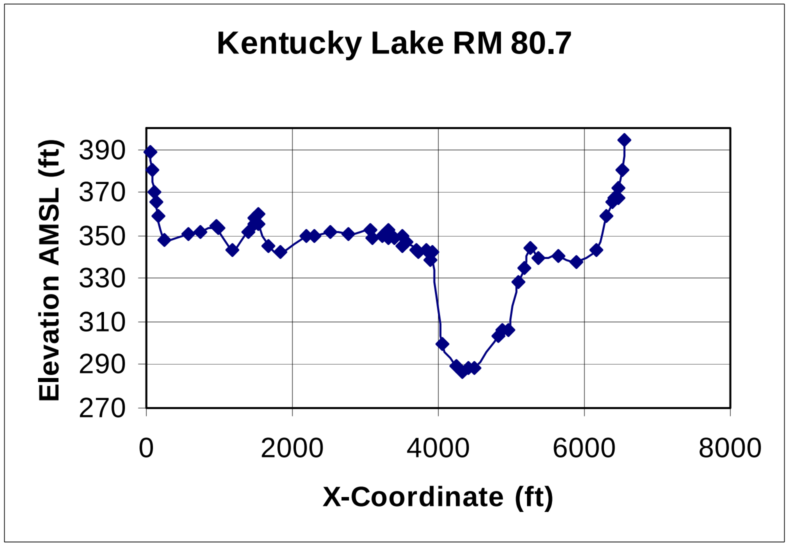
10000
X-Coordinate (ft)


Kentucky Lake RM 80.7
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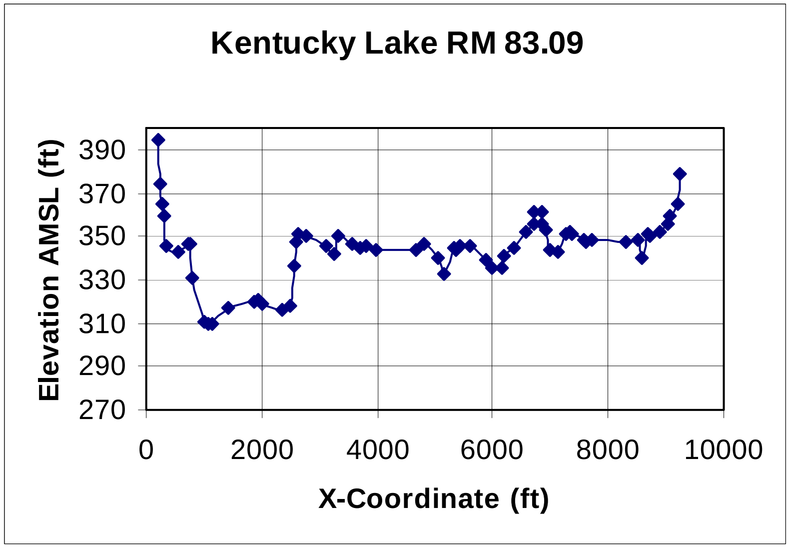
X-Coordinate (ft)


Kentucky Lake RM 83.09
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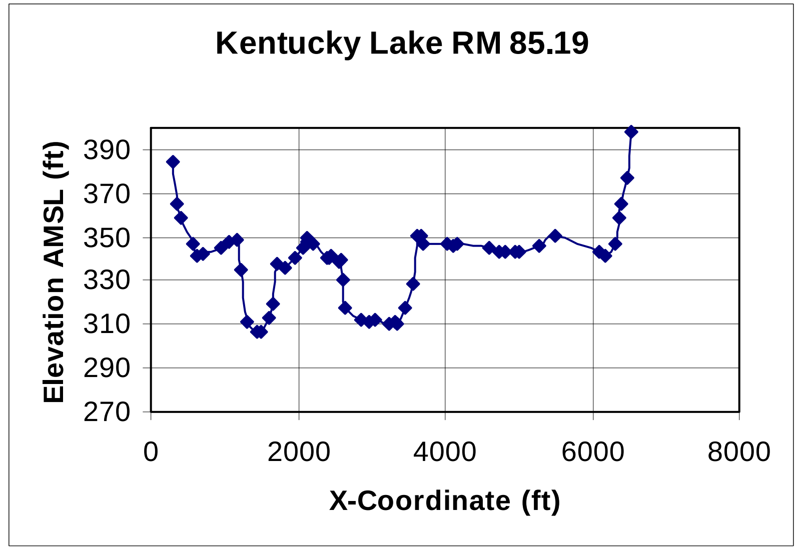
8000
10000


Kentucky Lake RM 85.19
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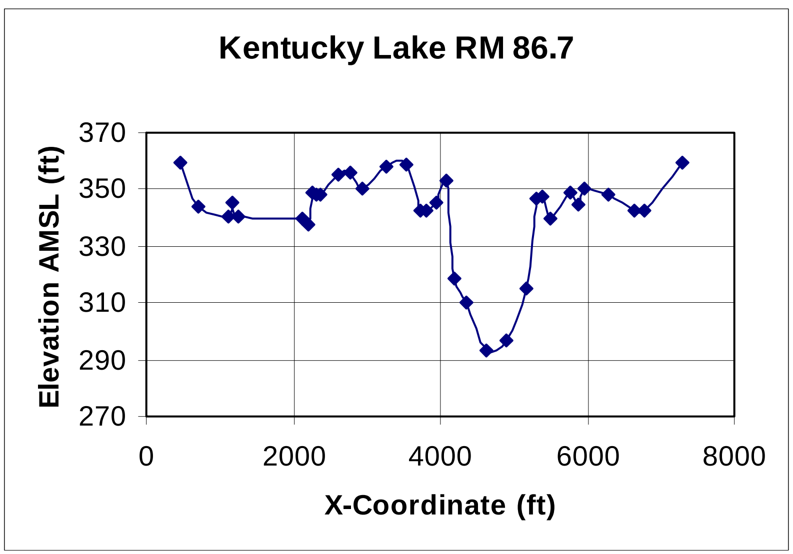
Kentucky Lake RM 86.7
Elevation AMSL (ft)
X-Coordinate (ft)
270
290
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330
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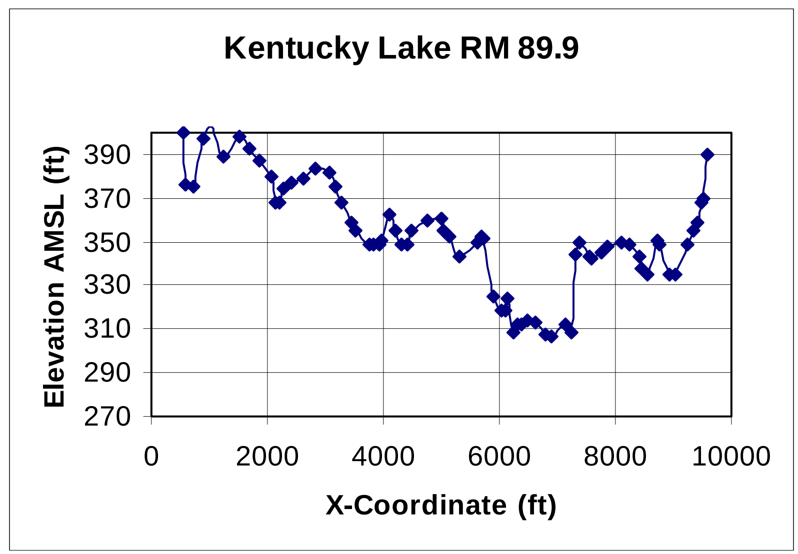
8000


Kentucky Lake RM 89.9
Elevation AMSL (ft)
X-Coordinate (ft)
270
290
310
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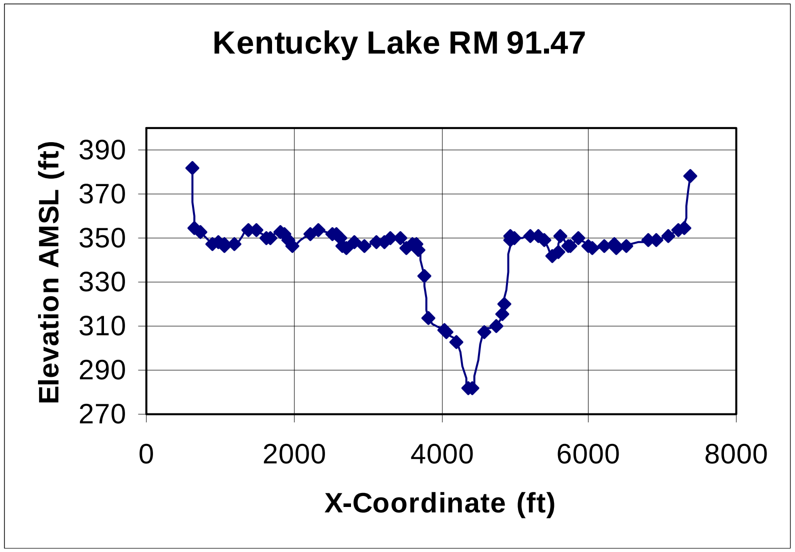
6000
8000
10000


Kentucky Lake RM 91.47
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390
370
350
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310
290
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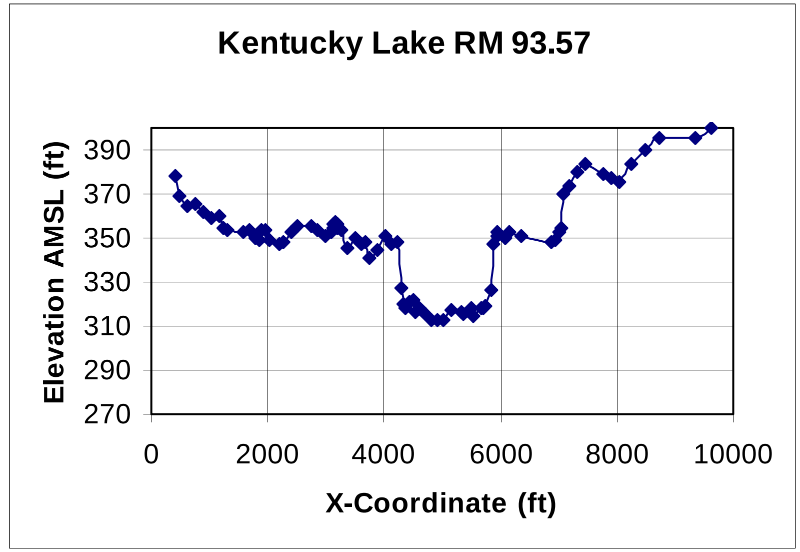
8000
X-Coordinate (ft)


Kentucky Lake RM 93.57
Elevation AMSL (ft)
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370
350
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310
290
270
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6000
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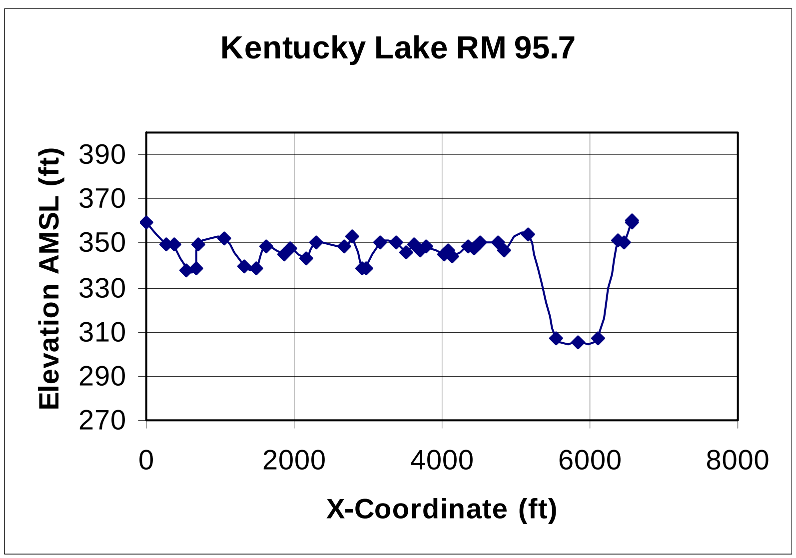
10000
X-Coordinate (ft)


Kentucky Lake RM 95.7
Elevation AMSL (ft)
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370
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330
310
290
270
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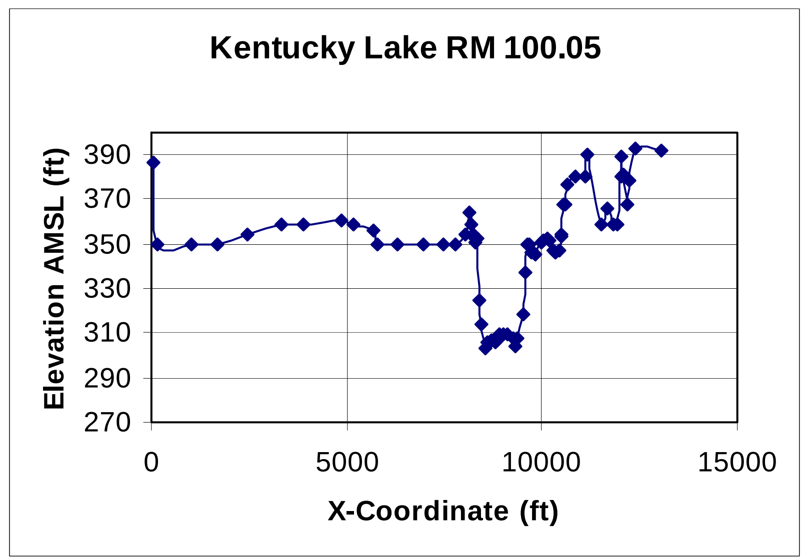
2000
4000
6000
8000
X-Coordinate (ft)


Kentucky Lake RM 100.05
Elevation AMSL (ft)
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370
350
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310
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270
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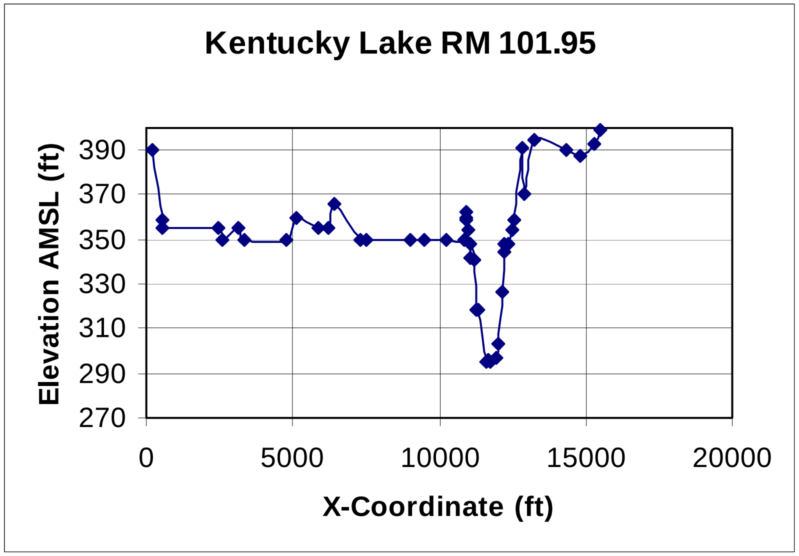
10000
15000
X-Coordinate (ft)


Kentucky Lake RM 101.95
Elevation AMSL (ft)
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370
350
330
310
290
270
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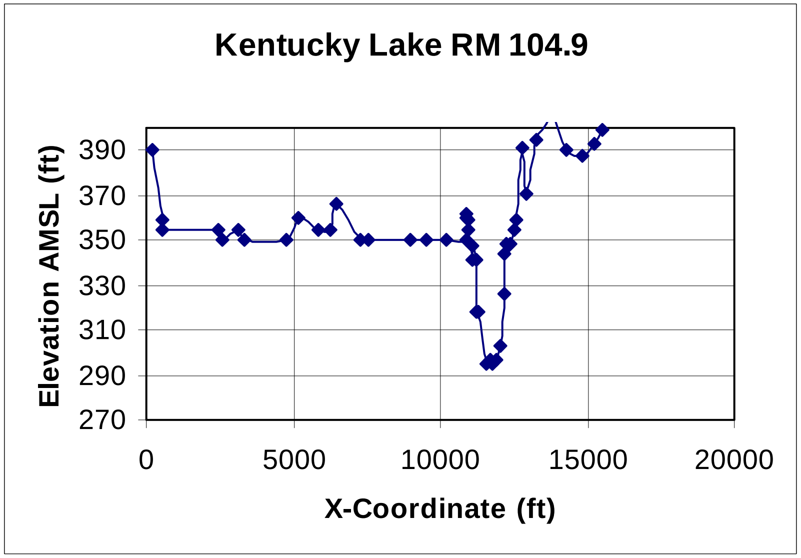
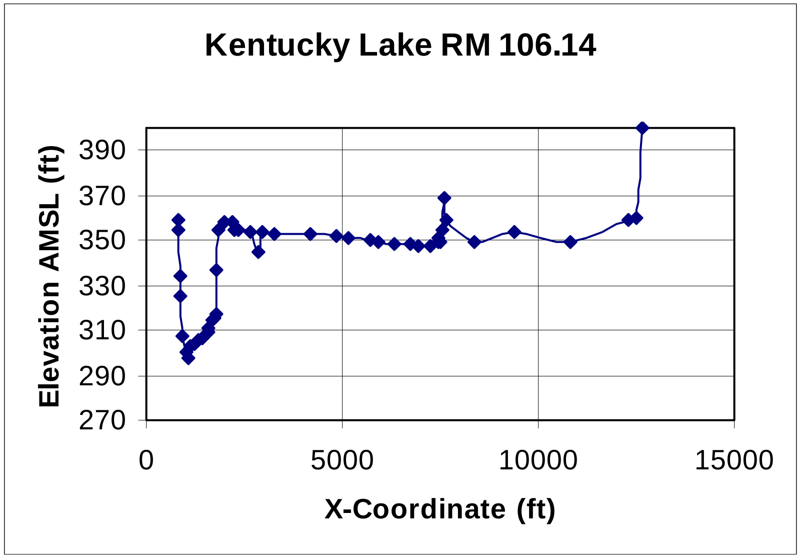
10000
15000
20000
X-Coordinate (ft)


Kentucky Lake RM 104.9
Elevation AMSL (ft)
390
370
350
330
310
290
270
0
5000
10000
15000
20000
X-Coordinate (ft)


Kentucky Lake RM 106.14
Elevation AMSL (ft)
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370
350
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310
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270
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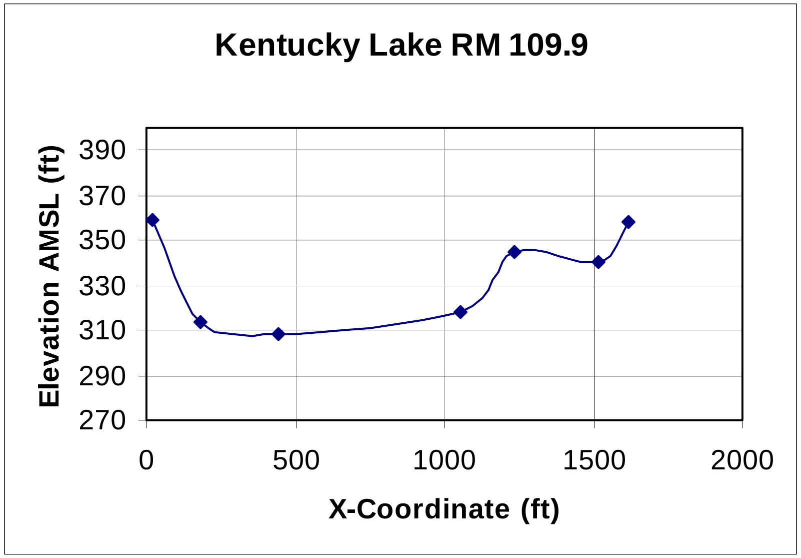
10000
15000
X-Coordinate (ft)


Kentucky Lake RM 109.9
Elevation AMSL (ft)
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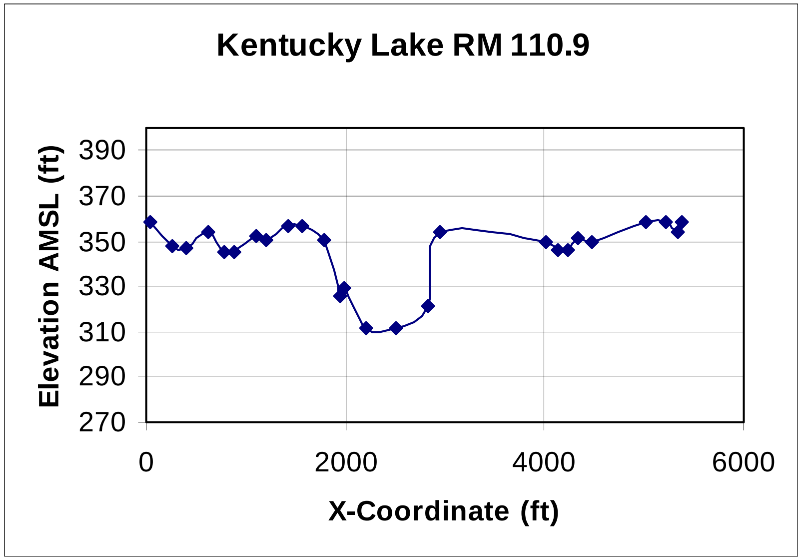
370
350
330
310
290
270
0
500
1000
1500
2000
X-Coordinate (ft)


Kentucky Lake RM 110.9
Elevation AMSL (ft)
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370
350
330
310
290
270
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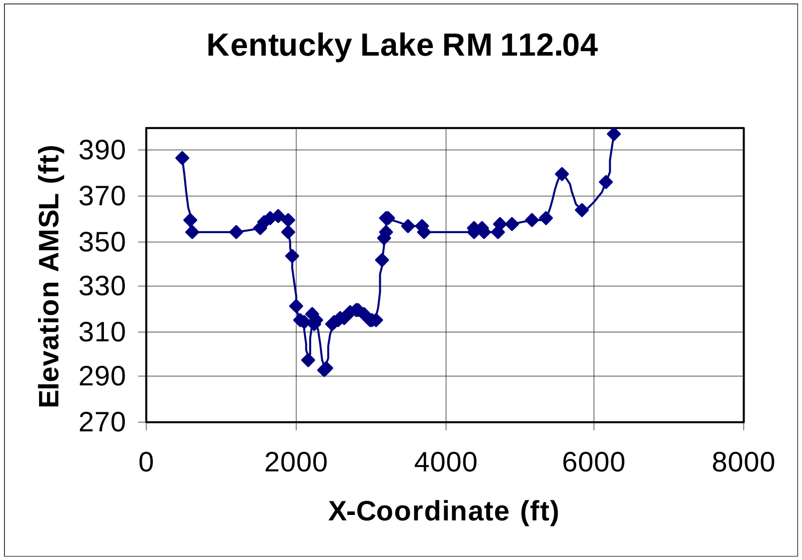
2000
4000
6000
X-Coordinate (ft)


Kentucky Lake RM 112.04
Elevation AMSL (ft)
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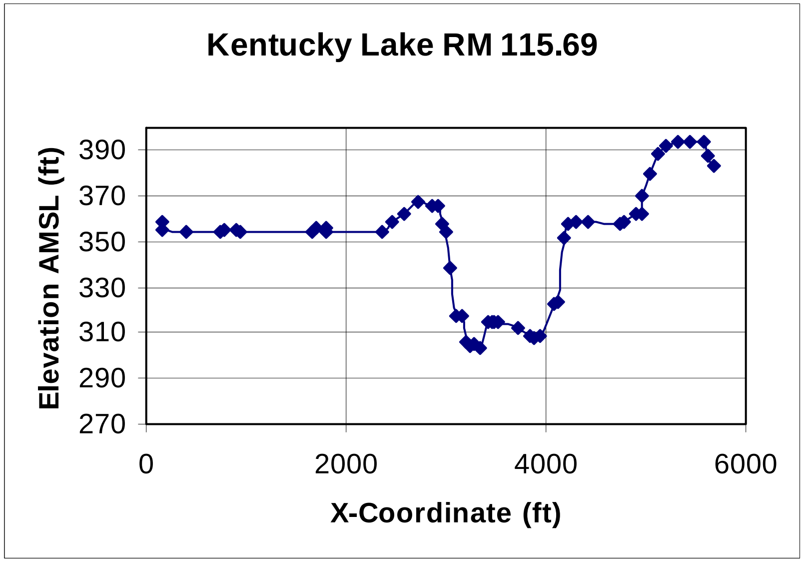
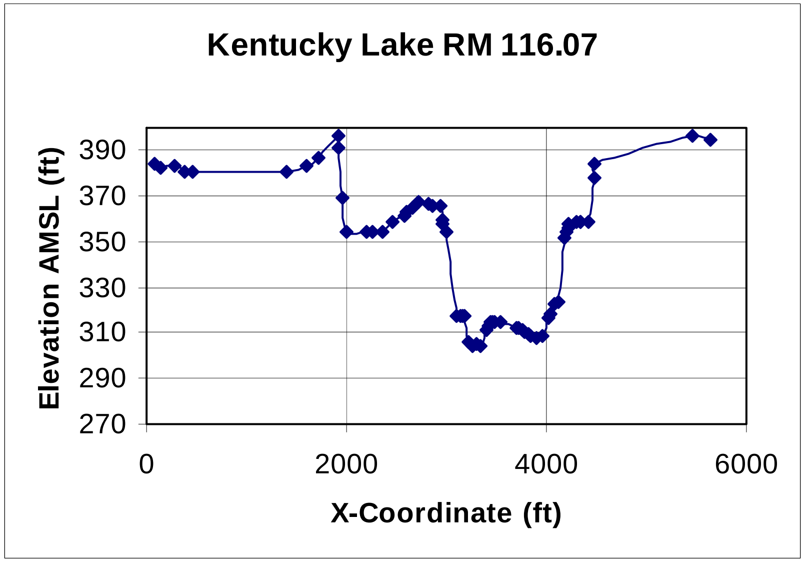
370
350
330
310
290
270
0
2000
4000
6000
8000
X-Coordinate (ft)


Kentucky Lake RM 115.69
Elevation AMSL (ft)
390
370
350
330
310
290
270
0
2000
4000
6000
X-Coordinate (ft)


Kentucky Lake RM 116.07
Elevation AMSL (ft)
390
370
350
330
310
290
270
0
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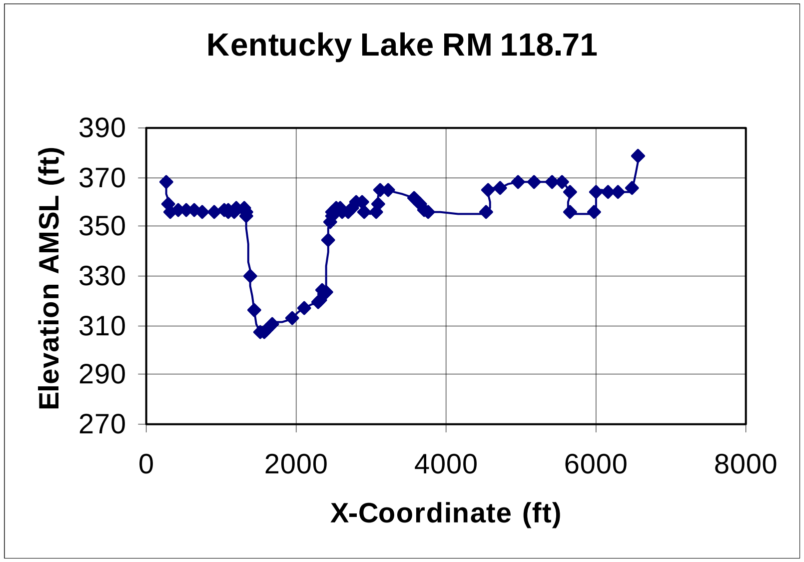
4000
6000
X-Coordinate (ft)


Kentucky Lake RM 118.71
Elevation AMSL (ft)
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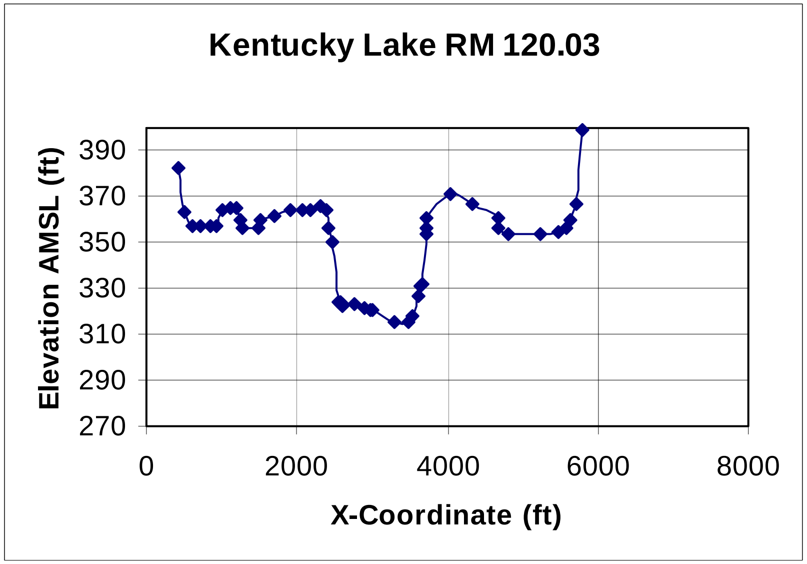
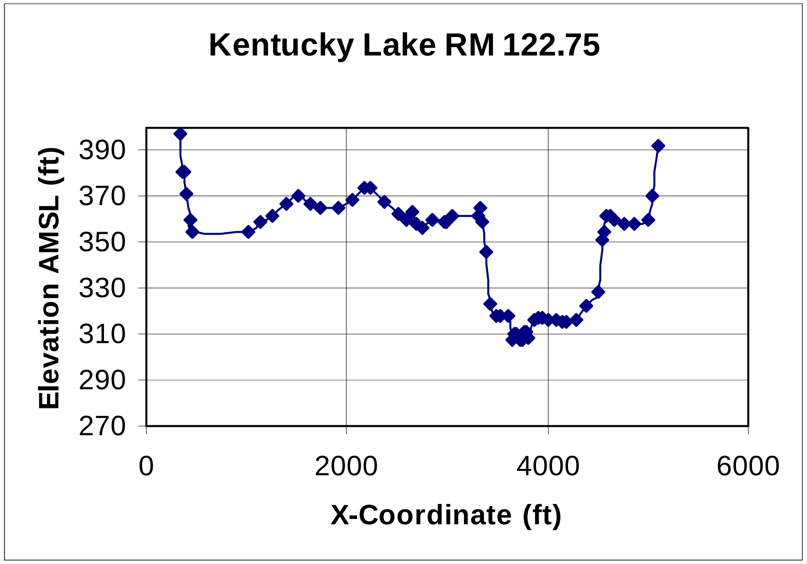
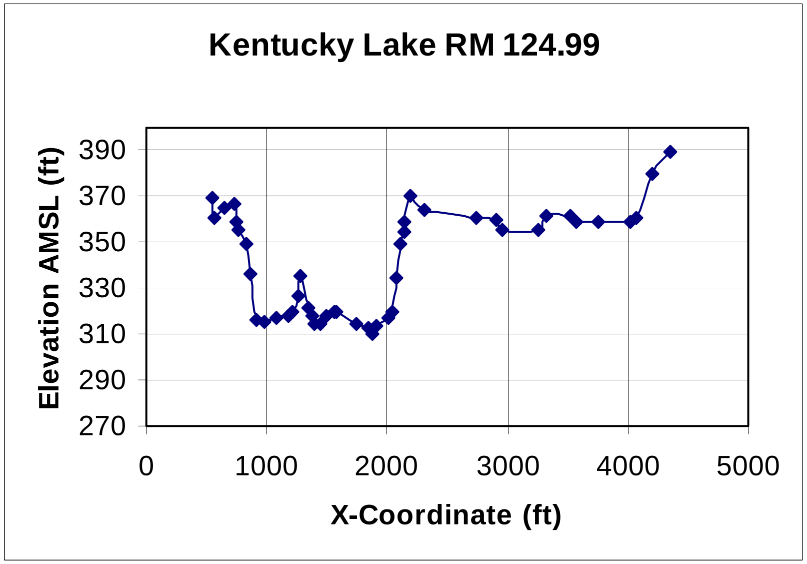
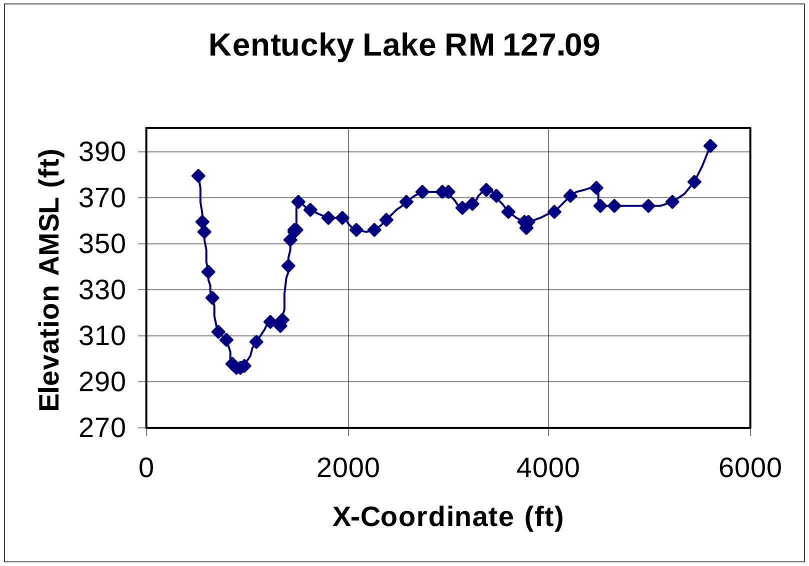
370
350
330
310
290
270
0
2000
4000
6000
8000
X-Coordinate (ft)


Kentucky Lake RM 120.03
Elevation AMSL (ft)
390
370
350
330
310
290
270
0
2000
4000
6000
8000
X-Coordinate (ft)


Kentucky Lake RM 122.75
Elevation AMSL (ft)
390
370
350
330
310
290
270
0
2000
4000
6000
X-Coordinate (ft)


Kentucky Lake RM 124.99
Elevation AMSL (ft)
390
370
350
330
310
290
270
0
1000
2000
3000
4000
5000
X-Coordinate (ft)


Kentucky Lake RM 127.09
Elevation AMSL (ft)
390
370
350
330
310
290
270
0
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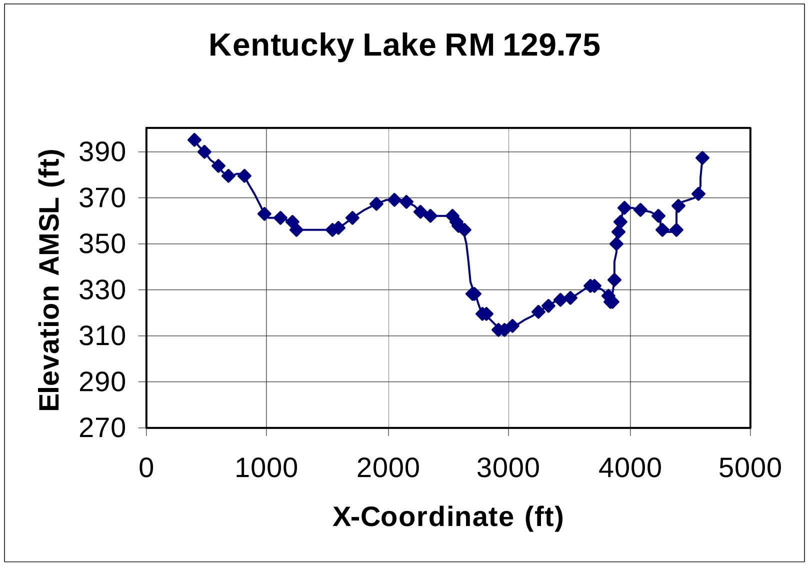
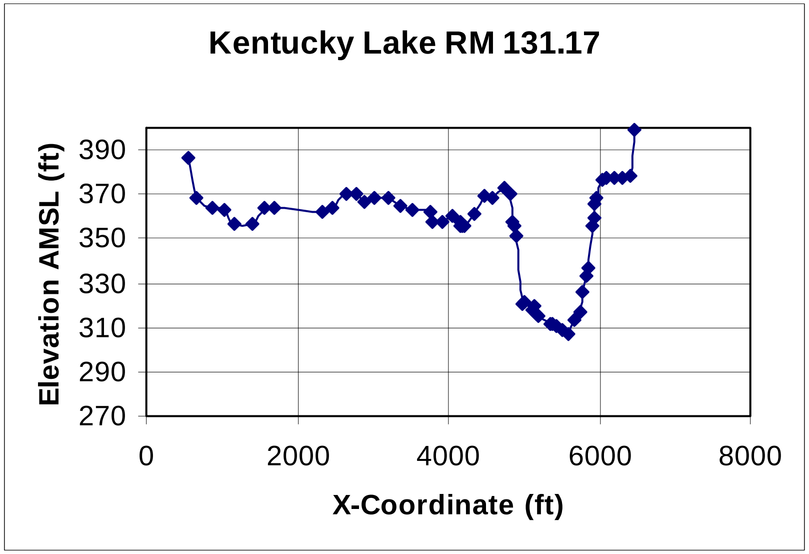
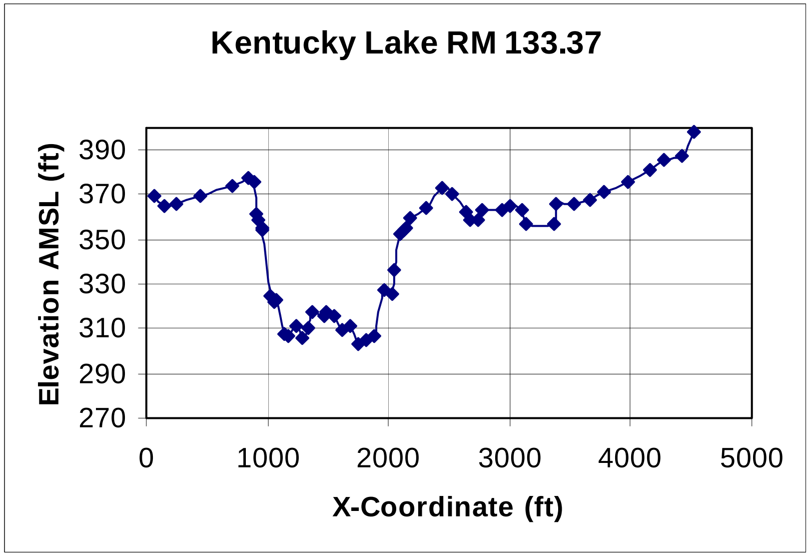
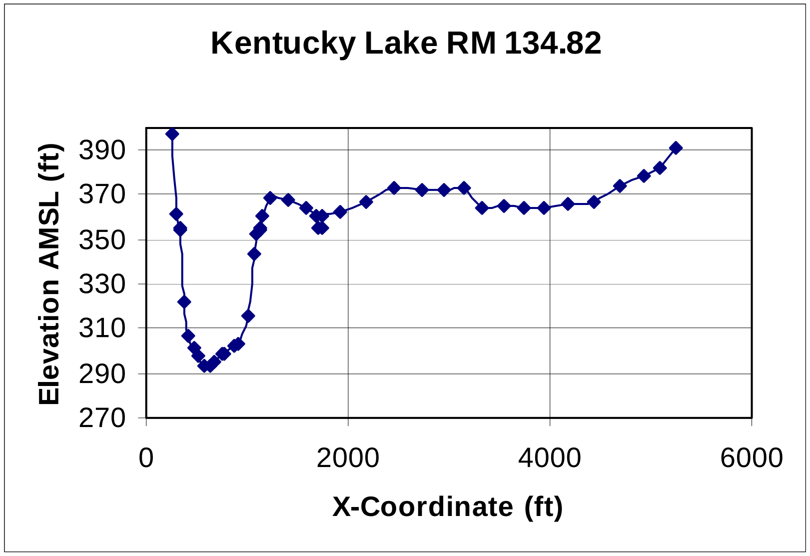
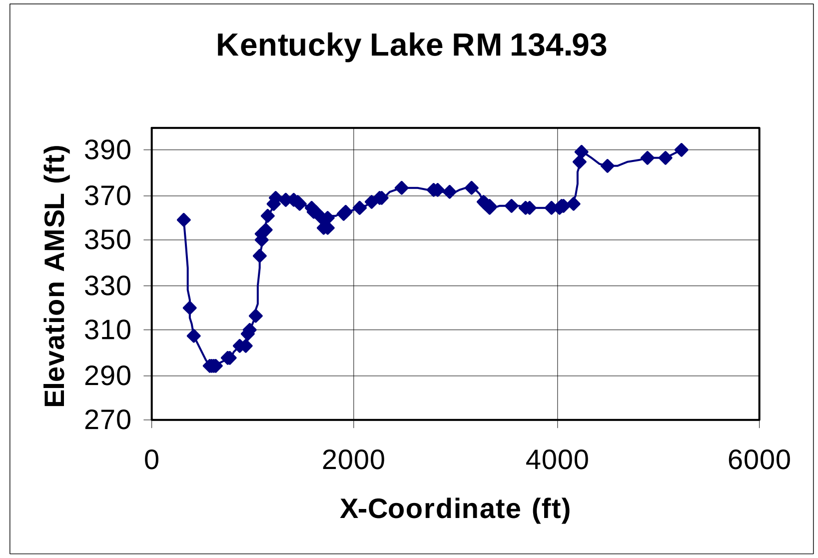
4000
6000
X-Coordinate (ft)

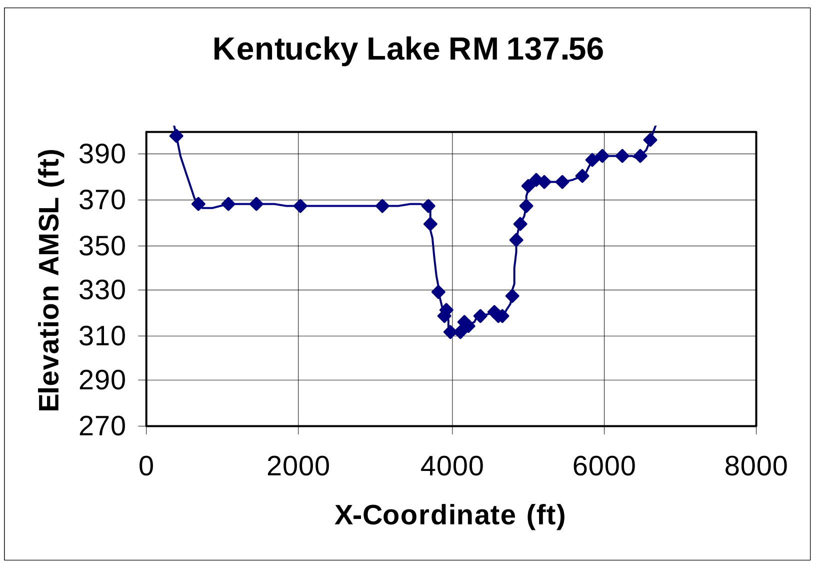

Kentucky Lake RM 129.75
Elevation AMSL (ft)
390
370
350
330
310
290
270
0
1000
2000
3000
4000
5000
X-Coordinate (ft)

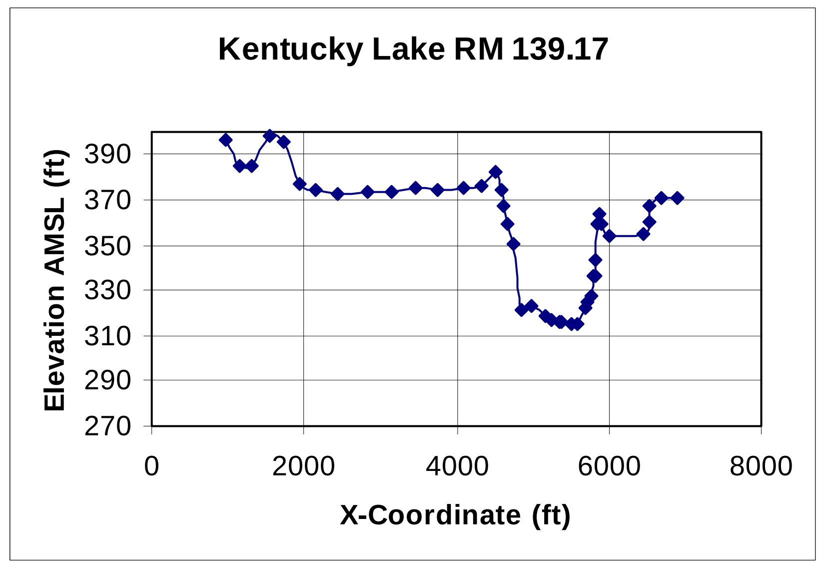

Kentucky Lake RM 131.17
Elevation AMSL (ft)
390
370
350
330
310
290
270
0
2000
4000
6000
8000
X-Coordinate (ft)

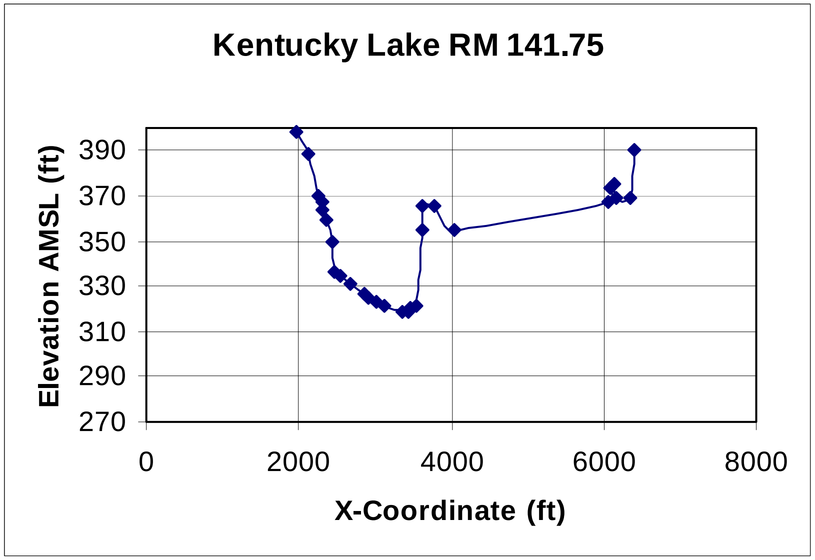

Kentucky Lake RM 133.37
Elevation AMSL (ft)
390
370
350
330
310
290
270
0
1000
2000
3000
4000
5000
X-Coordinate (ft)

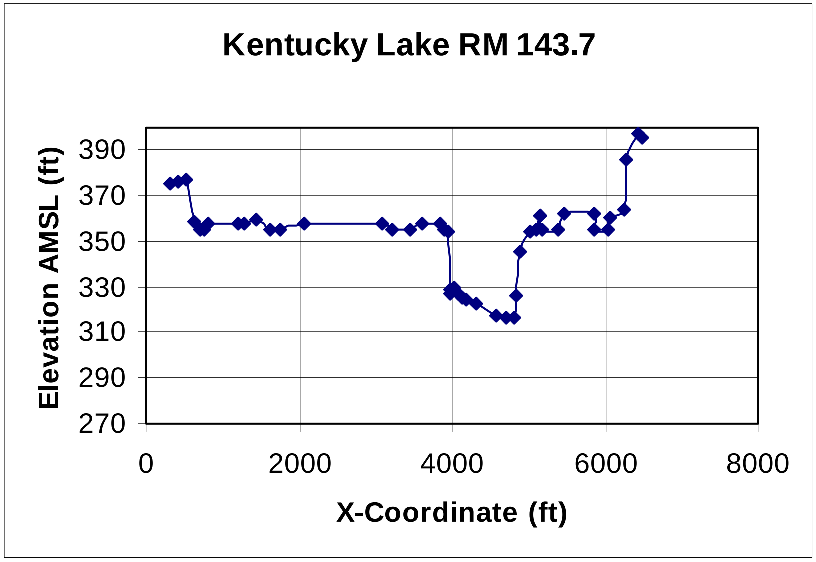

Kentucky Lake RM 134.82
Elevation AMSL (ft)
390
370
350
330
310
290
270
0
2000
4000
6000
X-Coordinate (ft)

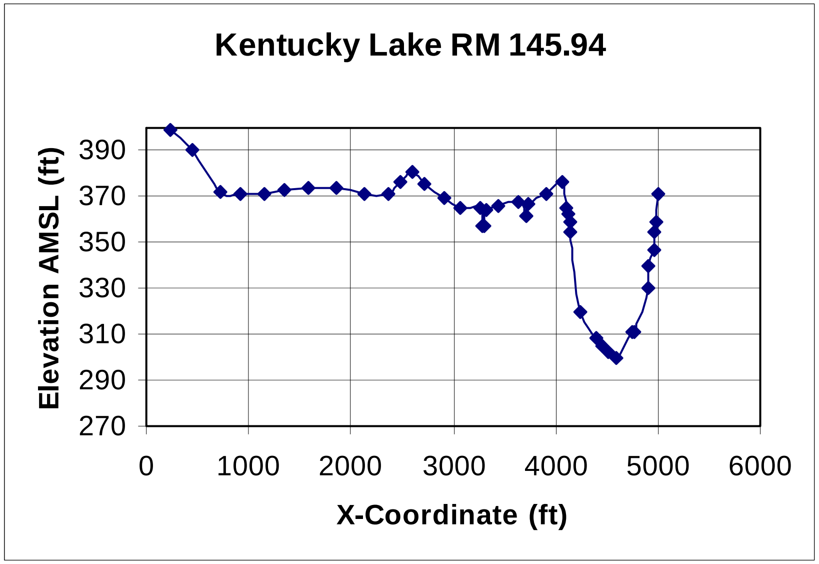

Kentucky Lake RM 134.93
Elevation AMSL (ft)
390
370
350
330
310
290
270
0
2000
4000
6000
X-Coordinate (ft)

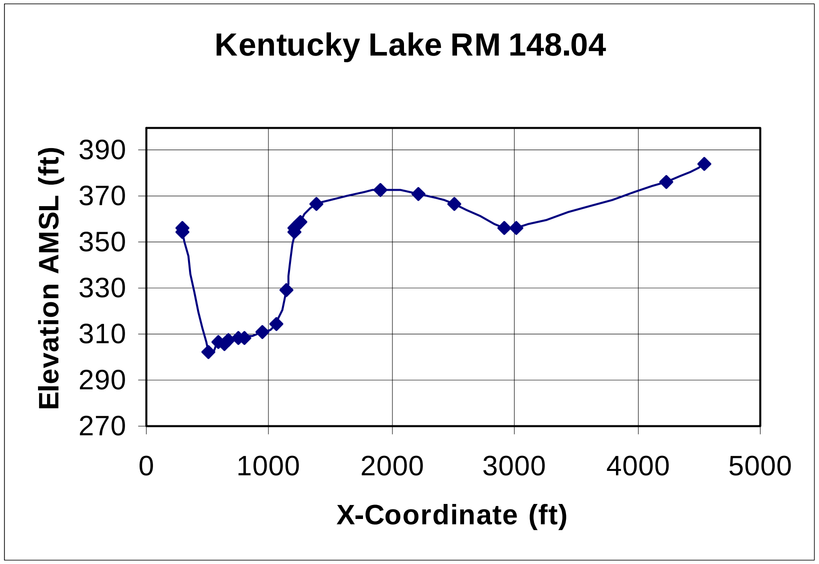

Kentucky Lake RM 137.56
Elevation AMSL (ft)
390
370
350
330
310
290
270
0
2000
4000
6000
8000
X-Coordinate (ft)

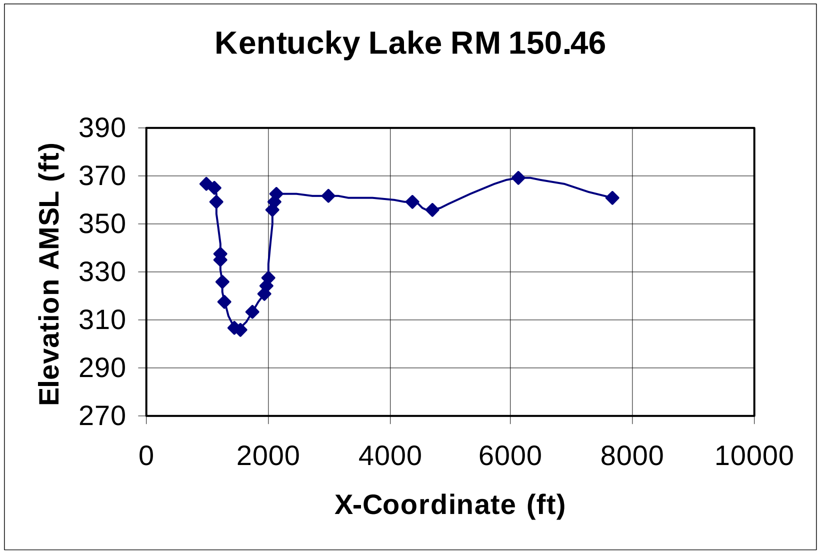

Kentucky Lake RM 139.17
Elevation AMSL (ft)
390
370
350
330
310
290
270
0
2000
4000
6000
8000
X-Coordinate (ft)


Kentucky Lake RM 141.75
Elevation AMSL (ft)
390
370
350
330
310
290
270
0
2000
4000
6000
8000
X-Coordinate (ft)

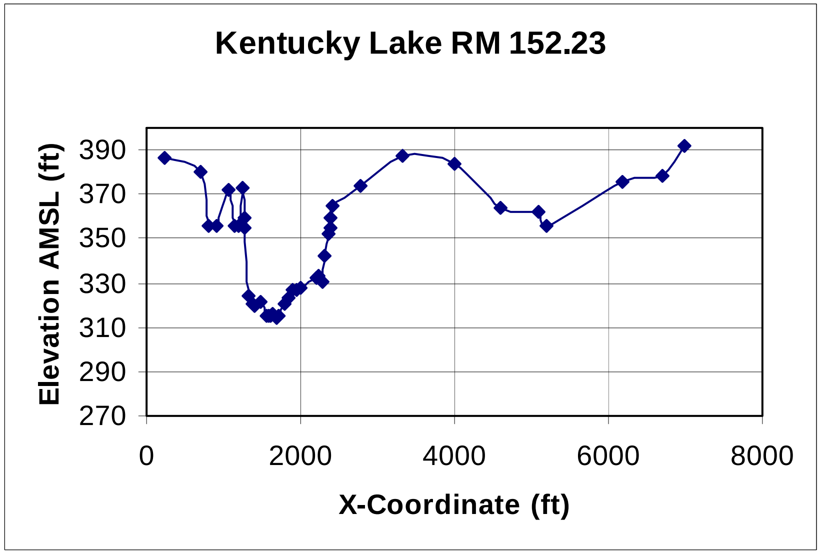

Kentucky Lake RM 143.7
Elevation AMSL (ft)
390
370
350
330
310
290
270
0
2000
4000
6000
8000
X-Coordinate (ft)


Kentucky Lake RM 145.94
Elevation AMSL (ft)
390
370
350
330
310
290
270
0
1000
2000
3000
4000
5000
6000
X-Coordinate (ft)

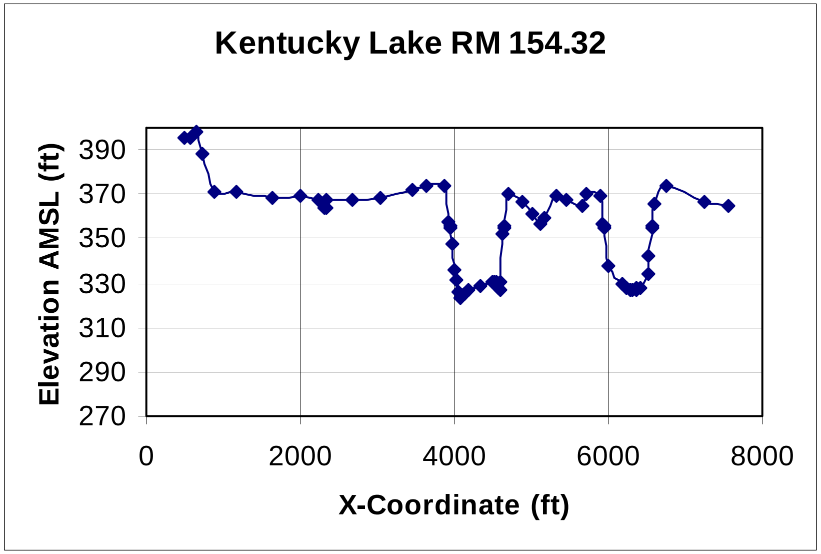

Kentucky Lake RM 148.04
Elevation AMSL (ft)
390
370
350
330
310
290
270
0
1000
2000
3000
4000
5000
X-Coordinate (ft)



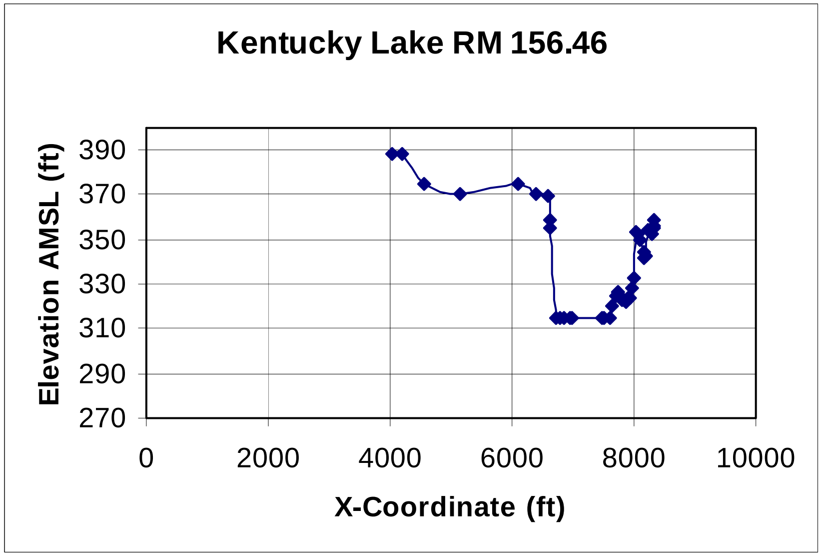
Kentucky Lake RM 150.46
Elevation AMSL (ft)
390
370
350
330
310
290
270
0
2000
4000
6000
8000
10000
X-Coordinate (ft)



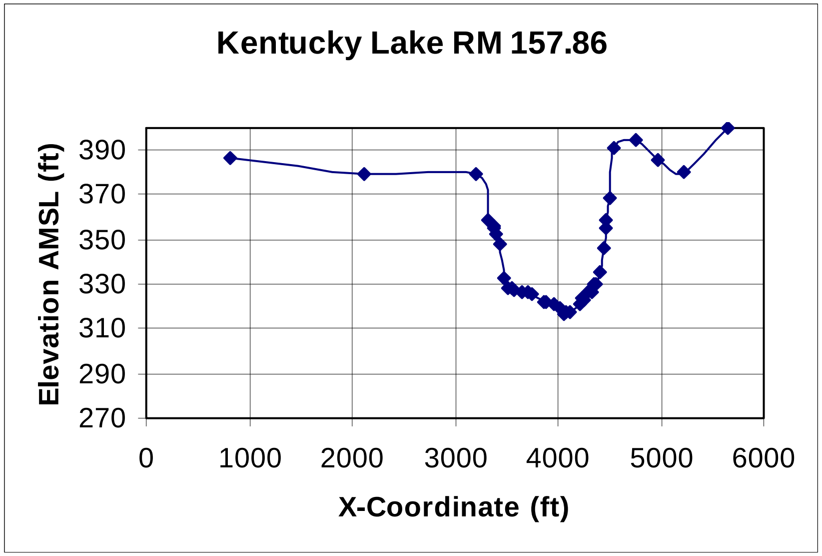
Kentucky Lake RM 152.23
Elevation AMSL (ft)
390
370
350
330
310
290
270
0
2000
4000
6000
8000
X-Coordinate (ft)



Kentucky Lake RM 154.32
Elevation AMSL (ft)
390
370
350
330
310
290
270
0
2000
4000
6000
8000
X-Coordinate (ft)



Kentucky Lake RM 156.46
Elevation AMSL (ft)
390
370
350
330
310
290
270
0
2000
4000
6000
8000
10000
X-Coordinate (ft)


Kentucky Lake RM 157.86
Elevation AMSL (ft)
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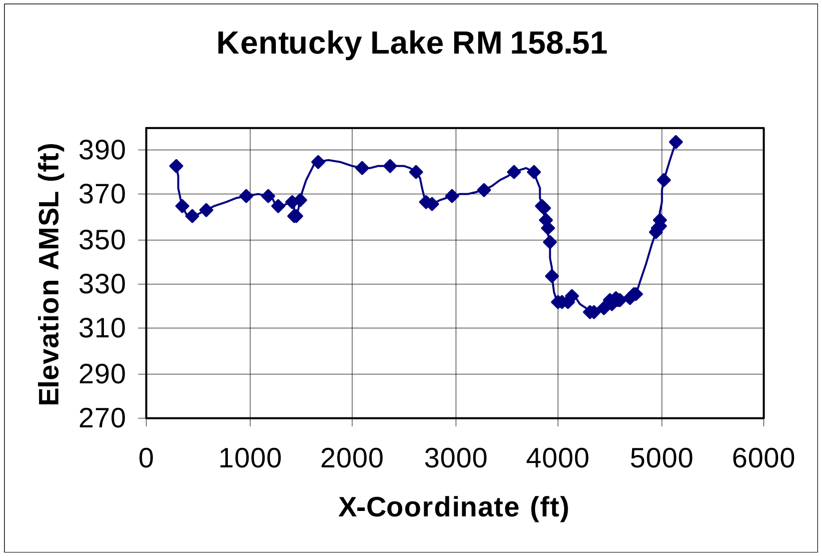
290
310
330
350
370
390
0
1000
2000
3000
4000
5000
6000
X-Coordinate (ft)


Kentucky Lake RM 158.51
Elevation AMSL (ft)
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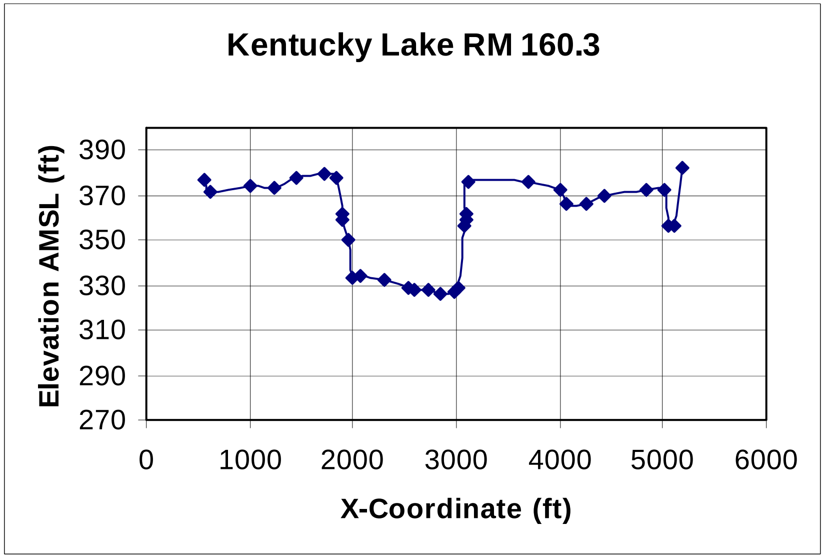
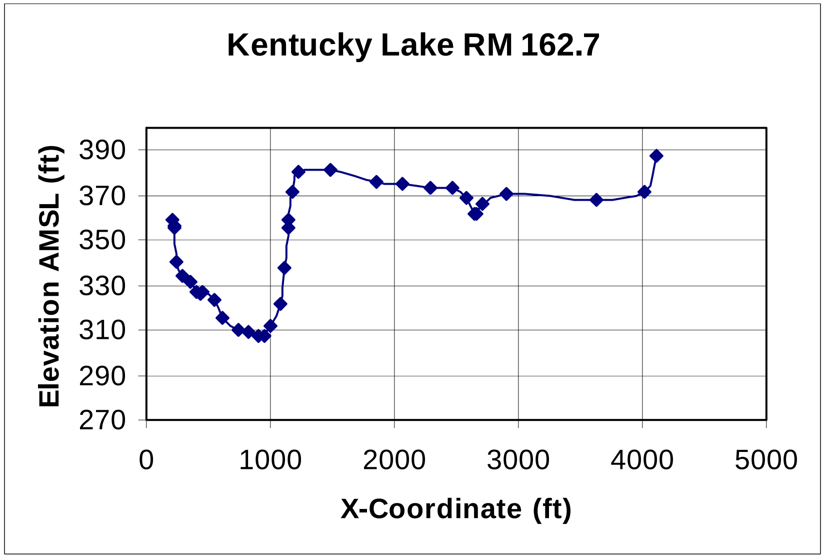
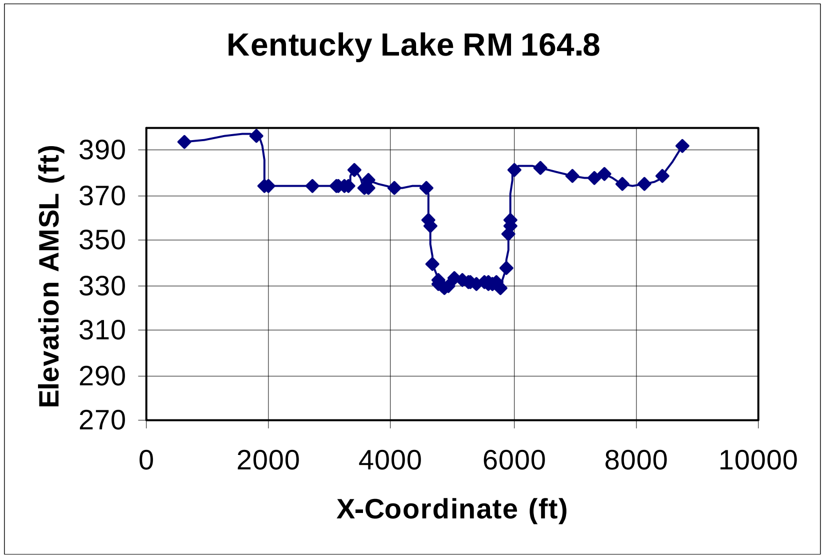
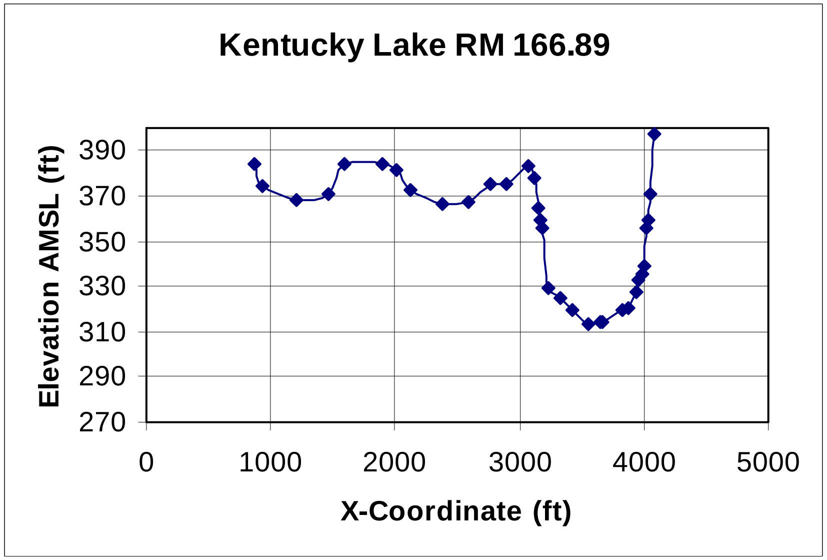
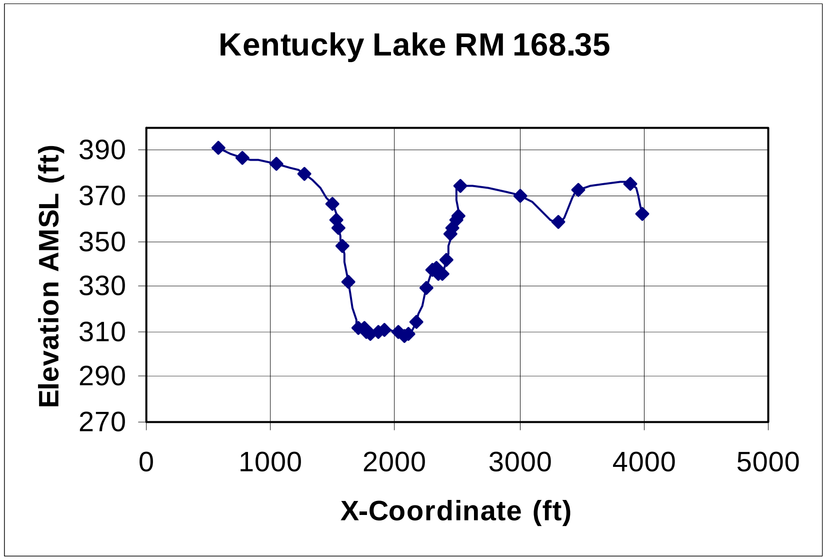
290
310
330
350
370
390
0
1000
2000
3000
4000
5000
6000
X-Coordinate (ft)

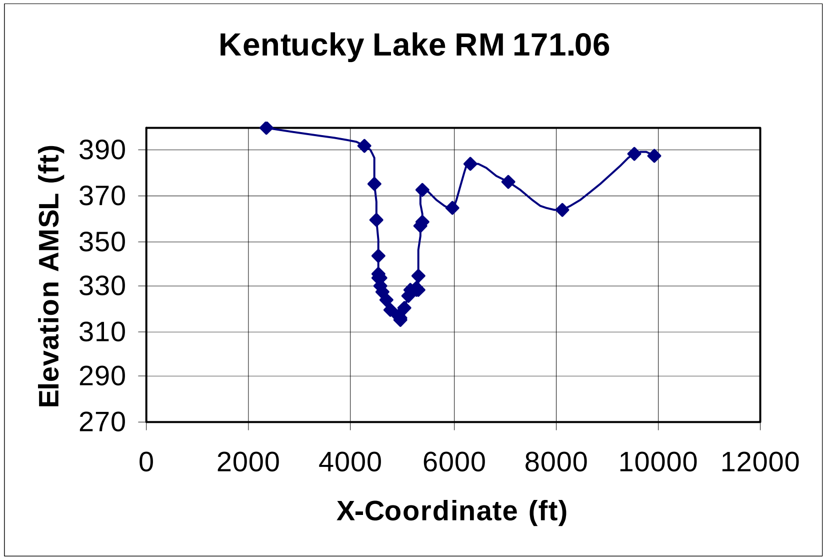

Kentucky Lake RM 160.3
Elevation AMSL (ft)
270
290
310
330
350
370
390
0
1000
2000
3000
4000
5000
6000
X-Coordinate (ft)

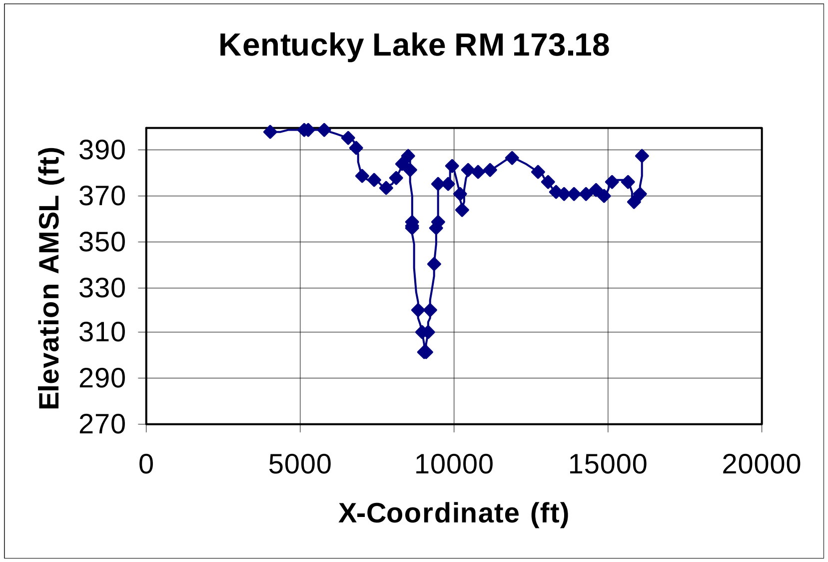

Kentucky Lake RM 162.7
Elevation AMSL (ft)
270
290
310
330
350
370
390
0
1000
2000
3000
4000
5000
X-Coordinate (ft)


Kentucky Lake RM 164.8
Elevation AMSL (ft)
390
370
350
330
310
290
270
0
2000
4000
6000
8000
10000
X-Coordinate (ft)


Kentucky Lake RM 166.89
Elevation AMSL (ft)
390
370
350
330
310
290
270
0
1000
2000
3000
4000
5000
X-Coordinate (ft)


Kentucky Lake RM 168.35
Elevation AMSL (ft)
390
370
350
330
310
290
270
0
1000
2000
3000
4000
5000
X-Coordinate (ft)


Kentucky Lake RM 171.06
Elevation AMSL (ft)
390
370
350
330
310
290
270
0
2000
4000
6000
8000
10000
12000
X-Coordinate (ft)


Kentucky Lake RM 173.18
Elevation AMSL (ft)
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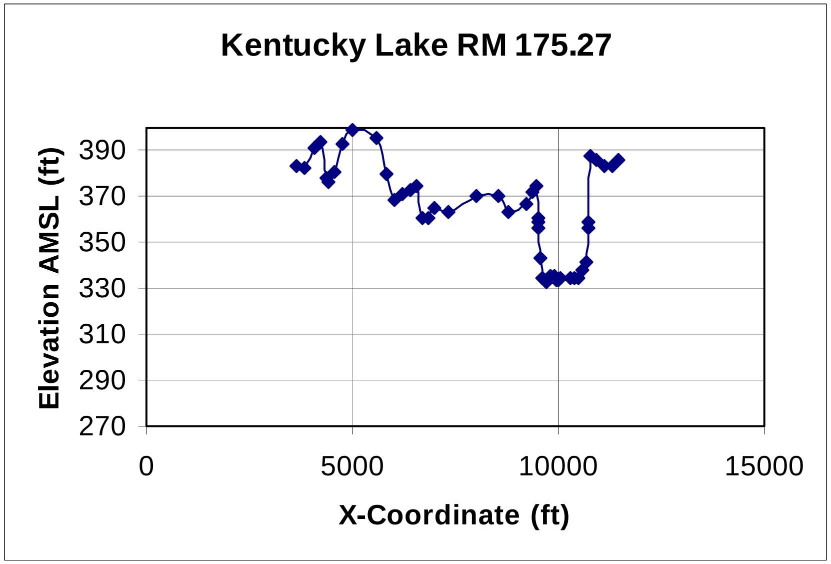
370
350
330
310
290
270
0
5000
10000
15000
20000
X-Coordinate (ft)


Kentucky Lake RM 175.27
Elevation AMSL (ft)
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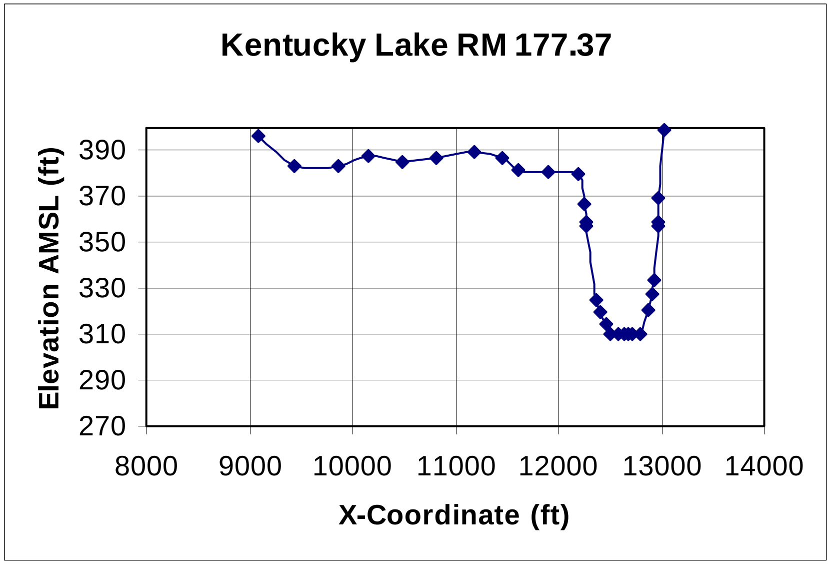
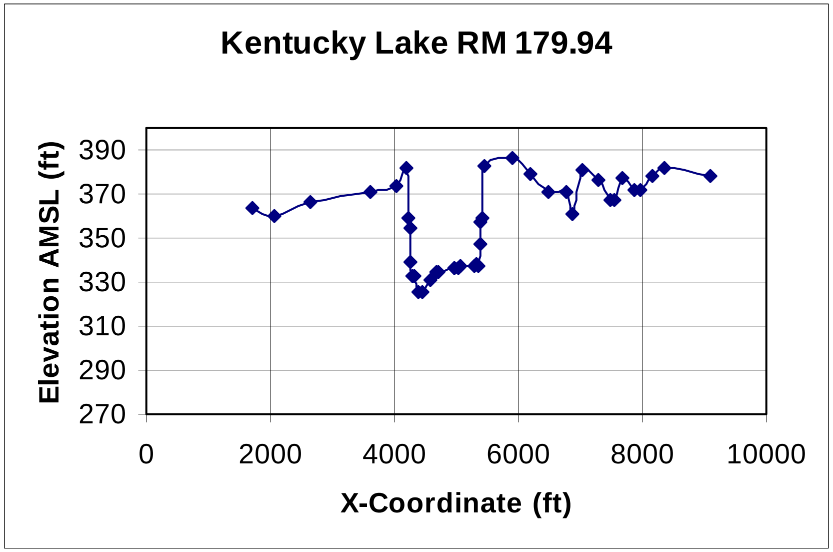
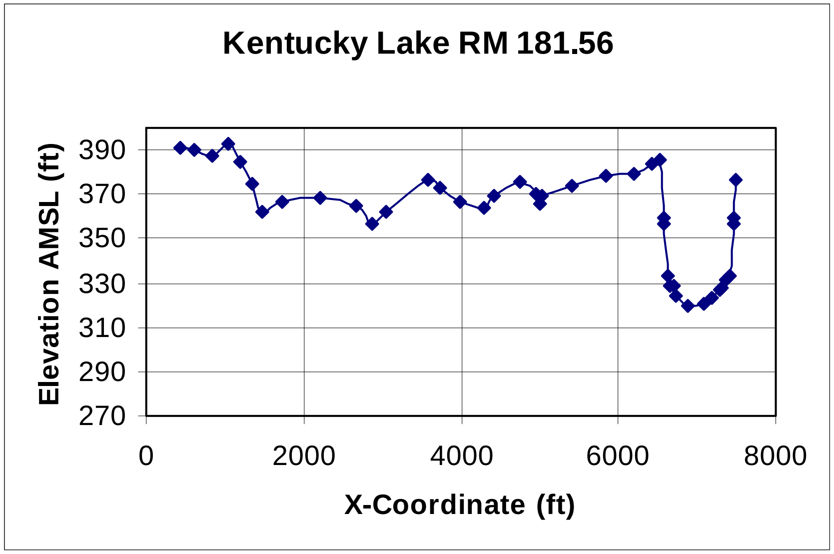
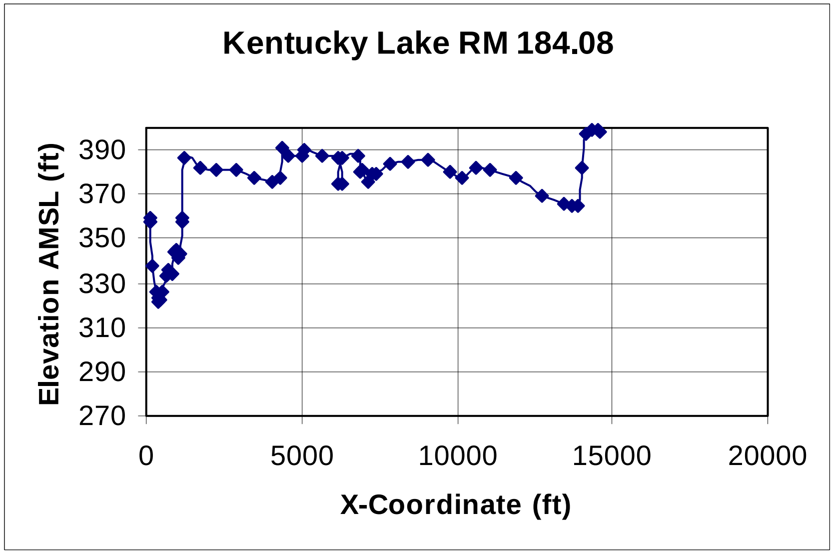
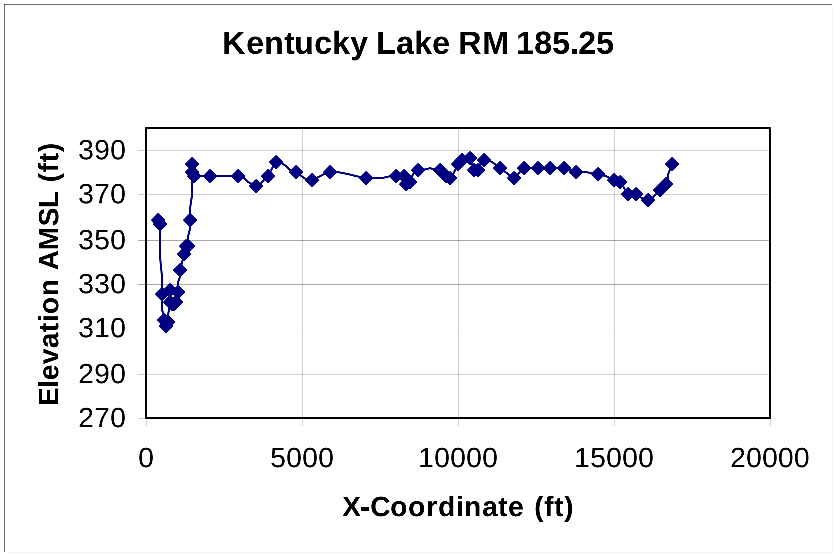
370
350
330
310
290
270
0
5000
10000
15000
X-Coordinate (ft)

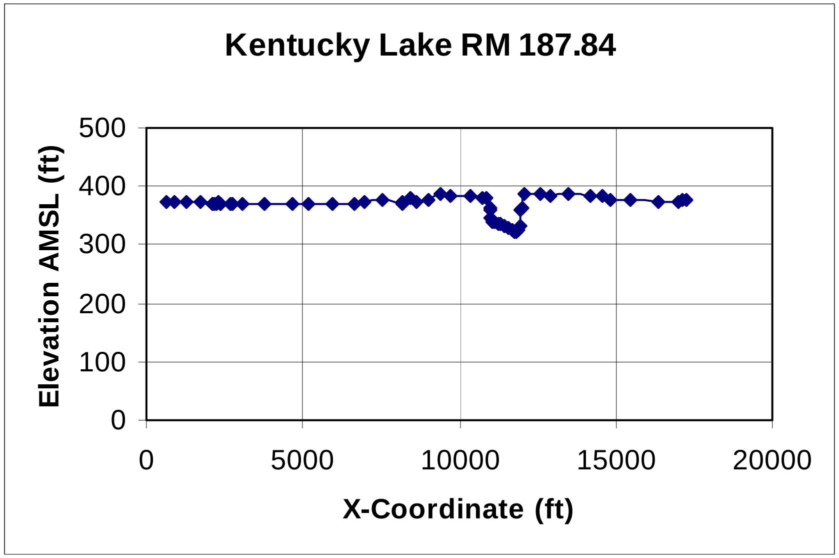

Kentucky Lake RM 177.37
Elevation AMSL (ft)
390
370
350
330
310
290
270
8000
9000
10000
11000
12000
13000
14000
X-Coordinate (ft)


Kentucky Lake RM 179.94
Elevation AMSL (ft)
390
370
350
330
310
290
270
0
2000
4000
6000
8000
10000
X-Coordinate (ft)


Kentucky Lake RM 181.56
Elevation AMSL (ft)
390
370
350
330
310
290
270
0
2000
4000
6000
8000
X-Coordinate (ft)


Kentucky Lake RM 184.08
Elevation AMSL (ft)
390
370
350
330
310
290
270
0
5000
10000
15000
20000
X-Coordinate (ft)


Kentucky Lake RM 185.25
Elevation AMSL (ft)
390
370
350
330
310
290
270
0
5000
10000
15000
20000
X-Coordinate (ft)


Kentucky Lake RM 187.84
Elevation AMSL (ft)
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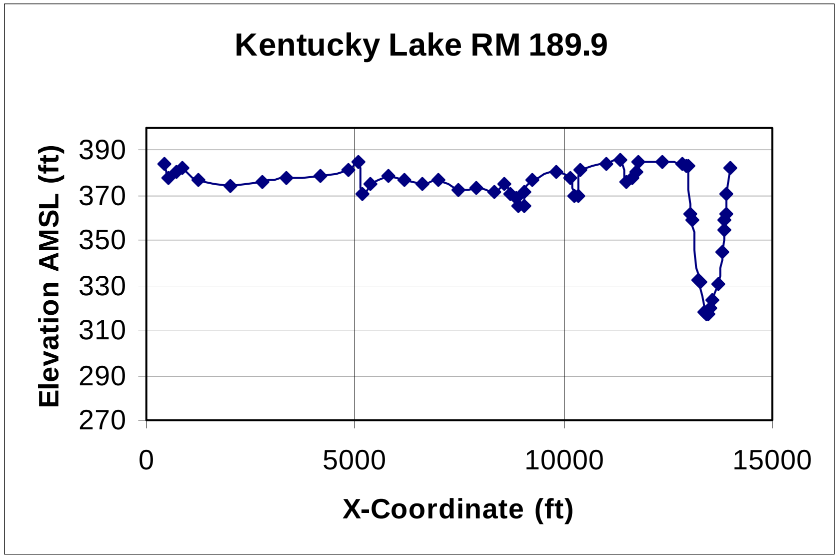
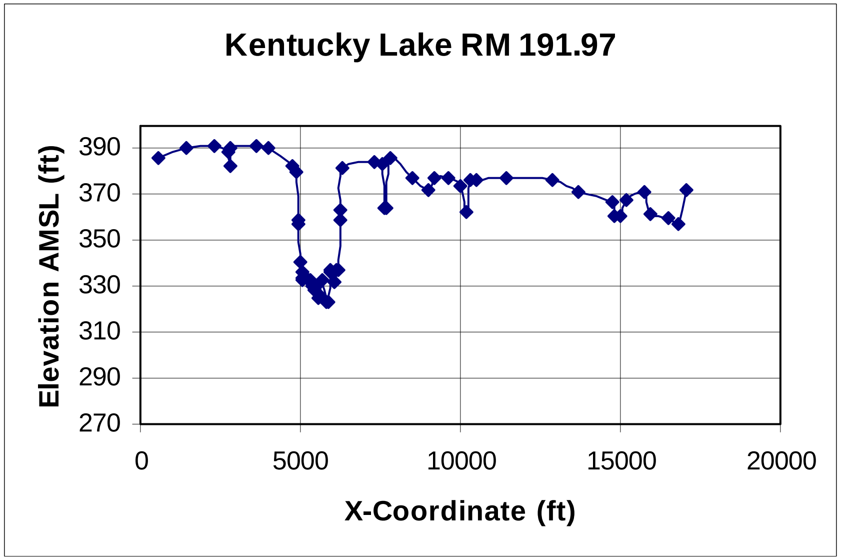
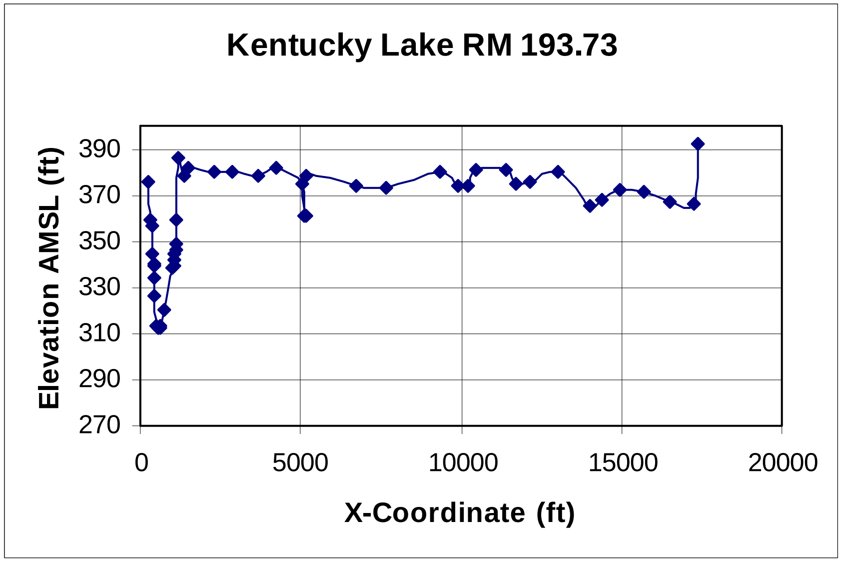
400
300
200
100
0
0
5000
10000
15000
20000
X-Coordinate (ft)


Kentucky Lake RM 189.9
Elevation AMSL (ft)
390
370
350
330
310
290
270
0
5000
10000
15000
X-Coordinate (ft)


Kentucky Lake RM 191.97
Elevation AMSL (ft)
390
370
350
330
310
290
270
0
5000
10000
15000
20000
X-Coordinate (ft)


Kentucky Lake RM 193.73
Elevation AMSL (ft)
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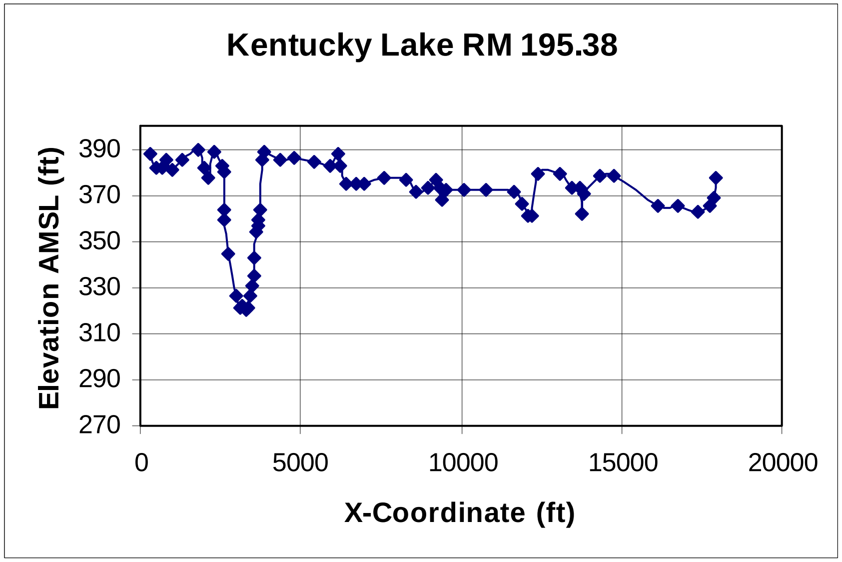
370
350
330
310
290
270
0
5000
10000
15000
20000
X-Coordinate (ft)


Kentucky Lake RM 195.38
Elevation AMSL (ft)
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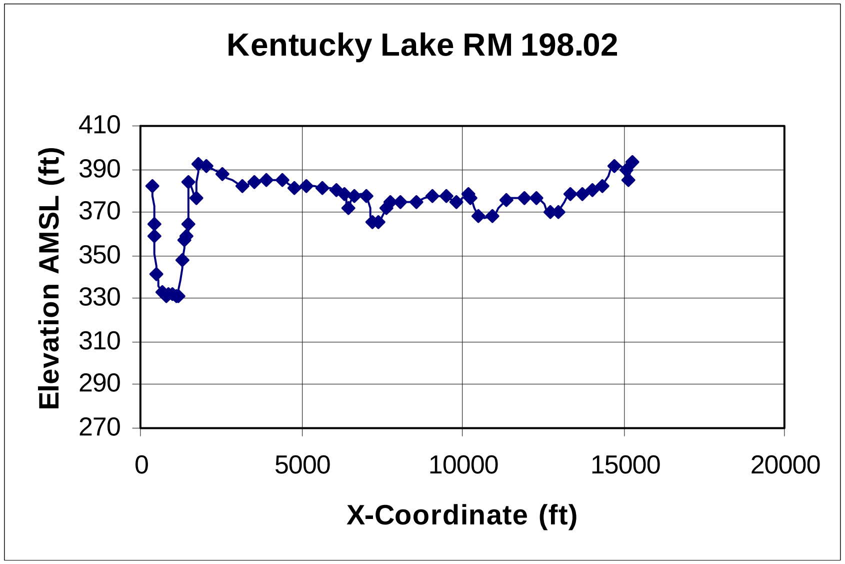
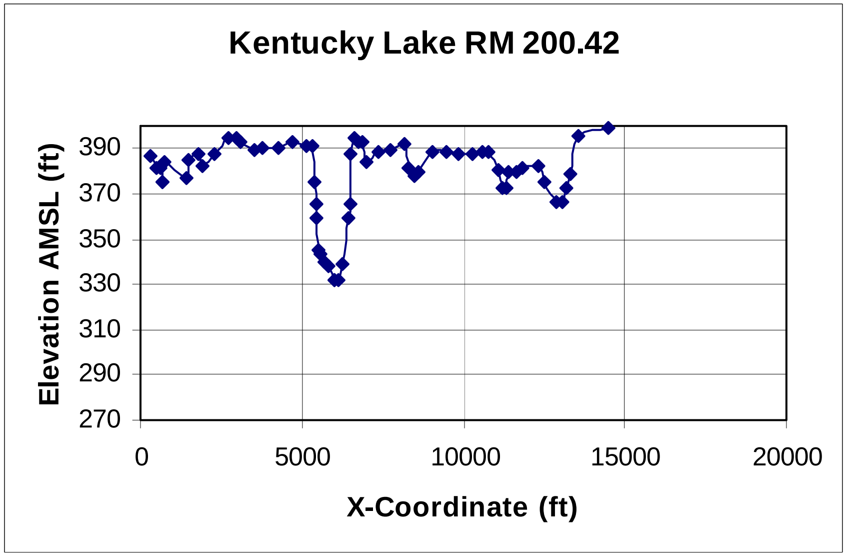
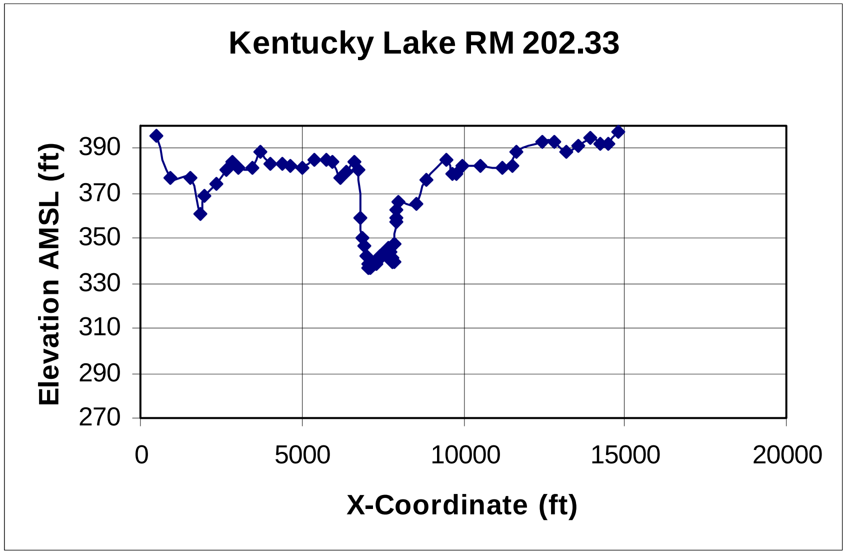
370
350
330
310
290
270
0
5000
10000
15000
20000
X-Coordinate (ft)


Kentucky Lake RM 198.02
Elevation AMSL (ft)
410
390
370
350
330
310
290
270
0
5000
10000
15000
20000
X-Coordinate (ft)


Kentucky Lake RM 200.42
Elevation AMSL (ft)
390
370
350
330
310
290
270
0
5000
10000
15000
20000
X-Coordinate (ft)


Kentucky Lake RM 202.33
Elevation AMSL (ft)
390
370
350
330
310
290
270
0
5000
10000
15000
20000
X-Coordinate (ft)

APPENDIX C

DATA USED IN GLLVHT MODEL FOR KENTUCKY LAKE

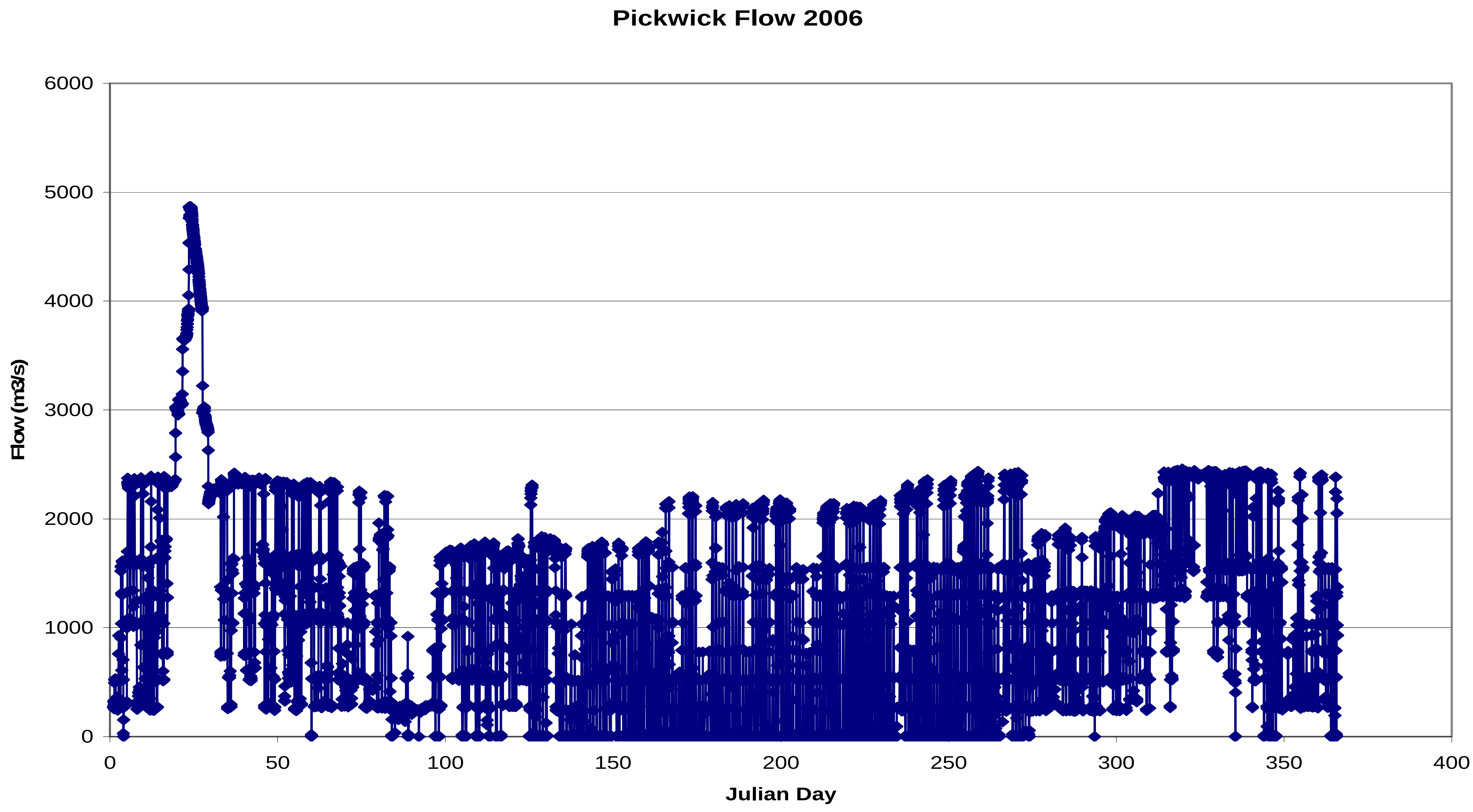


Figure A-1: Pickwick Dam flow for 2006.

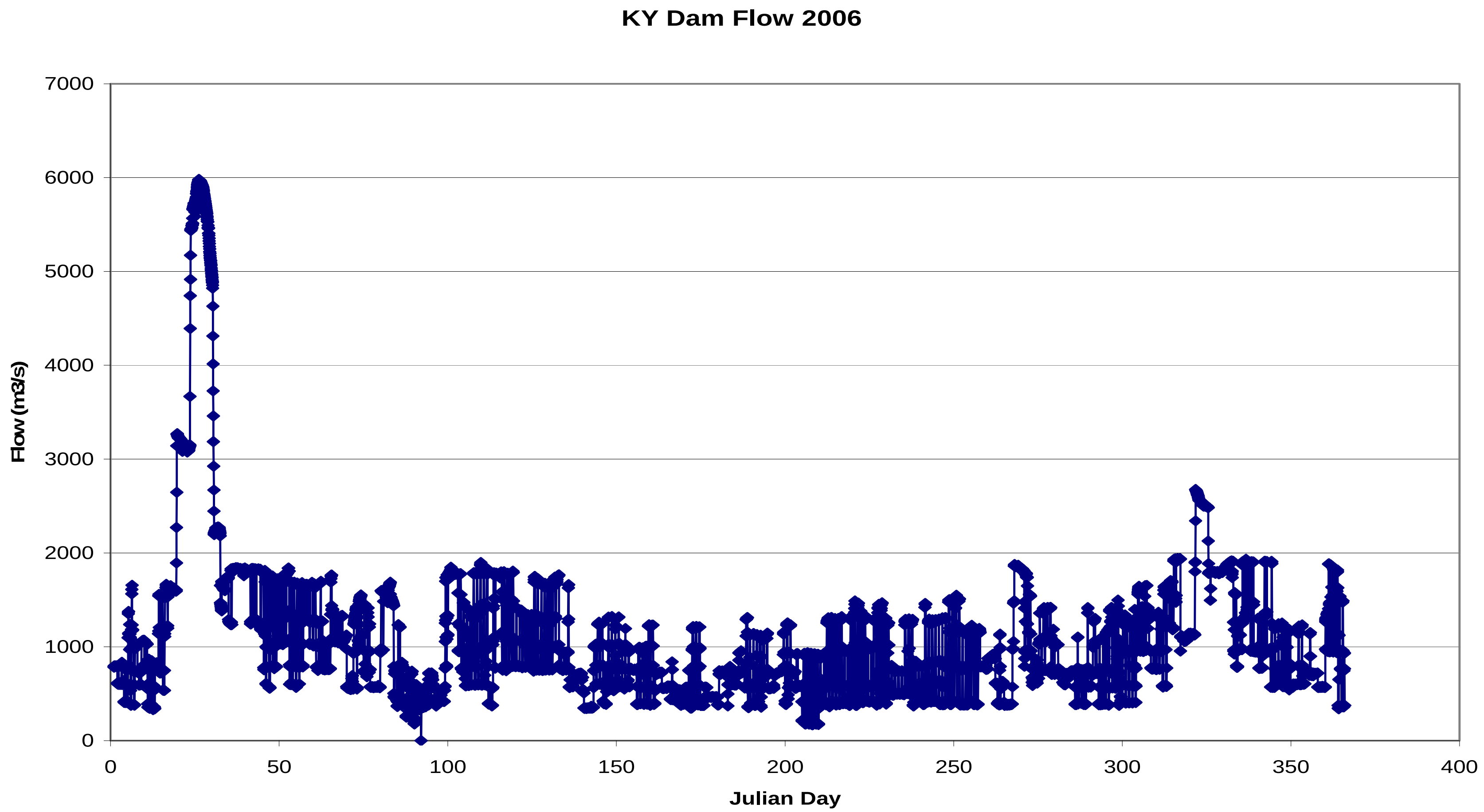


Figure A- 2: Kentucky Dam flow for 2006.

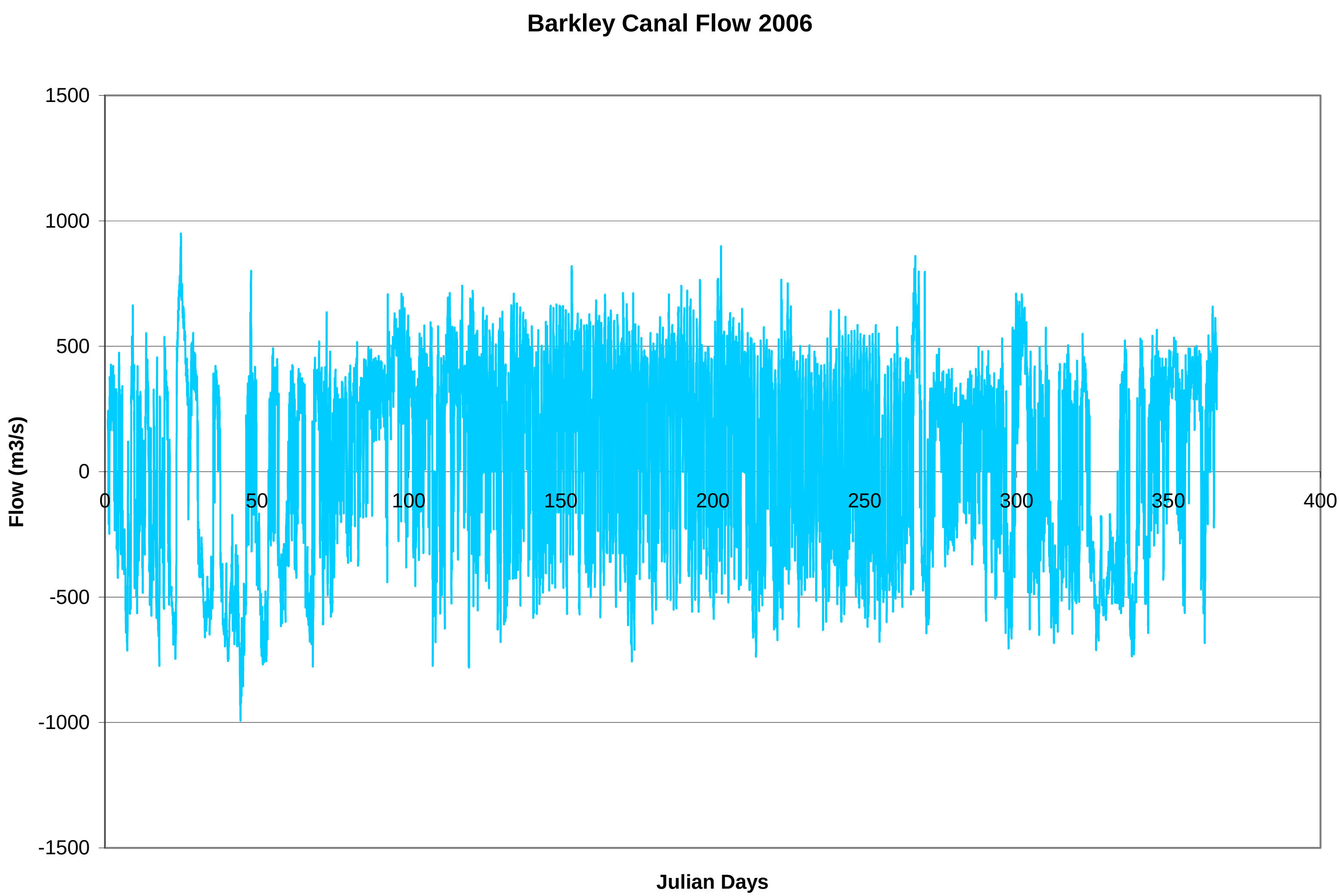


Figure A- 3: Flow for Barkley Canal in 2006.

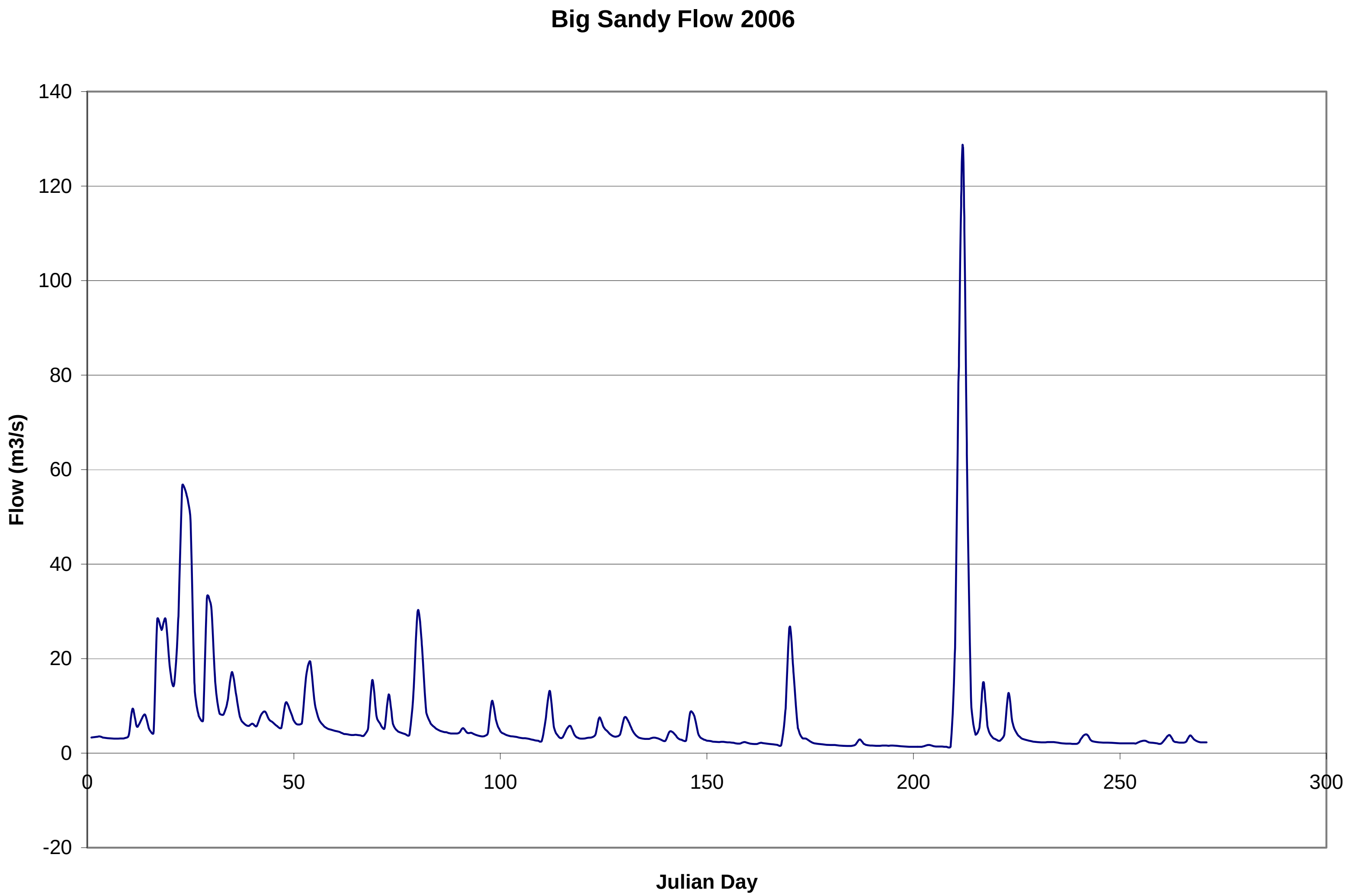


Figure A- 4: Flow for Big Sandy River in 2006.

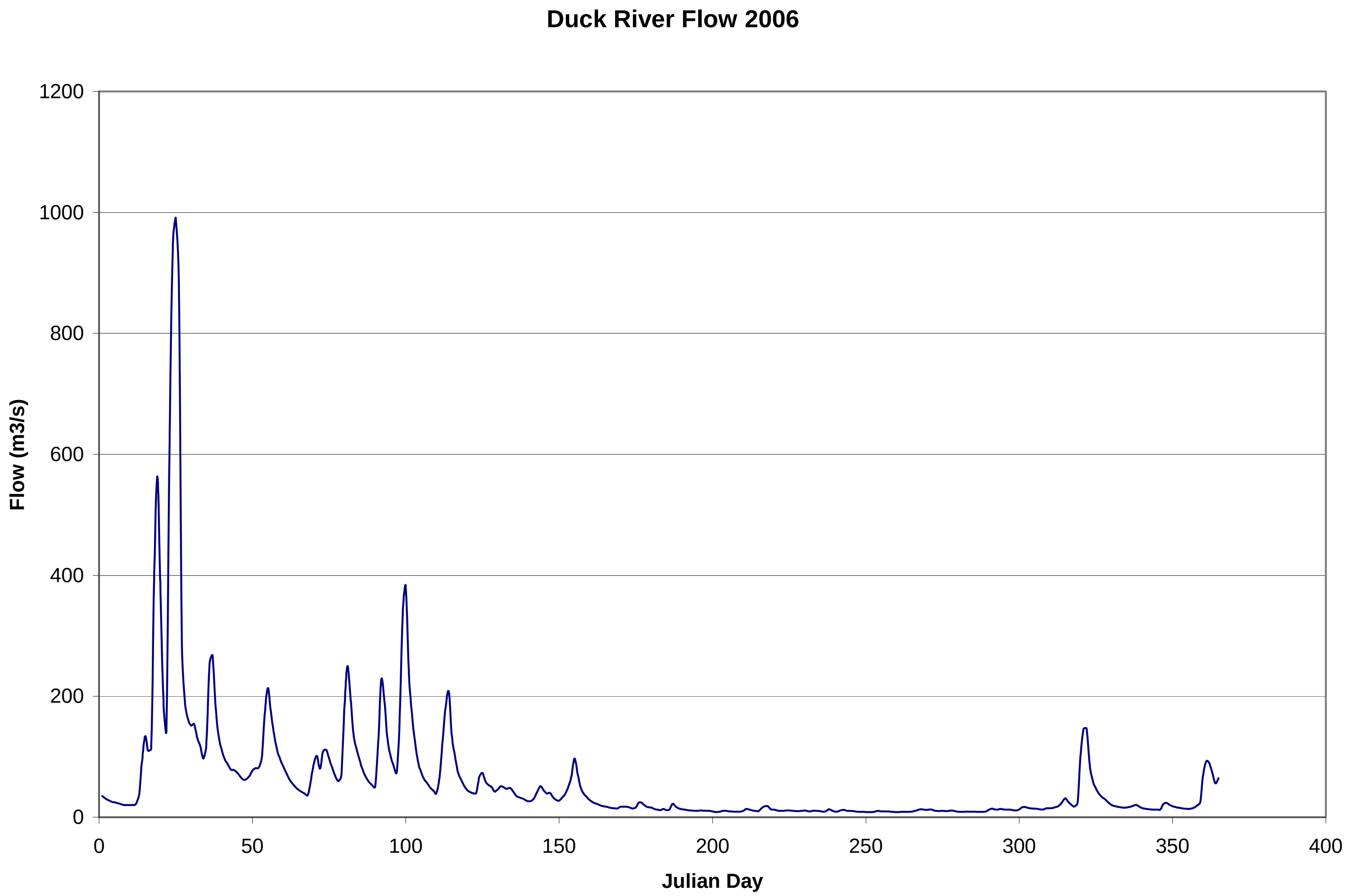


Figure A- 5: Flow for Duck River in 2006.

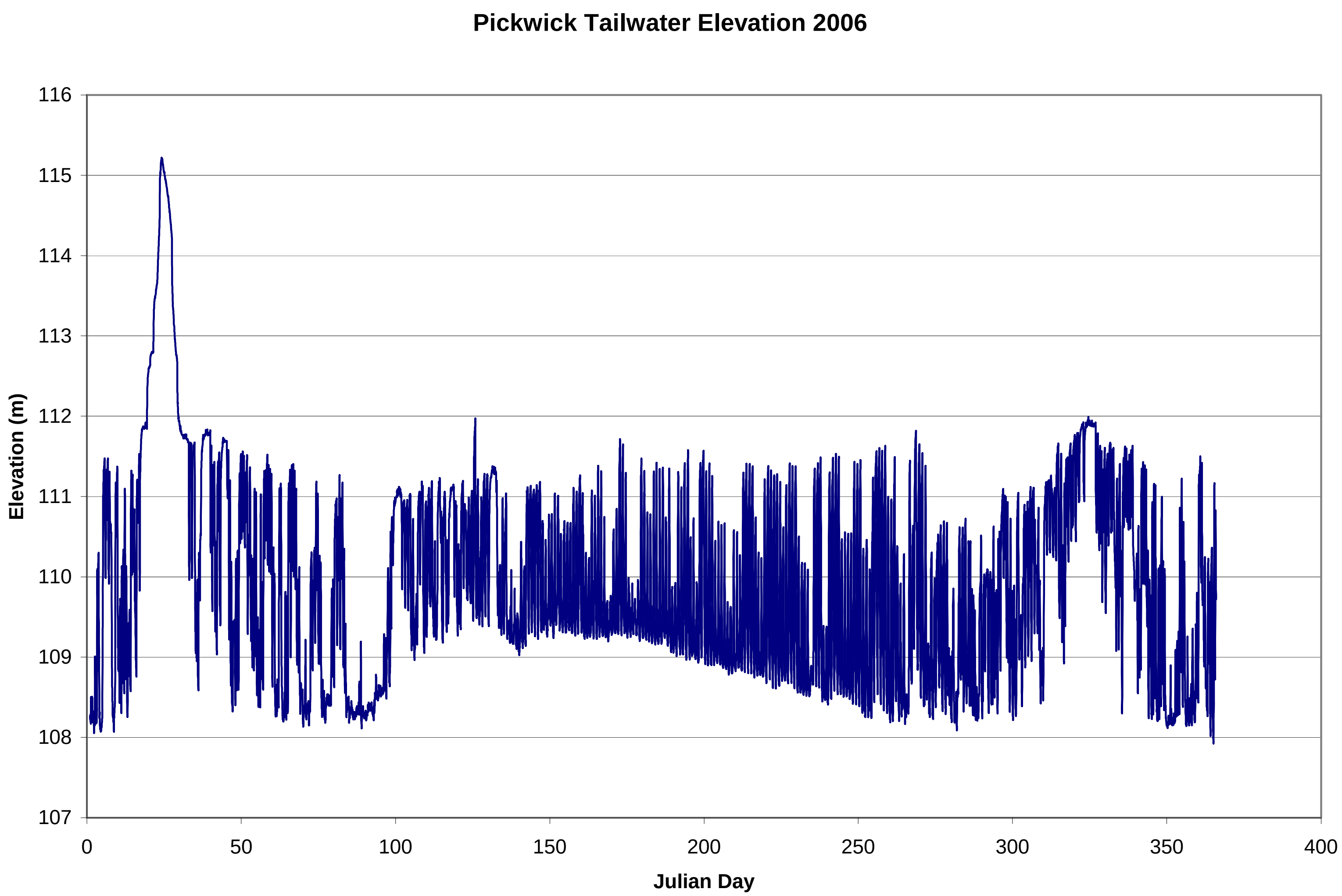


Figure A- 6: Pickwick Dam surface elevation.

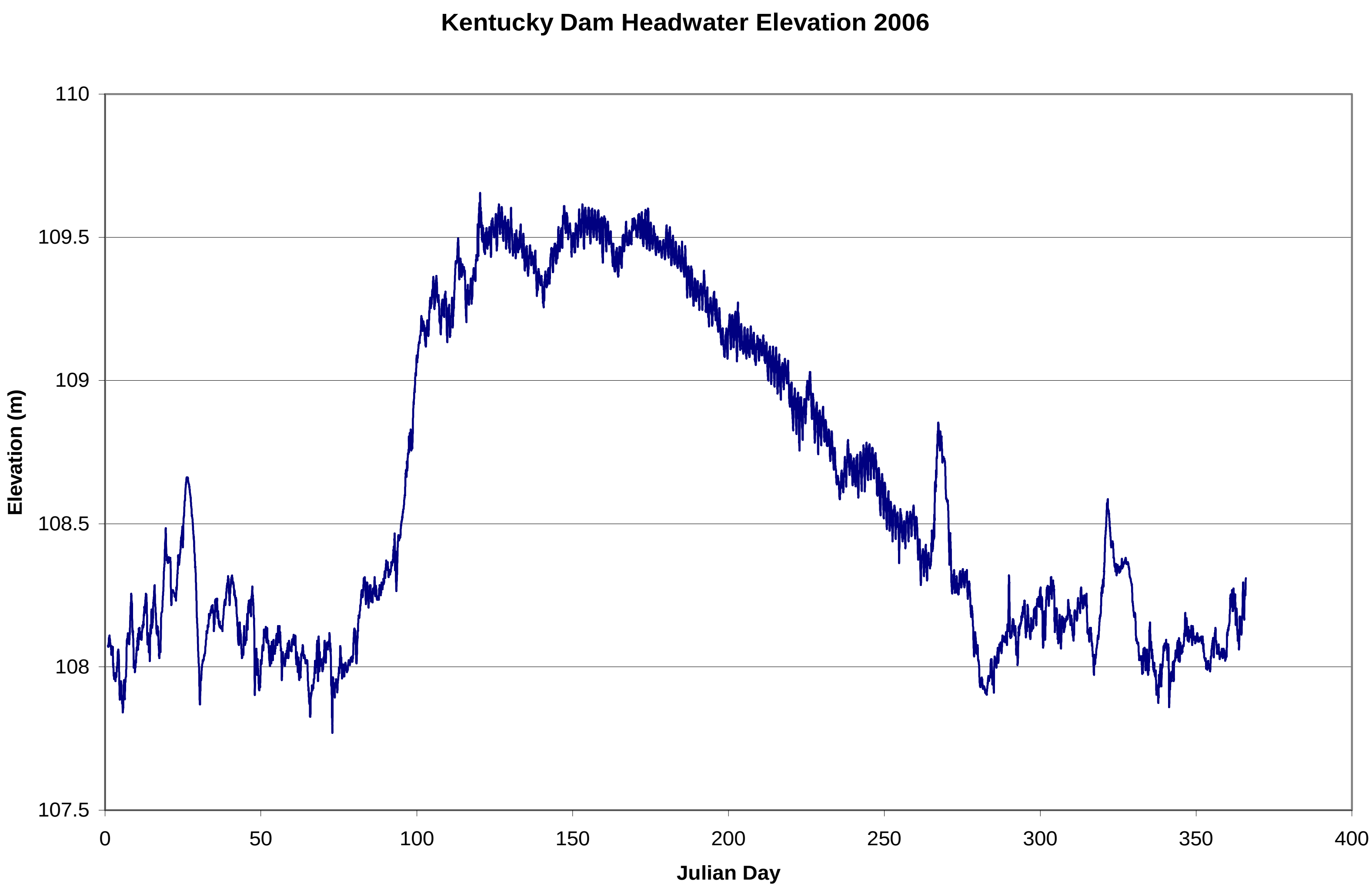


Figure A- 7: Kentucky Dam elevation.

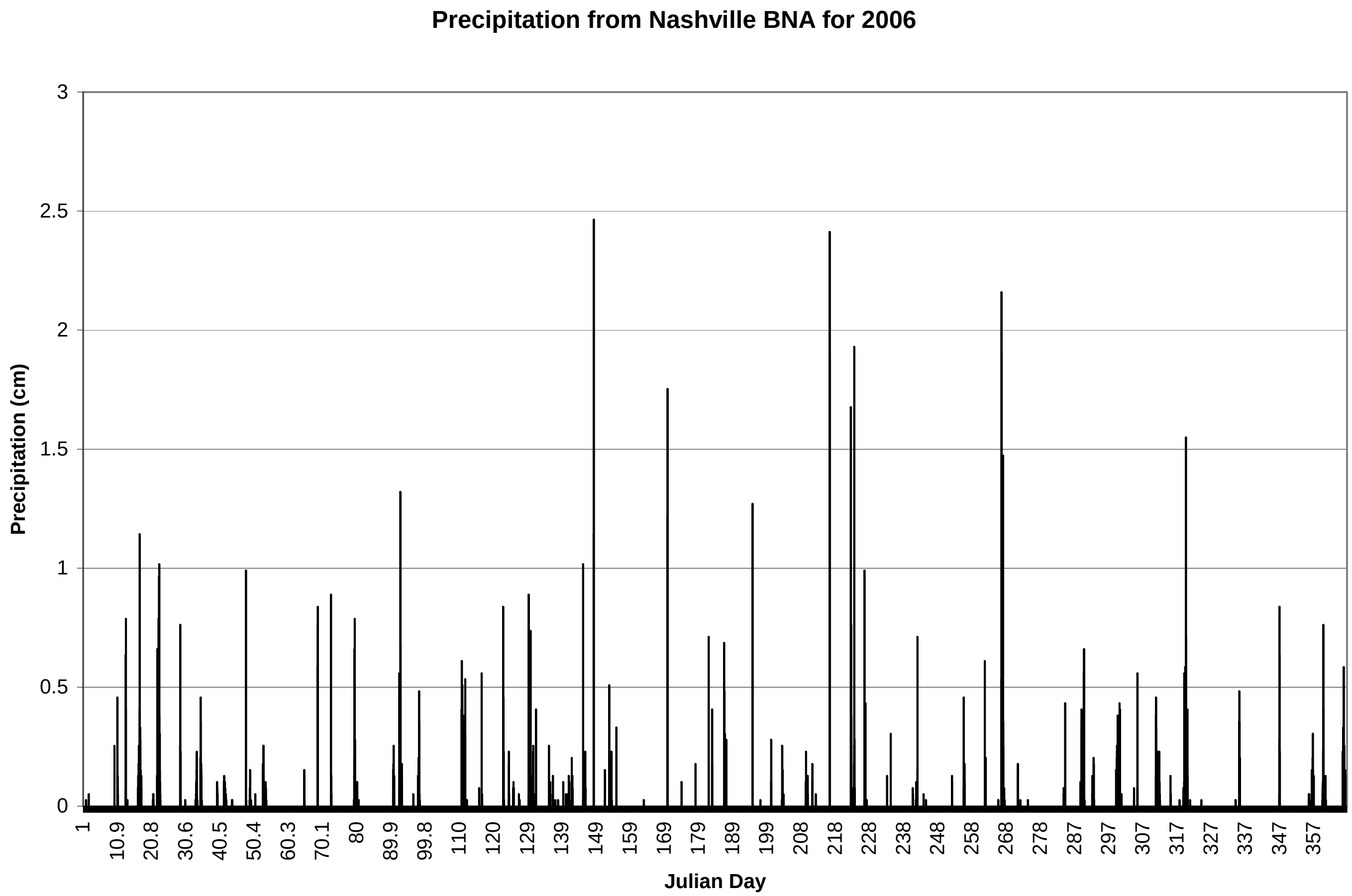


Figure A- 8: Precipitation data used for modeling Kentucky Lake (2006).

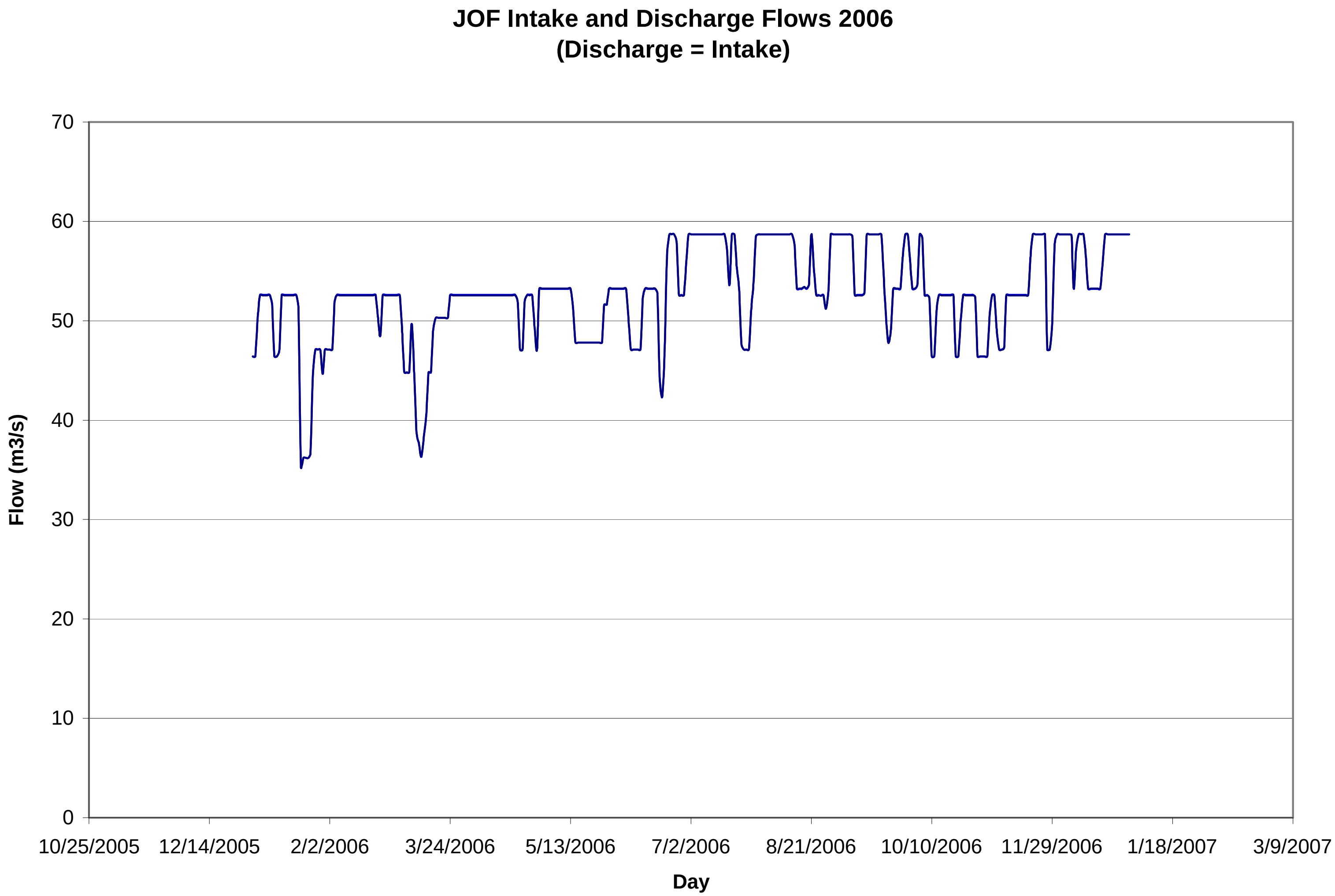


Figure A- 9: JOF Flows for 2006

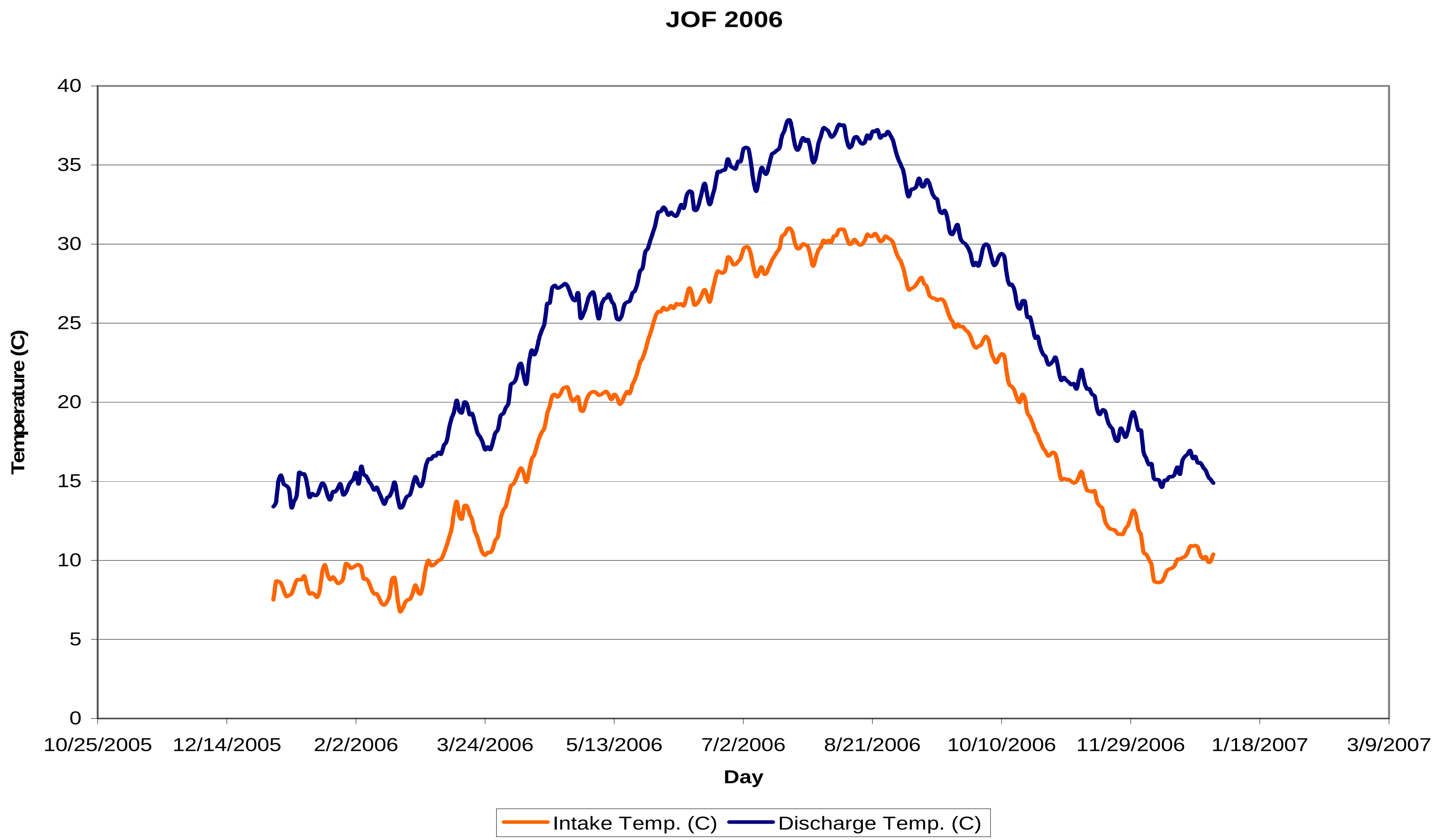


Figure A- 10: Johnsonville Fossil Plant intake and discharge temperatures 2006.

APPENDIX D

COSIM OIL SPILL CONTROL FILE

COSIM Microsoft Excel Control File for Average Probable Spill at Average Flow

EStr1	EStr2	EStr3	EStr4	EStr5
$GEMSSModelResults	14	1		
$GEMSS-COSIMControlFile-TrajectoryAndFates	1	1		
$Date: 10/14/2008				
$WaterBody Name: Lake Kentucky				
$Modeler Name: Janey Smith				
$Preliminary oil spill fate and trajectory model set up for Kentucky Lake				
##,				
#1: Spill Release Variables,				
##,				
ChemicalName,	Chemical/Oil name,	Diesel,		
NumSources,	Number of oil releases,	1		
ReleaseYear,	Release year,	2006		
ReleaseMonth,	Release month,	4		
ReleaseDay,	Release day,	12		
ReleaseHour,	Release hour,	0		
ReleaseMinute,	Release minute,	0		
ReleaseXLoc,	Release x-location,	1380700		
ReleaseYLoc,	Release y-location,	630875.6		
ReleaseXLocLon,	Release x-location,	0		
ReleaseYLocLat,	Release y-location,	0		
NDurations,	Number of release durations,	1		
ReleaseDuration,	Release duration,	8		
ReleaseDurationUnit,	Release duration units,	1		
ReleaseSpeed,	Release speed,	0		
ReleaseSpeedUnit,	Release speed units,	0		
ReleaseDirection,	Release direction,	0		

ReleaseAmount,	Release amount,	500		
ReleaseAmountUnit,	Release amount units,	2		
ReleaseDepth,	Release depth,	8.5		
ReleaseDepthUnit,	Release depth units,	0		
ReleaseTidalLagTime,	Release time offset with the high tide,	0		
ReleaseInitialThickness,	Initial Chemical film thickness m,	0.005		
ReleaseNumParticles,	Number of particles to be released in each event	0		
Particle Release Method,	method used to released total numer of particles,	1		
ReleaseType,	Type of release,	1		
ReleaseMaterialType,	Type of material released,	1		
ReleaseGas2OilRatio,	Ratio of gas volume to oil volume,	1000		
ReleaseGasAmount,	Release gas amount in tonnes/hr,	0.8		
ReleaseGasDensity,	Release gas density in kg/m3,	70		
ReleaseDropletMinSize,	Release gas droplet min size in microns,	1000		
ReleaseDropletMaxSize,	Release gas droplet max size in microns,	3000		
ReleaseConduitDiameter,	Release conduit diameter in m,	0.15		
ReleasePAngle,	Release angle from positve z-axis,	0		
ReleaseTAngle,	Release angle from postive x-axis,	0		
ReleaseTVData,	Release time varying location file,	0		
ReleaseTVDFileName,	Release time varying location file name 1,	No_Data_File,		
PlumeNumDropletSizes,	Plume number of droplet sizes,	10		
UseBlowOutPlumeModel,	Use blowout plume model for subsurface releases,	0		
BlowOutPlumeModelType,	Blowout plume model type,	0		
RiseVelCompMethod,	Particle rise velocity computation method,	0		
GasOilSurfTension,	Gas-oil surface tension,	0.005	N/m^2	
OilWatSurfTension,	Oil-wat surface tension,	0.013	N/m^2	
MaxDropSizeConstant,	Maximum droplet size estimation proportionality constant,	27.5		

MaxDropSizeExponent,	Maximum droplet size estimation exponent,	1.6		
BlowOutVoidRatio,	Blowout void ratio,	0.5		
UseJetMomentum,	Use jet momentum,	0		
###,				
#2: Scenario Variables,				
###,				
Scenario,	Scenario name with file path,	C:\GEMSS\Apps\Kentucky Lake\Output\AvgProb_AvgFlow,		
WriteDBUsingf90SQL,	Use Scenario Output Direct Database conversion,	0		
SimDays,	Number of Simulation Days,	3		
dt,	Simulation Time Step,	360		
idbg,	Debug switch,	0		
DisplayTime,	Ouput Frequency Time,	600		
ElaspedTimeForZeroParticles,	Elasped time since number of particles is zero,	4		
UseCheckForSParticles,	Use program exit check for surface particles,	1		
UseCheckForSSParticles,	Use program exit check for sub-surface particles,	0		
SetStartHourRandom,	Set the start hour random,	0		
CheckWaterSurfaceMassTime,	Time in days at which limiting surface mass needs to be checked,	20		
RunSpillModel,	Option to skip spill model when saving grid based output for meteorology and wind,	1		
###,				

#3: Grid Variables,				
##,				
igrid,	Grid Type,	1		
GridFile,	Grid file name,	**C:\GEMSS\Apps\Kentucky Lake\Grid\Spill_RM112_65_VSK.osg,**		
InputHDatumUnit,	Horizontal coordinate system for input model grid,	2		
InputVDatumUnit,	Vertical coordinate system for input model grid,	2		
OutputHDatumUnit,	Horizontal coordinate system for model output,	2		
OutputVDatumUnit,	Vertical coordinate system for model output,	2		
UpdateOSGDepths,	Update oil spill grid depths,	0		
SurferGRDFileName,	Surfer grid file name for use in depth interpolation,	**C:\GEMSS\Apps\Kentucky Lake\Grid\NotUsed.grd,**		
SurferDepthType,	Surfer depth data type,	0		
ScaleDepthUsingReleaseDepth,	Scale depth data using release depth,	1		
DepthSourceNumber,	Spill release number to be used for depth scaling,	1		
##,				
#4: Particle Variables,				
##,				
NumMaxSParticles,	Number of spillets to discretize surface oil,	1000		
NumMaxSSParticles,	Number of particles to represent	1000		

	subsurface oil,			
HPlumeGridType,	Plume gridding type in horizontal direction,	1		
HPlumeXGridSize,	Plume grid size in x-direction,	100		
HPlumeYGridSize,	Plume grid size in y-direction,	100		
VPlumeGridType,	Plume gridding type in vertical direction,	1		
VPlumeZGridSize,	Plume grid size in y-direction,	0.25		
NPlumeGridX,	Number of grids in the x-direction for the dynamic grid,	30		
NPlumeGridY,	Number of grids in the y-direction for the dynamic grid,	30		
NPlumeGridZ,	Number of grids in the z-direction for the dynamic grid,	10		
NPlumeGridXInc,	Number of grids in the x-direction for the dynamic grid,	1		
NPlumeGridYInc,	Number of grids in the y-direction for the dynamic grid,	1		
NPlumeGridZInc,	Number of grids in the z-direction for the dynamic grid,	1		
RotatePlumeGrid,	Rotate plume grid,	0		
PlumeGridAngle,	Plume Grid Rotation in degrees,	0		
PlumeGridXSEFactor,	Plume grid region stretching factor in east direction,	0		
PlumeGridXSWFactor,	Plume grid region stretching factor in west direction,	0		
PlumeGridYSNFactor,	Plume grid region stretching factor in north direction,	0		
PlumeGridYSSFactor,	Plume grid region stretching factor in south direction,	0		
CompressZeroMassSParticles,	Compress zero mass surface particles,	1		
CompressCloseSParticles,	Compress surface particles that are very close,	0		
SplitBigSParticles,	Split big mass particles for better resolution,	0		

SplitSParticles,	Split surface particles for better resolution,	0		
ProgramStopSParticlesLimit,	Numer of surface particles at which model will stop,	1		
##,				
#5: Meteorological Variables,				
##,				
MetDataType,	Switch to use Meterological time varying data,	1		
metss,	Use meterological data in current simulation status,	1	ta	td
Metfile1,	Meterological time varying data input file name,	**C:\GEMSS\Apps\Kentucky Lake\Meteorology\NashvilleMetData2006.met,**	1	1
xMet1,	x-coordinate of Meterological station 1,	1390105		
yMet1,	y-coordinate of Meterological station 1,	727124.9		
MetFileStatus,	Meteorologial file usage status for station 1,	1		
metinterp,	Switch to perform interpolation on met data,	0		
ta,	temperature of air C,	29	0	
td,	Dew point temperature C,	-99	0	
twb,	Wet bulb temperature C,	-99	0	
rt,	response temperature C,	29	0	
phi,	Wind direction degrees,	-99	,	
wad,	Wind speed m/sec,	-99	0	
cc,	Cloud coverage Octal,	-99	,	
solrad,	Solar radiation W/m^2,	-99	0	
ps,	Atmoshpheric pressure mm of Hg,	-99		
MetInterpolationMethod,	Met Interpolation Method,	1		

MetDataUseType,	Met Data Use Type,	1		
IDWPOW,	Exponent value for inverse weighting scheme,	2		
UWindScaleFactor,	Scale Factor in u-direction,	0		
WWindScaleFactor,	Scale Factor in v-direction,	0		
LimitingWindSpeed,	Limiting wind speed in m/sec,	50		
##,				
#6: Wave Variables,				
##,				
UseWaveDrift,	Switch to use wave data,	0		
Wavess,	Use wave data in current simulation status,	0		
WaveDataInputType,	Wave data input type,	0		
WaveFile1,	Wave time varying data input file name,	No_Data_File,		
xWave1,	x-coordinate of Meterological station 1,	-99		
yWave1,	y-coordinate of Meterological station 1,	-99		
WaveInterp,	Switch to perform interpolation on wave data,	1		
WaveNumberCompMethod,	Wave number computation method,	1		
##,				
#7: Hydrodynamic Currents Variables,				
##,				
CurrentsType,	Hydrodynamic currents type,	1	2	
NumCurrentFiles,	Number of Current Files,	1		
CurrentsFile1,	Hydrodynamic currents file,	**C:\GEMSS\Apps\Kentucky**		

		Lake\Currents\JanRun007b2r_part4_optimal_year.cur,		
dzmove,	Minimum vertical movement of particle in meters,	0.5		
MaxNumTSRCURZLevels,	Maximum number of z levels in all current meters,	0		
CurrentsDAType,	Hydrodynamic currents direct access data type,	1		
CMInterpolationMethod,	Current meter interpolation method,	0		
CMInterpolationExponent,	Current meter interpolation exponent,	0		
CurrentsUScaleFactor,	Hydrodynamic currents u-velocity scale factor,	1		
CurrentsVScaleFactor,	Hyrdodynamic currents v-velocity scale factor,	1		
CurrentsWScaleFactor,	Hyrdodynamic currents w-velocity scale factor,	1		
TidesUScaleFactor,	Tides u-velocity scale factor,	1		
TidesVScaleFactor,	Tides v-velocity scale factor,	1		
TidesWScaleFactor,	Tides w-velocity scale factor,	1		
UPlumeVelocityFactor,	Plume u-velocity scale factor,	1		
VPlumeVelocityFactor,	Plume v-velocity scale factor,	1		
CurrentsInterpolation,	Interpolation type at the spill location in a cell,	1		
DefaultCurrentCell,	Use default active current cell,	1		
DefaultCurrentICell,	Current I Cell for default use,	40		
DefaultCurrentJCell,	Current J Cell for default use,	22		
UseCurrentRegionExtension,	Use current region procedure,	0		
CurRegionX;CurRegionY,	Current default region point 1 x and y values,	214093.4	801405.2	
CurRegionX;CurRegionY,	Current default region point 2 x and y values,	238861	772899.9	
CurRegionX;CurRegionY,	Current default region point 3 x and y values,	255518.8	786823.6	
CurRegionX;CurRegionY,	Current default region point 4 x and y values,	230312.9	814780.8	

UseCurrentSearchTime,	Use current search time to start the cell location process,	0		
CurrentSearchTime,	Current search time in julian days sinc 1900,	25		
WaterTempInputType,	Water temperature input type,	0		
WaterTemp,	Water temperature C; units,	29	0	
WaterTempFile,	Water temperature TVD file name,	No_Data_File,		
WaterDensityInputType,	Water density input type,	0		
WaterDensity,	Water density gm/cc,	1.00715		
WaterDensityFile,	Water density TVD file name,	No_Data_File,		
WaterSalinityInputType,	Water salinity input type,	0		
WaterSalinity,	Salinity of water ppt,	15		
WaterSalinityFile,	Water salinity TVD file name,	No_Data_File,		
WaterViscosity,	Viscosity of water m2/sec,	0.000000821		
RandomMethod,	Random number generator method,	2		
ihtdcx,	transport diffusion coefficient scheme in x-direction,	1		
ihtdcy,	transport diffusion coefficient scheme in y-direction,	1		
htdcx,	transport diffusion coefficient in x-direction m2/sec,	5	1.1	
htdcy,	transport diffusion coefficient in y-direction m2/sec,	5	1.1	
ivtdcz,	transport diffusion coefficient scheme in z-direction,	1		
vtdcz,	transport diffusion coefficient in z-direction m2/sec,	0.001		
DoSPVertAdvect,	Do vertical advection,	0		
UseOBRetCoeff,	Use open boundary return coefficient,	1		
OBRetCoeff,	Open boundary particle return coefficient,	1		
###,				
#8: Grid Wind Output Variables,				

###,				
iGWO,	Grid Wind Output Selector Switch,	1		
iGWOss,	Ouput status,	0		
nGWO,	Number of output times,	1		
GWOYear,	GWO output year,	2006		
GWOMonth,	GWO output month,	4		
GWODay,	GWO output day,	12		
GWOHour,	GWO output hour,	0		
GWOMinute,	GWO output minutes,	0		
GWOFreqU,	Grid wind output frequency unit,	0		
GWOFreq,	Grid wind output frequency value,	180		
UseModelGridDomainForGWO,	Use oil spill grid domain for GWO,	0		
GWOXMin	Minimum distance in x-direction for GWO,	15400		
GWOXMax,	Maximum distance in x-direction for GWO,	15870		
GWOXMin	Minimum distance in y-direction for GWO,	15735		
GWOXMax,	Maximum distance in y-direction for GWO,	14610		
GWOIMax,	Number of grid cells in x-direction for GWO,	50		
GWOJMax,	Number of grid cells in y-direction for GWO,	50		
###,				
#9: Grid Current Output Variables,				
###,				
iGCO,	Grid Wind Output Selector Switch,	1		
iGCOss,	Ouput status,	0		
nGCO,	Number of output times,	1		

GCOYear,	GCO output year,	2006		
GCOMonth,	GCO output month,	4		
GCODay,	GCO output day,	12		
GCOHour,	GCO output hour,	0		
GCOMinute,	GCO output minutes,	0		
GCOFreqU,	Grid wind output frequency unit,	0		
GCOFreq,	Grid wind output frequency value,	180		
UseModelGridDomainForGCO,	Use oil spill grid domain for GCO,	0		
GCOXMin	Minimum distance in x-direction for GCO,	15400		
GCOXMax,	Maximum distance in x-direction for GCO,	15870		
GCOYMin	Minimum distance in y-direction for GCO,	15735		
GCOYMax,	Maximum distance in y-direction for GCO,	14610		
GCOZMax,	Minimum distance in z-direction for GCO,	0		
GCOZMin,	Maximum distance in z-direction for GCO,	-1000		
GCOIMax,	Number of grid cells in x-direction for GCO,	50		
GCOJMax,	Number of grid cells in y-direction for GCO,	50		
GCOKMax,	Number of grid cells in z-direction for GCO,	10		
###,				
#10: Snapshot Output Variables,				
###,				
isnp,	Snapshot output selector,	1		
isnpss,	Ouput status,	1		

snpfile,	Snapshot output file path and name,	**C:\GEMSS\Apps\Kentucky Lake\Output\JanRun007b2r_part4_optimal_year.snp,**		
nsnp,	Number of snapshot output times,	1		
snpyear,	Snapshot output year,	2006		
snpmonth,	Snapshot output month,	4		
snpday,	Snapshot output day,	12		
snphour,	Snapshot output hour,	0		
snpmin,	Snapshot output minutes,	0		
snpfrequ,	Snapshot output frequency unit,	0		
snpfreq,	Snapshot output frequency value,	60		
##,				
#11: Console Output Variables,				
##,				
icle,	Console output selector,	1		
icless,	Ouput status,	1		
ncle,	Number of console ouput times,	1		
cleyear,	Console output year,	2006		
clemonth,	Console output month,	4		
cleday,	Console output day,	12		
clehour,	Console output hour,	0		
clemin,	Console output minutes,	0		
clefrequ,	Console output frequency unit,	0		
clefreq,	Console output frequency value,	6		
##,				
#12: GPP Contour Output Variables,				
##				

###############,				
igpp,	GPP output selector,	1		
igppss,	Ouput status,	1		
ngpp,	Number of GPP contour output times,	1		
gppyear,	GPP contour output year,	2006		
gppmonth,	GPP contour output month,	4		
gppday,	GPP contour output day,	12		
gpphour,	GPP contour output hour,	0		
gppmin,	GPP contour output minutes,	0		
gppfrequ,	GPP contour output frequency unit,	0		
gppfreq,	GPP contour output frequency value,	60		
WriteDV3DSubSurfaceOutput,	Write concentration contour output for GEMSS post processing,	1	,	,
WriteDV3DSpillOutput,	Write spill contour output for output for GEMSS post processing,	1	,	,
SpillSizeEdgeFactor,	Spill size edge factor,	0.25	,	,
SPLNumXCells,	Number of grid cells in x-direction for the surface spill dynamic grid,	30	,	,
SPLNumYCells,	Numbrt of grid cells in y-direction for the suface spill dynamic grid,	30	,	,
SPLContourType,	Surface spill contour type,	1	,	,
SPLContourExponent,	Spill contour interpolation exponent,	2.0	,	,
SPLSmoothType,	Spill contour smoothening type,	1	,	,
SPLGridFactor,	Spill contour neigbouring cells influence factor,	0.5	,	,
SPLNumCycles,	Spill contour number of smoothening cycles,	2	,	,
SPLUseFourCellApproach,	Use spill contour four cell searching method,	1	,	,
SPLUseEightCellApproach,	Use spill conotur eight cell searching method,	1	,	,
SPLUseMaxFactor,	Use spill contour maximum factor,	0	,	,
################################# ################################# ###############,				

#13: COSIM Output Variables, ##,				
iCOCSV,	Console output selector,	1		
iCOCSVss,	Ouput status,	1		
WriteSurfaceParticlesToXYZOutput,	Write Surface Particles data to xyz format,	1		
WriteSubSurfaceParticlesToXYZOutput,	Write Sub Surface Particles data to xyz format,	1		
SSPMassType,	Subsurface particle mass data type,	2		
WriteShorelineHitToXYZOutput,	Write Shoreline hit to xyz format,	1		
WriteConcentrationToXYZOutput,	Write concentration to xyz format,	0		
ConcentrationComputationType,	Concentration Computation Type,	1		
ConcentrationOutputType,	Concentration Output Type,	1		
VertAvgDepth,	Depth for vertical averaging m,	2		
SmootheningType,	Concentration Interpolation smoothening type,	0		
UseFourCellApproach,	Smoothening using four cell stencil,	1		
UseEightCellApproch,	Smooehening using eight cell stencil,	1		
NCycles,	Number of smoothening cycles,	5		
AlfaSmooth,	smoothing factor,	0.7		
ConcHOInterpolationScheme,	Higher order interpolation scheme for concentration grid,	0		
IDWPOWConc,	Inverse distance power index,	2		
WriteMassBalance,	Oil mass compartment output,	1		
COCSVfile1,	Concentration output file path and name,	**C:\GEMSS\Apps\Kentucky Lake\Output\AvgProb_AvgFlowSps.txt,**		
COCSVfile2,	Concentration output file path and name,	**C:\GEMSS\Apps\Kentucky Lake\Output\AvgProb_AvgFlowSSps.txt,**		
COCSVfile3,	Concentration output file path and name,	**C:\GEMSS\Apps\Kentucky**		

		Lake\Output\AvgProb_AvgFlowShor.txt,		
COCSVfile4,	Concentration output file path and name,	**C:\GEMSS\Apps\Kentucky Lake\Output\AvgProb_AvgFlowConc.txt,**		
COCSVfile5,	Concentration output file path and name,	**C:\GEMSS\Apps\Kentucky Lake\Output\AvgProb_AvgFlowMBal.txt,**		
COCSVfile6,	Concentration output file path and name,	**C:\GEMSS\Apps\Kentucky Lake\Output\AvgProb_AvgFlowPlume.txt,**		
nCOCSV,	Number of console ouput times,	1		
COCSVyear,	Console output year,	2006		
COCSVmonth,	Console output month,	4		
COCSVday,	Console output day,	12		
COCSVhour,	Console output hour,	0		
COCSVmin,	Console output minutes,	0		
COCSVfrequ,	Console output frequency unit,	0		
COCSVfreq,	Console output frequency value,	60		
###,				
#14: Direct Access Output Variables,				
###,				
iCODAD,	Direct access output selector,	1		
iCODADss,	Ouput status,	0		
CODADfile,	Concentration output file path and name,	**C:\GEMSS\Apps\Kentucky Lake\Output\AvgPro**		

		b_AvgFlow.xyz,		
nCODAD,	Number of Direct access ouput times,	1		
CODADyear,	Direct access output year,	2006		
CODADmonth,	Direct access output month,	4		
CODADday,	Direct access output day,	12		
CODADhour,	Direct access output hour,	0		
CODADmin,	Direct access output minutes,	0		
CODADfrequ,	Direct access output frequency unit,	0		
CODADfreq,	Direct access output frequency value,	60		
##,				
#15: Time Series Output Variables,				
##,				
itsr,	Time series output selector,	1		
itsrss,	Ouput status,	0		
ntsr,	Number of time steries output times,	1		
tsryear,	Time series output year,	2006		
tsrmonth,	Time series output month,	4		
tsrday,	Time series output day,	12		
tsrhour,	Time series output hour,	0		
tsrmin,	Time series output minutes,	0		
tsrfrequ,	Time series output frequency unit,	0		
tsrfreq,	Time series output frequency value,	60		
##,				
#16: EIA Risk Contour Output Variables,				
##,				
iEIA,	Minimum distance in x-direction for	1	,	,

	EIA risk contour grid,			
iEIAss,	Maximum distance in x-direction for EIA risk contour grid,	0	,	,
EIAUseSpillGridDomain,	Use oil spill grid domain for EIA risk contouring,	1	,	,
EIAXMin,	Minimum distance in x-direction for EIA risk contour grid,	**15400**	,	,
EIAXMax,	Maximum distance in x-direction for EIA risk contour grid,	**15870**	,	,
EIAYMin,	Minimum distance in y-direction for EIA risk contour grid,	**15735**	,	,
EIAYMax,	Maximum distance in y-direction for EIA risk contour grid,	**14610**	,	,
EIAZMin,	Minimum elevation in z-direction for EIA risk contour grid,	-70	,	,
EIAZMax,	Maximum elevation in z-direction for EIA risk contour grid,	0.0	,	,
EIAIMax,	Numer of grid cells in x-direction for EIA risk contour grid,	100	,	,
EIAJMax,	Number of grid cells in y-direction for EIA risk contour grid,	100	,	,
EIAKMax,	Number of vertical layers in z-direction for EIA risk contour grid,	20	,	,
EIAVerticalLayeringMethod,	Vertical layering method,	2	,	,
EIAElev(1),	Elevation for layer 1,	0.0	,	,
EIAElev(2),	Elevation for layer 2,	-1.0	,	,
EIAElev(3),	Elevation for layer 3,	-2.0	,	,
EIAElev(4),	Elevation for layer 4,	-3.0	,	,
EIAElev(5),	Elevation for layer 5,	-4.0	,	,
EIAElev(6),	Elevation for layer 6,	-5.0	,	,
EIAElev(7),	Elevation for layer 7,	-7.0	,	,
EIAElev(8),	Elevation for layer 8,	-9.0	,	,
EIAElev(9),	Elevation for layer 9,	-11.0	,	,
EIAElev(10),	Elevation for layer 10,	-15.0	,	,

EIAElev(11),	Elevation for layer 11,	-20.0	,	,
EIAElev(12),	Elevation for layer 12,	-25.0	,	,
EIAElev(13),	Elevation for layer 13,	-30.0	,	,
EIAElev(14),	Elevation for layer 14,	-35.0	,	,
EIAElev(15),	Elevation for layer 15,	-40.0	,	,
EIAElev(16),	Elevation for layer 16,	-45.0	,	,
EIAElev(17),	Elevation for layer 17,	-50.0	,	,
EIAElev(18),	Elevation for layer 18,	-55.0	,	,
EIAElev(19),	Elevation for layer 19,	-60.0	,	,
EIAElev(20),	Elevation for layer 20,	-70.0	,	,
EIATimeFreq,	EIA time frequency for subsurface concentration computations in hours,	1	,	,
EIANumVars,	Number of risk contour variables,	11	,	,
EIAVarName,	EIA risk contour variable names,	Probability of Surface Oiling Exceeding,	Probability of Surface Oiling,	Impact of Surface Oiling,
EIAVarUnit,	EIA risk contour variable units,	g/m^2,	%,	%,
EIANumSubVars,	Number of EIA risk contour values for each variable,	6	1	1
EIAVarValue 1,	EIA risk contour values for variable 1,	0.04	0.07	0.1
EIAVarValue 2,	EIA risk contour values for variable 2,	999	,	,
EIAVarValue 3,	EIA risk contour values for variable 3,	999	,	,
EIAVarValue 4,	EIA risk contour values for variable 4,	999	,	,
EIAVarValue 5,	EIA risk contour values for variable 5,	999	,	,
EIAVarValue 6,	EIA risk contour values for variable 6,	999	,	,
EIAVarValue 7,	EIA risk contour values for variable 7,	999	,	,
EIAVarValue 8,	EIA risk contour values for variable 8,	999	,	,
EIAVarValue 9,	EIA risk contour values for variable 9,	999	,	,
EIAVarValue 10,	EIA risk contour values for variable 10,	999	,	,
EIAVarValue 11,	EIA risk contour values for variable 11,	999	,	,
EIAContourType,	EIA risk contour interpolation type,	2	,	,
EIAContourExponent,	EIA risk contour higher order interpolation exponent,	2.0	,	,
EIAUseSmoothing,	EIA risk contour smoothening type,	0	,	,
EIAGridFactor,	EIA risk contour neigbouring cells	0.5	,	,

	influence factor,			
EIANumCycles,	EIA risk contour number of smoothening cycles,	10	,	,
EIAUseFourCellApproach,	EIA risk contour four cell searching method,	1	,	,
EIAUseEightCellApproach,	EIA risk contour eight cell searching method,	1	,	,
EIAUseMaxFactor,	EIA risk contour maximum factor,	0	,	,
EIANumSSFractions,	Number of PAH fractions for EIA risk contouring,	14	,	,
##,				
#17: Advection and Diffusion Processes Variables,				
##,				
AdvectionProcess,	Use Advection and diffusion processes,	1		
AdvectionDriftFactor,	Drift Factor,	1		
AdvectionConstantDriftFactor,	Constant drift factor;	1		
APc1,	Percent drift factor,	3.5		
AdvectionVariableDriftFactorSY,	Variation with wind speed using Spaulding and Youseff,	2		
AdvectonVariableDriftAngle,	Drift Angle,	1		
AdvectionConstantDriftAngle,	Constant drift angle,	1		
Aptheta,	Deflection angle,	0		
AdvectionVariableDriftAngleSY,	Variation with wind speed using Spaulding and Youseff,	2		
AdvectionVariableDriftAngleS,	Variation with wind speed using Samuel's relation,	3		
AdvectionDiffusionProcess,	Diffusion,	1		
AdvectionBlowoutProcess,	Deep oil well blow out process,	4		
##				

###############,				
#18: Spreading Process Variables,				
################################## ################################## ###############,				
SpreadingProcess,	Use spreading process,	1		
SpreadingMackayThickSlick,	Mackay thick process,	1		
SMTSk1,	Spreading rate,	150		
SpreadingMackayThickAndThinSlick,	Mackay thick and thick processes,	2		
SMTThSaf,	Area Factor,	6		
SMTThSk1,	Thin spreading rate (1/sec),	1		
SMTThSk2,	Thick slick critical thickness,	0.0015		
SMTThSk3,	Spreading rate,	150		
SpreadingGenericForm,	Generic form,	3		
SGFk1,	Constant (1/sec),	150		
SGFTa,	Thickness exponent,	1		
SGFb,	Volume exponent,	0.33		
SGFc,	Time exponent,	0		
SGd,	Viscosity exponent,	0		
SGFk2,	Time decay (/day),	0		
UseEquivalentSpreadingFactor,	Use equivalent spreading factor	0		
################################## ################################## ###############,				
#19: Evaporation Process Variables,				
################################## ################################## ###############,				
EvaporationProcess,	Use evaporation process,	2		
EvaporationMackayEvaporativeExposure ,	Mackay evaporative exposure,	1		
ComputationVSKab,	Computation of A and B using VSK's empirical relation,	1		
EvaporationPayneDistillationCut,	Distillation cuts,	2		

NumOfCuts,	Number of distillation cuts,	14		
ISVaporPressureDataSupplied,	Vapor pressure data supplied in the oil data base,	1		
ISDensityDataSupplied,	Density supplied in the oil database,	1		
EvaporationMeasuredCurve,	Use time varying Fv vs t data,	3		
EMCFile,	Time varying data file name for evaporation data,	No_Data_File,		
MTCCompType,	Mass transfer coefficient computation type,	1		
##,				
#20: Emulsification Process Variables,				
##,				
EmulsificationProcess,	Use emulsification process,	1		
EmulsificationExponentialRise,	Emulsification exponential rise,	1		
EERc1,	Emulsification empirical constant,	0.000001		
EERc2,	Emulsification rate constant,	0.3		
EERevc0,	Emulsification viscosity constant,	0.65		
EERevc4,	Viscosity exponential rise constant due to evaporation,	10		
SSEmulsionFactor,	SSEmulsionFactor,	100		
EmulsificationInstantaneousRise,	Emulsification Instantaneous rise,	2		
EEIRtlag,	lag time for initialization of emlusification process,	6		
EEIRco,	Emlusification constant,	0.65		
EEIRc4,	Viscosity exponential rise constant due to evaporation,	10		
##,				
#21: Entrainment Process Variables,				

##,				
EntrainmentProcess,	Use entrainment process,	5		
EntrainmentAudunsonFirstOrderDecay,	First order decay entrainment consant (1/day),	1		
EFODwo,	reference wind speed for entrainment contant,	5		
EFODk1,	weathering decay constant for entrainment,	100		
EntrainmentMackayBreakingNonBreakingWave,	Mackays entrainment process using breaking and non-breaking approach,	2		
EMBNBka,	Rate of oil entry into the water column,	0.11		
EMBNButh,	Threshold wind speed for initiation of breaking waves,	5		
EMBNBkb,	Contant that controls the fraction below the critical size,	50		
EMBNBkc,	Downward diffusion velocity m/sec,	0.1		
EMBNBSDiam,	Diameter of small droplets microns,	50		
EMBNBLDiam,	Diameter of large droplets microns,	400		
EntrainmentGenericForm,	Entrainment generic form,	3		
ECFc1,	Entrainment generic rate constant,	0.0001		
ECFa,	Entrainment generic form spill thickness exponent,	0.1		
ECFb,	Entrainment generic form oil viscosity exponent,	0.5		
ECFc,	Entrainment generic form wind speed exponent,	2		
ECFke,	Entrainment decay constant,	0.1		
ECFuth,	Threshold wind speed for initiation of breaking waves,	5		
EntrainmentDelvigneAndSweeneyBreakingWaveAndDroplets,	Entrainment due to breaking waves and droplets method by Delvigne and Sweeney,	5		
EDSBNDsizes,	Number of droplet sizes,	10		
EDSBDdmin,	Minimum droplet diameter microns,	50		

EDSBDdmax,	Maximum droplet diameter microns,	300		
EDSBDThresholdWindSpeed,	Threshold wind spee m/sec,	4		
CalcDropDiam,	Calculate droplet diamter using weathering,	0		
SubSurfaceConcentrationComputationType,	Sub surface concentration computation type,	0		
##,				
#22: Dissolution Process Variables,				
##,				
DissolutionProcess,	Use of dissolution process,	2		
DissolutionFirstOrderDecay,	First order dissolution consant (1/day),	1		
DFOPc1,	Dissolution rate constant (mgms/m2/day),	500		
DFOPc2,	Dissolution decay constnat (1/day),	0.5		
DissolutionMackayMassTransferCoefficient,	Dissolution as a simple mass transfer rate process,	2		
DMMTCkd,	Dissolution mass transfer coefficient (cm/sec),	0.0007	0.000236	
SolFracMethod,	Method to compute solubility of each fraction,	1		
##,				
#23: Volatalization Process Variables,				
##,				
VoltalizationProcess,	Use of Volatilisation process from the water column,	1		
##################################				

################################## ###############,				
#24: Biodegradation Process Variables,				
################################## ################################## ###############,				
BiodegradationProcess,	Use of Biodegradation process,	0		
BiodegradationFirstOrderDecay,	Simple first order decay on each mass component,	1		
BFODs,	Biodegradation constant for oil on the surface (/day),	0.0007657		
BFODwc,	Biodegradation constant for oil in the water column (/day),	0.0007657		
BFODsr,	Biodegradation constant for oil on the shoreline (/day),	0.000766		
BiodegradationLinearRate,	Biodegradation using user defined linear rate,	2		
BLRs,	Biodegradation constant for oil on the surface gm/m3/day,	500		
BLRwc,	Biodegradation constant for oil in the water column gm/m3/day,	500		
BLRsr,	Biodegradation constant for oil on the shoreline gm/m3/day,	500		
################################## ################################## ###############,				
#25: Sedimentation Variables,				
################################## ################################## ###############,				
SedimentationProcess,	Use sedimentation process,	2		
SedimentationKolpackConstantRate,	Sedimentation by the absorbent of oil by sediment particles,	1		
SKCRcss,	Sediment load (gm/m3),	120		
SKCRcdiam,	Sediment particle diameter mm,	0.001		

SedimentationPartioningCoefficient,	Sedimentation using partioning coefficient,	2		
SPCkoc,	Dimensionless partioning coefficient,	10		
SPCcss,	Concentration of suspended matter mg/l,	100		
SPCSedimentParticleDensity,	Sediment Particle Density gm/cc,	1.5		
SPCComputeSettlingVelocity,	Compute settling velocity,	0		
SPCvsettle,	Specified Settling Velocity m/sec,	0.00001157		
DissolutionFromSedimentsProcess,	Dissolution from sediments,	1		
SeaBedDepositionProcess,	Sea bed and spill particle interaction method,	2		
##,				
#26: Shoreline Deposition Variables,				
##,				
ShorelineProcess,	Use shoreline process,	4		
StickyShoreline,	Oil deposition on the shoreline with limitless holding capacity,	1		
SlipperyShoreline,	Shoreline used as reflecting boundary; no oil sticks to the shore,	2		
ShorelineInteraction,	Oil deposition based on shoreline holding capacity,	3		
ShoreOilRemovalTime,	Return time for shore oil to the water mins,	120		
ShorePropertiesFileName,	Beach properties file name,	C:\GEMSS\apps\Kentucky Lake\Grid\Shoreline Classification Version 1.scd,		
itypedef,	Shoreline default Environmental Sensitive Index,	4		
ShoreReFloat,	Refloation of oil from the shore line,	1		

ShoreDataType,	Type of shoreline data to be used in the mode,	1		
##,				
#27: Clean Up Operations,				
##,				
CleanupType,	Type of cleanup equipment used,	0		
NumOfBooms,	Number of Booms used,	2		
BoomName1,	Boom name1,	East Shore,		
BoomStartDate1,	Boom Start Date,	04/12/2006,		
BoomStartTime1,	Boom Start Time,	00:00,		
BoomEndDate1,	Boom End Date,	04/18/2006,		
BoomEndTime1,	Boom End Time,	00:00,		
BoomName2,	Boom name 2,	West Shore,		
BoomStartDate2,	Boom Start Date 2,	04/12/2006,		
BoomStartTime2,	Boom Start Time 2,	00:00,		
BoomEndDate2,	Boom End Date 2,	04/18/2006,		
BoomEndTime2,	Boom End Time 2,	00:00,		
BoomDataType,	Boom Type,	2	2	
Boom1FileName,	Boom1 File Name,	C:\GEMSS\apps\Kentucky Lake\Response\BoomRM91.csv,		
Boom2FileName,	Boom2 File Name,	C:\GEMSS\apps\Kentucky Lake\Response\AltBoom3.csv,		
xBoom1	Start X for Booms,	0		
yBoom1	Start Y for Booms,	0		
xBoom2	End X for Booms,	0		
yBoom2	End Y for Booms,	0		
BoxCleanUpApproach,	Use Box Clean Up Type,	0		

BoxCleanUpFileName,	Time varying data for clean up,	No_Data_File,		
BoxCleanRadius,	Clean Radius needed to avoid cleanup close to the shore,	0		
################################## ################################## ###############,				
#28: Structures Variables,				
################################## ################################## ###############,				
StrucType,	Type of cleanup equipment used,	0		
NumOfStrucs,	Number of Strucs used,	0		
################################## ################################## ###############,				
#29: ReLocate Variables,				
################################## ################################## ###############,				
UseReLocateData,	Use of observed data to move the oil,	0		
ReLocateHeaderFile,	Relocate header file name,	No_Data_File,		
RelocatePolygonFile,	Relocate polygon file name,	No_Data_File,		
ReStartReLocate,	Restart the initial conditions with the beginning time loop,	3		
RlcUVelFactor,	U-velocity scale factor in x-direction,	1		
RlcVVelFactor,	V-velocity scale factor in y-direction,	1		
################################## ################################## ###############,				
#30: 3-D Model Additional Variables,				
################################## ################################## ###############,				
CSS,	Default suspended sediment concentration mg/l,	100		

ApplyWaterSedimentPartioning,	Use Water sediment partitioning,	1		
idmaxtype,	includes surface tension effects ,	1		
alfa,	surfacetension scaling factor,	1		
beta,	exponent scaling factor,	0		
npsize,	Number of droplet sizes,	10		
waveenergy,	energy dissipation rate,	1000		
dminfactor,	scaling factor for min. droplets,	1		
dmaxfactor,	scaling factor for max. droplets,	4		
entrainfactor,	scaling parameter for entrainment,	1		
whichprofile,	vertical wind induced profile,	2		
halfgaussian,	vertical diffusion profile,	2		
minpercent,	percent of total mass,	0.1		
subcompression,	particle reduction factor,	.false.		
tideprofile,	tideprofile,	.FALSE.		
CurrentProfile,	currprofile,	.FALSE.		
resurface_particles,	resurface,	.FALSE.		
SubSurfaceParticleDiffusion,	Sub surface dissolution,	0		
##,				
#31: Oil and Chemical General Parameters,				
##,				
ID,	**Chemical ID,**	**1**		
CommercialName,	Commercial name,	Diesel,		
SpillConstituent,	Slop Oil,	0		
Name,	Chemical name,	Fuel Oil No. 1 (J.P.-8),		
MolecularWeight,	Molecular weight (g/mole),	160		
Density,	Density (g/cm**3),	0.8		
Solubility,	Solubility (mg/l) at 25 degrees C,	1.61		
VaporPressure,	Vapor pressure (Pascals) at 25 degrees C,	0.0068		

DynamicViscosity,	Dynamic viscosity (cP) at 25 degrees C,	1.7		
ViscosityConstantB,	Viscosity exponent for variation with temperature,	24923		
SurfaceTension,	Surface tension (mN/M),	27.5		
WaterContent,	Emulsion constant,	0		
MinimumThickness,	Minimum thickness (mm),	0.01		
InitialBoilingPoint,	Initial boiling point in degree K,	551		
GradientOfDistillationCurve,	Gradient of distillation curve in degree K,	139.8		
CoefficientA,	Coefficient A,	20.3		
CoefficientB,	Coefficient B,	18.1		
ToxicFactor,	Percent Toxicity,	20.9		
NumberOfCuts,	Number of distillation cuts,	14		
Variables,	Parameter,	1	2	3
CutName,	CutName,	cut1- Pentane,	cut2- Hexane,	cut3- Benzene,
CutBoilingPoint,	Boiling point for each distillation cut C,	36	68.7	80
CutMeltingPoint,	Melting point for each distillation cut C,	-129.8	-95	5.5
CutAPIGravity,	API gravity for each distillation cut,	-99	-99	-99
CutPercentVolume in Release 1,	Percent volume in liquid,	9.125	9.125	0.3
CutSolubilityAt25C,	Solubility at 25 degrees C for each distillation cut mg/l,	38	9.5	1790
CutToxicity,	Percent Toxicity by weight,	-99	-99	-99
CutSolubilityEnhancementFactor,	Solubility enhancement factor,	1	1	1
OilWaterPartioningCoefficient,	Oil-water partioning coefficient,	1	1	1
CutMolecularWeight,	Molecular weight (g/mole),	72.151	86.178	78.12
CutVaporPressureAt25C,	Vapor pressure (Pascals) at 25 degrees C,	68524.3158	20170.6789	12639
CutDensity,	Density gm/cc,	0.6262	0.6548	0.8765
CutVPFactor,	Vapor pressure reduction factor,	1	1	1
CutLatentHeat,	Latent heat of liquid Kilo Joules/Kg,	-99	-99	-99
CutFluidPhase,	Fluid phase,	1	1	1

CutViscosity,	Cut Viscosity cP,	-99	-99	-99
CutDiffusivity,	Cut Diffusion coefficient,	-99	-99	-99
ID,	**Chemical ID,**	**2**	,	,
CommercialName,	CommercialName,	LNG-LIQUID,		
SpillConstituent,	SpillConstituent,	0		
Name,	Name,	LNG-LIQUID,		
MolecularWeight,	MolecularWeight,	22.2		
Density,	Density,	0.6807		
Solubility,	Solubility,	50		
VaporPressure,	VaporPressure,	1000		
DynamicViscosity,	DynamicViscosity,	0.421		
ViscosityConstantB,	ViscosityConstantB,	24923		
SurfaceTension,	SurfaceTension,	0		
WaterContent,	WaterContent,	40		
MinimumThickness,	MinimumThickness,	0.1		
InitialBoilingPoint,	InitialBoilingPoint,	-99		
GradientOfDistillationCurve,	GradientOfDistillationCurve,	-99		
CoefficientA,	CoefficientA,	-99		
CoefficientB,	CoefficientB,	-99		
ToxicFactor,	ToxicFactor,	-99		
NumberOfCuts,	NumberOfCuts,	14		
Variables,	Variables,	1	2	3
CutName,	CutName,	H2S,	CO2,	N2,
CutBoilingPoint,	Boiling point for each distillation cut C,	-60.33	-78.48	-195.798
CutMeltingPoint,	Melting point for each distillation cut C,	-99	-99	-99
CutAPIGravity,	API gravity for each distillation cut,	-99	-99	-99
CutPercentVolume in Release 1,	Percent volume in liquid,	0.3	0.84	0.17
CutSolubilityAt25C,	Solubility at 25 degrees C for each distillation cut mg/l,	3505	1449	18100
CutToxicity,	Percent Toxicity by weight,	-99	-99	-99
CutSolubilityEnhancementFactor,	Solubility enhancement factor,	1	1	1
OilWaterPartioningCoefficient,	Oil-water partioning coefficient,	1	1	1
CutMolecularWeight,	Moecular weight (g/mole),	34.08	44.01	28.0134
CutVaporPressureAt25C,	Vapor pressure (Pascals) at 25	2080000	6439000	8452.63

	degrees C,			
CutDensity,	Density gm/cc,	0.993	0.468	0.8064
CutVPFactor,	Vapor pressure reduction factor,	1	1	1
CutLatentHeat,	Latent heat of liquid Kilo Joules/Kg,	548.289	347.965	198.915
CutFluidPhase,	Fluid phase,	1	1	1
CutViscosity,	Cut Viscosity cP,	0.01166	0.0148	0.02
CutDiffusivity,	Cut Diffusion coefficient,	-99	-99	-99
ID,	**Chemical ID,**	**3**	,	,
CommercialName,	Commercial name,	Slop Oil,		
SpillConstituent,	Slop Oil,	0		
Name,	Chemical name,	MAHs and PAHs,		
MolecularWeight,	Molecular weight (g/mole),	160		
Density,	Density (g/cm**3),	0.8735		
Solubility,	Solubility (mg/l) at 25 degrees C,	60.4		
VaporPressure,	Vapor pressure (Pascals) at 25 degrees C,	689		
DynamicViscosity,	Dynamic viscosity (cP) at 25 degrees C,	2.76		
ViscosityConstantB,	Viscosity exponent for variation with temperature,	24923		
SurfaceTension,	Surface tension (mN/M),	27.5		
WaterContent,	Emulsion constant,	0		
MinimumThickness,	Minimum thickness (mm),	0.01		
InitialBoilingPoint,	Initial boiling point in degree K,	551		
GradientOfDistillationCurve,	Gradient of distillation curve in degree K,	139.8		
CoefficientA,	Coefficient A,	20.3		
CoefficientB,	Coefficient B,	18.1		
ToxicFactor,	Percent Toxicity,	3.11		
NumberOfCuts,	Number of distillation cuts,	10		
Variables,	Parameter,	1	2	3
CutName,	CutName,	C3,	C5,	C6,
CutBoilingPoint,	Boiling point for each distillation cut C,	80	110.6	136.1
CutMeltingPoint,	Melting point for each distillation cut C,	5.5	-59.17	-46.94
CutAPIGravity,	API gravity for each distillation cut,	-99	-99	-99

CutPercentVolume in Release 1,	Percent volume in liquid,	0.000124572	0.000125952	0.000125937
CutSolubilityAt25C,	Solubility at 25 degrees C for each distillation cut mg/l,	1790	526	169
CutToxicity,	Percent Toxicity by weight,	-99	-99	-99
CutSolubilityEnhancementFactor,	Solubility enhancement factor,	100	100	100
OilWaterPartioningCoefficient,	Oil-water partioning coefficient,	1	1	1
CutMolecularWeight,	Moecular weight (g/mole),	78.12	92.14	106.17
CutVaporPressureAt25C,	Vapor pressure (Pascals) at 25 degrees C,	12639	3786.4	1279.9
CutDensity,	Density gm/cc,	0.8765	0.8669	0.867
CutVPFactor,	Vapor pressure reduction factor,	1	1	1
CutLatentHeat,	Latent heat of liquid Kilo Joules/Kg,	-99	-99	-99
CutFluidPhase,	Fluid phase,	1	1	1
CutViscosity,	Cut Viscosity cP,	-99	-99	-99
CutDiffusivity,	Cut Diffusion coefficient,	-99	-99	-99
EOR				

APPENDIX E

VB.NET CODE

VB.net Code and COSIM Spreadsheet Cell Relationships

Parameter	Item	Cell in COSIM
Release Year	NumU/D4	D13
Release Month	NumU/D6	D14
Release Day	NumU/D5	D15
Release Hour	NumU/D1	D16
Release Minute	NumU/D2	D17
Relase X Location	TextBox18	D18
Release Y Location	TextBox19	D19
No. Releases	TextBox29	D22
Release Duration	TextBox28	D23
Release Amount	TextBox27	D28
Release Speed	TextBox25	D25
Release Depth	TextBox21	D30
Number of Simulation Days	TextBox35	D63
Simulation Time Step	TextBox34	D64
Snapshot Year	NumU/D8	D250
Snapshot Month	NumU/D3	D251
Snapshot Day	NumU/D7	D252
Snapshot Hour	NumU/D10	D253
Snapshot Minute	NumU/D9	D254
Snapshot Output Freq. Unit	ListBox8	D255
Snapshot Output Freq. Value	TextBox33	D256
Console Output Year	NumU/D8	D263
Console Output Month	NumU/D3	D264
Console Output Day	NumU/D7	D265
Console Output Hour	NumU/D10	D266
Cnsole Output Minute	NumU/D9	D267
Console Output Freq. Unit	ListBox8	D268
Console Output Freq. Value	TextBox33	D269
Contour (gpp) Output Year	NumU/D8	D276
Contour (gpp) Output Month	NumU/D3	D277
Contour (gpp) Output Day	NumU/D7	D278
Contour (gpp) Output Hour	NumU/D10	D279
Contour (gpp) Output Minute	NumU/D9	D280
Contour (gpp) Output Freq. Unit	ListBox8	D281
Contour (gpp) Output Freq. Value	TextBox33	D282

Parameter	Item	Cell in COSIM
Conc. Output Year	NumU/D8	D324
Conc. Output Month	NumU/D3	D325
Conc. Output Day	NumU/D7	D326
Conc. Output Hour	NumU/D10	D327
Conc. Output Minute	NumU/D9	D328
Conc. Output Freq. Unit	ListBox8	D329
Conc. Output Freq. Value	TextBox33	D330
Direct Access Output Year	NumU/D8	D338
Direct Access Output Month	NumU/D3	D339
Direct Access Output Day	NumU/D7	D340
Direct Access Output Hour	NumU/D10	D341
Direct Access Output Minute	NumU/D9	D342
Direct Access Output Freq. Unit	ListBox8	D343
Direct Access Output Freq. Value	TextBox33	D344
Time Series Output Year	NumU/D8	D351
Time Series Output Month	NumU/D3	D352
Time Series Output Day	NumU/D7	D353
Time Series Output Hour	NumU/D10	D354
Time Series Output Minute	NumU/D9	D355
Time Series Output Freq. Unit	ListBox8	D356
Time Series Output Freq. Value	TextBox33	D357

Parameter	Item	Cell in COSIM	Value for COSIM
Release Duration Unit	ListBox5	D24	0= minutes, 1 = hours, 3 = days
Release Depth Unit	ListBox4	D31	0 = m, 1 = ft, 2 = cm, 3 = fathoms, 4 = m to ft
Release Amount Units	ListBox2	D29	1 = L, 2 = gal, 3 = m3, 4 = tons, 5 = barrels
Release Speed	ListBox3	D26	0 = m/s, 1 = cm/s, 2 = ft/s, 3 = mph, 4 = knots
Frequency Units	ListBox1, 8	See above	0= minutes, 1 = hours, 3 = days
Shoreline	ListBox6	D522	1=100%Absorbtive, 2=100%Reflective, 4=Use ESI codes

On/Off Switches	Item	Cell in COSIM	Value for COSIM
Advection/Diffusion	ChkBox1	D422	1
Spreading	ChkBox2	D437	1
Evaporation	ChkBox4	D456	2
Emulsificatin	ChkBox3	D469	1
Entrainment	ChkBox6	D483	5
Dissolution	ChkBox8	D511	2
Volatilization	ChkBox10	D521	1
Biodegradation	ChkBox5	D525	1
Sedimentation	ChkBox7	D537	2
Wind	ChkBox12	D136,D137	0 = off, 1 = 100% on

File Paths	Item	Cell in COSIM	Combined Items for Input
Scenario	TextBox12	D61	
OutputFolderLoc	TextBox2	N/A	
Snapshot Output	TextBox14	D248	
Oil Spill grid	TextBox11	D77	
Meteorological Data	TextBox7	D119	
Currents	TextBox13	D155	
Shoreline Properties	TextBox6	D557	
Surface Conc. Output		D317	OutputFolderLoc+ScenarioName+Sps.txt
Subsurface Conc.		D318	OutputFolderLoc+ScenarioName+SSps.txt
Shoreline Output		D319	OutputFolderLoc+ScenarioName+Shor.txt
Concentration Output		D320	OutputFolderLoc+ScenarioName+Conc.txt
Mass Balance		D321	OutputFolderLoc+ScenarioName+MBal.txt
Plume		D322	OutputFolderLoc+ScenarioName+Plume.txt
Direct Access (.xyz)		D336	OutputFolderLoc+ScenarioName+xyz.txt

Other	Item	Cell in COSIM
Default I Cell currents	TextBox31	D171
Default J Cell currents	TextBox30	D172
Met. Station Loc. X-coord	TextBox4	D120
Met. Station Loc. X-coord	TextBox3	D121
Default Temp. (deg. C)	TextBox32	D181

SMIS2Tool

Tool Inheriting Base Command

```
Imports System.Runtime.InteropServices
Imports System.Drawing
Imports ESRI.ArcGIS.ADF.BaseClasses
Imports ESRI.ArcGIS.ADF.CATIDs
Imports ESRI.ArcGIS.Framework
Imports ESRI.ArcGIS.ArcMapUI
Imports System.Windows.Forms

<ComClass(Tool1.ClassId, Tool1.InterfaceId, Tool1.EventsId), _
 ProgId("SMIS2ToolTest.Tool1")> _
Public NotInheritable Class Tool1
    Inherits BaseTool

#Region "COM GUIDs"
    ' These  GUIDs provide the COM identity for this class
    ' and its COM interfaces. If you change them, existing
    ' clients will no longer be able to access the class.
    Public Const ClassId As String = "6a8e0c6d-ceb3-45c0-b84c-
174a7bd9efc2"
    Public Const InterfaceId As String = "5da40341-dc9c-4ea9-b2f2-
6447f3b80cd5"
    Public Const EventsId As String = "05778c0c-11ec-456c-8097-
45f4d87d2a99"
#End Region

#Region "COM Registration Function(s)"
    <ComRegisterFunction(), ComVisibleAttribute(False)> _
    Public Shared Sub RegisterFunction(ByVal registerType As Type)
        ' Required for ArcGIS Component Category Registrar support
        ArcGISCategoryRegistration(registerType)

        'Add any COM registration code after the
ArcGISCategoryRegistration() call

    End Sub

    <ComUnregisterFunction(), ComVisibleAttribute(False)> _
    Public Shared Sub UnregisterFunction(ByVal registerType As Type)
        ' Required for ArcGIS Component Category Registrar support
        ArcGISCategoryUnregistration(registerType)

        'Add any COM unregistration code after the
ArcGISCategoryUnregistration() call

    End Sub

#Region "ArcGIS Component Category Registrar generated code"
    Private Shared Sub ArcGISCategoryRegistration(ByVal registerType As
Type)
        Dim regKey As String =
String.Format("HKEY_CLASSES_ROOT\CLSID\{{{0}}}", registerType.GUID)
```

```
        MxCommands.Register(regKey)

    End Sub
    Private Shared Sub ArcGISCategoryUnregistration(ByVal registerType
As Type)
        Dim regKey As String =
String.Format("HKEY_CLASSES_ROOT\CLSID\{{{0}}}", registerType.GUID)
        MxCommands.Unregister(regKey)

    End Sub

#End Region
#End Region

    Public lat As Integer
    Public longit As Integer
    Private m_application As IApplication

    ' A creatable COM class must have a Public Sub New()
    ' with no parameters, otherwise, the class will not be
    ' registered in the COM registry and cannot be created
    ' via CreateObject.
    Public Sub New()
        MyBase.New()
        MyBase.m_category = "Developer Samples"  'localizable text
        MyBase.m_caption = "Spill Info Tool "   'localizable text
        MyBase.m_message = "Spill Info Tool"   'localizable text
        MyBase.m_toolTip = "Spill Info Tool" 'localizable text
        MyBase.m_name = "DeveloperSamples_SpillInfoTool"  'unique id,
non-localizable (e.g. "MyCategory_ArcMapTool")

        Try
            'TODO: change resource name if necessary
            Dim bitmapResourceName As String = "oil_drop.bmp"
            MyBase.m_bitmap = New Bitmap(Me.GetType(),
bitmapResourceName)
            MyBase.m_cursor = New
System.Windows.Forms.Cursor(Me.GetType(), Me.GetType().Name + ".cur")
        Catch ex As Exception
            System.Diagnostics.Trace.WriteLine(ex.Message, "Invalid
Bitmap")
        End Try
    End Sub

    Public Overrides Sub OnCreate(ByVal hook As Object)
        If Not hook Is Nothing Then
            m_application = CType(hook, IApplication)

            'Disable if it is not ArcMap
            If TypeOf hook Is IMxApplication Then
                MyBase.m_enabled = True
            Else
                MyBase.m_enabled = False
            End If
        End If
    End Sub
```

```
    Public Overrides Sub OnMouseDown(ByVal Button As Integer, ByVal
Shift As Integer, ByVal X As Integer, ByVal Y As Integer)

        'Get latitude and longitude from mouse down event
        Dim pMxDoc As ESRI.ArcGIS.ArcMapUI.IMxDocument
        Dim pPoint As ESRI.ArcGIS.Geometry.IPoint
        Dim pClone As ESRI.ArcGIS.esriSystem.IClone
        Dim pGeometry As ESRI.ArcGIS.Geometry.IGeometry

        'Get the point where the user clicked
        pMxDoc = m_application.Document
        If pMxDoc.CurrentLocation.IsEmpty Then Exit Sub

        'Clone the point because we don't want to alter
        'the actual document's current location point

        pClone = pMxDoc.CurrentLocation
        pPoint = pClone.Clone

        pGeometry = pPoint
        Dim pAV As ESRI.ArcGIS.Carto.IActiveView
        pAV = pMxDoc.FocusMap
        pPoint = pAV.ScreenDisplay.DisplayTransformation.ToMapPoint(X,
Y)

        If Not pPoint.SpatialReference Is Nothing Then
            If TypeOf pPoint.SpatialReference Is
ESRI.ArcGIS.Geometry.IUnknownCoordinateSystem Then
                MsgBox("unknown coordinate system")
            Else
                If TypeOf pPoint.SpatialReference Is
ESRI.ArcGIS.Geometry.IProjectedCoordinateSystem Then
                    Dim pPCS As
ESRI.ArcGIS.Geometry.IProjectedCoordinateSystem
                    pPCS = pPoint.SpatialReference
                    'MsgBox("lat: " & pPoint.Y & "long: " & pPoint.X)
                    Dim pSpillForm As New SpillForm
                    pSpillForm.TextBox18.Text = pPoint.Y
                    pSpillForm.TextBox19.Text = pPoint.X
                    pSpillForm.TextBox3.Text = pPoint.Y
                    pSpillForm.TextBox4.Text = pPoint.X
                    pSpillForm.ShowDialog()
                Else
                    'already a geocoordsystem, don't do anything
                End If
            End If
        Else

            MsgBox("map has no spatial reference")

        End If
        lat = pPoint.Y
        longit = pPoint.X
    End Sub

    Public Overrides Sub OnClick()
```

```
        MsgBox("Please click on the map to identify the spill
location.")
    End Sub

    Public Overrides Sub OnMouseMove(ByVal Button As Integer, ByVal
Shift As Integer, ByVal X As Integer, ByVal Y As Integer)
    End Sub

    Public Overrides Sub OnMouseUp(ByVal Button As Integer, ByVal Shift
As Integer, ByVal X As Integer, ByVal Y As Integer)
    End Sub

#Region "Get MxDocument from ArcMap"
    ' ArcGIS Snippet Title:
    ' Get MxDocument from ArcMap
    '
    ' Add the following references to the project:
    ' ESRI.ArcGIS.ArcMapUI
    ' ESRI.ArcGIS.Framework
    ' ESRI.ArcGIS.System
    '
    ' Intended ArcGIS Products for this snippet:
    ' ArcGIS Desktop
    '
    ' Required ArcGIS Extensions:
    ' (NONE)
    '
    ' Notes:
    ' This snippet is intended to be inserted at the base level of a
Class.
    ' It is not intended to be nested within an existing Sub or
Function.
    '
    ' Use the following XML documentation comments to use this snippet:
    ''' <summary>Get MxDocument from ArcMap.</summary>
    '''
    ''' <param name="application">An IApplication interface that is the
ArcMap application.</param>
    '''
    ''' <returns>An IMxDocument interface.</returns>
    '''
    ''' <remarks></remarks>
    Public Function GetMxDocument(ByVal application As
ESRI.ArcGIS.Framework.IApplication) As ESRI.ArcGIS.ArcMapUI.IMxDocument

        If application Is Nothing Then
            Return Nothing
        End If

        Dim mxDocument As ESRI.ArcGIS.ArcMapUI.IMxDocument =
(CType(application.Document, ESRI.ArcGIS.ArcMapUI.IMxDocument)) '
Explicit Cast

        Return mxDocument

    End Function
```

```
#End Region
End Class
```

Spill Form

```
Imports System.Windows.Forms
Imports System.Windows.Forms.FileDialog
Imports System
Imports ESRI.ArcGIS.ADF
Imports ESRI.ArcGIS.ArcMap
Imports ESRI.ArcGIS.ArcMapUI
Imports ESRI.ArcGIS.Carto
Imports ESRI.ArcGIS.Display
Imports ESRI.ArcGIS.esriSystem
Imports ESRI.ArcGIS.Framework
Imports ESRI.ArcGIS.Geometry
Imports ESRI.ArcGIS.Output
Imports ESRI.ArcGIS.SystemUI

Public Class SpillForm

    Dim OutFreq As Integer
    Dim iSelectedItem1 As Integer
    Dim iSelectedItem2 As Integer
    Dim iSelectedItem3 As Integer
    Dim iSelectedItem4 As Integer
    Dim iSelectedItem5 As Integer
    Dim iSelectedItem6 As Integer
    Dim iSelectedItem8 As Integer
    Dim AdvOn As Integer
    Dim BioDegOn As Integer
    Dim EvapOn As Integer
    Dim EmulsOn As Integer
    Dim EntrainOn As Integer
    Dim DissolOn As Integer
    Dim VolOn As Integer
    Dim SpreadOn As Integer
    Dim SedOn As Integer
    Dim ShoreOn As Integer
    Dim WindOn As Integer
    Dim ScenarioName As String
    Dim CtrlFile As String
    Dim MetFile As String
    Dim CurrFile As String
    Dim SNPFile As String
    Dim OSGFile As String
    Dim OutFolder As String
    Dim SurfFile As String
    Dim SubSurfFile As String
    Dim ShoreFile As String
    Dim ConcFile As String
    Dim MBFile As String
    Dim PlumeFile As String
```

```
    Private Sub Button3_Click(ByVal sender As System.Object, ByVal e As
System.EventArgs) Handles Button3.Click
        'Dim MyWBName As Object
        Dim MyWBName As String
        Dim oExcel As Excel.Application
        Dim oBook As Excel.Workbook
        Dim oSheet As Object
        Dim oSheet2 As Object

        oExcel = CreateObject("Excel.Application")
        oExcel.Visible = True

        MyWBName = TextBox1.Text
        'MsgBox(MyWBName)
        oBook = oExcel.Workbooks.Open(MyWBName)
        'MsgBox("The current workbook is " & MyWBName)
        oSheet = oExcel.ActiveSheet
        oSheet2 = oSheet.Copy(After:=oSheet) 'copies worksheet,
creating new worksheet edited values
        'oSheet2.Name = ScenarioName   'Renames the new worksheet
oSheet2
        oBook.Close(SaveChanges:=True)

        'MsgBox("The current sheet is " & oSheet)

        oBook = oExcel.Workbooks.Open(MyWBName)
        oSheet2 = oExcel.ActiveSheet
        'Spill Release Info
        oSheet2.Cells.Range("D22").Value = Chr(39) & TextBox29.Text
'No. Releases
        oSheet2.Cells.Range("D23").Value = Chr(39) & TextBox28.Text
'Release Duration
        oSheet2.Cells.Range("D28").Value = Chr(39) & TextBox27.Text
'Release Amount
        oSheet2.Range("D25").Value = Chr(39) & TextBox25.Text
'Release Speed
        oSheet2.Range("D30").Value = Chr(39) & TextBox21.Text
'Release Depth
        oSheet2.Range("D63").Value = Chr(39) & TextBox35.Text   'Number
of Simulation Days
        oSheet2.Range("D64").Value = Chr(39) & TextBox34.Text
'Simulation Time Step
        oSheet2.Range("D18").Value = Chr(39) & TextBox18.Text  'Release
X Location (StatePlane)
        oSheet2.Range("D19").Value = Chr(39) & TextBox19.Text  'Release
Y Location (StatePlane)
        oSheet2.Range("D120").Value = Chr(39) & TextBox4.Text 'Met.
Station x-coord
        oSheet2.Range("D121").Value = Chr(39) & TextBox3.Text
'Met.Statin y-coord
        oSheet2.Range("D181").Value = Chr(39) & TextBox32.Text 'Default
Temp(C)
        oSheet2.Range("D171").Value = Chr(39) & TextBox31.Text 'Default
I-Cell for Currents
```

```
        oSheet2.Range("D172").Value = Chr(39) & TextBox30.Text 'Devault
J-Cell for Currents

        'File Locations
        oSheet2.Cells.Range("D248").Value = TextBox14.Text & Chr(44)
'Snapshot File
        oSheet2.Cells.Range("D155").Value = TextBox13.Text & Chr(44)
'Currents File
        oSheet2.Cells.Range("D119").Value = TextBox7.Text & Chr(44)
'Met Data File
        oSheet2.Range("D557").Value = TextBox6.Text & Chr(44)
'Shoreline File
        oSheet2.Range("D77").Value = TextBox11.Text & Chr(44)
'Spill Grid File
        oSheet2.Range("D256").Value = TextBox5.Text & Chr(44)
'Hydro Snapshot File Frequency Value

        'Ouptput Options
        oSheet2.Range("D317").Value = OutFolder & "\" & ScenarioName &
"Sps.txt" & Chr(44)           'Surface Conc. File Path
        oSheet2.Range("D318").Value = OutFolder & "\" & ScenarioName &
"SSps.txt" & Chr(44)          'Subsurface Conc. File Path
        oSheet2.Range("D319").Value = OutFolder & "\" & ScenarioName &
"Shor.txt" & Chr(44)          'Shoreline File Path
        oSheet2.Range("D320").Value = OutFolder & "\" & ScenarioName &
"Conc.txt" & Chr(44)          'Concentration File Path
        oSheet2.Range("D321").Value = OutFolder & "\" & ScenarioName &
"MBal.txt" & Chr(44)          'Mass Balance File Path
        oSheet2.Range("D322").Value = OutFolder & "\" & ScenarioName &
"Plume.txt" & Chr(44)         'Plume File Path
        oSheet2.Range("D336").Value = OutFolder & "\" & ScenarioName &
".xyz" & Chr(44)           'Direct Access (.xyz) File Path
        oSheet2.Range("D61").Value = OutFolder & "\" & ScenarioName &
Chr(44)                        'Scenario Name and File Path
        oSheet2.Range("D269,D282,D330,D344,D357").Value = Chr(39) &
TextBox33.Text                  'Output Frequency Value

        'Spill Release Units Assignments
        oSheet2.Range("D24").Value = iSelectedItem5
'Release Duration
        oSheet2.Range("D31").Value = Chr(39) & iSelectedItem4
'Release Depth
        oSheet2.Range("D29").Value = Chr(39) & iSelectedItem2
'Release Amount
        oSheet2.Range("D26").Value = Chr(39) & iSelectedItem3
'Release Speed
        oSheet2.Range("D268,D281,D329,D343,D356").Value = Chr(39) &
iSelectedItem8      'Output Files Frequency Units
        oSheet2.Range("D552").Value = Chr(39) & iSelectedItem6
'Shoreline Options
        oSheet2.Range("D255").Value = Chr(39) & iSelectedItem1
'Snapshot Frequency Units

        'On/Off Options
        oSheet2.Range("D422").Value = Chr(39) & AdvOn
'advection/diffusion
```

```
        oSheet2.Range("D456").Value = Chr(39) & EvapOn
'evaporation
        oSheet2.Range("D469").Value = Chr(39) & EmulsOn
'emulsification
        oSheet2.Range("D483").Value = Chr(39) & EntrainOn
'entrainment
        oSheet2.Range("D511").Value = Chr(39) & DissolOn
'dissolution
        oSheet2.Range("D521").Value = Chr(39) & VolOn
'volatilization
        oSheet2.Range("D437").Value = Chr(39) & SpreadOn
'spreading
        oSheet2.Range("D525").Value = Chr(39) & BioDegOn
'biodegredation
        oSheet2.Range("D537").Value = Chr(39) & SedOn
'sedimentation
        oSheet2.Range("D136,D137").Value = Chr(39) & WindOn    'wind
effects

        oSheet2.Range("D13").Value = Chr(39) & NumericUpDown4.Value
'Release Year
        oSheet2.Range("D14").Value = Chr(39) & NumericUpDown6.Value
'Release Month
        oSheet2.Range("D15").Value = Chr(39) & NumericUpDown5.Value
'Release Day
        oSheet2.Range("D16").Value = Chr(39) & NumericUpDown1.Value
'Release Hour
        oSheet2.Range("D17").Value = Chr(39) & NumericUpDown2.Value
'Release Minute
        oSheet2.Range("D250,D263,D276,D324,D338,D351,D206,D226").Value
= Chr(39) & NumericUpDown8.Value      'Output Year
        oSheet2.Range("D251,D264,D277,D325,D339,D352,D207,D227").Value
= Chr(39) & NumericUpDown3.Value      'Output Month
        oSheet2.Range("D252,D265,D278,D326,D340,D353,D208,D228").Value
= Chr(39) & NumericUpDown7.Value      'Output Day
        oSheet2.Range("D253,D266,D279,D327,D341,D354,D209,D229").Value
= Chr(39) & NumericUpDown10.Value     'Output Hour
        oSheet2.Range("D254,D267,D280,D328,D342,D355,D210,D230").Value
= Chr(39) & NumericUpDown9.Value      'Output Minute

        oSheet2.Name = ScenarioName   'Renames the new worksheet
oSheet2

        oExcel.Application.Quit()
        oExcel = Nothing
        'oExcel.Save()
    End Sub
    Private Sub Button2_Click(ByVal sender As System.Object, ByVal e As
System.EventArgs) Handles Button2.Click
        MsgBox("Do you want to reset?")

        TextBox1.Text = ""
        TextBox2.Text = ""
        TextBox3.Text = ""
        TextBox4.Text = ""
        TextBox5.Text = ""
```

```
        TextBox6.Text = ""
        TextBox7.Text = ""
        TextBox11.Text = ""
        TextBox12.Text = ""
        TextBox18.Text = ""
        TextBox19.Text = ""
        TextBox21.Text = ""
        TextBox25.Text = ""
        TextBox27.Text = ""
        TextBox28.Text = ""
        TextBox29.Text = ""
        TextBox30.Text = ""
        TextBox31.Text = ""
        TextBox32.Text = ""
        TextBox33.Text = ""
        TextBox34.Text = ""
        TextBox35.Text = ""
    End Sub
    'Locate COSIM control file (*.xls)
    Private Sub Button4_Click(ByVal sender As System.Object, ByVal e As
System.EventArgs) Handles Button4.Click
        OpenFileDialog6.InitialDirectory = "C:\GEMSS\Apps"
        OpenFileDialog6.Filter = "Spill Control File(*.xls)|*.xls"
        OpenFileDialog6.Title = "Open Spill Control File"
        OpenFileDialog6.ShowDialog()
        TextBox1.Text = OpenFileDialog6.FileName
        CtrlFile = OpenFileDialog6.FileName
    End Sub
    'Locate shoreline properties file (*.scd)
    Private Sub Button13_Click(ByVal sender As System.Object, ByVal e
As System.EventArgs) Handles Button13.Click
        OpenFileDialog1.InitialDirectory = "C:\GEMSS\Apps"
        OpenFileDialog1.Filter = "Shoreline Properties
Files(*.scd)|*.scd"
        OpenFileDialog1.Title = "Open Shoreline Properties File"
        OpenFileDialog1.ShowDialog()
        TextBox6.Text = OpenFileDialog1.FileName
    End Sub
    'Locate the spill grid file
    Private Sub Button14_Click(ByVal sender As System.Object, ByVal e
As System.EventArgs) Handles Button14.Click
        OpenFileDialog3.InitialDirectory = "C:\GEMSS\Apps"
        OpenFileDialog3.Filter = "Spill Grid Files(*.osg)|*.osg"
        OpenFileDialog3.Title = "Open Spill Grid File"
        OpenFileDialog3.ShowDialog()
        TextBox11.Text = OpenFileDialog3.FileName
    End Sub
    'Locate the snapshot output file
    Private Sub Button15_Click(ByVal sender As System.Object, ByVal e
As System.EventArgs) Handles Button15.Click
        OpenFileDialog4.InitialDirectory = "C:\GEMSS\Apps"
        OpenFileDialog4.Filter = "Snapshot Files(*.snp)|*.snp"
        OpenFileDialog4.Title = "Open Snapshot File"
        OpenFileDialog4.ShowDialog()
        TextBox14.Text = OpenFileDialog4.FileName
    End Sub
```

```
    'Locate the currents file
    Private Sub Button16_Click(ByVal sender As System.Object, ByVal e
As System.EventArgs) Handles Button16.Click
        OpenFileDialog5.InitialDirectory = "C:\GEMSS\Apps"
        OpenFileDialog5.Filter = "Currents Files(*.cur)|*.cur"
        OpenFileDialog5.Title = "Open Currents File"
        OpenFileDialog5.ShowDialog()
        TextBox13.Text = OpenFileDialog5.FileName
    End Sub
    'Locate the meteorological data file
    Private Sub Button17_Click(ByVal sender As System.Object, ByVal e
As System.EventArgs) Handles Button17.Click
        OpenFileDialog2.InitialDirectory = "C:\GEMSS\Apps"
        OpenFileDialog2.Filter = "Meteorologic Files(*.met)|*.met"
        OpenFileDialog2.Title = "Open Meterological Data File"
        OpenFileDialog2.ShowDialog()
        TextBox7.Text = OpenFileDialog2.FileName
    End Sub
    'Locate the folder to send the output files to
    Private Sub Button18_Click(ByVal sender As System.Object, ByVal e
As System.EventArgs) Handles Button18.Click
        FolderBrowserDialog1.RootFolder =
Environment.SpecialFolder.MyComputer
        FolderBrowserDialog1.Description = "Select Output Folder
Location"
        If FolderBrowserDialog1.ShowDialog() =
Windows.Forms.DialogResult.OK Then
            TextBox2.Text = FolderBrowserDialog1.SelectedPath
            OutFolder = FolderBrowserDialog1.SelectedPath
        End If
    End Sub
    'Select the units that were used in creating the snapshot output
file in GEMSS and assign the corresponding numeric code for COSIM
    Private Sub ListBox1_SelectedIndexChanged(ByVal sender As
System.Object, ByVal e As System.EventArgs) Handles
ListBox1.SelectedIndexChanged
        If ListBox1.SelectedItem Is Nothing Then
            iSelectedItem1 = 1
        Else
            Select Case ListBox1.SelectedItem
                Case "min"
                    iSelectedItem1 = 0
                Case "hours"
                    iSelectedItem1 = 1
                Case "days"
                    iSelectedItem1 = 2
            End Select
        End If
    End Sub
    'Select the units for the release amount and assign the
corresponding numeric code for COSIM
    Private Sub ListBox2_SelectedIndexChanged(ByVal sender As
System.Object, ByVal e As System.EventArgs) Handles
ListBox2.SelectedIndexChanged
        Select Case ListBox2.SelectedItem
            Case "liters"
```

```
                iSelectedItem2 = 1
            Case "gallons"
                iSelectedItem2 = 2
            Case "m3"
                iSelectedItem2 = 3
            Case "tons"
                iSelectedItem2 = 4
            Case "barrels"
                iSelectedItem2 = 5
        End Select

    End Sub
    'Select the units for the release speed and assign the
corresponding numeric code for COSIM
    Private Sub ListBox3_SelectedIndexChanged(ByVal sender As
System.Object, ByVal e As System.EventArgs) Handles
ListBox3.SelectedIndexChanged
        Select Case ListBox3.SelectedItem
            Case "m/s"
                iSelectedItem3 = 0
            Case "cm/s"
                iSelectedItem3 = 1
            Case "ft/s"
                iSelectedItem3 = 2
            Case "mph"
                iSelectedItem3 = 3
            Case "knots"
                iSelectedItem3 = 4
        End Select
    End Sub
    'Select the units for the release depth and assign the
corresponding numeric code for COSIM
    Private Sub ListBox4_SelectedIndexChanged(ByVal sender As
System.Object, ByVal e As System.EventArgs) Handles
ListBox4.SelectedIndexChanged
        Select Case ListBox4.SelectedItem
            Case "m"
                iSelectedItem4 = 0
            Case "ft"
                iSelectedItem4 = 1
            Case "cm"
                iSelectedItem4 = 2
            Case "fathoms"
                iSelectedItem4 = 3
            Case "m to ft"
                iSelectedItem4 = 4
        End Select
    End Sub
    'Use listbox to select units for spill duration and assign the
corresponding numeric code for COSIM
    Private Sub ListBox5_SelectedIndexChanged(ByVal sender As
System.Object, ByVal e As System.EventArgs) Handles
ListBox5.SelectedIndexChanged
        Select Case ListBox5.SelectedItem
            Case "min"
                iSelectedItem5 = 0
```

```
            Case "hours"
                iSelectedItem5 = 1
            Case "days"
                iSelectedItem5 = 2
        End Select
    End Sub
    'Use listbox to select units for shoreline properties and assign
the corresponding numeric code for COSIM
    Private Sub ListBox6_SelectedIndexChanged(ByVal sender As
System.Object, ByVal e As System.EventArgs) Handles
ListBox6.SelectedIndexChanged
        Select Case ListBox6.SelectedItem
            Case "100% Absorbtive"
                iSelectedItem6 = 0
            Case "100% Reflective"
                iSelectedItem6 = 1
            Case "Use ESI Codes"
                iSelectedItem6 = 2
        End Select
    End Sub
    'Use listbox to select units for output frequency and assign the
corresponding numeric code for COSIM
    Private Sub ListBox8_SelectedIndexChanged(ByVal sender As
System.Object, ByVal e As System.EventArgs) Handles
ListBox8.SelectedIndexChanged
        Select Case ListBox8.SelectedItem
            Case "min"
                iSelectedItem8 = 0
            Case "hours"
                iSelectedItem8 = 1
            Case "days"
                iSelectedItem8 = 2
        End Select
    End Sub
    'Use checkbox to turn on/off advection/diffusion and define numeric
code for COSIM
    Private Sub CheckBox1_CheckedChanged(ByVal sender As System.Object,
ByVal e As System.EventArgs) Handles CheckBox1.CheckedChanged
        If CheckBox1.Checked = True Then
            AdvOn = 1
        ElseIf CheckBox1.Checked = False Then
            AdvOn = 0
        End If
    End Sub
    'Use checkbox to turn on/off spreading and define numeric code for
COSIM
    Private Sub CheckBox2_CheckedChanged(ByVal sender As System.Object,
ByVal e As System.EventArgs) Handles CheckBox2.CheckedChanged
        If CheckBox2.Checked = True Then
            SpreadOn = 1
        ElseIf CheckBox2.Checked = False Then
            SpreadOn = 0
        End If
    End Sub
    'Use checkbox to turn on/off emulsification and define numeric code
for COSIM
```

```
    Private Sub CheckBox3_CheckedChanged(ByVal sender As System.Object,
ByVal e As System.EventArgs) Handles CheckBox3.CheckedChanged
        If CheckBox3.Checked = True Then
            EmulsOn = 1
        ElseIf CheckBox3.Checked = False Then
            EmulsOn = 0
        End If
    End Sub
    'Use checkbox to turn on/off evaporation and define numeric code
for COSIM
    Private Sub CheckBox4_CheckedChanged(ByVal sender As System.Object,
ByVal e As System.EventArgs) Handles CheckBox4.CheckedChanged
        If CheckBox4.Checked = True Then
            EvapOn = 2
        ElseIf CheckBox4.Checked = False Then
            EvapOn = 0
        End If
    End Sub
    'Use checkbox to turn on/off biodegradation and define numeric code
for COSIM
    Private Sub CheckBox5_CheckedChanged(ByVal sender As System.Object,
ByVal e As System.EventArgs) Handles CheckBox5.CheckedChanged
        If CheckBox5.Checked = True Then
            BioDegOn = 1
        ElseIf CheckBox5.Checked = False Then
            BioDegOn = 0
        End If
    End Sub
    'Use checkbox to turn on/off etrainment and define numeric code for
COSIM
    Private Sub CheckBox6_CheckedChanged(ByVal sender As System.Object,
ByVal e As System.EventArgs) Handles CheckBox6.CheckedChanged
        If CheckBox6.Checked = True Then
            EntrainOn = 5
        ElseIf CheckBox6.Checked = False Then
            EntrainOn = 0
        End If
    End Sub
    'Use checkbox to turn on/off sedimentation and define numeric code
for COSIM
    Private Sub CheckBox7_CheckedChanged(ByVal sender As System.Object,
ByVal e As System.EventArgs) Handles CheckBox7.CheckedChanged
        If CheckBox7.Checked = True Then
            SedOn = 2
        ElseIf CheckBox7.Checked = False Then
            SedOn = 0
        End If
    End Sub
    'Use checkbox to turn on/off dissolution and define numeric code
for COSIM
    Private Sub CheckBox8_CheckedChanged(ByVal sender As System.Object,
ByVal e As System.EventArgs) Handles CheckBox8.CheckedChanged
        If CheckBox8.Checked = True Then
            DissolOn = 2
        ElseIf CheckBox8.Checked = False Then
            DissolOn = 0
```

```
        End If
    End Sub
    'Use checkbox to turn on/off volatilization and define numeric code
for COSIM
    Private Sub CheckBox10_CheckedChanged(ByVal sender As
System.Object, ByVal e As System.EventArgs) Handles
CheckBox10.CheckedChanged
        If CheckBox10.Checked = True Then
            VolOn = 1
        ElseIf CheckBox10.Checked = False Then
            VolOn = 0
        End If
    End Sub
    'Use checkbox to set the output start date and time to the same as
the spill start date and time
    Private Sub CheckBox11_CheckedChanged(ByVal sender As
System.Object, ByVal e As System.EventArgs) Handles
CheckBox11.CheckedChanged
        If CheckBox11.Checked = True Then
            NumericUpDown8.Value = NumericUpDown4.Value
            NumericUpDown3.Value = NumericUpDown6.Value
            NumericUpDown7.Value = NumericUpDown5.Value
            NumericUpDown10.Value = NumericUpDown1.Value
            NumericUpDown9.Value = NumericUpDown2.Value

        ElseIf CheckBox11.Checked = False Then
            NumericUpDown8.Value = NumericUpDown8.Value
            NumericUpDown3.Value = NumericUpDown3.Value
            NumericUpDown7.Value = NumericUpDown7.Value
            NumericUpDown10.Value = NumericUpDown10.Value
            NumericUpDown9.Value = NumericUpDown9.Value
        End If
    End Sub
    'Use checkbox to turn on/off wind effects and define numeric code
for COSIM
    Private Sub CheckBox12_CheckedChanged(ByVal sender As
System.Object, ByVal e As System.EventArgs) Handles
CheckBox12.CheckedChanged
        If CheckBox12.Checked = True Then
            WindOn = 1
        ElseIf CheckBox12.Checked = False Then
            WindOn = 0
        End If
    End Sub
    Private Sub TextBox29_KeyPress(ByVal sender As Object, ByVal e As
System.Windows.Forms.KeyPressEventArgs) Handles TextBox29.KeyPress
        'Limits the input to the number of releases textbox to numbers
only
        If Char.IsNumber(e.KeyChar) Then
            e.Handled = False
        Else
            MsgBox("Please only enter numbers in this field.")
            e.Handled = True
        End If
    End Sub
```

```vb
    Private Sub TextBox28_KeyPress(ByVal sender As Object, ByVal e As
System.Windows.Forms.KeyPressEventArgs) Handles TextBox28.KeyPress
        'Limits the input to the duration textbox to numbers only
        If Char.IsNumber(e.KeyChar) Then
            e.Handled = False
        Else
            MsgBox("Please only enter numbers in this field.")
            e.Handled = True
        End If
    End Sub
    Private Sub TextBox27_KeyPress(ByVal sender As Object, ByVal e As
System.Windows.Forms.KeyPressEventArgs) Handles TextBox27.KeyPress
        'Limits the input to the amount textbox to numbers only
        If Char.IsNumber(e.KeyChar) Then
            e.Handled = False
        Else
            MsgBox("Please only enter numbers in this field.")
            e.Handled = True
        End If
    End Sub
    Private Sub TextBox25_KeyPress(ByVal sender As Object, ByVal e As
System.Windows.Forms.KeyPressEventArgs) Handles TextBox25.KeyPress
        'Limits the input to the speed of release textbox to numbers
only
        If Char.IsNumber(e.KeyChar) Then
            e.Handled = False
        Else
            MsgBox("Please only enter numbers in this field.")
            e.Handled = True
        End If
    End Sub
    Private Sub TextBox3_KeyPress(ByVal sender As Object, ByVal e As
System.Windows.Forms.KeyPressEventArgs) Handles TextBox3.KeyPress
        'Limits the input to the meteorological x-location textbox to
numbers only
        If Char.IsNumber(e.KeyChar) Then
            e.Handled = False
        Else
            MsgBox("Please only enter numbers in this field.")
            e.Handled = True
        End If
    End Sub
    Private Sub TextBox4_KeyPress(ByVal sender As Object, ByVal e As
System.Windows.Forms.KeyPressEventArgs) Handles TextBox4.KeyPress
        'Limits the input to the meteorological y-location textbox to
numbers only
        If Char.IsNumber(e.KeyChar) Then
            e.Handled = False
        Else
            MsgBox("Please only enter numbers in this field.")
            e.Handled = True
        End If
    End Sub

    Private Sub TextBox5_KeyPress(ByVal sender As Object, ByVal e As
System.Windows.Forms.KeyPressEventArgs) Handles TextBox5.KeyPress
```

```
        If Char.IsNumber(e.KeyChar) Then
            e.Handled = False
        Else
            MsgBox("Please only enter numbers in this field.")
            e.Handled = True
        End If
    End Sub
    Private Sub TextBox18_KeyPress(ByVal sender As Object, ByVal e As
System.Windows.Forms.KeyPressEventArgs) Handles TextBox18.KeyPress
        If Char.IsNumber(e.KeyChar) Then
            e.Handled = False
        Else
            MsgBox("Please only enter numbers in this field.")
            e.Handled = True
        End If
    End Sub
    Private Sub TextBox19_KeyPress(ByVal sender As Object, ByVal e As
System.Windows.Forms.KeyPressEventArgs) Handles TextBox19.KeyPress
        If Char.IsNumber(e.KeyChar) Then
            e.Handled = False
        Else
            MsgBox("Please only enter numbers in this field.")
            e.Handled = True
        End If
    End Sub
    Private Sub TextBox21_KeyPress(ByVal sender As Object, ByVal e As
System.Windows.Forms.KeyPressEventArgs) Handles TextBox21.KeyPress
        'Limits the input of the spill depth textbox to numbers only
        If Char.IsNumber(e.KeyChar) Then
            e.Handled = False
        Else
            MsgBox("Please only enter numbers in this field.")
            e.Handled = True
        End If
    End Sub
    Private Sub TextBox30_KeyPress(ByVal sender As Object, ByVal e As
System.Windows.Forms.KeyPressEventArgs) Handles TextBox30.KeyPress
        'Limits the input of the default currents J location textbox to
numbers only
        If Char.IsNumber(e.KeyChar) Then
            e.Handled = False
        Else
            MsgBox("Please only enter numbers in this field.")
            e.Handled = True
        End If
    End Sub
    Private Sub TextBox31_KeyPress(ByVal sender As Object, ByVal e As
System.Windows.Forms.KeyPressEventArgs) Handles TextBox31.KeyPress
        'Limits the input of the default currents I location textbox to
numbers only
        If Char.IsNumber(e.KeyChar) Then
            e.Handled = False
        Else
            MsgBox("Please only enter numbers in this field.")
            e.Handled = True
        End If
```

```
    End Sub
    Private Sub TextBox32_KeyPress(ByVal sender As Object, ByVal e As
System.Windows.Forms.KeyPressEventArgs) Handles TextBox32.KeyPress
        'Limits the input of the default temperature textbox to numbers
only
        If Char.IsNumber(e.KeyChar) Then
            e.Handled = False
        Else
            MsgBox("Please only enter numbers in this field.")
            e.Handled = True
        End If
    End Sub
    Private Sub TextBox33_KeyPress(ByVal sender As Object, ByVal e As
System.Windows.Forms.KeyPressEventArgs) Handles TextBox32.KeyPress
        'Limits the input of the output frequency textbox to numbers
only
        If Char.IsNumber(e.KeyChar) Then
            e.Handled = False
        Else
            MsgBox("Please only enter numbers in this field.")
            e.Handled = True
        End If
    End Sub
    Private Sub TextBox34_KeyPress(ByVal sender As Object, ByVal e As
System.Windows.Forms.KeyPressEventArgs) Handles TextBox34.KeyPress
        'Limits the input of the simulation time step to numbers only
        If Char.IsNumber(e.KeyChar) Then
            e.Handled = False
        Else
            MsgBox("Please only enter numbers in this field.")
            e.Handled = True
        End If
    End Sub
    Private Sub TextBox35_KeyPress(ByVal sender As Object, ByVal e As
System.Windows.Forms.KeyPressEventArgs) Handles TextBox35.KeyPress
        'Limits the input of the simulation days textbox to numbers
only
        If Char.IsNumber(e.KeyChar) Then
            e.Handled = False
        Else
            MsgBox("Please only enter numbers in this field.")
            e.Handled = True
        End If
    End Sub
    Private Sub TextBox12_TextChanged(ByVal sender As System.Object,
ByVal e As System.EventArgs) Handles TextBox12.TextChanged
        ScenarioName = TextBox12.Text
    End Sub

End Class
```

RunCOSIM

Tool Inheriting Base Command

```
Imports System.Runtime.InteropServices
Imports System.Drawing
Imports ESRI.ArcGIS.ADF.BaseClasses
Imports ESRI.ArcGIS.ADF.CATIDs
Imports ESRI.ArcGIS.Framework
Imports ESRI.ArcGIS.ArcMapUI
Imports System.Windows.Forms
Imports ESRI.ArcGIS.Carto

<ComClass(RunCOSIMCmd.ClassId, RunCOSIMCmd.InterfaceId,
RunCOSIMCmd.EventsId), _
 ProgId("RunCOSIM2.RunCOSIMCmd")> _
Public NotInheritable Class RunCOSIMCmd
    Inherits BaseCommand

#Region "COM GUIDs"
    ' These  GUIDs provide the COM identity for this class
    ' and its COM interfaces. If you change them, existing
    ' clients will no longer be able to access the class.
    Public Const ClassId As String = "ebf6bda0-6050-4889-92ba-
5a6eada2d0d6"
    Public Const InterfaceId As String = "7e0897c1-72f6-4f80-8010-
7535abab1866"
    Public Const EventsId As String = "a88629bf-9b72-4246-ab74-
c7518912f4d5"
#End Region

#Region "COM Registration Function(s)"
    <ComRegisterFunction(), ComVisibleAttribute(False)> _
    Public Shared Sub RegisterFunction(ByVal registerType As Type)
        ' Required for ArcGIS Component Category Registrar support
        ArcGISCategoryRegistration(registerType)

        'Add any COM registration code after the
ArcGISCategoryRegistration() call

    End Sub

    <ComUnregisterFunction(), ComVisibleAttribute(False)> _
    Public Shared Sub UnregisterFunction(ByVal registerType As Type)
        ' Required for ArcGIS Component Category Registrar support
        ArcGISCategoryUnregistration(registerType)

    End Sub

#Region "ArcGIS Component Category Registrar generated code"
    Private Shared Sub ArcGISCategoryRegistration(ByVal registerType As
Type)
        Dim regKey As String =
String.Format("HKEY_CLASSES_ROOT\CLSID\{{{0}}}", registerType.GUID)
        MxCommands.Register(regKey)
```

```
    End Sub
    Private Shared Sub ArcGISCategoryUnregistration(ByVal registerType
As Type)
        Dim regKey As String =
String.Format("HKEY_CLASSES_ROOT\CLSID\{{{0}}}", registerType.GUID)
        MxCommands.Unregister(regKey)

    End Sub

#End Region
#End Region


    Private m_application As IApplication

    ' A creatable COM class must have a Public Sub New()
    ' with no parameters, otherwise, the class will not be
    ' registered in the COM registry and cannot be created
    ' via CreateObject.
    Public Sub New()
        MyBase.New()

        ' TODO: Define values for the public properties
        MyBase.m_category = "Developer Samples"  'localizable text
        MyBase.m_caption = "Run COSIM"   'localizable text
        MyBase.m_message = "Run COSIM"   'localizable text
        MyBase.m_toolTip = "Run COSIM" 'localizable text
        MyBase.m_name = "DeveloperSamples_RunCOSIM"  'unique id, non-
localizable (e.g. "MyCategory_ArcMapCommand")

        Try
            'TODO: change bitmap name if necessary
            Dim bitmapResourceName As String = "arrow_go.bmp"
            MyBase.m_bitmap = New Bitmap(Me.GetType(),
bitmapResourceName)
        Catch ex As Exception
            System.Diagnostics.Trace.WriteLine(ex.Message, "Invalid
Bitmap")
        End Try
    End Sub


    Public Overrides Sub OnCreate(ByVal hook As Object)
        If Not hook Is Nothing Then
            m_application = CType(hook, IApplication)

            'Disable if it is not ArcMap
            If TypeOf hook Is IMxApplication Then
                MyBase.m_enabled = True
            Else
                MyBase.m_enabled = False
            End If
        End If
    End Sub
```

```
    Public Overrides Sub OnClick()
        'TODO: Add RunCOSIMCmd.OnClick implementation
        Dim mxDocument As IMxDocument = GetMxDocument(m_application)
        Dim pCOSIMForm As New Form1
        pCOSIMForm.ShowDialog()
    End Sub


#Region "Get MxDocument from ArcMap"
    ' ArcGIS Snippet Title:
    ' Get MxDocument from ArcMap
    '
    ' Add the following references to the project:
    ' ESRI.ArcGIS.ArcMapUI
    ' ESRI.ArcGIS.Framework
    ' ESRI.ArcGIS.System
    '
    ' Intended ArcGIS Products for this snippet:
    ' ArcGIS Desktop
    '
    ' Required ArcGIS Extensions:
    ' (NONE)
    '
    ' Notes:
    ' This snippet is intended to be inserted at the base level of a
Class.
    ' It is not intended to be nested within an existing Sub or
Function.
    '
    ' Use the following XML documentation comments to use this snippet:
    ''' <summary>Get MxDocument from ArcMap.</summary>
    '''
    ''' <param name="application">An IApplication interface that is the
ArcMap application.</param>
    '''
    ''' <returns>An IMxDocument interface.</returns>
    '''
    ''' <remarks></remarks>
    Public Function GetMxDocument(ByVal application As
ESRI.ArcGIS.Framework.IApplication) As ESRI.ArcGIS.ArcMapUI.IMxDocument

        If application Is Nothing Then
            Return Nothing
        End If

        Dim mxDocument As ESRI.ArcGIS.ArcMapUI.IMxDocument =
(CType(application.Document, ESRI.ArcGIS.ArcMapUI.IMxDocument)) '
Explicit Cast

        Return mxDocument

    End Function
#End Region
End Class
```

Run COSIM Form

```
Public Class Form1
    Dim ctrlfile As String
    Dim batcontents As String
    Dim scenario As String
    Private Sub Button2_Click(ByVal sender As System.Object, ByVal e As
System.EventArgs) Handles Button2.Click
        'Navigate to and select the COSIM Excel control file
        OpenFileDialog1.InitialDirectory = ("C:\GEMSS\Apps")
        OpenFileDialog1.Filter = "COSIM Coontrol Files(*.xls)|*.xls"
        OpenFileDialog1.ShowDialog()
        'Place the control file path in TextBox2
        TextBox2.Text = OpenFileDialog1.FileName
    End Sub
    Private Sub Button1_Click(ByVal sender As System.Object, ByVal e As
System.EventArgs) Handles Button1.Click
        'Open and write batch file
        Dim batfile As String = "C:\GEMSS\RunCOSFate.bat"
        Dim objWriter As New System.IO.StreamWriter(batfile)

        'Grab the Excel controle file path
        ctrlfile = TextBox2.Text
        'Define the scenario/worksheet to be run
        scenario = TextBox1.Text
        'Combine file name and scenario name to proper format for batch
file contents
        batcontents = "COSIMFatesModel.exe 1 " & Chr(34) & ctrlfile &
Chr(34) & " " & Chr(34) & scenario & Chr(34) & " " & Chr(34) &
"C:\GEMSS" & Chr(34) & " " & "0 0 "

        'check to see if the batch file exists and if so, edit to
contain batcontents
        If System.IO.File.Exists(batfile) = True Then
            objWriter.WriteLine(batcontents)
            objWriter.Close()
            MsgBox("Batch file was updated.")
        Else
            MsgBox("File does not exist.")
        End If
    End Sub

    Private Sub Button3_Click(ByVal sender As System.Object, ByVal e As
System.EventArgs) Handles Button3.Click

        'open command prompt and run batch file
        Dim p As Process = New Process
        p.StartInfo.FileName = "cmd.exe"
        p.StartInfo.WorkingDirectory = "C:/GEMSS"
        p.StartInfo.Arguments = " /C start RunCOSFate.bat"
        p.StartInfo.WindowStyle = ProcessWindowStyle.Normal
        p.StartInfo.CreateNoWindow = False
        p.Start()

    End Sub
End Class
```

Spill Output Prep Tool

Tool Inheriting Base Command

```
Imports System.Runtime.InteropServices
Imports System.Drawing
Imports ESRI.ArcGIS.ADF.BaseClasses
Imports ESRI.ArcGIS.ADF.CATIDs
Imports ESRI.ArcGIS.Framework
Imports ESRI.ArcGIS.ArcMapUI
Imports System.Windows.Forms
Imports ESRI.ArcGIS.Geodatabase
Imports ESRI.ArcGIS.DataSourcesGDB
Imports ESRI.ArcGIS.Carto


<ComClass(OutputTool2.ClassId, OutputTool2.InterfaceId,
OutputTool2.EventsId), _
 ProgId("SMISOutputTableEditing.OutputTool")> _
Public NotInheritable Class OutputTool2
    Inherits BaseTool

#Region "COM GUIDs"
    ' These  GUIDs provide the COM identity for this class
    ' and its COM interfaces. If you change them, existing
    ' clients will no longer be able to access the class.
    Public Const ClassId As String = "b3482e9d-bfe1-41bb-8dc2-
a2831aa292e2"
    Public Const InterfaceId As String = "2e347b44-b16c-4029-93aa-
f6cbcee3ab31"
    Public Const EventsId As String = "77ec42d8-3852-4aef-b9fe-
ca0e664b9cd7"
#End Region

#Region "COM Registration Function(s)"
    <ComRegisterFunction(), ComVisibleAttribute(False)> _
    Public Shared Sub RegisterFunction(ByVal registerType As Type)
        ' Required for ArcGIS Component Category Registrar support
        ArcGISCategoryRegistration(registerType)
    End Sub

    <ComUnregisterFunction()> _
    Public Shared Sub UnregisterFunction(ByVal registerType As Type)
        ' Required for ArcGIS Component Category Registrar support
        ArcGISCategoryUnregistration(registerType)
    End Sub

#Region "ArcGIS Component Category Registrar generated code"
    Private Shared Sub ArcGISCategoryRegistration(ByVal registerType As
Type)
        Dim regKey As String =
String.Format("HKEY_CLASSES_ROOT\CLSID\{{{0}}}", registerType.GUID)
        MxCommands.Register(regKey)
```

```
    End Sub
    Private Shared Sub ArcGISCategoryUnregistration(ByVal registerType
As Type)
        Dim regKey As String =
String.Format("HKEY_CLASSES_ROOT\CLSID\{{{0}}}", registerType.GUID)
        MxCommands.Unregister(regKey)

    End Sub

#End Region
#End Region

    Private m_application As IApplication

    ' A creatable COM class must have a Public Sub New()
    ' with no parameters, otherwise, the class will not be
    ' registered in the COM registry and cannot be created
    ' via CreateObject.
    Public Sub New()
        MyBase.New()
        MyBase.m_category = "Developer Samples"  'localizable text
        MyBase.m_caption = "Spill Output Prep"   'localizable text
        MyBase.m_message = "Spill Output Prep"   'localizable text
        MyBase.m_toolTip = "Splits output table based upon time step"
'localizable text
        MyBase.m_name = "DeveloperSamples_OutputTableEdit"  'unique id,
non-localizable (e.g. "MyCategory_ArcMapTool")

        Try
            'TODO: change resource name if necessary
            Dim bitmapResourceName As String = "spilloutput.bmp"
            MyBase.m_bitmap = New Bitmap(Me.GetType(),
bitmapResourceName)
            MyBase.m_cursor = New
System.Windows.Forms.Cursor(Me.GetType(), Me.GetType().Name + ".cur")
        Catch ex As Exception
            System.Diagnostics.Trace.WriteLine(ex.Message, "Invalid
Bitmap")
        End Try
    End Sub

    Public Overrides Sub OnCreate(ByVal hook As Object)
        If Not hook Is Nothing Then
            m_application = CType(hook, IApplication)
            m_application = hook
            'Disable if it is not ArcMap
            If TypeOf hook Is IMxApplication Then
                MyBase.m_enabled = True
            Else
                MyBase.m_enabled = False
            End If
        End If
    End Sub

    Public Overrides Sub OnClick()
```

```
        'Open SMISOutputForm
        Dim mxDocument As IMxDocument = GetMxDocument(m_application)
        Dim pOutForm As New SMISOutputForm2(m_application)
        pOutForm.ShowDialog()
    End Sub

    Public Overrides Sub OnMouseDown(ByVal Button As Integer, ByVal
Shift As Integer, ByVal X As Integer, ByVal Y As Integer)

    End Sub

    Public Overrides Sub OnMouseMove(ByVal Button As Integer, ByVal
Shift As Integer, ByVal X As Integer, ByVal Y As Integer)
    End Sub

    Public Overrides Sub OnMouseUp(ByVal Button As Integer, ByVal Shift
As Integer, ByVal X As Integer, ByVal Y As Integer)
    End Sub


#Region "Get MxDocument from ArcMap"
    ' ArcGIS Snippet Title:
    ' Get MxDocument from ArcMap
    '
    ' Add the following references to the project:
    ' ESRI.ArcGIS.ArcMapUI
    ' ESRI.ArcGIS.Framework
    ' ESRI.ArcGIS.System
    '
    ' Intended ArcGIS Products for this snippet:
    ' ArcGIS Desktop
    '
    ' Required ArcGIS Extensions:
    ' (NONE)
    '
    ' Notes:
    ' This snippet is intended to be inserted at the base level of a
Class.
    ' It is not intended to be nested within an existing Sub or
Function.
    '
    ' Use the following XML documentation comments to use this snippet:
    ''' <summary>Get MxDocument from ArcMap.</summary>
    '''
    ''' <param name="application">An IApplication interface that is the
ArcMap application.</param>
    '''
    ''' <returns>An IMxDocument interface.</returns>
    '''
    ''' <remarks></remarks>
    Public Function GetMxDocument(ByVal application As
ESRI.ArcGIS.Framework.IApplication) As ESRI.ArcGIS.ArcMapUI.IMxDocument

        If application Is Nothing Then
            Return Nothing
```

```
        End If

        Dim mxDocument As ESRI.ArcGIS.ArcMapUI.IMxDocument =
(CType(application.Document, ESRI.ArcGIS.ArcMapUI.IMxDocument)) '
Explicit Cast

        Return mxDocument

    End Function
#End Region
End Class
```

Spill Output Form

```
Imports System.Data.OleDb
Imports ESRI.ArcGIS.ADF.BaseClasses
Imports ESRI.ArcGIS.ADF.CATIDs
Imports ESRI.ArcGIS.Framework
Imports ESRI.ArcGIS.ArcMapUI
Imports System.Windows.Forms
Imports ESRI.ArcGIS.Carto
Imports ESRI.ArcGIS.ArcMap
Imports ESRI.ArcGIS.Display
Imports ESRI.ArcGIS.SystemUI
Imports ESRI.ArcGIS.Geodatabase
Imports ESRI.ArcGIS.datasourcesGDB
Imports ESRI.ArcGIS.esriSystem
Imports ESRI.ArcGIS.Geometry
Imports ESRI.ArcGIS.ADF
Imports ESRI.ArcGIS.Output
Imports ESRI.ArcGIS.DataSourcesFile
Imports ESRI.ArcGIS.GeoDatabaseUI
Imports ESRI.ArcGIS.Location
Imports ESRI.ArcGIS.LocationUI


Public Class SMISOutputForm2
    Private dtTimeIDs As DataTable
    Dim dgvSurfaceData As New DataGridView
    Dim MainConnectionString As String
    Dim DBProvider As String
    Dim DBSource As String
    Dim DBPath As String
    Dim NewDBSource As String
    Public FileLoc As String
    Dim con As New OleDb.OleDbConnection
    Dim NewDBConnectionStringTemplate As String
    Public Scenario As String
    Public timeselect As String
    Private mpApplication As IApplication
    Private tblpth As String
    Private pDoc As ESRI.ArcGIS.ArcMapUI.IMxDocument
    Private pMap As IMap
    Private pFlayer As IFeatureLayer
```

```
    Private pSpatialReferenceFactory As ISpatialReferenceFactory
    Private pProjectedCoordinateSystem As IProjectedCoordinateSystem
    Private pFact As IWorkspaceFactory
    Private pWorkspace As IWorkspace
    Private pFeatws As IFeatureWorkspace
    Private pTable As ITable
    Private folderloc As String
    Private shpfilename As String

    Public Sub New(ByVal pApp As IApplication)
        MyBase.New()
        InitializeComponent()
        mpApplication = pApp
    End Sub

    Private Sub Button2_Click(ByVal sender As System.Object, ByVal e As
System.EventArgs) Handles Button2.Click
        OpenFileDialog1.InitialDirectory = "C:\GEMSS\Apps\Kentucky
Lake\Output"
        OpenFileDialog1.Filter = "Output Files(*.mdb)|*.mdb"
        OpenFileDialog1.Title = "Open Spill Output File"
        OpenFileDialog1.ShowDialog()
        TextBox3.Text = OpenFileDialog1.FileName
    End Sub
    Private Sub Button1_Click(ByVal sender As System.Object, ByVal e As
System.EventArgs) Handles Button1.Click
        FolderBrowserDialog1.RootFolder =
Environment.SpecialFolder.MyComputer
        FolderBrowserDialog1.Description = "Select Output Folder
Location"
        If FolderBrowserDialog1.ShowDialog() =
Windows.Forms.DialogResult.OK Then
            TextBox2.Text = FolderBrowserDialog1.SelectedPath
        End If
    End Sub

    Private Sub btnCreateDB_Click(ByVal sender As System.Object, ByVal
e As System.EventArgs) Handles btnCreateDB.Click

        DBProvider = "Provider=Microsoft.Jet.OLEDB.4.0;"
        'DBSource = "Data Source = C:/GEMSS/Apps/Kentucky
Lake/Output/avg_highflow.mdb"
        DBSource = "Data Source = " & TextBox3.Text
        DBPath = TextBox3.Text
        Scenario = TextBox1.Text
        FileLoc = TextBox2.Text

        'MsgBox(DBSource)
        MainConnectionString = DBProvider & DBSource
        'MsgBox(MainConnectionString)
        'Private NewDBPath As String = "C:\GEMSS\Apps\Kentucky
Lake\Output\avg_highflow_new_TimeID{0}.mdb"
        NewDBSource = FileLoc & "\" & Scenario & "_new_TimeID{0}.mdb"
        Dim NewDBPath As String = FileLoc & "\" & Scenario &
"_new_TimeID{0}.mdb"
        'MsgBox(NewDBSource)
```

```
        'MsgBox(NewDBPath)

        NewDBConnectionStringTemplate =
"Provider=Microsoft.Jet.OLEDB.4.0;Data Source={0}"
        'Private NewDBConnectionStringTemplate As String =
"Provider=Microsoft.Jet.OLEDB.4.0;Data Source={0}"

        Dim conn As New OleDbConnection(MainConnectionString)
        Dim comm As OleDb.OleDbCommand = conn.CreateCommand()
        comm.CommandText = "SELECT DISTINCT TimeID FROM tblSurface"
        comm.CommandType = CommandType.Text


        dtTimeIDs = New DataTable()
        'conn.ConnectionString = MainConnectionString
        conn.Open()
        'MsgBox("You are using " & DBPath & "as the current database.")
        dtTimeIDs.Load(comm.ExecuteReader())
        conn.Close()
        'MsgBox("Database is now closed.")

        Me.lbTimeIDs.DataSource = dtTimeIDs
        Me.lbTimeIDs.DisplayMember = "TimeID"

        'Creates individual tables for each time step.
        Dim InsertQryStr As String = "INSERT INTO {0} SELECT * FROM
tblSurface WHERE TimeID={1}"
        Dim thisDBPath As String
        Dim con2 As New OleDbConnection
        Dim com2 As OleDbCommand

        For i As Integer = 0 To Me.dtTimeIDs.Rows.Count
            If i > 35 Then
                Exit For
            Else
                thisDBPath = String.Format(NewDBPath,
Me.dtTimeIDs.Rows(i)(0).ToString())
                'thisDBPath = NewDBPath & ",Me.dtTimeIDs.Rows(i)
(0).ToString()"
                'MsgBox("ThisDBPath = " & thisDBPath)
                'MsgBox("DBPath = " & DBPath)
                'Me.lbTimeIDs.DisplayMember = DBPath
                System.IO.File.Copy(DBPath, thisDBPath)

                con2.ConnectionString =
String.Format(NewDBConnectionStringTemplate, thisDBPath)
                com2 = con2.CreateCommand()
                com2.CommandText = "DELETE FROM tblSurface WHERE
TimeID<>" + Me.dtTimeIDs.Rows(i)(0).ToString()
                com2.CommandType = CommandType.Text
                con2.Open()
                com2.ExecuteNonQuery()
                con2.Close()

            End If
        Next
```

```
    End Sub
    Private Sub lbTimeIDs_SelectedIndexChanged(ByVal sender As
System.Object, ByVal e As System.EventArgs) Handles
lbTimeIDs.SelectedIndexChanged
    End Sub


    Private Sub AddTbl_Click(ByVal sender As System.Object, ByVal e As
System.EventArgs) Handles AddTbl.Click
        'Get a table based on the time selected in the list box and add
it to ArcMap
        Dim FileLoc As String
        Dim Scenario As String
        Dim tblpth As String
        Dim timeselect As String = lbTimeIDs.SelectedItem(0).ToString()

        Scenario = TextBox1.Text
        FileLoc = TextBox2.Text
        tblpth = FileLoc & "\" & Scenario & "_new_TimeID" & timeselect
& ".mdb"
        MsgBox(tblpth)
        'tblpth = timeselect

        'locate and open the table
        Try
            Dim pFact As IWorkspaceFactory
            Dim pWorkspace As IWorkspace
            Dim pFeatws As IFeatureWorkspace
            Dim pTable As ITable
            pFact = New AccessWorkspaceFactory
            pWorkspace = pFact.OpenFromFile(tblpth, 0)
            pFeatws = pWorkspace
            pTable = pFeatws.OpenTable("tblSurface")

            'add the table
            Dim pDoc As ESRI.ArcGIS.ArcMapUI.IMxDocument
            'Dim Application As New ESRI.ArcGIS.ArcMap.Application
            Dim pMap As IMap
            pDoc = mpApplication.Document
            pMap = pDoc.FocusMap

            Dim pStTab As IStandaloneTable
            pStTab = New StandaloneTable
            pStTab.Table = pTable
            Dim pStTabColl As IStandaloneTableCollection
            pStTabColl = pMap
            pStTabColl.AddStandaloneTable(pStTab)

            'NEW
            Dim pTableName As IName
            Dim pDS As IDataset
            pDS = pTable
            pTableName = pDS.FullName

            Dim pXYEvent2FieldsProperties As IXYEvent2FieldsProperties
            pXYEvent2FieldsProperties = New XYEvent2FieldsProperties
```

```
            With pXYEvent2FieldsProperties
                .XFieldName = "x"
                .YFieldName = "y"
                .ZFieldName = "C9"

            End With

            Dim pSpatialReferenceFactory As ISpatialReferenceFactory
            Dim pProjectedCoordinateSystem As
IProjectedCoordinateSystem
            pSpatialReferenceFactory = New SpatialReferenceEnvironment
            pProjectedCoordinateSystem =
pSpatialReferenceFactory.CreateProjectedCoordinateSystem(esriSRProjCSTy
pe.esriSRProjCS_NAD1983SPCS_TNFT)
            'pProjectedCoordinateSystem =
pSpatialReferenceFactory.CreateProjectedCoordinateSystem(esriSRProjCS_N
AD1983UTM_11N)

            'Create XY name object and set its properties
            Dim pXYEventSourceName As IXYEventSourceName
            Dim pXYName As IName
            Dim pXYEventSource As IEventSource
            pXYEventSourceName = New XYEventSourceName
            With pXYEventSourceName
                .EventProperties = pXYEvent2FieldsProperties
                .SpatialReference = pProjectedCoordinateSystem
                .EventTableName = pTableName
            End With

            pXYName = pXYEventSourceName
            pXYEventSource = pXYName.Open

            'Create New Map Layer
            Dim pFlayer As IFeatureLayer
            pFlayer = New FeatureLayer
            pFlayer.FeatureClass = pXYEventSource
            pFlayer.Name = Scenario & "_TimeID" & timeselect

            'Add the layer extension
            Dim pLayerExt As ILayerExtensions
            Dim pRESPageExt As New XYDataSourcePageExtension
            pLayerExt = pFlayer
            pLayerExt.AddExtension(pRESPageExt)

            pMap.AddLayer(pFlayer)

pDoc.ActivatedView.PartialRefresh(esriViewDrawPhase.esriViewGeography,
Nothing, Nothing)

            pDoc.UpdateContents()
        Catch ex As Exception
            MsgBox(ex.Message)
        End Try
    End Sub
```

```
    Private Sub Button3_Click(ByVal sender As System.Object, ByVal e As
System.EventArgs) Handles Button3.Click
        'Export XY Event to shapefile
        Try
            Dim timeselect As String =
lbTimeIDs.SelectedItem(0).ToString()
            Dim pDoc As IMxDocument
            pDoc = mpApplication.Document
            Dim pMap As IMap
            pMap = pDoc.FocusMap
            Dim pFLayer As IFeatureLayer
            Dim pFc As IFeatureClass
            Dim pINFeatureClassName As IFeatureClassName
            Dim pDataset As IDataset
            Dim pInDsName As IDatasetName

            Dim pFSel As IFeatureSelection
            Dim pSelSet As ISelectionSet
            Dim pFeatureClassName As IFeatureClassName
            Dim pOutDatasetName As IDatasetName
            Dim pWorkspaceName As IWorkspaceName
            Dim pExportOp As IExportOperation

            pFLayer = pMap.Layer(0)
            pFc = pFLayer.FeatureClass

            'Get the FcName from the featureclass
            pDataset = pFc
            pINFeatureClassName = pDataset.FullName
            pInDsName = pINFeatureClassName

            'NOTE: Selection set needs to be all records
            'Get the selection set
            pFSel = pFLayer
            pSelSet = pFSel.SelectionSet

            'pSelSet = pFlayer
            'Define the output feature class name
            pFeatureClassName = New FeatureClassName

            pOutDatasetName = pFeatureClassName
            pOutDatasetName.Name = Scenario & "_TimeID" & timeselect &
"shp" '"Spill Results"
            pWorkspaceName = New WorkspaceName
            pWorkspaceName.PathName = FileLoc
'"D:\Chirag\Data\NEW_CODE"

            pWorkspaceName.WorkspaceFactoryProgID =
"esriDataSourcesFile.ShapefileWorkspaceFactory"

            pOutDatasetName.WorkspaceName = pWorkspaceName

            pFeatureClassName.FeatureType = pFc.FeatureType
            'esriFeatureType.esriFTSimple

            pFeatureClassName.ShapeType = pFc.ShapeType
```

```
            'esriGeometryType.esriGeometryAny

            pFeatureClassName.ShapeFieldName = pFc.ShapeFieldName
            'pOutDatasetName.Name

            Dim pFile As New IO.FileInfo(FileLoc & "\" & Scenario &
"_new_TimeID" & timeselect & "shp" & ".shp")
            If pFile.Exists Then
                Dim pFolder As New IO.DirectoryInfo(FileLoc)
                Dim pShpFiles() As IO.FileInfo
                pShpFiles = pFolder.GetFiles(FileLoc & "\" & Scenario &
"_new_TimeID" & timeselect & "shp" & ".*")

                Dim i As Integer
                i = pShpFiles.Length
                While i > 0
                    pShpFiles(i - 1).Delete()
                    i = i - 1
                End While
            End If

            'Export
            pExportOp = New ExportOperation
            pExportOp.ExportFeatureClass(pInDsName, Nothing, pSelSet,
Nothing, pOutDatasetName, 0)

            Dim pWorkspaceFactorty As IWorkspaceFactory
            pWorkspaceFactorty = New ShapefileWorkspaceFactory
            Dim pShpWorkspace As IWorkspace
            pShpWorkspace = pWorkspaceFactorty.OpenFromFile(FileLoc, 0)
            Dim pFeatureWorkspace As IFeatureWorkspace

            pFeatureWorkspace = pShpWorkspace
            Dim pShpFeatureClass As IFeatureClass

            pShpFeatureClass =
pFeatureWorkspace.OpenFeatureClass(Scenario & "_TimeID" & timeselect &
"shp")

            Dim pShpFeatLayer As IFeatureLayer
            pShpFeatLayer = New FeatureLayer
            pShpFeatLayer.FeatureClass = pShpFeatureClass
            pShpFeatLayer.Name = pShpFeatLayer.FeatureClass.AliasName

            'Add shapefile to map
            pMap.AddLayer(pShpFeatLayer)

pDoc.ActivatedView.PartialRefresh(esriViewDrawPhase.esriViewGeography,
Nothing, Nothing)

            pDoc.UpdateContents()
        Catch ex As Exception
            MsgBox(ex.Message)
        End Try
    End Sub
End Class
```

Output .mdb to .shp Tool

Tool Inheriting Base Command

```
Imports System.Data.OleDb
Imports ESRI.ArcGIS.ADF.BaseClasses
Imports ESRI.ArcGIS.ADF.CATIDs
Imports ESRI.ArcGIS.Framework
Imports ESRI.ArcGIS.ArcMapUI
Imports System.Windows.Forms
Imports ESRI.ArcGIS.Carto
Imports ESRI.ArcGIS.ArcMap
Imports ESRI.ArcGIS.Display
Imports ESRI.ArcGIS.SystemUI
Imports ESRI.ArcGIS.Geodatabase
Imports ESRI.ArcGIS.datasourcesGDB
Imports ESRI.ArcGIS.esriSystem
Imports ESRI.ArcGIS.Geometry
Imports ESRI.ArcGIS.ADF
Imports ESRI.ArcGIS.Output
Imports ESRI.ArcGIS.DataSourcesFile
Imports ESRI.ArcGIS.GeoDatabaseUI
Imports ESRI.ArcGIS.Location
Imports ESRI.ArcGIS.LocationUI


Public Class SMISOutputForm2
    Private dtTimeIDs As DataTable
    Dim dgvSurfaceData As New DataGridView
    Dim MainConnectionString As String
    Dim DBProvider As String
    Dim DBSource As String
    Dim DBPath As String
    Dim NewDBSource As String
    Public FileLoc As String
    Dim con As New OleDb.OleDbConnection
    Dim NewDBConnectionStringTemplate As String
    Public Scenario As String
    Public timeselect As String
    Private mpApplication As IApplication
    Private tblpth As String
    Private pDoc As ESRI.ArcGIS.ArcMapUI.IMxDocument
    Private pMap As IMap
    Private pFlayer As IFeatureLayer
    Private pSpatialReferenceFactory As ISpatialReferenceFactory
    Private pProjectedCoordinateSystem As IProjectedCoordinateSystem
    Private pFact As IWorkspaceFactory
    Private pWorkspace As IWorkspace
    Private pFeatws As IFeatureWorkspace
    Private pTable As ITable
    Private folderloc As String
    Private shpfilename As String
```

```
    Public Sub New(ByVal pApp As IApplication)
        MyBase.New()
        InitializeComponent()
        mpApplication = pApp
    End Sub

    Private Sub Button2_Click(ByVal sender As System.Object, ByVal e As
System.EventArgs) Handles Button2.Click
        OpenFileDialog1.InitialDirectory = "C:\GEMSS\Apps\Kentucky
Lake\Output"
        OpenFileDialog1.Filter = "Output Files(*.mdb)|*.mdb"
        OpenFileDialog1.Title = "Open Spill Output File"
        OpenFileDialog1.ShowDialog()
        TextBox3.Text = OpenFileDialog1.FileName
    End Sub
    Private Sub Button1_Click(ByVal sender As System.Object, ByVal e As
System.EventArgs) Handles Button1.Click
        FolderBrowserDialog1.RootFolder =
Environment.SpecialFolder.MyComputer
        FolderBrowserDialog1.Description = "Select Output Folder
Location"
        If FolderBrowserDialog1.ShowDialog() =
Windows.Forms.DialogResult.OK Then
            TextBox2.Text = FolderBrowserDialog1.SelectedPath
        End If
    End Sub

    Private Sub btnCreateDB_Click(ByVal sender As System.Object, ByVal
e As System.EventArgs) Handles btnCreateDB.Click

        DBProvider = "Provider=Microsoft.Jet.OLEDB.4.0;"
        'DBSource = "Data Source = C:/GEMSS/Apps/Kentucky
Lake/Output/avg_highflow.mdb"
        DBSource = "Data Source = " & TextBox3.Text
        DBPath = TextBox3.Text
        Scenario = TextBox1.Text
        FileLoc = TextBox2.Text

        'MsgBox(DBSource)
        'Private MainConnectionString As String =
"Provider=Microsoft.Jet.OLEDB.4.0;Data Source=" & DBPath
        'con.ConnectionString = DBProvider & DBSource
        MainConnectionString = DBProvider & DBSource
        'MsgBox(MainConnectionString)

        'Private NewDBPath As String = "C:\GEMSS\Apps\Kentucky
Lake\Output\avg_highflow_new_TimeID{0}.mdb"
        NewDBSource = FileLoc & "\" & Scenario & "_new_TimeID{0}.mdb"
        Dim NewDBPath As String = FileLoc & "\" & Scenario &
"_new_TimeID{0}.mdb"
        'MsgBox(NewDBSource)
        'MsgBox(NewDBPath)

        NewDBConnectionStringTemplate =
"Provider=Microsoft.Jet.OLEDB.4.0;Data Source={0}"
```

```
        'Private NewDBConnectionStringTemplate As String =
"Provider=Microsoft.Jet.OLEDB.4.0;Data Source={0}"

        Dim conn As New OleDbConnection(MainConnectionString)
        Dim comm As OleDb.OleDbCommand = conn.CreateCommand()
        comm.CommandText = "SELECT DISTINCT TimeID FROM tblSurface"
        comm.CommandType = CommandType.Text


        dtTimeIDs = New DataTable()
        'conn.ConnectionString = MainConnectionString
        conn.Open()
        'MsgBox("You are using " & DBPath & "as the current database.")
        dtTimeIDs.Load(comm.ExecuteReader())
        conn.Close()
        'MsgBox("Database is now closed.")

        Me.lbTimeIDs.DataSource = dtTimeIDs
        Me.lbTimeIDs.DisplayMember = "TimeID"

        'Creates individual tables for each time step.
        Dim InsertQryStr As String = "INSERT INTO {0} SELECT * FROM
tblSurface WHERE TimeID={1}"
        Dim thisDBPath As String
        Dim con2 As New OleDbConnection
        Dim com2 As OleDbCommand

        For i As Integer = 0 To Me.dtTimeIDs.Rows.Count
            If i > 35 Then
                Exit For
            Else
                thisDBPath = String.Format(NewDBPath,
Me.dtTimeIDs.Rows(i)(0).ToString())
                'MsgBox("ThisDBPath = " & thisDBPath)
                'MsgBox("DBPath = " & DBPath)
                'Me.lbTimeIDs.DisplayMember = DBPath
                System.IO.File.Copy(DBPath, thisDBPath)

                con2.ConnectionString =
String.Format(NewDBConnectionStringTemplate, thisDBPath)
                com2 = con2.CreateCommand()
                com2.CommandText = "DELETE FROM tblSurface WHERE
TimeID<>" + Me.dtTimeIDs.Rows(i)(0).ToString()
                com2.CommandType = CommandType.Text
                con2.Open()
                com2.ExecuteNonQuery()
                con2.Close()
            End If
        Next
    End Sub
    Private Sub lbTimeIDs_SelectedIndexChanged(ByVal sender As
System.Object, ByVal e As System.EventArgs) Handles
lbTimeIDs.SelectedIndexChanged
    End Sub
```

```
    Private Sub AddTbl_Click(ByVal sender As System.Object, ByVal e As
System.EventArgs) Handles AddTbl.Click
        'Get a table based on the time selected in the list box and add
it to ArcMap
        Dim FileLoc As String
        Dim Scenario As String
        Dim tblpth As String
        Dim timeselect As String = lbTimeIDs.SelectedItem(0).ToString()


        'Dim timeselect As String =
lbTimeIDs.Items(lbTimeIDs.SelectedIndex).ToString()
        'MsgBox("Seleccted time is " & timeselect)
        'Dim timeselect As String = lbTimeIDs.SelectedItem
        'From Experts-Exchange
        'timeselect = Me.lbTimeIDs.SelectedItem[{0}].ToString();

        Scenario = TextBox1.Text
        FileLoc = TextBox2.Text
        tblpth = FileLoc & "\" & Scenario & "_new_TimeID" & timeselect
& ".mdb"
        MsgBox(tblpth)
        'tblpth = timeselect

        'locate and open the table
        Try
            Dim pFact As IWorkspaceFactory
            Dim pWorkspace As IWorkspace
            Dim pFeatws As IFeatureWorkspace
            Dim pTable As ITable
            pFact = New AccessWorkspaceFactory
            pWorkspace = pFact.OpenFromFile(tblpth, 0)
            pFeatws = pWorkspace
            pTable = pFeatws.OpenTable("tblSurface")

            'add the table
            Dim pDoc As ESRI.ArcGIS.ArcMapUI.IMxDocument
            'Dim Application As New ESRI.ArcGIS.ArcMap.Application
            Dim pMap As IMap
            pDoc = mpApplication.Document
            pMap = pDoc.FocusMap

            Dim pStTab As IStandaloneTable
            pStTab = New StandaloneTable
            pStTab.Table = pTable
            Dim pStTabColl As IStandaloneTableCollection
            pStTabColl = pMap
            pStTabColl.AddStandaloneTable(pStTab)

            'NEW
            Dim pTableName As IName
            Dim pDS As IDataset
            pDS = pTable
            pTableName = pDS.FullName

            Dim pXYEvent2FieldsProperties As IXYEvent2FieldsProperties
```

```
            pXYEvent2FieldsProperties = New XYEvent2FieldsProperties
            With pXYEvent2FieldsProperties
                .XFieldName = "x"
                .YFieldName = "y"
                .ZFieldName = "C9"

            End With

            Dim pSpatialReferenceFactory As ISpatialReferenceFactory
            Dim pProjectedCoordinateSystem As
IProjectedCoordinateSystem
            pSpatialReferenceFactory = New SpatialReferenceEnvironment
            pProjectedCoordinateSystem =
pSpatialReferenceFactory.CreateProjectedCoordinateSystem(esriSRProjCSTy
pe.esriSRProjCS_NAD1983SPCS_TNFT)
            'pProjectedCoordinateSystem =
pSpatialReferenceFactory.CreateProjectedCoordinateSystem(esriSRProjCS_N
AD1983UTM_11N)

            'Create XY name object and set its properties
            Dim pXYEventSourceName As IXYEventSourceName
            Dim pXYName As IName
            Dim pXYEventSource As IEventSource
            pXYEventSourceName = New XYEventSourceName
            With pXYEventSourceName
                .EventProperties = pXYEvent2FieldsProperties
                .SpatialReference = pProjectedCoordinateSystem
                .EventTableName = pTableName
            End With

            pXYName = pXYEventSourceName
            pXYEventSource = pXYName.Open

            'Create New Map Layer
            Dim pFlayer As IFeatureLayer
            pFlayer = New FeatureLayer
            pFlayer.FeatureClass = pXYEventSource
            pFlayer.Name = Scenario & "_TimeID" & timeselect

            'Add the layer extension
            Dim pLayerExt As ILayerExtensions
            Dim pRESPageExt As New XYDataSourcePageExtension
            pLayerExt = pFlayer
            pLayerExt.AddExtension(pRESPageExt)

            pMap.AddLayer(pFlayer)

pDoc.ActivatedView.PartialRefresh(esriViewDrawPhase.esriViewGeography,
Nothing, Nothing)

            pDoc.UpdateContents()
        Catch ex As Exception
            MsgBox(ex.Message)
        End Try

    End Sub
```

```
    Private Sub Button3_Click(ByVal sender As System.Object, ByVal e As
System.EventArgs) Handles Button3.Click
        'Export XY Event to shapefile
        Try
            Dim timeselect As String =
lbTimeIDs.SelectedItem(0).ToString()
            Dim pDoc As IMxDocument
            pDoc = mpApplication.Document
            Dim pMap As IMap
            pMap = pDoc.FocusMap
            Dim pFLayer As IFeatureLayer
            Dim pFc As IFeatureClass
            Dim pINFeatureClassName As IFeatureClassName
            Dim pDataset As IDataset
            Dim pInDsName As IDatasetName

            Dim pFSel As IFeatureSelection
            Dim pSelSet As ISelectionSet
            Dim pFeatureClassName As IFeatureClassName
            Dim pOutDatasetName As IDatasetName
            Dim pWorkspaceName As IWorkspaceName
            Dim pExportOp As IExportOperation

            pFLayer = pMap.Layer(0)
            pFc = pFLayer.FeatureClass

            'Get the FcName from the featureclass
            pDataset = pFc
            pINFeatureClassName = pDataset.FullName
            pInDsName = pINFeatureClassName

            'NOTE: Selection set needs to be all records
            'Get the selection set
            pFSel = pFLayer
            pSelSet = pFSel.SelectionSet

            'pSelSet = pFlayer
            'Define the output feature class name
            pFeatureClassName = New FeatureClassName

            pOutDatasetName = pFeatureClassName
            pOutDatasetName.Name = Scenario & "_TimeID" & timeselect &
"shp" '"Spill Results"
            pWorkspaceName = New WorkspaceName
            pWorkspaceName.PathName = FileLoc
'"D:\Chirag\Data\NEW_CODE"

            pWorkspaceName.WorkspaceFactoryProgID =
"esriDataSourcesFile.ShapefileWorkspaceFactory"

            pOutDatasetName.WorkspaceName = pWorkspaceName

            pFeatureClassName.FeatureType = pFc.FeatureType
            'esriFeatureType.esriFTSimple

            pFeatureClassName.ShapeType = pFc.ShapeType
```

```
            'esriGeometryType.esriGeometryAny

            pFeatureClassName.ShapeFieldName = pFc.ShapeFieldName
            'pOutDatasetName.Name

            Dim pFile As New IO.FileInfo(FileLoc & "\" & Scenario &
"_new_TimeID" & timeselect & "shp" & ".shp")
            If pFile.Exists Then
                Dim pFolder As New IO.DirectoryInfo(FileLoc)
                Dim pShpFiles() As IO.FileInfo
                pShpFiles = pFolder.GetFiles(FileLoc & "\" & Scenario &
"_new_TimeID" & timeselect & "shp" & ".*")

                Dim i As Integer
                i = pShpFiles.Length
                While i > 0
                    pShpFiles(i - 1).Delete()
                    i = i - 1
                End While
            End If

            'Export
            pExportOp = New ExportOperation
            pExportOp.ExportFeatureClass(pInDsName, Nothing, pSelSet,
Nothing, pOutDatasetName, 0)

            Dim pWorkspaceFactorty As IWorkspaceFactory
            pWorkspaceFactorty = New ShapefileWorkspaceFactory

            Dim pShpWorkspace As IWorkspace
            pShpWorkspace = pWorkspaceFactorty.OpenFromFile(FileLoc, 0)
            Dim pFeatureWorkspace As IFeatureWorkspace

            pFeatureWorkspace = pShpWorkspace
            Dim pShpFeatureClass As IFeatureClass

            pShpFeatureClass =
pFeatureWorkspace.OpenFeatureClass(Scenario & "_TimeID" & timeselect &
"shp")

            Dim pShpFeatLayer As IFeatureLayer
            pShpFeatLayer = New FeatureLayer
            pShpFeatLayer.FeatureClass = pShpFeatureClass
            pShpFeatLayer.Name = pShpFeatLayer.FeatureClass.AliasName

            'Add shapefile to map
            pMap.AddLayer(pShpFeatLayer)

pDoc.ActivatedView.PartialRefresh(esriViewDrawPhase.esriViewGeography,
Nothing, Nothing)
            pDoc.UpdateContents()
        Catch ex As Exception
            MsgBox(ex.Message)
        End Try
    End Sub
End Class
```

Tbl2Shp Form

```
Imports ESRI.ArcGIS.Geodatabase
Imports System.Windows.Forms
Imports ESRI.ArcGIS.DataSourcesGDB
Imports ESRI.ArcGIS.ArcMap
Imports ESRI.ArcGIS.SystemUI
Imports ESRI.ArcGIS.Carto
Imports System.Data.OleDb
Imports ESRI.ArcGIS.ADF.BaseClasses
Imports ESRI.ArcGIS.ADF.CATIDs
Imports ESRI.ArcGIS.Framework
Imports ESRI.ArcGIS.ArcMapUI
Imports ESRI.ArcGIS.Display
Imports ESRI.ArcGIS.esriSystem
Imports ESRI.ArcGIS.Geometry
Imports ESRI.ArcGIS.ADF
Imports ESRI.ArcGIS.Output
Imports ESRI.ArcGIS.DataSourcesFile
Imports ESRI.ArcGIS.GeoDatabaseUI
Imports ESRI.ArcGIS.Location
Imports ESRI.ArcGIS.LocationUI

Public Class Tbl2ShpForm
    'Private dtTimeIDs As DataTable
    'Private dgvSurfaceData As New DataGridView
    'Dim MainConnectionString As String
    'Public FileLoc As String
    'Private con As New OleDb.OleDbConnection
    'Private NewDBConnectionStringTemplate As String
    'Public Scenario As String
    'Public timeselect As String
    Private tblpth As String
    Private mpApplication As IApplication
    Private pDoc As ESRI.ArcGIS.ArcMapUI.IMxDocument
    Private pMap As IMap
    Private pFlayer As IFeatureLayer
    Private pSpatialReferenceFactory As ISpatialReferenceFactory
    Private pProjectedCoordinateSystem As IProjectedCoordinateSystem
    Private pFact As IWorkspaceFactory
    Private pWorkspace As IWorkspace
    Private pFeatws As IFeatureWorkspace
    Private pTable As ITable
    Private folderloc As String
    Private shpfilename As String
    Public Sub New(ByVal pApp As IApplication)
        MyBase.New()
        InitializeComponent()
        mpApplication = pApp
    End Sub
    Private Sub TblOpen_Click(ByVal sender As System.Object, ByVal e As
System.EventArgs) Handles TblOpen.Click
        OpenFileDialog1.InitialDirectory = "C:\GEMSS\Apps\Kentucky
Lake\Output"
        OpenFileDialog1.Filter = "Output Files (*.mdb)|*.mdb"
        OpenFileDialog1.ShowDialog()
        TextBox1.Text = OpenFileDialog1.FileName
```

```
    End Sub

    Private Sub Button1_Click(ByVal sender As System.Object, ByVal e As
System.EventArgs) Handles Button1.Click
        tblpth = TextBox1.Text
        shpfilename = TextBox3.Text
        folderloc = TextBox2.Text

        'locate and open the table

        Try
            pFact = New AccessWorkspaceFactory
            pWorkspace = pFact.OpenFromFile(tblpth, 0)

            pFeatws = pWorkspace
            pTable = pFeatws.OpenTable("tblSurface")

            'add the table
            pDoc = mpApplication.Document
            pMap = pDoc.FocusMap
            Dim pStTab As IStandaloneTable
            pStTab = New StandaloneTable
            pStTab.Table = pTable
            Dim pStTabColl As IStandaloneTableCollection

            pStTabColl = pMap
            pStTabColl.AddStandaloneTable(pStTab)

            'NEW
            Dim pTableName As IName
            Dim pDS As IDataset

            pDS = pTable

            pTableName = pDS.FullName

            Dim pXYEvent2FieldsProperties As IXYEvent2FieldsProperties
            pXYEvent2FieldsProperties = New XYEvent2FieldsProperties

            With pXYEvent2FieldsProperties
                .XFieldName = "x"
                .YFieldName = "y"
                .ZFieldName = "C5"

            End With

            Dim pSpatialReferenceFactory As ISpatialReferenceFactory
            Dim pProjectedCoordinateSystem As
IProjectedCoordinateSystem
            pSpatialReferenceFactory = New SpatialReferenceEnvironment
            pProjectedCoordinateSystem =
pSpatialReferenceFactory.CreateProjectedCoordinateSystem(esriSRProjCSTy
pe.esriSRProjCS_NAD1983SPCS_TNFT)

            'Create XY name object and set its properties
            Dim pXYEventSourceName As IXYEventSourceName
```

```
            Dim pXYName As IName
            Dim pXYEventSource As IEventSource
            pXYEventSourceName = New XYEventSourceName
            With pXYEventSourceName
                .EventProperties = pXYEvent2FieldsProperties
                .SpatialReference = pProjectedCoordinateSystem
                .EventTableName = pTableName
            End With

            pXYName = pXYEventSourceName
            pXYEventSource = pXYName.Open

            'Create New Map Layer
            'Dim pFlayer As IFeatureLayer
            pFlayer = New FeatureLayer
            pFlayer.FeatureClass = pXYEventSource
            pFlayer.Name = shpfilename '"Spill Results XY Events"

            'Add the layer extension
            Dim pLayerExt As ILayerExtensions
            Dim pRESPageExt As New XYDataSourcePageExtension
            pLayerExt = pFlayer
            pLayerExt.AddExtension(pRESPageExt)
            pMap.AddLayer(pFlayer)


pDoc.ActivatedView.PartialRefresh(esriViewDrawPhase.esriViewGeography,
Nothing, Nothing)
            pDoc.UpdateContents()

            'Export XY Event to shapefile
            'Dim pFLayer2 As IFeatureLayer

            Dim pFc As IFeatureClass
            Dim pINFeatureClassName As IFeatureClassName
            Dim pDataset As IDataset
            Dim pInDsName As IDatasetName

            Dim pFSel As IFeatureSelection
            Dim pSelSet As ISelectionSet
            Dim pFeatureClassName As IFeatureClassName
            Dim pOutDatasetName As IDatasetName
            Dim pWorkspaceName As IWorkspaceName
            Dim pExportOp As IExportOperation

            pFlayer = pMap.Layer(0)
            pFc = pFlayer.FeatureClass

            'Get the FcName from the featureclass
            pDataset = pFc
            pINFeatureClassName = pDataset.FullName
            pInDsName = pINFeatureClassName

            'NOTE: Selection set needs to be all records
            'Get the selection set
            pFSel = pFlayer
```

```
            pSelSet = pFSel.SelectionSet

            'pSelSet = pFlayer
            'Define the output feature class name
            pFeatureClassName = New FeatureClassName

            pOutDatasetName = pFeatureClassName
            pOutDatasetName.Name = shpfilename
            pWorkspaceName = New WorkspaceName
            pWorkspaceName.PathName = folderloc
'"D:\Chirag\Data\NEW_CODE"

            pWorkspaceName.WorkspaceFactoryProgID =
"esriDataSourcesFile.ShapefileWorkspaceFactory"

            pOutDatasetName.WorkspaceName = pWorkspaceName
            pFeatureClassName.FeatureType = pFc.FeatureType
            'esriFeatureType.esriFTSimple
            pFeatureClassName.ShapeType = pFc.ShapeType
            'esriGeometryType.esriGeometryAny
            pFeatureClassName.ShapeFieldName = pFc.ShapeFieldName
            'pOutDatasetName.Name

            Dim pFile As New IO.FileInfo(folderloc & shpfilename &
".shp")
            If pFile.Exists Then
                Dim pFolder As New IO.DirectoryInfo(folderloc)
                Dim pShpFiles() As IO.FileInfo
                pShpFiles = pFolder.GetFiles(shpfilename & ".*")
'("Spill Results.*")

                Dim i As Integer
                i = pShpFiles.Length
                While i > 0
                    pShpFiles(i - 1).Delete()
                    i = i - 1
                End While
            End If

            'Export
            pExportOp = New ExportOperation
            pExportOp.ExportFeatureClass(pInDsName, Nothing, pSelSet,
Nothing, pOutDatasetName, 0)

            Dim pWorkspaceFactorty As IWorkspaceFactory
            pWorkspaceFactorty = New ShapefileWorkspaceFactory
            Dim pShpWorkspace As IWorkspace
            pShpWorkspace = pWorkspaceFactorty.OpenFromFile(folderloc,
0)
            Dim pFeatureWorkspace As IFeatureWorkspace
            pFeatureWorkspace = pShpWorkspace
            Dim pShpFeatureClass As IFeatureClass
            pShpFeatureClass =
pFeatureWorkspace.OpenFeatureClass(shpfilename)  '("Spill Results")
            Dim pShpFeatLayer As IFeatureLayer
            pShpFeatLayer = New FeatureLayer
```

```
            pShpFeatLayer.FeatureClass = pShpFeatureClass
            pShpFeatLayer.Name = pShpFeatLayer.FeatureClass.AliasName

            'Add shapefile to map
            pMap.AddLayer(pShpFeatLayer)

pDoc.ActivatedView.PartialRefresh(esriViewDrawPhase.esriViewGeography,
Nothing, Nothing)

            pDoc.UpdateContents()

        Catch ex As Exception
            MsgBox(ex.Message)
        End Try
    End Sub

    Private Sub Button2_Click(ByVal sender As System.Object, ByVal e As
System.EventArgs) Handles Button2.Click
        FolderBrowserDialog1.RootFolder =
Environment.SpecialFolder.MyComputer
        FolderBrowserDialog1.Description = "Select Shapefile Folder
Location"
        If FolderBrowserDialog1.ShowDialog() =
Windows.Forms.DialogResult.OK Then
            TextBox2.Text = FolderBrowserDialog1.SelectedPath
        End If
    End Sub
End Class
```

Zoom to Layer Tool

Zoom To Layer Command

```
Imports System.Runtime.InteropServices
Imports System.Drawing
Imports ESRI.ArcGIS.ADF.BaseClasses
Imports ESRI.ArcGIS.ADF.CATIDs
Imports ESRI.ArcGIS.Framework
Imports ESRI.ArcGIS.ArcMapUI

<ComClass(ZoomtoLayer.ClassId, ZoomtoLayer.InterfaceId,
ZoomtoLayer.EventsId), _
 ProgId("ArcMapClassLibrary1.Command1")> _
Public NotInheritable Class ZoomtoLayer
    Inherits BaseCommand

#Region "COM GUIDs"
    ' These  GUIDs provide the COM identity for this class
    ' and its COM interfaces. If you change them, existing
    ' clients will no longer be able to access the class.
    Public Const ClassId As String = "0accbd26-b38a-4c1d-9899-
d7123b037a14"
    Public Const InterfaceId As String = "f56db80b-eea3-4493-89bb-
6a80a295556a"
    Public Const EventsId As String = "abb26e87-dcf1-4c30-87ff-
97180fa14205"
#End Region

#Region "COM Registration Function(s)"
    <ComRegisterFunction(), ComVisibleAttribute(False)> _
    Public Shared Sub RegisterFunction(ByVal registerType As Type)
        ' Required for ArcGIS Component Category Registrar support
        ArcGISCategoryRegistration(registerType)
    End Sub

    <ComUnregisterFunction(), ComVisibleAttribute(False)> _
    Public Shared Sub UnregisterFunction(ByVal registerType As Type)
        ' Required for ArcGIS Component Category Registrar support
        ArcGISCategoryUnregistration(registerType)
    End Sub

#Region "ArcGIS Component Category Registrar generated code"
    Private Shared Sub ArcGISCategoryRegistration(ByVal registerType As
Type)
        Dim regKey As String =
String.Format("HKEY_CLASSES_ROOT\CLSID\{{{0}}}", registerType.GUID)
        MxCommands.Register(regKey)
    End Sub
    Private Shared Sub ArcGISCategoryUnregistration(ByVal registerType
As Type)
        Dim regKey As String =
String.Format("HKEY_CLASSES_ROOT\CLSID\{{{0}}}", registerType.GUID)
        MxCommands.Unregister(regKey)
    End Sub
```

```
#End Region
#End Region
    Private m_application As IApplication

    ' A creatable COM class must have a Public Sub New()
    ' with no parameters, otherwise, the class will not be
    ' registered in the COM registry and cannot be created
    ' via CreateObject.
    Public Sub New()
        MyBase.New()

        ' TODO: Define values for the public properties
        MyBase.m_category = "Developer Samples"  'localizable text
        MyBase.m_caption = "Zoom to Layer VB.net"   'localizable text
        MyBase.m_message = "Zoom to the extent of the active layer in
the TOC"   'localizable text
        MyBase.m_toolTip = "Zoom To Layer VB.NET" 'localizable text
        MyBase.m_name = "Developer Samples_Zoom To Layer VB.NET"
'unique id, non-localizable (e.g. "MyCategory_ArcMapCommand")

        Try
            'TODO: change bitmap name if necessary
            Dim bitmapResourceName As String = Me.GetType().Name +
"ZoomtoLayer.bmp"
            MyBase.m_bitmap = New Bitmap(Me.GetType(),
bitmapResourceName)
        Catch ex As Exception
            System.Diagnostics.Trace.WriteLine(ex.Message, "Invalid
Bitmap")
        End Try

    End Sub

    Public Overrides Sub OnCreate(ByVal hook As Object)
        If Not hook Is Nothing Then
            m_application = CType(hook, IApplication)

            'Disable if it is not ArcMap
            If TypeOf hook Is IMxApplication Then
                MyBase.m_enabled = True
            Else
                MyBase.m_enabled = False
            End If
        End If
    End Sub

    Public Overrides Sub OnClick()
    End Sub
    Public Overrides Sub OnClick()
        Dim mxDocument As IMxDocument = GetMxDocument(m_application)
        ZoomtoLayer(mxDocument)
    End Sub

#Region "Get MxApplication from ArcMap"
    ' ArcGIS Snippet Title:
```

```
    ' Get MxApplication from ArcMap
    '
    ' Add the following references to the project:
    ' ESRI.ArcGIS.ArcMapUI
    ' ESRI.ArcGIS.Framework
    ' ESRI.ArcGIS.System
    '
    ' Intended ArcGIS Products for this snippet:
    ' ArcGIS Desktop
    '
    ' Required ArcGIS Extensions:
    ' (NONE)
    '
    ' Notes:
    ' This snippet is intended to be inserted at the base level of a
Class.
    ' It is not intended to be nested within an existing Sub or
Function.
    '
    ' Use the following XML documentation comments to use this snippet:
    ''' <summary>Get MxApplication from ArcMap</summary>
    '''
    ''' <param name="application">An IApplication interface that is the
ArcMap application.</param>
    '''
    ''' <returns>An IMxApplication interface.</returns>
    '''
    ''' <remarks>The IMxApplication interface allows access the
AppDisplay object, the selection environment, and the default printer
page settings.</remarks>
    Public Function GetMap(ByVal application As
ESRI.ArcGIS.Framework.IApplication) As ESRI.ArcGIS.Carto.IMap

        If application Is Nothing Then
            Return Nothing
        End If

        Dim mxDocument As ESRI.ArcGIS.ArcMapUI.IMxDocument =
(CType(application.Document, ESRI.ArcGIS.ArcMapUI.IMxDocument)) '
Explicit Cast
        Dim activeView As ESRI.ArcGIS.Carto.IActiveView =
mxDocument.ActiveView
        Dim map As ESRI.ArcGIS.Carto.IMap = activeView.FocusMap

        Return map
    End Function
#End Region
End Class
```

APPENDIX F

SPILL SCENARIOS PLUME PLOTS

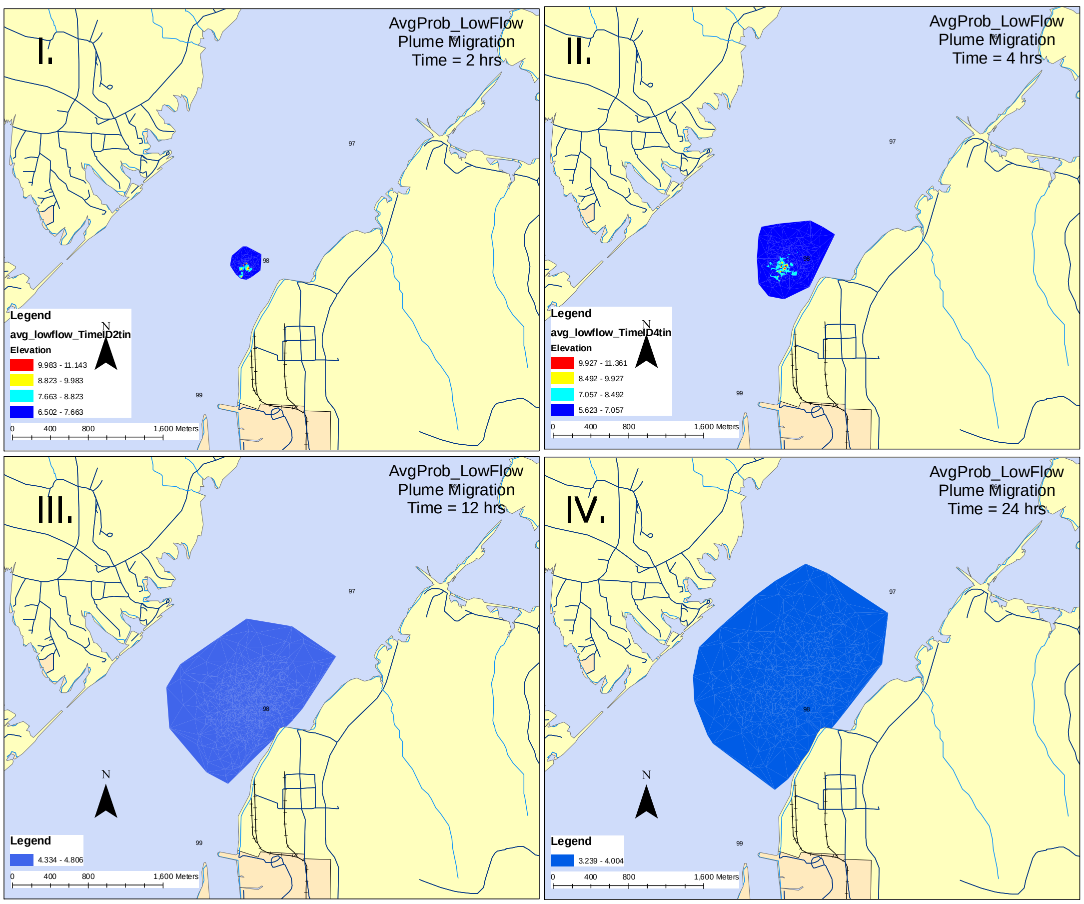


Figure A- 11: Average probable spill at low flow.

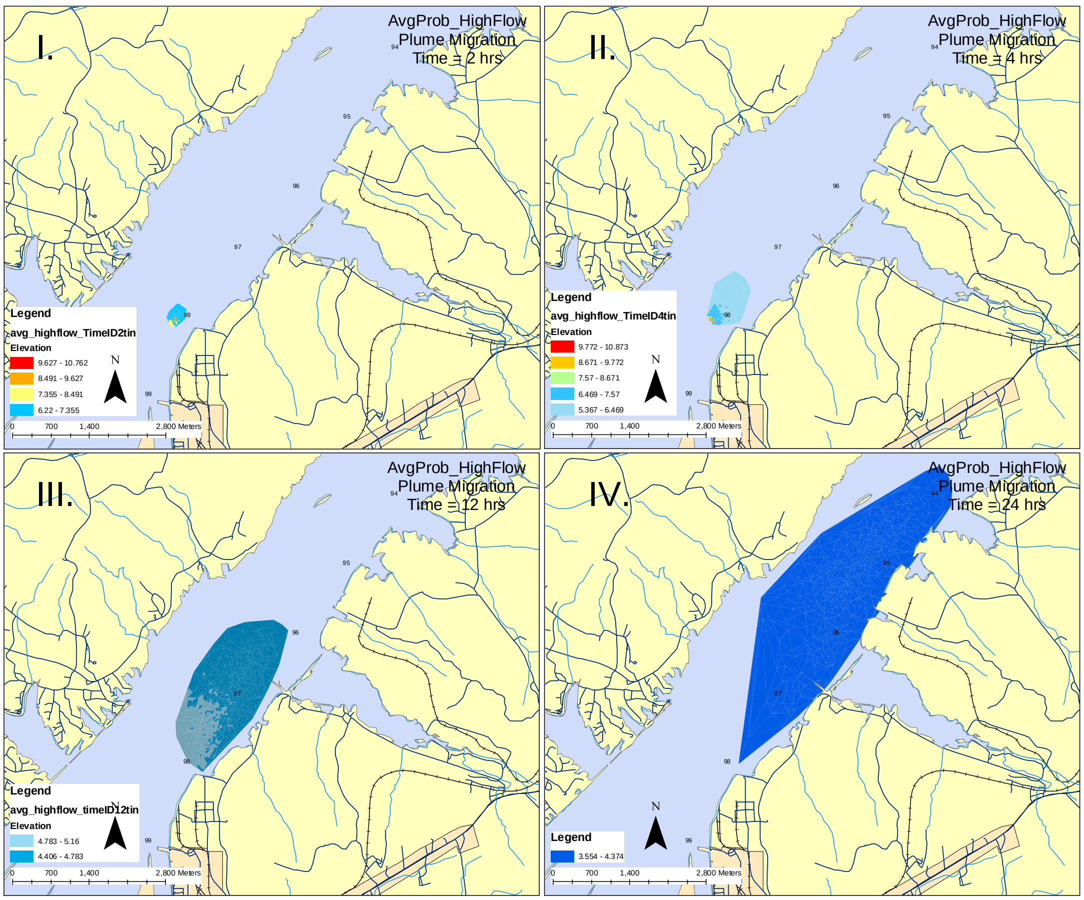


Figure A- 12: Average probable at high flow.

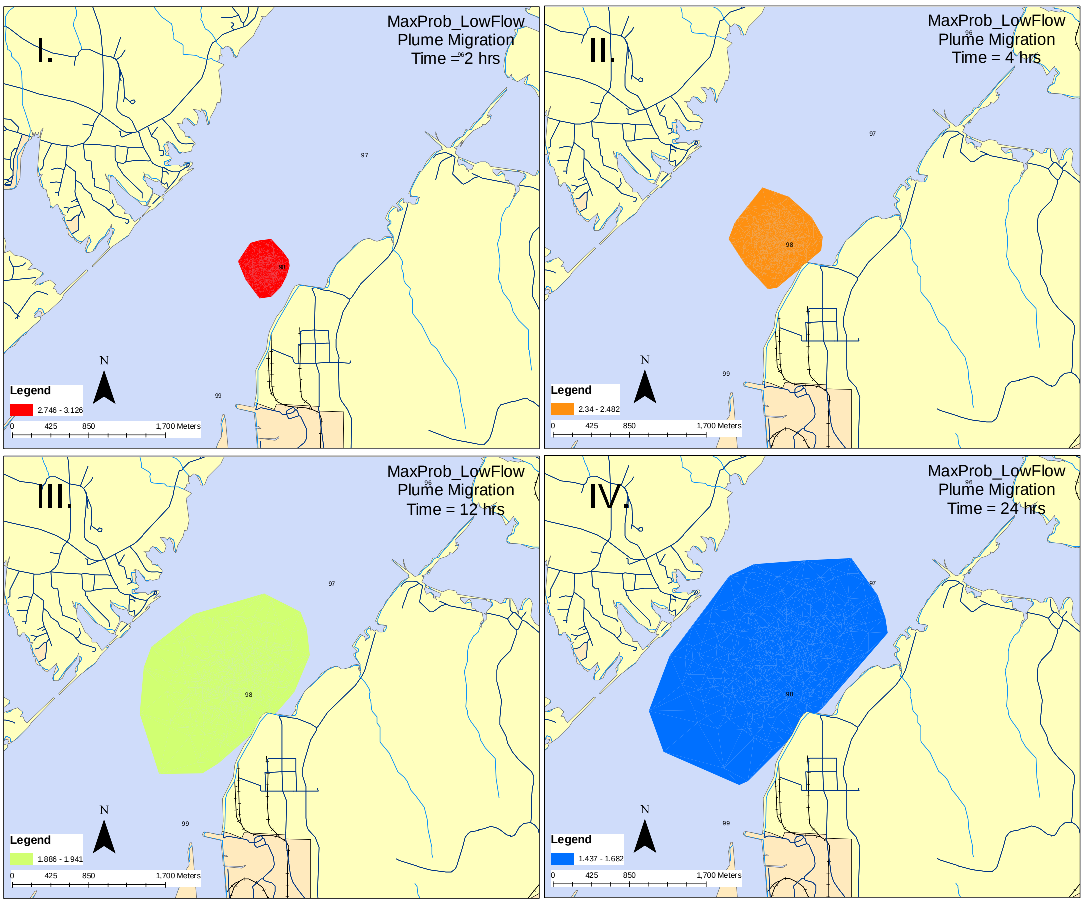


Figure A- 13: Maximum probable at low flow.

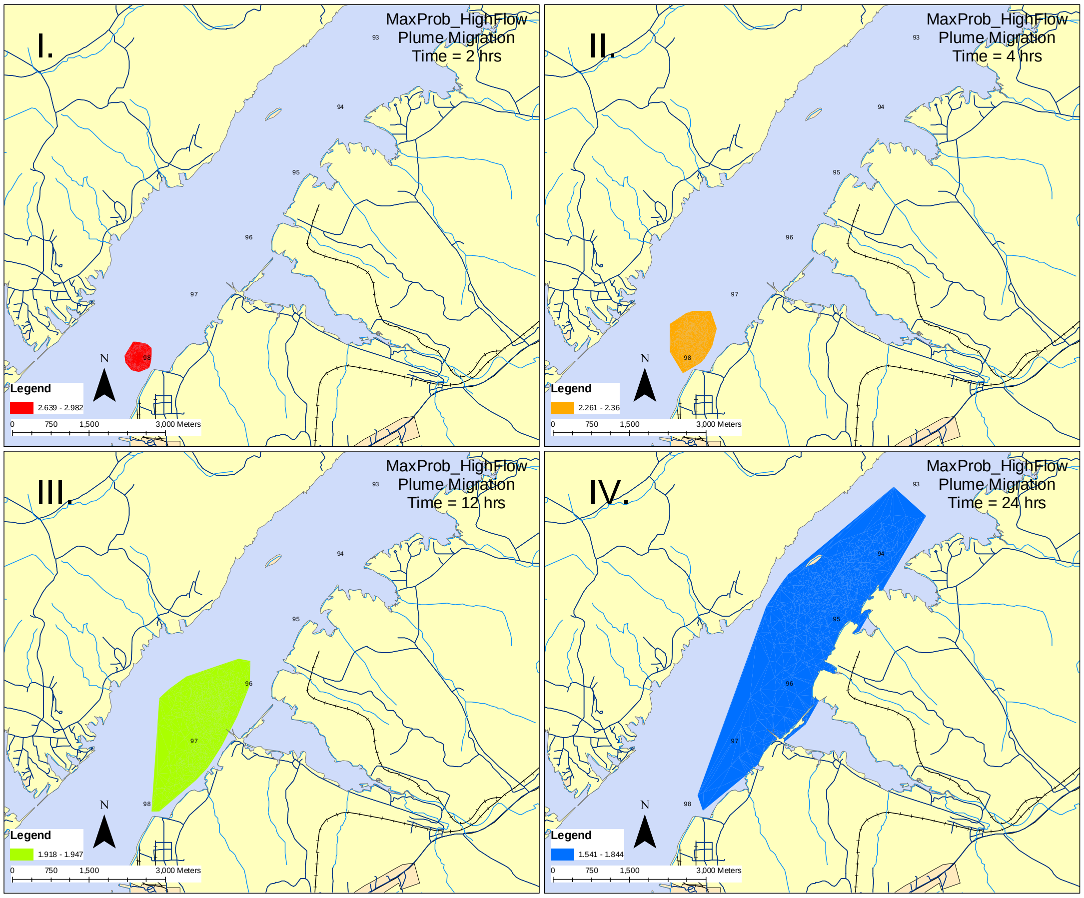


Figure A- 14: Maximum probable at high flow.

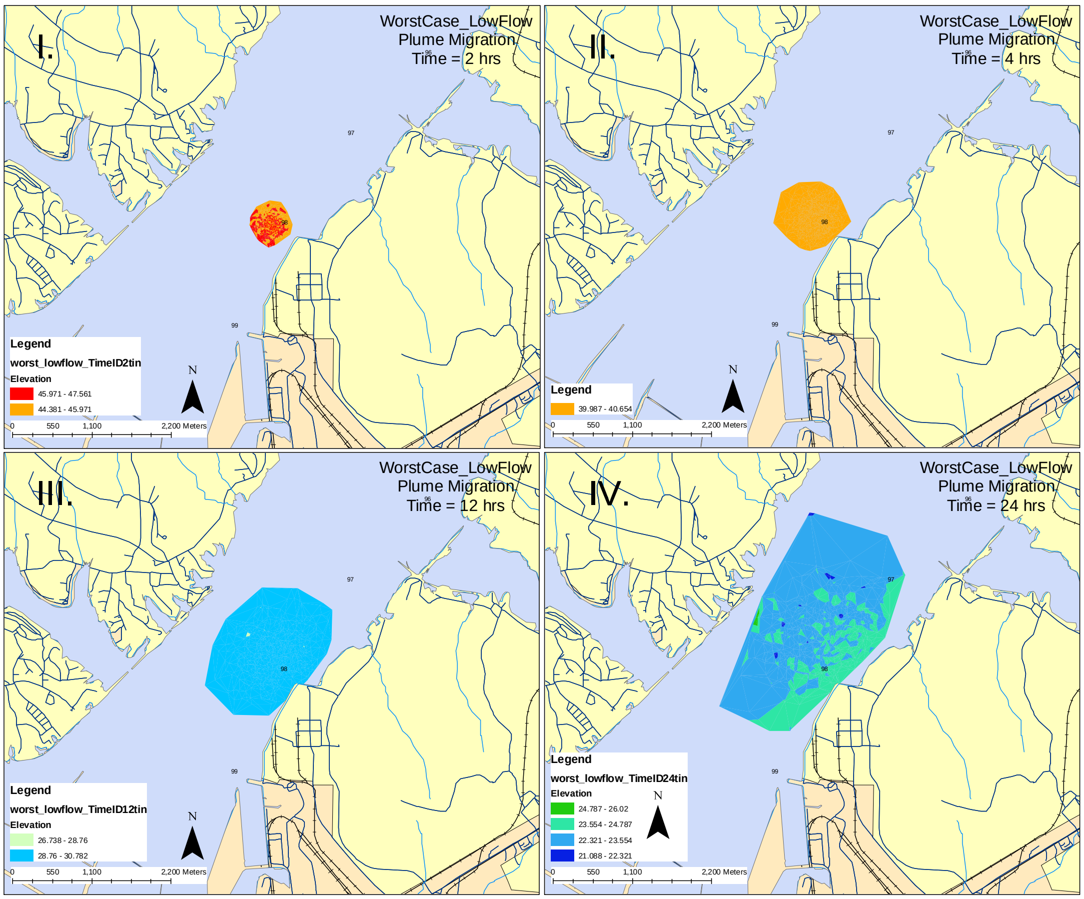


Figure A- 15: Worst case scenario at low flow.

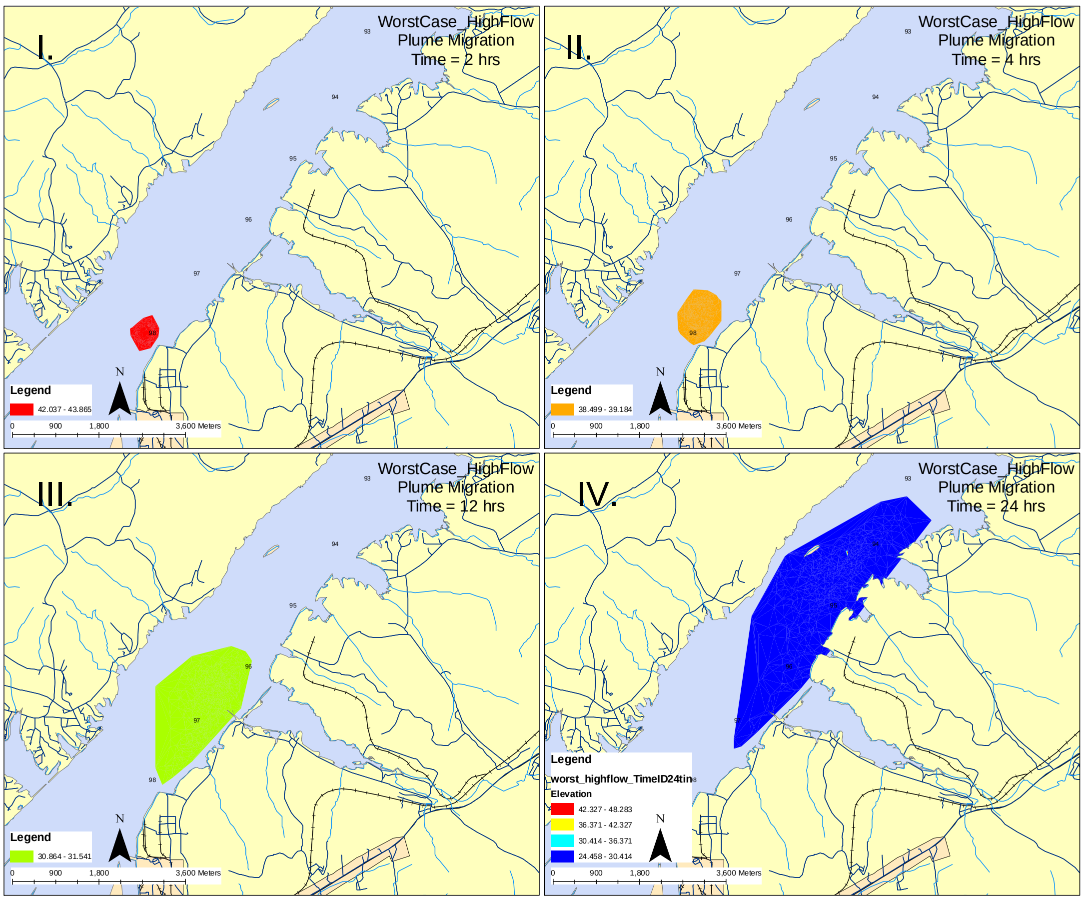


Figure A- 16: Worst case at high flow.

(TVA 2006)

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