U.S. Department of the Interior
U.S. Geological Survey

A Two-Dimensional Hydrodynamic Model of the St. Clair–Detroit River Waterway in the Great Lakes Basin

By DAVID J. HOLTSCHLAG, and
JOHN A. KOSCHIK, Detroit District, U.S. Army Corps of Engineers

Water-Resources Investigations Report 01-4236

Prepared in cooperation with the
MICHIGAN DEPARTMENT OF ENVIRONMENTAL QUALITY,
SOURCE WATER ASSESSMENT PROGRAM AND
DETROIT WATER AND SEWERAGE DEPARTMENT

Lansing, Michigan
2002

U.S. DEPARTMENT OF THE INTERIOR
GALE A. NORTON, Secretary

U.S. GEOLOGICAL SURVEY
Charles G. Groat, Director

For additional information write:

District Chief
U.S. Geological Survey
6520 Mercantile Way, Suite 5
Lansing, MI 48911-5991

Copies of this report can be purchased from:

U.S. Geological Survey
Branch of Information Services
Box 25286
Denver, CO 80225-0286

CONTENTS

FIGURES

TABLES

CONVERSION FACTORS, ABBREVIATIONS, AND VERTICAL DATUM

CONVERSION FACTORS

Multiply	By	To obtain
acre (ac)	0.4047	hectare
cubic foot per second (ft^3/s)	0.02832	cubic meter per second
gallon (gal)	3.785	liter
inches (in.)	25.4	millimeters
International foot (ft)	0.3048 (exactly)	meters
mile (mi)	1.609	kilometer
square mile (mi^2)	2.590	square kilometer

Temperature in degrees Celsius (˚C) can be converted to degrees Fahrenheit (˚F) by the following equation:

$$^\circ C = (^\circ F-32)/1.8$$

VERTICAL DATUM

The vertical datum currently used throughout the Great Lakes is the International Great Lakes Datum of 1985 (IGLD 1985), although references to the earlier datum of 1955 are still common. This datum is a dynamic height system for measuring elevation, which varies with the local gravitational force, rather than an orthometric system, which provides an absolute distance above a fixed point. The primary reason for adopting a dynamic height system within the Great Lakes is to provide an accurate measurement of potential hydraulic head. The reference zero for IGLD (1985) is a tide gage at Rimouski, Quebec, which is located near the outlet of the Great Lakes–St. Lawrence River system. The mean water level at the Rimouski, Quebec, gage approximates mean sea level.

A Two-Dimensional Hydrodynamic Model of the St. Clair–Detroit River Waterway in the Great Lakes Basin

By David J. Holtschlag, *and* John A. Koschik,
Detroit District, U.S. Army Corps of Engineers

Abstract

The St. Clair–Detroit River Waterway connects Lake Huron with Lake Erie in the Great Lakes basin to form part of the international boundary between the United States and Canada. A two-dimensional hydrodynamic model is developed to compute flow velocities and water levels as part of a source-water assessment of public water intakes. The model, which uses the generalized finite-element code RMA2, discretizes the waterway into a mesh formed by 13,783 quadratic elements defined by 42,936 nodes. Seven steady-state scenarios are used to calibrate the model by adjusting parameters associated with channel roughness in 25 material zones in sub-areas of the waterway. An inverse modeling code is used to systematically adjust model parameters and to determine their associated uncertainty by use of nonlinear regression. Calibration results show close agreement between simulated and expected flows in major channels and water levels at gaging stations. Sensitivity analyses describe the amount of information available to estimate individual model parameters, and quantify the utility of flow measurements at selected cross sections and water-level measurements at gaging stations. Further data collection, model calibration analysis, and grid refinements are planned to assess and enhance two-dimensional flow simulation capabilities describing the horizontal flow distributions in St. Clair and Detroit Rivers and circulation patterns in Lake St. Clair.

INTRODUCTION

The Michigan Department of Environmental Quality (MDEQ) Source Water Assessment Program (SWAP), with the cooperation of the Detroit Water and Sewerage Department (DWSD) is assessing the vulnerability of public water intakes to contamination on the St. Clair–Detroit River Waterway. Public intakes on the waterway provide water to about 4.5 million people in the Detroit, Michigan area, as well as about 2 million others in Michigan and Canada. As part of this assessment, the U.S. Geological Survey (USGS) and the Detroit District of the U.S. Army Corps of Engineers (USACE) are developing a two-dimensional hydrodynamic model of the waterway.

This report facilitates the implementation of the SWAP by documenting the initial implementation and calibration of a hydrodynamic model, which provides a generalized description of advective movement in the waterway. Model hydrodynamics will be combined with field characterizations of stochastic dispersion characteristics, which are to be determined from drifting buoy studies (Holtschlag and Aichele, 2001), to implement a particle-tracking analysis. Particle-tracking analysis is a computer simulation technique that represents the movement of hypothetical particles in the water. Particle-tracking simulations running forward in time will be used to identify areas likely to be impacted by downstream movement of constituents from point sources; simulations running backward in time will be used to identify areas likely to be contributing to public water intakes or other areas of concern.

Location of Study Area

St. Clair River, Lake St. Clair, and Detroit River form a waterway that is part of the international boundary between the United States and Canada (fig. 1). The waterway, which connects Lake Huron with Lake Erie, is a major navigational and recreational resource of the Great Lakes basin. St. Clair River (the upper connecting channel) extends about 39 mi from its headwaters at the outlet of Lake Huron near Port Huron, Michigan, to an extensive delta area. Throughout its length, water levels (water-surface elevations) decrease about 5 ft as the river discharges an average of 183,000 ft^3/s from a drainage area of about 222,400 mi^2. Local tributaries to St. Clair River include Black River at Port Huron, Michigan, Pine River at St. Clair, Michigan, and Belle River at Marine City, Michigan. Lake St. Clair receives water from St. Clair River, and lesser amounts from Clinton River in Michigan and the Thames and Sydenham Rivers in Ontario, Canada. Along the 25-ft deep navigational channel, the lake has a length of 35 mi. The lake's round shape, with a surface area of 430 mi^2, and shallow depths that average about 11 ft, make it equally susceptible to winds from all directions. Detroit River (the lower connecting channel) receives water from Lake St. Clair and lesser amounts from River Rouge in Michigan, where it flows 32 mi to Lake Erie. Water levels fall about 3 ft within Detroit River, which has an average flow of about 187,000 ft^3/s.

Purpose and Scope

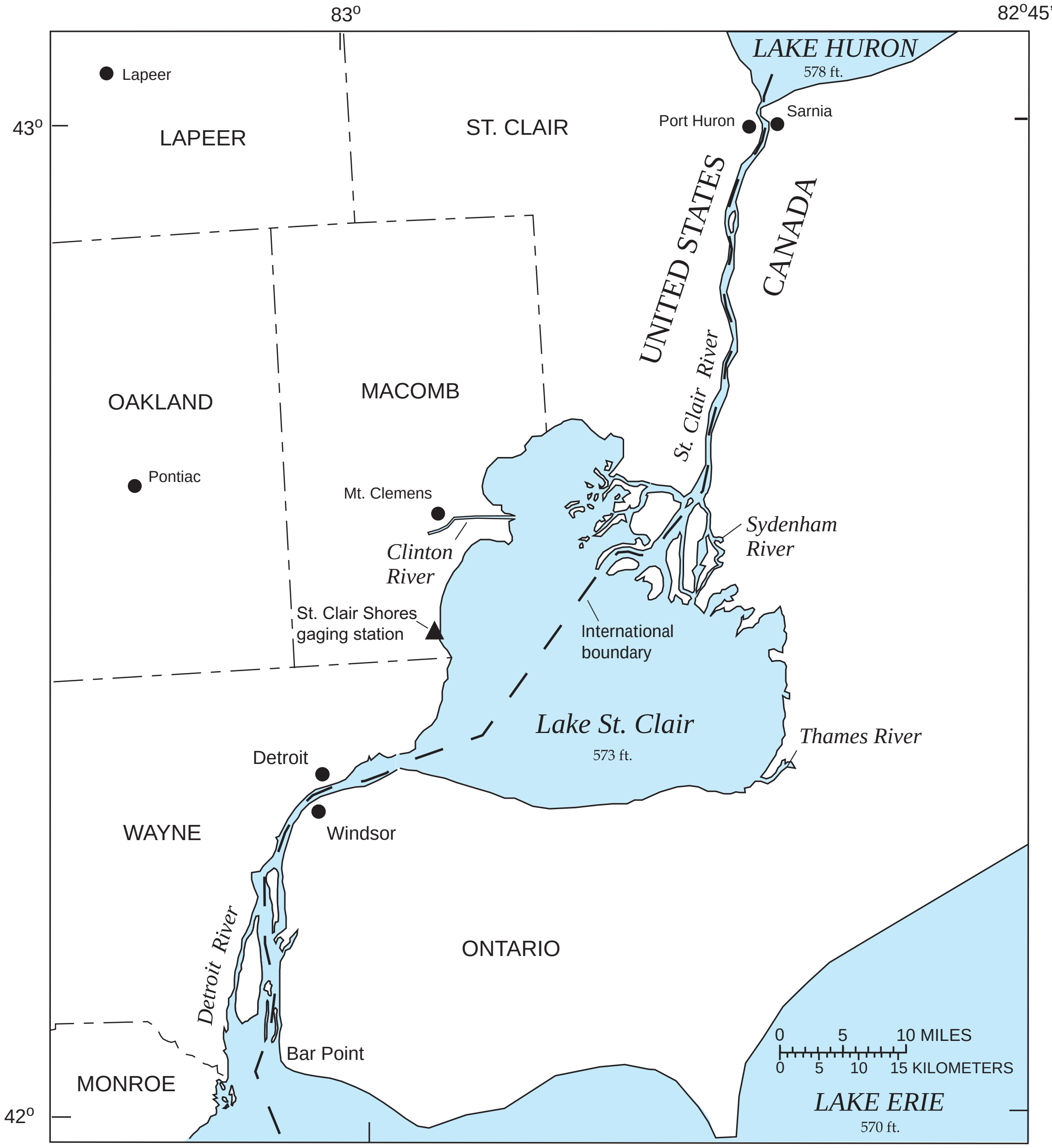
As part of the Source Water Assessment Program (SWAP) of the Michigan Department of Environmental Quality (MDEQ), this report documents the initial implementation and calibration of a two-dimensional hydrodynamic model of the St. Clair–Detroit River Waterway. The model extends from a National Oceanic and Atmospheric Administration (NOAA) gaging station at Fort Gratiot near Port Huron, Michigan, at the headwaters of St. Clair River on Lake Huron, to a Canadian Hydrographic Service (CHS) gage at Bar Point, Ontario, at the mouth of Detroit River on Lake Erie.

In this report, model implementation and calibration efforts have focused on reproducing flows (total discharges) in major branches formed by numerous islands and dikes in the waterway and by matching water levels near gaging stations. Additional field data collection, analysis, and model calibration are required to assess and enhance the model's ability to reproduce horizontal velocity distributions within channels of the St. Clair and Detroit Rivers and circulation patterns in Lake St. Clair.

The model developed in this report is based on a two-dimensional approximation to a flow system that may exhibit three-dimensional flow characteristics, particularly near abrupt changes in flow direction or depth. Further, the model is intended for applications involving the far field problem in which vertical accelerations are negligible and velocity vectors generally point in the same direction over the entire depth of the water column at any instant of time. The model assumes a homogeneous fluid with a free surface. Thus, simulations during periods of temperature stratification or ice cover would be of uncertain reliability. The Coriolis force, an inertial force caused by the earth's rotation, was not included in model computations at this stage in model implementation.

Previous Studies

The U.S. Army Corps of Engineers (USACE) Waterway Experiment Station (WES) in Vicksburg, Mississippi, developed a prototype two-dimensional model of the St. Clair–Detroit River Waterway for the Detroit District USACE (Ron Heath, USACE-WES, written commun., 1999). The resulting model was modified and adapted for use in a joint study by Environment Canada and the Detroit District USACE, to assess the effects of encroachments on water levels in St. Clair and Detroit Rivers (Aaron Thompson, Environment Canada, written commun., July 2000). Tsanis, Shen, and Venkatesh (1996) implemented RMA2 on St. Clair and Detroit Rivers; results indicated that simulated currents closely matched field measurements of drifting buoys. Williamson, Scott, and Lord (1997) developed a two-dimensional finite-element model of the St. Clair–Detroit River system for the Canadian Coast Guard for water-level prediction and assessment of structures in the river systems. Schwab and others (1989) compared currents measured on Lake St. Clair with particle tracking results computed based on two-dimensional hydrodynamic model simulations.



Base from U.S. Geological Survey 1:500,000 map, 1970.

EXPLANATION

- INTERNATIONAL BOUNDARY
- U.S. COUNTY BOUNDARY
- CITY CENTER
- GAGING STATION

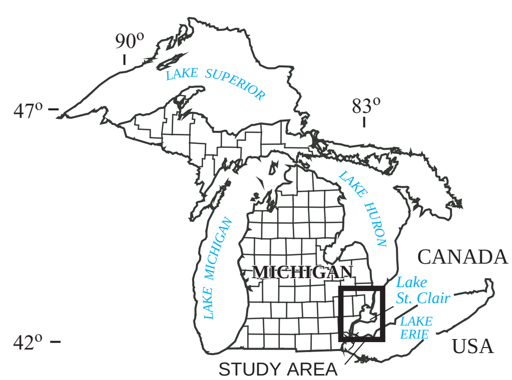


Figure 1. St. Clair–Detroit River study area.

Acknowledgments

A binational technical workgroup provided suggestions, recommendations, and data that facilitated model implementation. Workgroup members and associates included Bradley Brogren, Michigan Department of Environmental Quality, Source Water Assessment Program; Gang Song, Detroit Water and Sewerage Department; Syed Moin, Aaron Thompson, and Ralph Moulton of Environment Canada, Canada Centre for Inland Waters; Jeffrey Oyler, National Oceanic and Atmospheric Administration, National Ocean Service; Ronald Solvason, Canadian Hydrographic Service; Saad Jasim, Windsor Utilities Commission; and Stanley Reitsma, Great Lakes Institute for Environmental Research, University of Windsor. Eileen Poeter, Colorado School of Mines, Department of Geology and Geological Engineering, provided generous technical assistance with the implementation of UCODE (Poeter and Hill, 1998). Brian Link and Lisa Taylor of NOAA provided bathymetry data for the model.

IMPLEMENTATION OF THE HYDRODYNAMIC MODEL

In this report, implementation of the hydrodynamic model refers to the process of creating input files that describe the geometry, bathymetry, hydraulic characteristic, and boundary conditions of the St. Clair–Detroit River Waterway for simulation by use of the generalized hydrodynamic model RMA2. This process includes: (1) delineation of the St. Clair–Detroit River Waterway and discretization into finite elements, (2) specification of type and location of boundary conditions needed to simulate flow, (3) initial grouping of elements into material zones thought likely to have similar hydraulic properties, (4) estimation of channel and lake bottom elevations from scattered bathymetry data, and (5) editing and manipulation of the mesh to ensure an efficient and accurate simulation.

RMA2 Code

RMA2 (Donnell and others, 2000) is a generalized computer code for two-dimensional hydrodynamic simulation. It computes depth-averaged horizontal velocity components and water levels for subcritical, free-surface flow. RMA2 implements a finite-element solution of the Reynolds form of the Navier-Stokes equation for turbulent flows. Friction is calculated with the Manning's equation, and eddy viscosity parameters are used to control numerical stability and describe energy losses associated with viscosity and turbulence. U.S. Army Corps of Engineers (USACE) Waterway Experiment Station (WES) maintains RMA2 in the public domain. A compiled version of RMA2 version 4.35 (Donnell and others, 1997) that was dimensioned for a maximum of 165,000 nodes and 55,000 elements was used in the implementation of the model to accommodate 84 continuity check lines used to sum simulated flow at selected locations.

Applications and Capabilities

RMA2 is a general-purpose code designed to solve the far-field problem in which vertical accelerations are negligible and velocity vectors have similar magnitude and direction throughout the depth of the water column at any instant of time. RMA2 is widely used (Soong and Bhowmik, 1993; Hauck, 1992; and Deering, 1990) for two-dimensional steady state and transient simulations of flows and water levels around islands in rivers, reservoirs, and estuaries. The model assumes a vertically homogeneous fluid and no stratification.

Equations Governing Two-Dimensional Surface-Water Flow

Form of the Equations

RMA2 solves the depth-integrated equations of fluid mass and momentum conservation in two horizontal directions (Donnell and others, 2000, p. 3). The continuous forms of these equations are:

$$h\frac{\partial u}{\partial t}+h\cdot u\frac{\partial u}{\partial x}+h\cdot v\frac{\partial u}{\partial y}-\frac{h}{\rho}\left(E_{xx}\frac{\partial^2 u}{\partial x^2}+E_{xy}\frac{\partial^2 u}{\partial y^2}\right)$$
$$+g\cdot h\left(\frac{\partial a}{\partial x}+\frac{\partial h}{\partial x}\right)+\frac{g\cdot u\cdot n^2}{\left(1.486\cdot h^{1/6}\right)^2}\left(u^2+v^2\right)^{1/2} \quad (1)$$
$$-\zeta\cdot V_a^2\cdot\cos\Psi-2h\cdot v\cdot\omega\cdot\sin\Phi=0,$$

$$h\frac{\partial v}{\partial t}+h\cdot u\frac{\partial v}{\partial x}+h\cdot v\frac{\partial v}{\partial y}-\frac{h}{\rho}\left(E_{yx}\frac{\partial^2 v}{\partial x^2}+E_{yy}\frac{\partial^2 v}{\partial y^2}\right)$$
$$+g\cdot h\left(\frac{\partial a}{\partial y}+\frac{\partial h}{\partial y}\right)+\frac{g\cdot v\cdot n^2}{\left(1.486\cdot h^{1/6}\right)^2}\left(u^2+v^2\right)^{1/2}$$
$$-\zeta\cdot V_a^2\cdot\sin\Psi+2h\cdot\omega\cdot u\cdot\sin\Phi=0, \quad (2)$$

$$\frac{\partial h}{\partial t}+h\left(\frac{\partial u}{\partial x}+\frac{\partial v}{\partial y}\right)+u\frac{\partial h}{\partial x}+v\frac{\partial h}{\partial y}=0, \quad (3)$$

where

h	=	depth,
u,v	=	velocities in the Cartesian directions,
x,y,t	=	Cartesian coordinates and time,
ρ	=	density of fluid,
$E_{..}$	=	eddy viscosity parameter, for *xx* = normal direction on x axis surface, for *yy* = normal direction on y axis surface, for *xy* and *yx* = shear direction on each surface,
g	=	acceleration due to gravity,
a	=	elevation of channel or lakebed bottom,
n	=	Manning's *n* parameter quantifying roughness characteristics,
1.486	=	conversion from SI (metric) to English units,
ζ	=	empirical wind shear coefficient,
V_a	=	wind speed,
Ψ	=	wind direction,
ω	=	rate of earth's angular rotation, and
ϕ	=	local latitude.

Discretization and Solution of the Equations

In this report, the St. Clair–Detroit River Waterway is discretized into a set of piecewise continuous functions described by finite elements. This discretization is used to approximate the continuous variation of flow velocities and water levels described by the governing equations. The two-dimensional elements used exclusively in the model are either triangular or quadrilateral elements defined by three or four corner nodes, respectively. In addition to corner nodes, all elements contain midside nodes to improve the ability to model curved boundaries. With the addition of midside nodes, quadratic interpolation of flow velocities throughout the element also is possible.

Equations (1), (2), and (3) are solved by the finite element method using the Galerkin method of weighted residuals (Donnell and others, 2000, p. 4). Shape functions, used for interpolation of flow velocities and water depths computed at the nodes to other areas in the element, are quadratic for velocity and linear for depth. Integration in space is performed by Gaussian integration. Derivatives in time are approximated by nonlinear finite differences. Flows and water levels are assumed to vary over each time interval in the form:

$$f(t)=f(0)+A\cdot t+B\cdot t^C \qquad t_0\le t<t_0+\Delta t \quad (4)$$

which is differentiated with respect to time, and cast in finite difference form. Letters *A*, *B*, and *C* are constants.

The solution is fully implicit and the set of simultaneous equations is solved by Newton-Raphson nonlinear iteration (Donnell and others, 2000, p. 4). Generally, less than eight iterations are required to obtain a valid solution, depending upon the difference between the initial conditions and the final solution, and the specified convergence criteria. The computer code executes the solution by means of a front-type solver, which assembles a portion of the matrix and solves it before assembling the next portion of the matrix.

Surface-Water Modeling System

The Surface-Water Modeling System (SMS) is computer program for pre- and post-processing of selected surface-water models, including RMA2 (Environmental Modeling Research Laboratory, 1999).

SMS has three primary modules needed to develop a hydrodynamic model for simulation with RMA2. These include the Map Module, the Mesh Module, and the Scatter Point Module. The modules were used in turn to develop a geometry file describing the location of nodes that define the size and shape of finite elements and the hydraulic properties of elements needed for flow computations.

Conceptual Model as a Feature Map

The conceptual model of flow in the waterway synthesizes available geographic and hydraulic data into a form that is suitable to model building. Principally, the conceptual model describes the geometry of the waterway and the boundaries of the flow-system. The conceptual model was developed within the Map Module of the SMS by use of feature objects. The feature map describing the conceptual model was used to generate the finite element mesh of the numerical model needed for flow computations.

Geographic Data

The geometry of the waterway was delineated based on the channel configurations shown on recreational charts of Detroit River, Lake St. Clair, and St. Clair River (National Oceanic and Atmospheric Administration, 1999). Shoreline information on the charts was integrated into the conceptual model by scanning portions of the charts to create electronic image files. These images files, in Tagged Image File Format (TIFF), were geographically referenced to the southern zone (2113) of the Michigan State Plane Coordinate System, North American Datum of 1983 (MSPCS 83) by use of latitude and longitude tick marks shown on the charts. The TIFF files provided a background upon which feature objects were digitized to represent the channel and shoreline within the Map Module.

Feature objects include nodes, vertices, arcs, and polygons. A feature arc is a line segment formed by end points referred to as feature nodes and intermediate points called feature vertices. Generally, two longitudinal arcs of approximately equal lengths were used to describe opposite sides of the shoreline. After initial positioning needed to delineate the shoreline meanders, the features vertices were automatically redistributed to improve the uniformity of spacing and to provide a nearly equal number of vertices on either side of the reach. Upper and lower limits of the reach were designated by defining transverse arcs that connected the upstream and downstream nodes of the longitudinal arcs. Feature vertices were automatically distributed across the transverse arcs. Generally, the distances between vertices in the transverse arcs were spaced at about one half the distances of vertices along the longitudinal arcs to provide detail in describing the variability of cross channel velocities. For uniform reaches, the number of vertices at either end of the reach was the same unless changes were needed to accommodate an island or tributary. The arcs describing the reaches were joined to form feature polygons, defined along the perimeter by the locations of feature nodes and vertices.

Polygons were assigned a mesh generation method and hydraulic properties. Together with the distribution of feature nodes and vertices, the mesh generation method controls the initial placement of nodes that delineate finite elements inside the polygons. Different meshing methods produce different types of elements and different arrangements of nodes. In this report, the two mesh generation methods used were the coons patch and adaptive tessellation.

A coons patch requires that the surrounding polygon contain either three or four arcs, and was the method commonly applied to triangular and quadrilateral polygons defining the connecting channels. A coons patch produces a highly regular mesh pattern that initially contains either triangular or quadrilateral elements. In contrast, adaptive tessellation is applicable to a polygon that contains any number of arcs and is thus adaptable to irregularly shaped polygons, like those defining Lake St. Clair. Tessellation initially forms a dense mesh of triangular elements. Many of the triangular elements are automatically combined to form quadrilateral elements, which provide a more concise mesh, and provides for faster solutions and greater numerically stability. The mesh resulting from adaptive tessellation contains a mixture of triangular and quadratic elements that has a less regular appearance than elements in a coons patch.

All polygons were assigned an initial value 0.027 for Manning’s *n*, a hydraulic parameter that describes channel roughness in equations (1) and (2). The initial value was selected because it was thought to be within the plausible range of likely Manning’s *n* values. Higher *n* values indicate greater friction losses and result in reduced flow or higher water levels within a particular channel of the waterway. This value was modified during the calibration phase to improve the match between expected and simulated flows and water levels.

In addition to channel roughness, each polygon was initially assigned a starting value for eddy viscosity, E in equations (1) and (2). Eddy viscosity controls both the stability of the numerical solution and the distribution of velocities across the channel. In particular, the Galerkin method of weighted residuals used by RMA2 uses the eddy viscosity terms to stabilize the numerical solution (Donnell and others, 2000, p. 46). Values of eddy viscosity that are too small allow changes in the direction of velocity vectors that are too great for the numerical solution to converge. Thus, a minimum value of eddy viscosity is required to achieve numerical stability. Lower values of eddy viscosity allow greater variability in the velocity distribution within the waterway.

In this report, eddy viscosity is assumed to be isotropic, that is $E_{xx} = E_{xy} = E_{yx} = E_{yy}$ in equations (1) and (2). Further, simulations were started with eddy viscosities that were initially assigned based on polygon (material type). After these simulations had converged, eddy viscosities were reassigned based on the assigned Peclet number, P. The Peclet number dynamically adjusts the value of E after each model iteration based on the computed velocity, size, and fluid density of each element. In particular,

$$E = \frac{\rho \cdot u \cdot dx}{P} \tag{5}$$

where

ρ = fluid density,
u = average elemental velocity,
dx = length of element in streamwise direction, and
E = eddy viscosity.

Boundary Conditions

Boundary conditions (BC) describe hydraulic conditions, such as flows and water levels, at the limits of the model area, which are constant for steady-state simulations and vary with time for transient simulations. Boundary conditions are needed to eliminate the constants of integration that arise when numerically integrating the governing equations to solve for u, v, and h (Equation 1–3) in the interior of the solution domain (Donnell and others, 2000, p. 38). In this report, flow boundaries were used to describe conditions at the headwaters of St. Clair River near the gaging station at Fort Gratiot (NOAA station number 9014098), at selected intervening tributaries, including Black River, Pine River, Belle River, Clinton River, Sydenham River, Thames River, and River Rouge, and for the net inflow over Lake St. Clair (fig. 2). A water-level boundary was used to describe the hydraulic condition at the mouth of Detroit River near Bar Point, Ontario, where the Canadian Hydrographic Service operates a gaging station. Boundary condition locations were defined as an attribute of a feature arc. All flow boundaries conditions specified that the flow direction at the boundary was perpendicular to the corresponding feature arc.

Geometry, Continuity-Check Lines

According to Donnell and others (2000, p. 54), RMA2 globally maintains mass (flow) conservation in a weighted residual manner. Locally, Geometry, Continuity-Check Lines (GCLs) can be used to check for apparent mass changes by a different method using direct integration. Large discrepancies, greater than 3 percent, between the results of these two methods indicate probable oscillations in the numerical solution and a need to correct large boundary break angles, and (or) a need to improve model resolution. Large mass conservation discrepancies can lead to difficulty when the hydrodynamics are used for transport models.

GCLs were used to integrate simulated velocities in order to compute flow at selected cross sections. These simulated flows were compared with expected flows to aid model calibration. To minimize the discrepancy between inflows specified at the boundaries and flows simulated at the GCLs, the GCLs were oriented as nearly perpendicular to flow as possible, the utility SLOPEFIX was applied to curve the land and water interface, GCLs were extended across the waterway from land to land, and the water-level convergence criterion was set to low value (0.0001 ft).

Material Zones

Material zones define sub-areas of the waterway with constant Manning’s n values and Peclet numbers. Material zones were formed by grouping contiguous polygons within a branch or reach of the waterway. In some reaches, for example, two material zones were

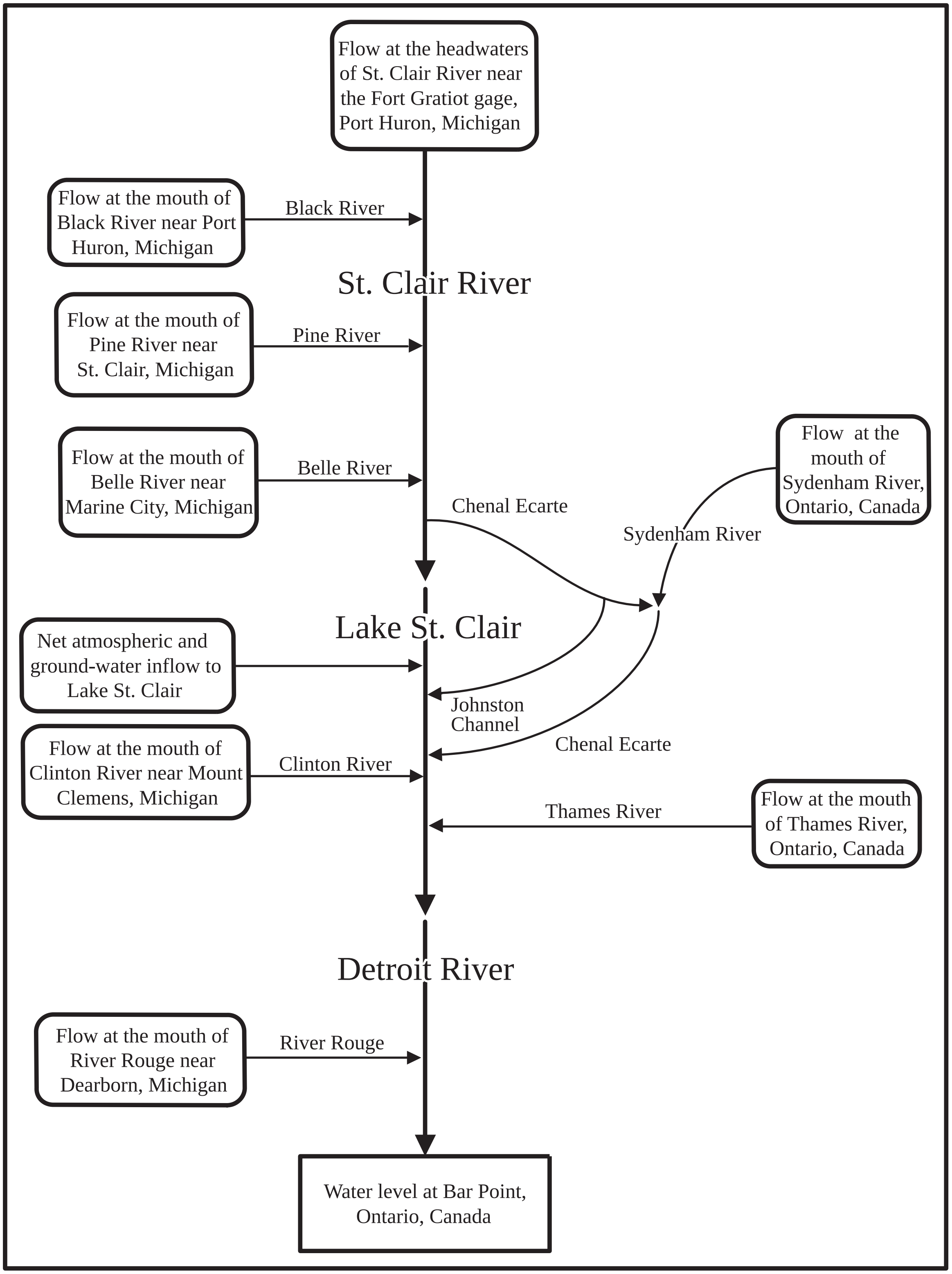


Figure 2. Boundary conditions for the St. Clair–Detroit River Waterway.

designated for the two branches formed on either side of an island. This configuration allowed the estimation of parameters describing the effective Manning's *n* values on both branches, based on available flow information for each branch. In reaches without islands, material zones joined polygons between gaging stations, so that water-level data could be used to determine the effective Manning's *n* values. In all cases, the effective Manning's *n* values estimated for a material zone reflected both the hydraulic roughness of the channel, and small discrepancies between model and waterway geometry and bathymetry.

Numerical Model as Finite-Element Mesh

Once all the polygons in the model area were delineated, meshing techniques specified, boundary conditions described, and material zone assignments made, the feature map was converted to a finite element mesh. Conversion of the conceptual model created a finite element mesh with 42,936 nodes forming 1,773 triangular elements and 12,010 quadrilateral elements. The average size of an element was 0.035 mi^2 (22.4 ac); elements ranged in size from 0.000728 mi^2 (0.466 ac) to 0.241 mi^2 (154 ac). Bathymetry data were used to estimate channel and lakebed elevations at nodes. Finally, the mesh was edited to enhance numerical stability and efficiency, in preparation for model calibration.

Bathymetry Data

Bathymetry data were obtained from three sources. Bathymetry data for St. Clair and Detroit Rivers were obtained primarily from a bathymetry survey by NOAA in 2000 (Brian Link, NOAA, Great Lakes Environmental Research Laboratory, written commun., 2000). In this survey, data were generally obtained as transects separated by about 328 ft (100 m). The data included about 20,900 soundings of St. Clair River and 22,700 soundings of Detroit River. NOAA provided a preliminary conversion of depths to elevations (referenced to IGLD 1985) by analyzing water levels at gaging stations during the time of the survey. Horizontal coordinates of the soundings were converted from UTM (Universal Transverse Mercator) Zone 17 meters to MSCPS 83 (Zone 2113) International feet by use of the computer program Corpscon (U.S. Army Corps of Engineers, 2000).

Bathymetry data for Lake St. Clair were obtained from a compilation of bathymetry surveys conducted by the USACE, NOAA National Ocean Service (NOS), and the Canadian Hydrographic Service (CHS) (Lisa Taylor, NOAA, written commun., 1999). Data from these surveys include about 119,000 soundings of Lake St. Clair and distributaries in the St. Clair Delta. Data from the NOAA 2000 survey were used in areas of the St. Clair Delta where data from the NOAA 2000 survey and earlier surveys of Lake St. Clair overlapped. Finally, about 200 supplementary bathymetry data points were obtained by use of depth information shown on NOAA recreational charts for localized areas where other survey information was sparse.

In all, about 134,000 bathymetry soundings were used to describe the bathymetry of the St. Clair–Detroit River Waterway. Linear interpolation was used to compute channel elevations at nodes based on the scattered bathymetry soundings. In linear interpolation, the soundings are first triangulated to form a temporary triangular network. Then, nodes are located in the triangular network and elevations at nodes are interpolated from soundings forming the vertices of the surrounding triangle (Environmental Modeling Research Laboratory, 1999, p. 13-6).

Editing the Finite-Element Mesh

The geometry of the finite-element mesh determines the accuracy and stability of RMA2 simulations. Elements that were automatically generated from the feature map did not always have geometric properties that satisfied critical mesh-quality criteria. These criteria include: (1) a minimum interior angle greater than 20 degrees, (2) concave quadrilaterals, (3) changes in adjacent element areas that are less than 50 percent, (4) eight or fewer connecting elements, and a maximum interior angle 130 degrees. Tools provided in the SMS environment were used to identify and correct these deficiencies.

In some model areas, modifications to the feature map were used to regenerate a mesh that met the critical mesh-quality criteria. In other areas, mesh-editing tools within the Mesh Module of SMS were used to manually correct deficiencies. Mesh editing tools include moving nodes, splitting quadrangles, swapping diagonal components of split quadrangles, and merging triangular elements. When editing was completed, all mesh quality criteria were satisfied, except those relating to bathymetry. To conform to the data from the bathymetry surveys, node elevations did not always produce elements that satisfied the mesh-quality criteria of ambiguous gradient and maximum slope. Because of the flow depths generally involved and the boundary conditions specified, these deficiencies are not expected to degrade the accuracy or stability of RMA2 simulations.

Curving Element Edges

Prior to release 4.2 of RMA2, mass (flow) losses could occur at irregular boundaries of the finite element mesh. Although curving (isoperimetric) external boundaries are no longer needed to prevent this loss, they may be used to improve mesh aesthetics, to add length without additional resolution, and to aid in flow conservation when RMA2 results are used for transport applications (Donnell and others, 2000, p. 11). In this report, external boundaries were curved in an attempt to improve the apparent flow continuity at GCLs by use of the utility program SLOPEFIX (Donnell and others, 2000, p. 232). SLOPEFIX curves a boundary by moving the midside nodes. The utility program was used to read an RMA2 geometry file, curve the boundaries, and rewrite the geometry file. The program does not curve edges involved with boundary-condition assignments tagged as GCLs. The output geometry file generated by SLOPEFIX was re-edited to ensure that mesh-quality criteria were still satisfied.

Renumbering the Mesh

The finite-element mesh represents thousands of equations, which if solved simultaneously, could cause a computer to run out of memory. Thus, RMA2 uses an iterative numerical technique to solve the governing partial differential equations. The front width, the number of equations in the numerical model's solution matrix that are assembled simultaneously, determine the size of the matrix that is used by the finite element solvers. A smaller front width leads to a smaller matrix and more efficient solution. To minimize the front width of the finite-element mesh, the mesh was renumbered starting from a node string at the downstream stage boundary on the mouth of Detroit River. The front width of the model after renumbering was 488.

Model Parameters

Model parameters are hydraulic characteristics of the waterway that are represented in the equations of motion, equations (1) and (2), but that cannot be measured directly in the field. Instead, values of model parameters are inferred from flow and water-level data. In this report Manning's *n* values, which nominally quantify channel roughness or resistance to flow, were the primary model parameters. The effective Manning's *n* values inferred from flow and water-level information were used to describe both the effects of channel roughness and the effects of small discrepancies between the actual and model characterization of waterway geometry and bathymetry.

Manning's *n* values were assigned to 25 material zones within the waterway. The material zones correspond to reaches within the waterway where water-level or flow data is available to support estimation of the effective Manning's *n* values. Thus, flow measurements were used to infer possibly different effective Manning's *n* values on individual branches around major islands because of discrepancies between model and waterway bathymetries, rather than actual differences in channel roughness characteristics. Identifying whether differences in effective Manning's *n* values between material zones are caused by differences in channel roughness characteristics or small discrepancies between actual and model characterization of waterway geometry and bathymetry is problematic because both factors affect channel conveyance, which determines water-level and flow characteristics.

Values of channel roughness vary continuously over the model area both spatially and temporally (Sellinger and Quinn, 2001, and Williamson, Scott and Lord, 1997). In this report, however, it was necessary to limit the number of model parameters to permit effective estimation with available data. Elements that were thought to have similar roughness characteristics were grouped together into material zones where measurements could be used to estimate their magnitudes and uncertainties. Material zone designations and element geometry can be accessed on the Internet at the URL (Universal Resource Locator): http://mi.water.usgs.gov.

Eddy viscosity is a second model parameter that controls the numerical stability of the solution and the variation of velocities through a cross section. Eddy viscosity values were dynamically assigned on the basis of a uniform Peclet number equal to 15, which is within the recommended range of 15 through 40 (Donnell and others, 2000, p. 48). Peclet numbers greater than 20 were found to cause numerical instability in some simulations.

CALIBRATION OF THE HYDRODYNAMIC MODEL

Model calibration is a process of adjusting model parameters to improve the match between simulated and expected values. Traditionally, this is a manual process. In this report, however, a universal inverse modeling code (UCODE, version 3.02, Poeter and Hill, 1998) was used to make these adjustments systematically. Specifically, 25 values of effective Manning's *n*, were estimated for identified material zones in the St. Clair–Detroit River Waterway by the use of UCODE, a procedure that applies a nonlinear regression technique to minimize the sum of squared weighted residuals (differences between simulated and expected values of flows and water levels). In addition to parameter estimates, UCODE provides information on the uncertainty of individual parameters, correlations among parameters, and the sensitivity of parameters to individual measurements.

Parameter Estimation Code

UCODE is a universal code for parameter estimation that is written in the programming language PERL (Practical Extraction and Report Language). UCODE was used to help (1) manipulate RMA2 input and output files, (2) execute RMA2 with different parameter sets, (3) compare simulated with expected values, (4) apply a nonlinear regression code (Hill, 1998) to adjust parameter values in response to the comparison, (5) generate statistics for use in evaluating the uncertainty and correlation structure of estimated parameters, and (6), identify the contribution of individual observations or observation sets on parameter estimates.

Parameter estimation with UCODE proceeds through a set of iterations until the user-specified criteria for convergence is attained or the specified maximum number of iterations is completed. In this report, convergence criteria specified that either the maximum parameter change be less than 2 percent or that the differences in the sum of squared weighted residuals change by less than 2 percent over three iterations.

Within an iteration, each parameter is, in turn, changed (perturbed) by one percent, while the remaining parameters are held constant at their initial values or the values estimated at the end of the previous iteration. RMA2 is executed for each unique parameter set to complete the iteration. When an iteration is completed, parameter sensitivities are calculated for each observation as the ratio of change in simulated values to the change in parameter values. These sensitivities together with the model residuals are used with nonlinear regression to update all parameter estimates simultaneously for the next iteration.

To initiate the parameter estimation process, UCODE reads a universal (UNI) input file, such as SCD.SS.UNI (Appendix A). This file contains solution control variables, the name of the inversion model (MRDRIVE.EXE, which computes the nonlinear regression), commands needed to execute RMA2 scenarios, variables governing the output, and a list of observations including their expected values and uncertainties.

Next, UCODE reads a prepare (PRE) file, such as SCD.SS.PRE (Appendix B). The PRE file indicates whether function files are used in the analysis (they were not); the name of template (TPL) files and corresponding RMA2 input control files; and the names of parameters being estimated. Reasonable minimum and maximum values for estimated parameters are specified in the PRE file. These limits, however, do not constrain the final estimated parameter values, but only provide a range for comparison. All parameters were estimated in log space, so that the only effective constraint was that parameters in arithmetic space were greater than zero. This constraint is consistent with the physically-plausible range for Manning's *n* values. The PRE file also specifies parameter starting values, perturbations (the fractional amount that parameters are perturbed to calculate sensitivities), format for reading and writing the parameter values, and whether or not a particular parameter is to be estimated in a particular run.

Next, UCODE reads the template (TPL) files, such as SCD.SS1.TPL (Appendix C). TPL files are identical to the corresponding input control files for RMA2, except that parameters values are replaced with parameter names enclosed by special delimiters. Finally, UCODE reads an extract (EXT) file, such as SCD.SS.EXT (Appendix D). Information in the EXT file is used to find simulated values in RMA2 output files that match measurements described in the UNI file.

Calibration Scenarios

Calibration scenarios are idealized hydraulic conditions associated with selected flow measurement events that were developed to efficiently calibrate the model throughout a wide range of flow and water-level conditions. The scenarios use steady-state simulations to approximate transient flow and water-level conditions during flow-measurements events. This approach reduces computational requirements to a feasible level with available computer resources. Criteria used to develop the scenarios are described in the following paragraphs.

In this report, a flow-measurement event refers to a period of about 3 days when sets of 20 or more flow measurements were obtained at various cross sections on St. Clair or Detroit Rivers. In 1996, the Detroit District USACE, the primary agency measuring flows on the Great Lakes, began using ADCP (Acoustic Doppler Current Profilers) equipment to measure flow. Flow measurement events are scheduled at about 6-week intervals during the ice-free season; measurement events on the two connecting channels (St. Clair and Detroit Rivers) generally occur within 14 days of one another. Selected cross sections used in the calibration are shown on figures 3 and 4. From 1996 to 2000, about 18 flow measurements sets have been obtained on both St. Clair and Detroit Rivers.

Water levels are monitored continually at gaging stations along the waterway (table 1). Thus, water level data are available from most stations for all flow measurement events. Average water levels, computed from hourly water-level values during flow measurement events, are shown (fig. 5) for selected gaging stations on St. Clair River. Of the 18 flow measurement events on St. Clair River from 1996 to 2000, seven events were selected as calibration scenarios because they were considered sufficient to span the range in flows and water levels during the period in which ADCP measurements were available.

Boundary Conditions

Calibration scenarios were simulated by specifying event-specific flows at the headwaters of St. Clair River (table 2); average inflows of selected intervening tributaries and direct inflow to Lake St. Clair (table 3), and event-specific water levels at the mouth of Detroit River (table 2). Flows at the headwaters of St. Clair River were based on the average flow measured at individual cross sections during the corresponding measurement event. Inflows from all intervening tributaries on the St. Clair–Detroit River Waterway and direct inflow to Lake St. Clair contribute only a minor component of the total flow in the waterway. To provide flexibility for future applications, however, average inflows for selected intervening tributaries were estimated and included in the model calibration analysis. Inflow estimates at the mouth of these tributaries were based on flow records at upstream or nearby gaging stations and adjusted for differences between the gaged drainage area and the drainage area at the mouth of the tributary. Water levels at the mouth of Detroit River were based on average water levels during the measurement event at the Bar Point gage (table 1, CHS gage number 12 005). No wind data were included in the boundary specifications.

Expected Flows and Water-Levels Used in Calibration

Both flow and water-level information was used to calibrate the model. Flow information described the expected flow through the major channels in the waterway formed by islands and dikes. Belle Isle, for example, causes flow in Detroit River to branch into Fleming Channel and a channel near Scott Middle Ground (fig. 4). ADCP flow measurements near the branches were used to develop regression equations to quantify the relation between flow proportions in individual channels and flow magnitude in the main channel (Holtschlag and Koschik, 2001). These equations were used to compute the expected flows and corresponding standard errors in the individual channels around islands as a function of flows specified for each scenario at the headwaters of St. Clair River (table 4).

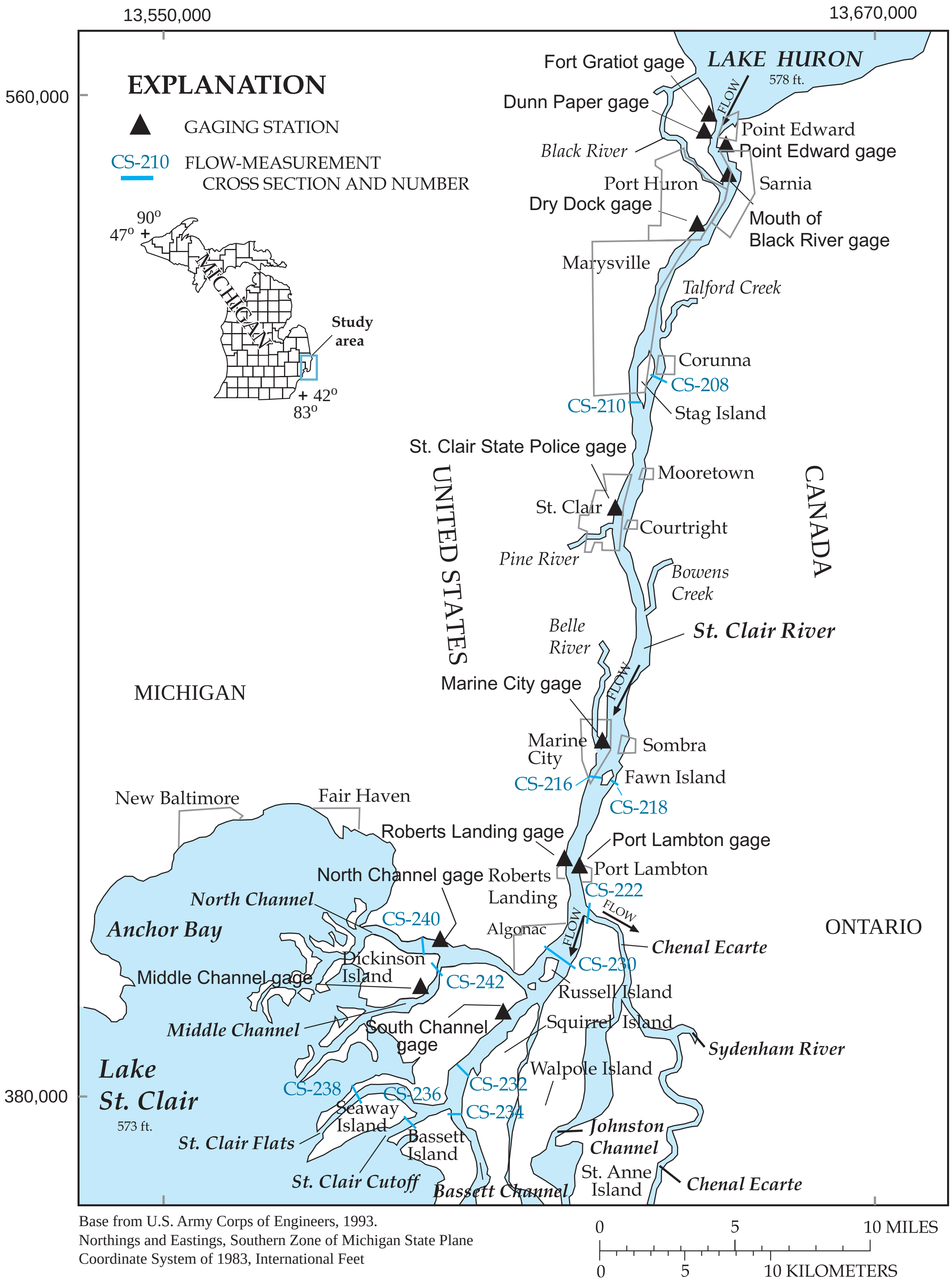


Figure 3. Locations of flow-measurement cross sections and water-level gaging stations on St. Clair River.

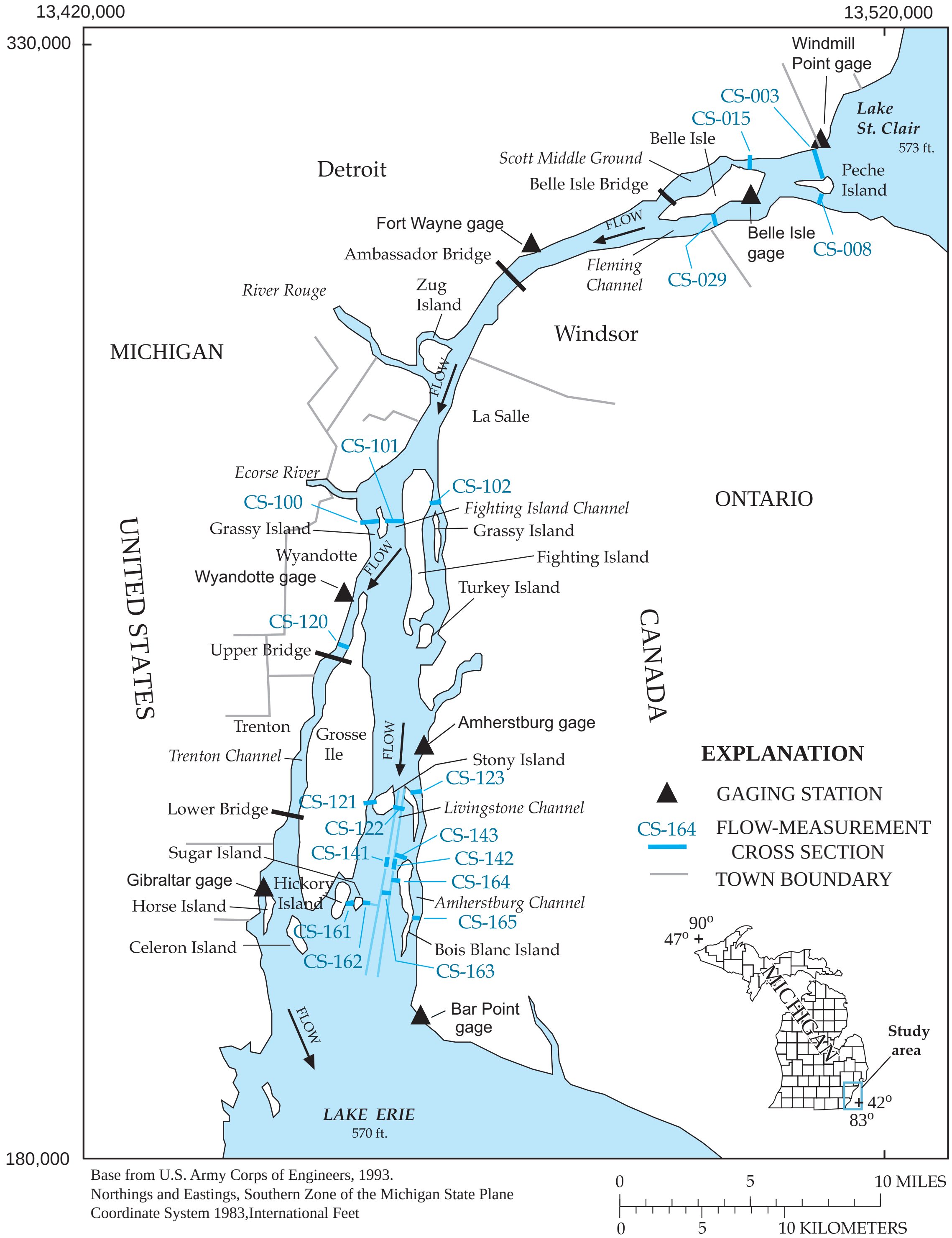


Figure 4. Locations of flow-measurement cross sections and water-level gaging stations on Detroit River.

Table 1. Water-level gaging stations on the St. Clair–Detroit River Waterway

[MSPCS 83 is the Michigan State Plane Coordinate System of 1983. No. number]

Water body	Operating agency	Gaging station No.	Brief gaging station name	Gage location, in MSPCS 83 International Feet (zone 2113)		Nearest model node No.
				Easting	Northing	
St. Clair River	NOAA[1]	9014098	Fort Gratiot	13,643,354	555,153	42,935
	CHS[2]	11 940	Point Edward	13,643,720	549,313	42,479
	NOAA	9014096	Dunn Paper	13,643,352	553,801	42,839
	NOAA	9014090	Mouth of Black River	13,644,341	543,047	41,658
	NOAA	9014087	Dry Dock	13,638,138	532,639	40,852
	NOAA	9014084	Marysville	13,632,429	518,293	39,920
	NOAA	9014080	St. Clair State Police	13,627,991	483,990	37,154
	USACE[3]	CE 214 2CC	Roberts Landing	13,622,120	427,154	32,920
	CHS	11 950	Port Lambton	13,623,527	427,226	32,901
	NOAA	9014070	Algonac	13,617,678	413,229	31,568
	USACE	CE 213 45C	North Channel	13,600,268	415,000	29,958
	USACE	CE 212 72A	Middle Channel	13,583,967	396,640	25,937
	USACE	CE 734 37A	South Channel	13,605,954	397,300	29,241
Lake St. Clair	NOAA	9034052	St. Clair Shores	13,524,546	358,232	18,594
Detroit River	NOAA	9044049	Windmill Point	13,511,750	315,966	16,127
	USACE	CE 737 832	Belle Isle	13,503,340	309,393	15,302
	NOAA	9044036	Fort Wayne	13,467,999	293,618	12,815
	NOAA	9044030	Wyandotte	13,453,697	258,449	8,923
	CHS	11 995	Amherstburg	13,463,040	237,404	6,141
	NOAA	9044020	Gibraltar	13,443,806	217,802	2,803
	CHS	12 005	Bar Point	13,463,182	207,175	1

[1]NOAA is the National Oceanic and Atmospheric Administration.
[2]CHS is the Canadian Hydrographic Service.
[3]USACE is the U.S. Army Corps of Engineers.

Water levels measured at gaging stations upstream of Bar Point, Ontario, also were used in model calibration. The expected values of water level for each scenario were computed as the average of hourly water levels recorded during the corresponding measurement event (table 5). The standard errors of the water-level data included both static and dynamic components. The static component accounted for possible small errors in the absolute datum of the gaging station and differences between the location of the station and the nearest model node used for comparison. The static component was 0.02 ft for all stations. The dynamic component accounted for the variability of water levels during the corresponding measurement event; it was computed as the standard deviation of hourly water-level values. The standard errors of the water-level data were computed as the square root of the sum of the variances of the static and dynamic components, although a minimum standard error of 0.05 was applied to all water-level values. The standard errors of the flow data, measured in cubic feet per second, and water-level data, measured in feet, were used to weight the two types of data properly so that they could be used together in the calibration analysis.

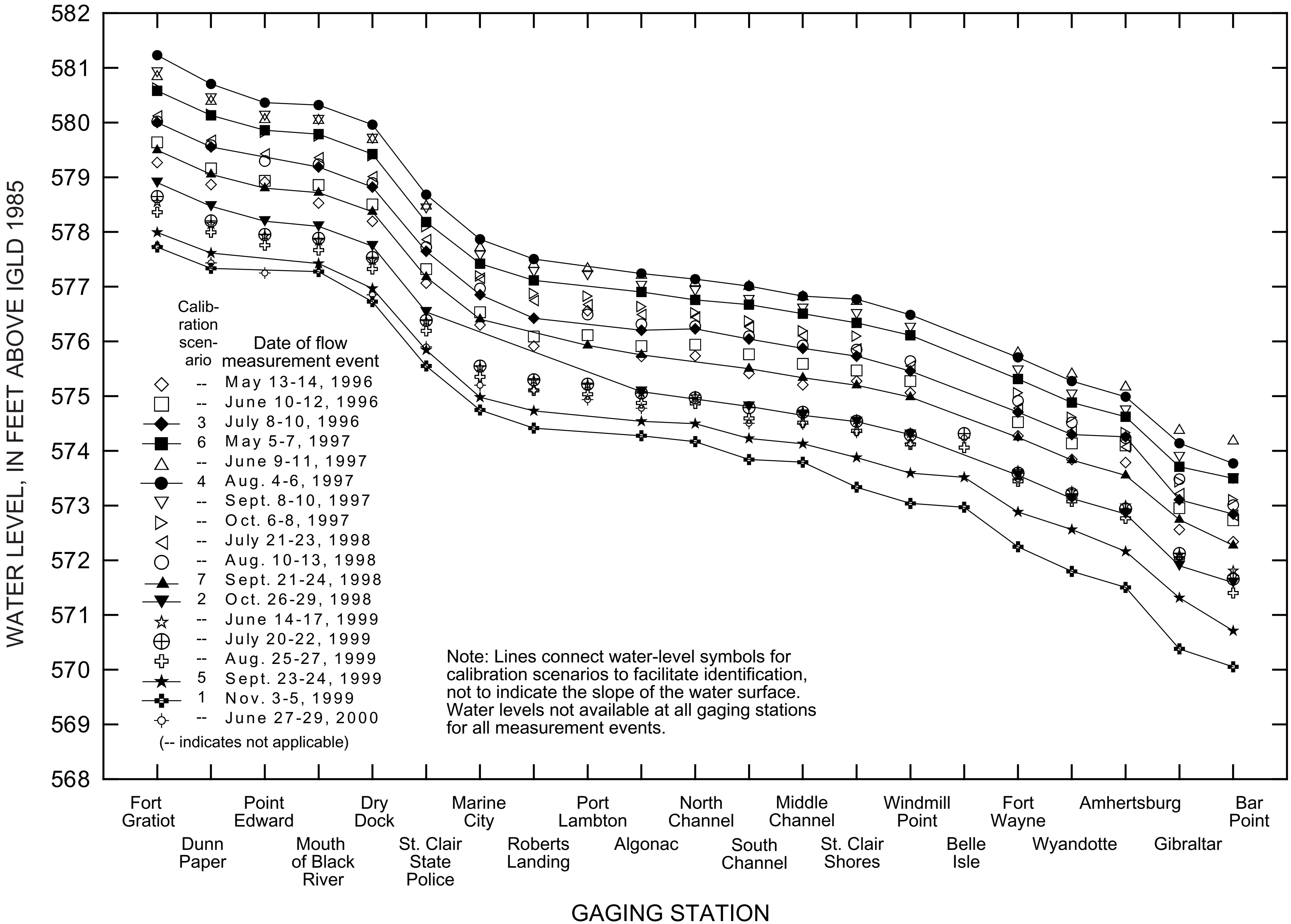


Figure 5. Water levels during flow-measurement events on St. Clair River and selected calibration scenarios.

Parameter Estimation Results

In addition to parameter estimates and uncertainties, parameter estimation results include parameter sensitivity information that describes the ability to estimate model parameters given the network of flow and water-level information available, and the implications of the parameter estimates on the accuracy of model estimates of flows and water levels. Parameter estimation, however, is constrained by the availability of computer resources needed to simulate the model iteratively with alternative sets of parameter values and to evaluate alternative material zone configurations.

Parameter estimation by use of UCODE is an efficient, but computer-intensive process. Seven steady-state calibration scenarios were used to estimate 25 model parameters associated with channel roughness in designated material zones. Each steady-state simulation required about 0.25 hours on a dual Intel Pentium III 550 MHz (megahertz) Xeon ™ processor running under the Microsoft Windows NT operating system. Each simulation started with initial conditions (flow velocities and water levels at individual nodes) computed from the previous iteration from the corresponding scenario. Thus, 10 iterations of a 25-parameter estimation with seven steady-state scenarios required about 438 hours of computer time. This estimation process was repeated several times either to achieve convergence of the estimation process, or to evaluate alternative parameterizations using different material zone configurations. The parameter estimation results that follow converged under the criterion that changes in the weighted sum of square residuals from three consecutive parameter estimation runs differed by less than 2 percent.

Parameters Estimates and Uncertainties

Parameter estimates and corresponding widths of 95-percent confidence intervals (fig. 6) ranged widely among the 25 designated material zones. Parameter estimates associated with Manning's *n* ranged from 0.0084 for the material zone River Rouge on Detroit River (DETRRouge) to 0.0660 for the material zone Bois Blanc Island on lower Detroit River (DETBobloIs). Parameter values are thought to account both for discrepancies in flow areas between actual conditions and the model representations, as well as for actual differences in channel roughness characteristics. To limit parameter estimates to physically plausible values, parameter estimation occurred in log space; corresponding estimates were exponentiated prior to substitution into the hydrodynamic model.

Table 2. Boundary specifications for calibration scenarios near the headwaters of St. Clair River and near the mouth of Detroit River

Scenario	Dates of flow-measurement event	Expected flow near the headwaters of St. Clair River at Fort Gratiot (in cubic feet per second)	Expected water level near the mouth of Detroit River at Bar Point, Ontario (in feet above IGLD 1985)
1	November 3–5, 1999	173,201	570.052
2	October 26–29, 1998	194,065	571.591
3	July 8–10, 1996	217,259	572.884
4	August 4–6, 1997	222,539	573.770
5	September 23–24, 1999	174,993	570.710
6	May 5–7, 1997	213,719	573.498
7	September 21–24, 1998	197,907	572.271

Table 3. Selected local inflows to the St. Clair–Detroit River Waterway

Water body	Waterway component receiving inflow	Approximate drainage area (square miles)	Approximate average flow (cubic feet per second)
Black River	St. Clair River	746	489
Pine River	St. Clair River	194	119
Belle River	St. Clair River	777	478
Sydenham River	Lake St. Clair	2,043	1,861
Clinton River	Lake St. Clair	1,206	928
Thames River	Lake St. Clair	4,330	4,857
Net lake inflow (Atmospheric, and surface- and ground-water sources)	Lake St. Clair	670	626
River Rouge	Detroit River	467	312

Table 4. Expected flows and standard errors for scenarios used in model calibration

Flow-measurement cross section	Flows (Expected values and standard errors are in cubic feet per second)													
	Scenario 1		Scenario 2		Scenario 3		Scenario 4		Scenario 5		Scenario 6		Scenario 7	
	Expected	Standard error	Expected	Standard error	Expected	Standard error	Expected	Standard error	Expected	Standard error	Expected	Standard error	Expected	Standard error
St. Clair River														
CS208	55,557	1,236	63,820	1,282	73,406	1,449	75,647	1,511	56,253	1,238	71,916	1,413	65,379	1,299
CS210	118,133	1,236	130,733	1,282	144,342	1,449	147,380	1,511	119,228	1,238	142,292	1,413	133,017	1,299
CS216	144,166	889	160,258	946	177,855	1,083	181,818	1,127	145,557	892	175,189	1,056	163,195	963
CS218	30,121	889	34,893	946	40,490	1,083	41,807	1,127	30,521	892	39,616	1,056	35,799	963
CS222	6,399	625	8,023	654	10,043	741	10,535	773	6,531	627	9,720	722	8,342	663
CS230	167,888	625	187,128	654	208,302	741	213,090	773	169,547	627	205,085	722	190,652	663
CS232	78,880	2,225	86,231	2,310	93,919	2,663	95,599	2,783	79,527	2,225	92,778	2,590	87,539	2,348
CS240	57,495	1,673	66,226	1,744	76,344	2,015	78,706	2,113	58,231	1,675	74,772	1,957	67,873	1,772
CS242	31,513	1,833	34,671	1,944	38,040	2,218	38,786	2,304	31,789	1,838	37,535	2,165	35,240	1,977
CS234	6,356	832	6,948	907	7,568	991	7,703	1,010	6,408	838	7,476	978	7,054	921
CS236	42,615	2,217	46,586	2,388	50,740	2,646	51,647	2,715	42,965	2,229	50,123	2,602	47,293	2,425
CS238	29,909	2,414	32,696	2,624	35,611	2,877	36,248	2,938	30,154	2,432	35,179	2,837	33,192	2,664
Detroit River														
CS003	134,187	1,770	149,522	1,973	166,571	2,197	170,452	2,248	135,504	1,788	163,969	2,163	152,347	2,010
CS008	48,373	1,770	53,901	1,973	60,047	2,197	61,446	2,248	48,848	1,788	59,109	2,163	54,919	2,010
CS015	55,684	1,460	64,196	1,503	74,176	1,675	76,523	1,740	56,397	1,462	72,617	1,637	65,811	1,520
CS029	126,876	1,460	139,228	1,503	152,442	1,675	155,374	1,740	127,954	1,462	150,461	1,637	141,455	1,520
CS100	47,784	1,179	53,236	1,313	59,296	1,463	60,676	1,497	48,252	1,190	58,371	1,440	54,240	1,338
CS101	95,824	1,110	105,960	1,185	117,038	1,331	119,531	1,375	96,700	1,115	115,360	1,304	107,809	1,204
CS102	39,264	929	44,540	987	50,596	1,109	52,003	1,148	39,711	933	49,658	1,086	45,529	1,002
CS120	40,517	1,776	45,140	1,979	50,278	2,204	51,448	2,255	40,914	1,794	49,494	2,170	45,991	2,016
CS121	9,572	2,050	14,495	2,283	20,889	2,543	22,480	2,602	9,964	2,070	19,850	2,504	15,487	2,327
CS122	48,136	1,764	51,722	1,870	55,251	2,113	55,987	2,185	48,459	1,769	54,743	2,068	55,340	1,902
CS123	84,647	2,197	92,379	2,277	100,512	2,594	102,295	2,703	85,327	2,197	99,302	2,529	93,760	2,312
CS141	21,484	2,431	23,157	2,623	24,831	2,829	25,185	2,874	21,634	2,448	24,588	2,798	23,448	2,658
CS142	12,201	2,146	13,316	2,342	14,488	2,548	14,745	2,593	12,299	2,163	14,313	2,517	13,515	2,377
CS143	20,396	1,701	22,259	1,858	24,218	2,027	24,648	2,065	20,559	1,714	23,927	2,002	22,591	1,886
CS161	21,531	2,017	26,574	2,216	32,964	2,500	34,541	2,581	21,939	2,034	31,933	2,450	27,574	2,257
CS162	9,524	1,027	11,078	1,105	12,756	1,225	13,123	1,257	9,658	1,033	12,506	1,204	11,362	1,123
CS163	38,854	2,886	41,880	3,116	44,907	3,386	45,547	3,448	39,125	2,905	44,468	3,344	42,407	3,160
CS164	8,195	2,009	8,943	2,192	9,730	2,385	9,903	2,427	8,260	2,025	9,613	2,356	9,077	2,225
CS165	64,252	2,269	70,120	2,502	76,294	2,750	77,647	2,805	64,767	2,289	75,375	2,713	71,169	2,543

Table 5. Expected water levels and standard errors for scenarios used in model calibration

Station name	Water level (Expected values and standard errors are in feet)													
	Scenario 1		Scenario 2		Scenario 3		Scenario 4		Scenario 5		Scenario 6		Scenario 7	
	Expected	Standard error	Expected	Standard error	Expected	Standard error	Expected	Standard error	Expected	Standard error	Expected	Standard error	Expected	Standard error
Fort Gratiot	577.724	0.396	578.902	0.207	580.003	0.156	581.230	0.135	577.992	0.191	580.580	0.274	579.495	0.191
Dunn Paper	577.335	.325	578.470	.189	579.554	.134	580.705	.110	577.615	.161	580.131	.220	579.052	.168
Port Edward	[1]NA	NA	578.196	.159	NA	NA	580.363	.120	NA	NA	579.860	.214	578.800	.148
Mouth of Black River	577.277	.233	578.102	.163	579.187	.131	580.320	.099	577.423	.144	579.788	.202	578.718	.153
Dry Dock	576.727	.330	577.742	.147	578.819	.122	579.961	.093	576.967	.107	579.423	.172	578.370	.135
St. Clair State Police	575.550	.183	576.537	.096	577.647	.100	578.682	.064	575.843	.075	578.182	.099	577.176	.086
Marine City	574.747	.100	NA	NA	576.854	.071	577.867	.052	574.980	.068	577.420	.089	576.405	.065
Roberts Landing	574.415	.093	NA	NA	576.422	.021	577.505	.040	574.730	.064	577.115	.102	NA	NA
Port Lambton	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	575.927	.049
Algonac	574.276	.063	575.083	.025	576.203	.071	577.241	.025	574.538	.059	576.903	.070	575.753	.046
North Channel	574.169	.051			576.229	.051	577.138	.038	574.496	.067	576.759	.104		
South Channel	573.842	.060	574.812	.031	576.044	.069	577.010	.036	574.227	.115	576.672	.089	575.502	.055
Middle Channel	573.793	.046	574.650	.022	575.873	.044	576.827	.030	574.128	.065	576.508	.076	575.335	.048
St. Clair Shores	573.335	.119	574.533	.036	575.731	.053	576.770	.033	573.878	.060	576.339	.087	575.198	.050
Windmill Point	573.039	.119	574.297	.050	575.459	.059	576.485	.054	573.591	.102	576.111	.124	574.983	.096
Belle Isle	572.970	.149	NA	NA	NA	NA	NA	NA	573.516	.105	NA	NA	NA	NA
Fort Wayne	572.247	.238	573.553	.064	574.708	.111	575.709	.051	572.881	.130	575.314	.140	574.246	.111
Wyandotte	571.797	.304	573.129	.085	574.297	.148	575.275	.060	572.562	.120	574.882	.176	573.830	.142
Amherstburg	571.507	.334	572.848	.097	574.257	.170	574.988	.069	572.161	.194	574.624	.198	573.551	.160
Gibraltar	570.381	.641	571.900	.161	573.107	.293	574.138	.117	571.314	.304	573.710	.351	572.742	.224

[1]NA indicates that data were not available or that data from a nearby gaging station were used in its place.

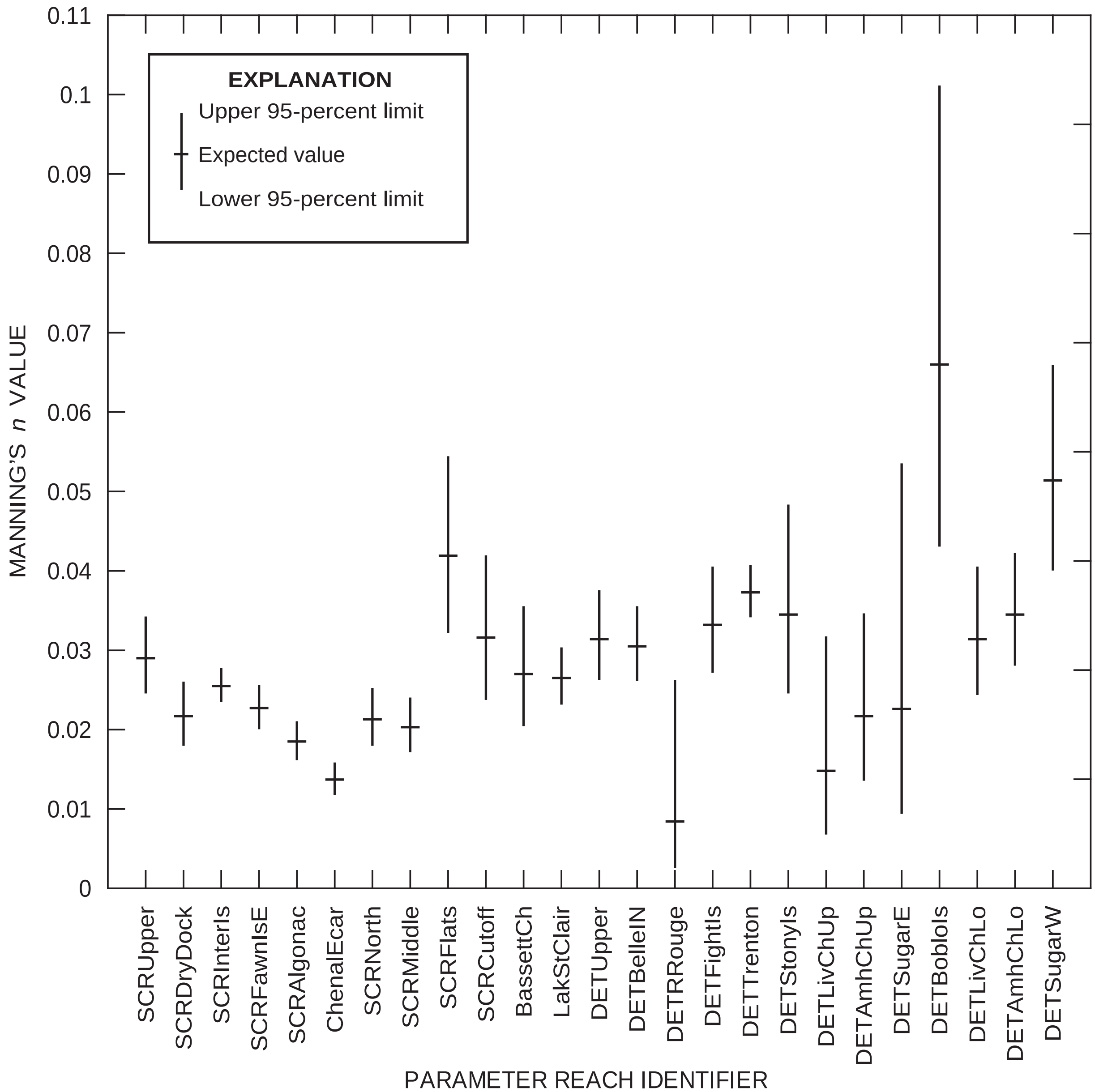


Figure 6. Estimated Manning's *n* values and 95-percent confidence intervals for 25 material zones in the St. Clair–Detroit River Waterway.

High parameter correlation (0.97) was detected between the parameter associated with channel roughness of upper Livingstone Channel on lower Detroit River (DETLivChUp) and upper Amherstburg Channel on lower Detroit River. In addition, moderate correlation (0.95) was detected between upper Detroit River (DETUpper) and the channel north of Belle Isle on upper Detroit River (DETBelleIN), near Scott Middle Ground. Correlation among parameters implies ambiguity in the true parameter values. That is, simultaneous changes in two highly correlated parameters may produce the same value of the weighted sum of squares of residuals. Additional calibration data or a reconfiguration of material zones is needed if either estimated parameter is physically implausible. Other than the two parameter pairs identified, no other parameter correlations greater than 0.85 were detected.

Parameter Sensitivities

Parameter sensitivity measures the extent to which model estimates of flow or water level change in response to changes in parameter values. Thus, a sensitivity value is calculated for each observation of flow and water level with respect to each parameter. UCODE applies the central-difference estimator as the final estimator of sensitivity as

$$s_{ij} \equiv \frac{\partial \hat{y}_i}{\partial b_j} \cong \frac{\Delta_2 \hat{y}_i}{\Delta_2 b_j} = \frac{\hat{y}_i[\vec{b}+\Delta\vec{b}_j] - \hat{y}_i[\vec{b}-\Delta\vec{b}_j]}{(\vec{b}+\Delta\vec{b}_j)-(\vec{b}-\Delta\vec{b}_j)}, \quad (6)$$

where

s_{ij} is the sensitivity of the i^{th} observation to the j^{th} parameter, which is defined using,

$\frac{\partial y_i}{\partial b_j}$ the partial derivative of the change in i^{th} simulated value with respect to the j^{th} parameter.

$\frac{\Delta_2 \hat{y}}{\Delta_2 b}$ indicate the central difference estimate of the change in the simulated value caused by the parameter value change Δ_b

$\vec{b}$ a vector of the values of the estimated parameters, in this report, corresponding to channel roughness values,

$\Delta\vec{b}$ a vector in which all values are zero except for the parameter for which sensitivities are being calculated, and

$\hat{y}[\vec{b}+\Delta\vec{b}]$ and $\hat{y}[\vec{b}-\Delta\vec{b}]$ indicates the flow or water-level simulated by use of the parameter values represented by $(\vec{b}+\Delta\vec{b})$ or $(\vec{b}-\Delta\vec{b})$, respectively (Poeter and Hill, 1998, p. 8).

In this report, sensitivities were calculated by perturbing parameters by one percent.

Scaling the parameter sensitivity values by the magnitudes of the corresponding parameter and the uncertainties of the observations facilitates the evaluation of the importance of different observations to the estimation of a single parameter or the importance of different parameters to the calculation of a simulated value (Hill, 1998, p. 15). In both cases, greater absolute values are associated with greater importance. Scaled parameter sensitivities are calculated as

$$ss_{ij} = \left(\frac{\partial \hat{y}_i}{\partial b_j}\right) b_j \omega_{ii}^{1/2}, \quad (7)$$

where

$\frac{\partial \hat{y}_i}{\partial b_j}$ is estimated by the central difference estimator Equation 6,

b_j is the estimated parameter, and

w_{ii} is the variance associated with the i^{th} measurement.

Parameter composite scaled sensitivities (*ParmCSS*) are calculated for each parameter by summing the scaled sensitivities over all measurements. *ParmCSS* indicate the total amount of information provided by the measurements for the estimation of the corresponding parameters. In particular, *ParmCSS* values were computed as:

$$ParmCSS_j = \left[\sum_{i=1}^{ND} \left(ss_{ij} \right)^2 \Big|_{\vec{b}} \Big/ ND \right]^{1/2},$$

where *ND* is the number of measurements in the regression analysis. In this report, the number of measurements is 338. Results of the sensitivity analysis indicate a wide variation in composite scaled sensitivities for the 25 model parameters (fig. 7). The effective Manning's *n* for Detroit River near Fighting Island (DETFightIs) has the greatest sensitivity and Detroit River at Sugar Island East (DETSugarE) has the least composite scaled sensitivity.

Measurement composite scaled sensitivities (*MeasCSS*) are calculated in a manner similar to *ParmCSS*. Here, however, the summations also occurred over the scenarios and the parameters to

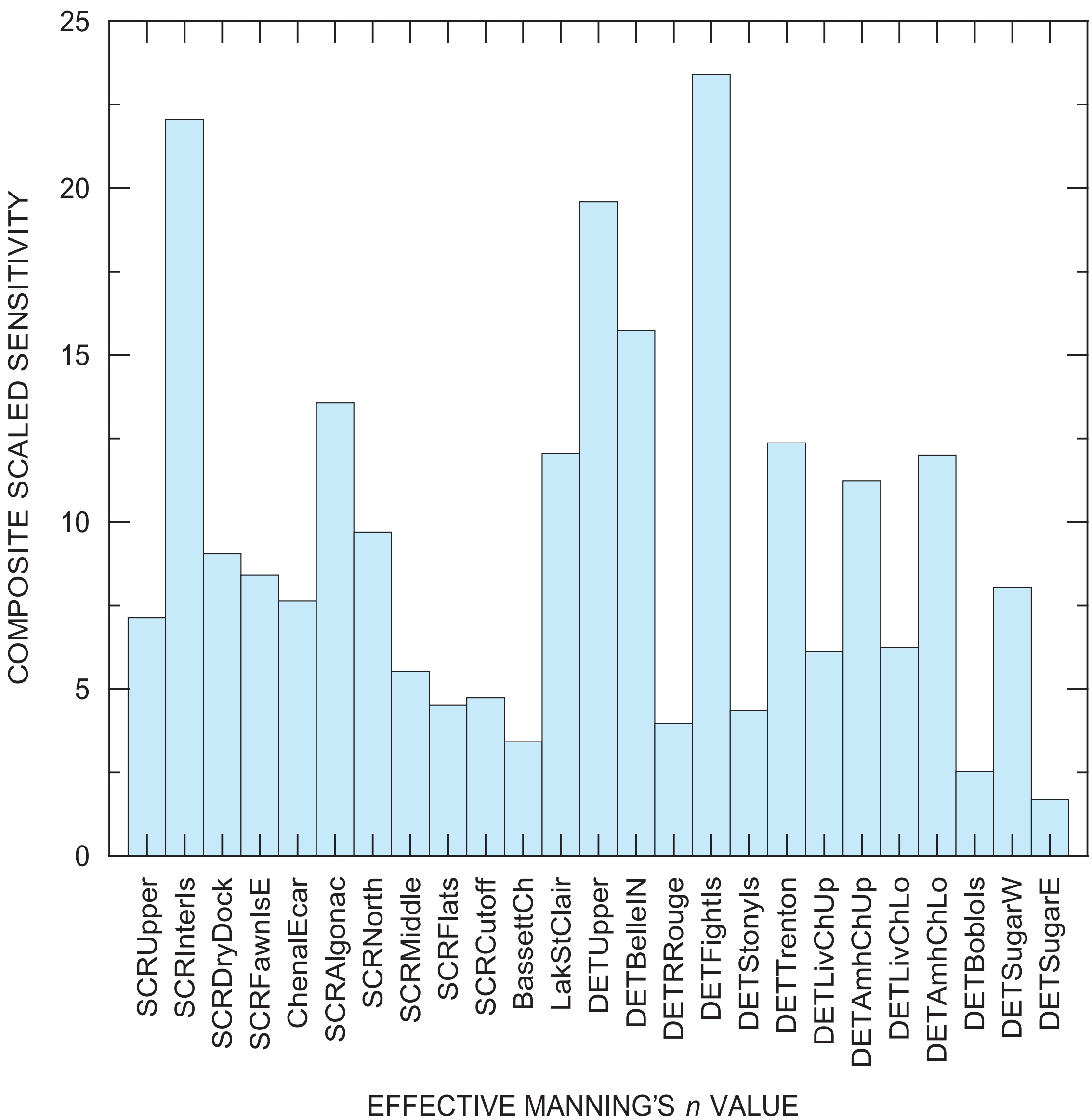


Figure 7. Composite scaled sensitivities for Manning's *n* parameters in corresponding material zones.

identify the total amount of information provided by different types of measurements at various locations. Values of *MeasCSS* were computed as:

$$MeasCSS_i = \left[\sum_{j=1}^{7} \sum_{k=1}^{NP} \left(ss_{jk} \right)^2 \Big|_{\vec{m}} \Big/ (7 \cdot NP) \right]^{1/2}.$$

The information provided, as described by the *MeasCSS* values, varied widely between measurement types and among measurement locations (figs. 8 and 9). The average *MeasCSS* value for water-level measurements was 13.6 and the average *MeasCSS* for flow measurements was 7.31, which reflects generally greater weights for water-level measurements. Standard deviations of *MeasCSS* were more near equal with value of 4.98 and 4.83 for water level and flow measurements, respectively. Water-level measurements on St. Clair River at Roberts Landing and Port Huron (each scenario contained only one of these measurements) were most informative; water levels on Detroit River at Gibraltar were least informative. Flow measurements near Belle Isle at cross sections CS-015 and CS-029 were most informative; flow measurements on Detroit River west of American Grassy Island were least informative about model parameters.

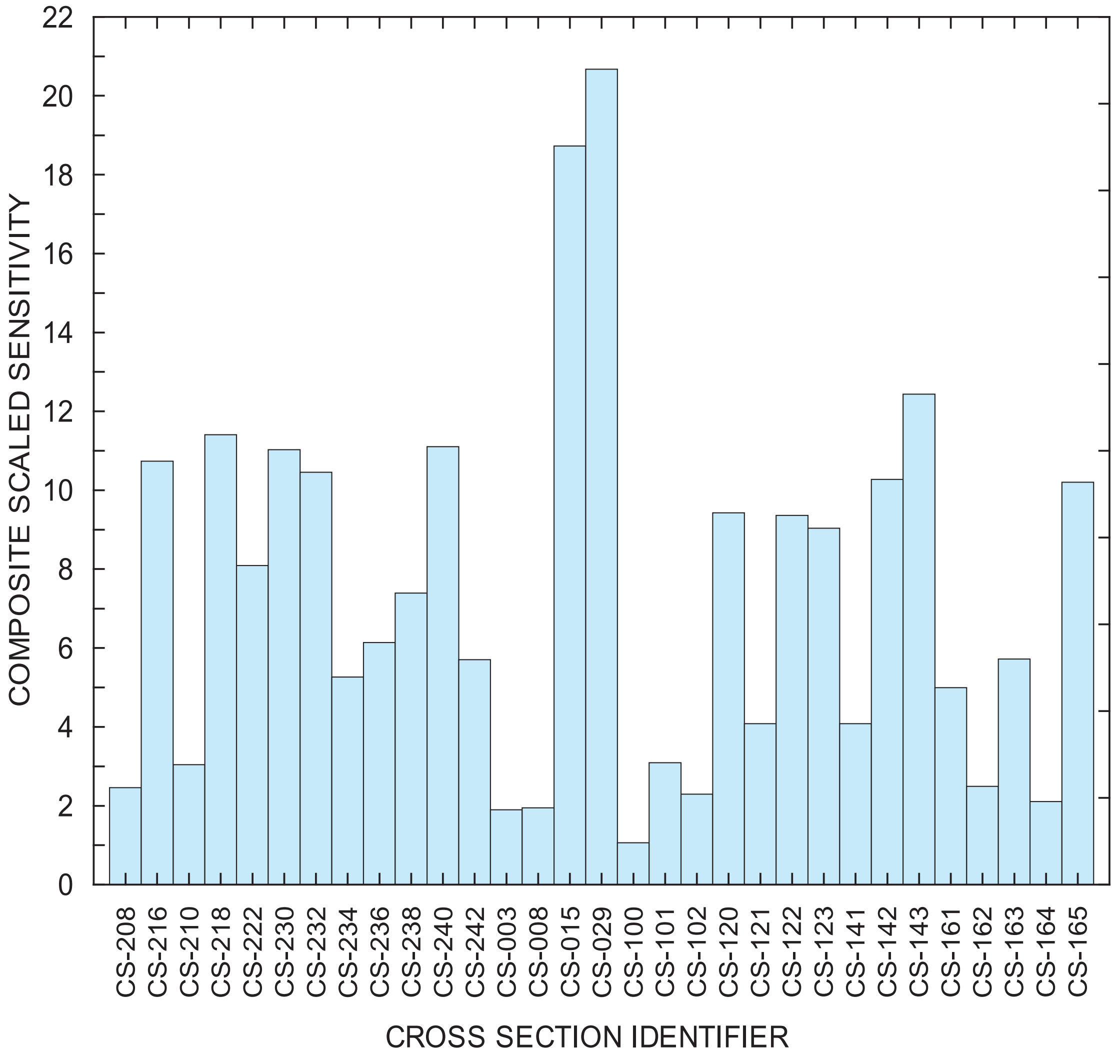


Figure 8. Composite scaled sensitivities of flows at measurement cross sections on St. Clair and Detroit Rivers.

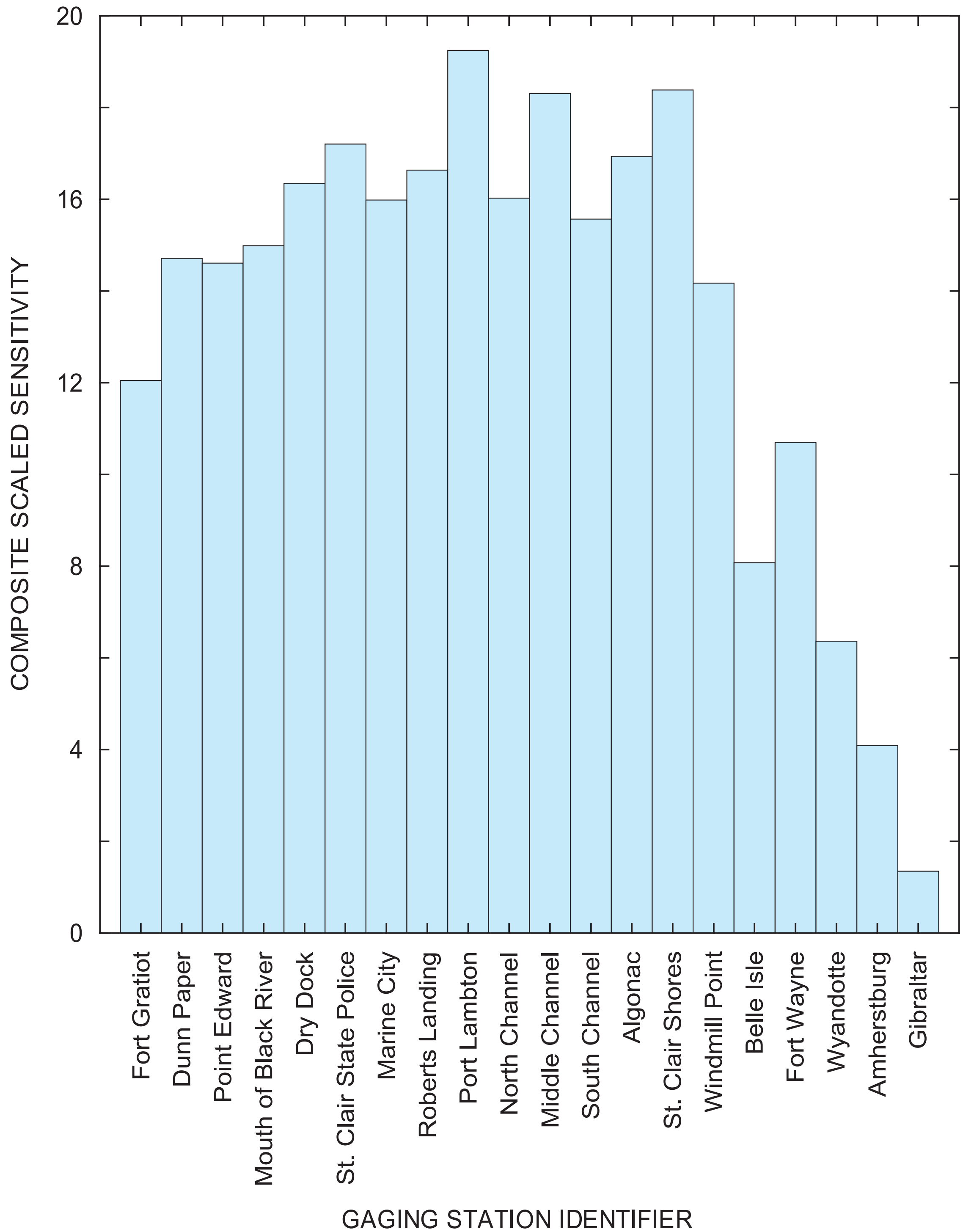


Figure 9. Composite scaled sensitivities of water levels at selected gaging stations on the St. Clair–Detroit River Waterway.

SIMULATED AND EXPECTED FLOWS AND WATER LEVELS

Overall, simulated and expected values of flows and water levels on St. Clair–Detroit River Waterway are in close agreement (figs. 10–13). Inspection of the distribution of residuals, formed by the differences between expected and simulated flows and water levels, however, provides additional detail on the model fit. In particular, expected flows are consistently greater than simulated flows for all scenarios (fig. 14). This apparent bias may be due to an under accounting of simulated flows at GCLs, rather than an actual flow loss in the model. According to B.P. Donnell (USACE, written commun., 2001), a 3-5 percent under accounting of flows at GCLs is normal, although sometimes this discrepancy can be reduced by lowering the convergence parameter in RMA2 to 0.0001 ft or less, increasing the local mesh density, and applying the SLOPEFIX utility. In addition, some scenarios show consistent discrepancies between expected and simulated water levels. In particular, expected water levels are consistently lower than simulated water levels for scenarios 2 and 3, and expected water levels are consistently higher than simulated water levels for scenario 5 (fig. 15). The steady-state approximation to transient conditions during the measurement events may explain some of the discrepancies in the calibration scenarios.

Expected flows are consistently higher than simulated flows at some flow-measurement cross-sections. On St. Clair River, expected flows are consistently higher than simulated flows at on the east side of Stag Island (CS-208), and consistently lower on the west side (CS-210) (fig. 16). Similarly, for Detroit River, expected flows are consistently higher on the south side of Peche Island (CS-008) than on the north side (CS-003). This discrepancy might be resolved by introducing additional material zones, although the low sensitivities in these areas (fig. 8) may make improvements problematic. Sensitivities could change, however, with changes in material configurations. Expected water levels at the Dry Dock gaging station on St. Clair River are generally higher than simulated values (fig. 17). Given, the generally high sensitivities to water levels at both the Mouth of Black River and Dry Dock gaging stations (fig. 9) and high composite scaled sensitivities for parameters SCRDryDock and SCRInterIs (fig. 7), some subdivision or reconfiguration of the boundaries defining the nearby material zones may improve the model fit. Simulated water levels at Belle Isle (fig. 17) appear higher than expected values, however, this discrepancy is based on data from only two calibration scenarios.

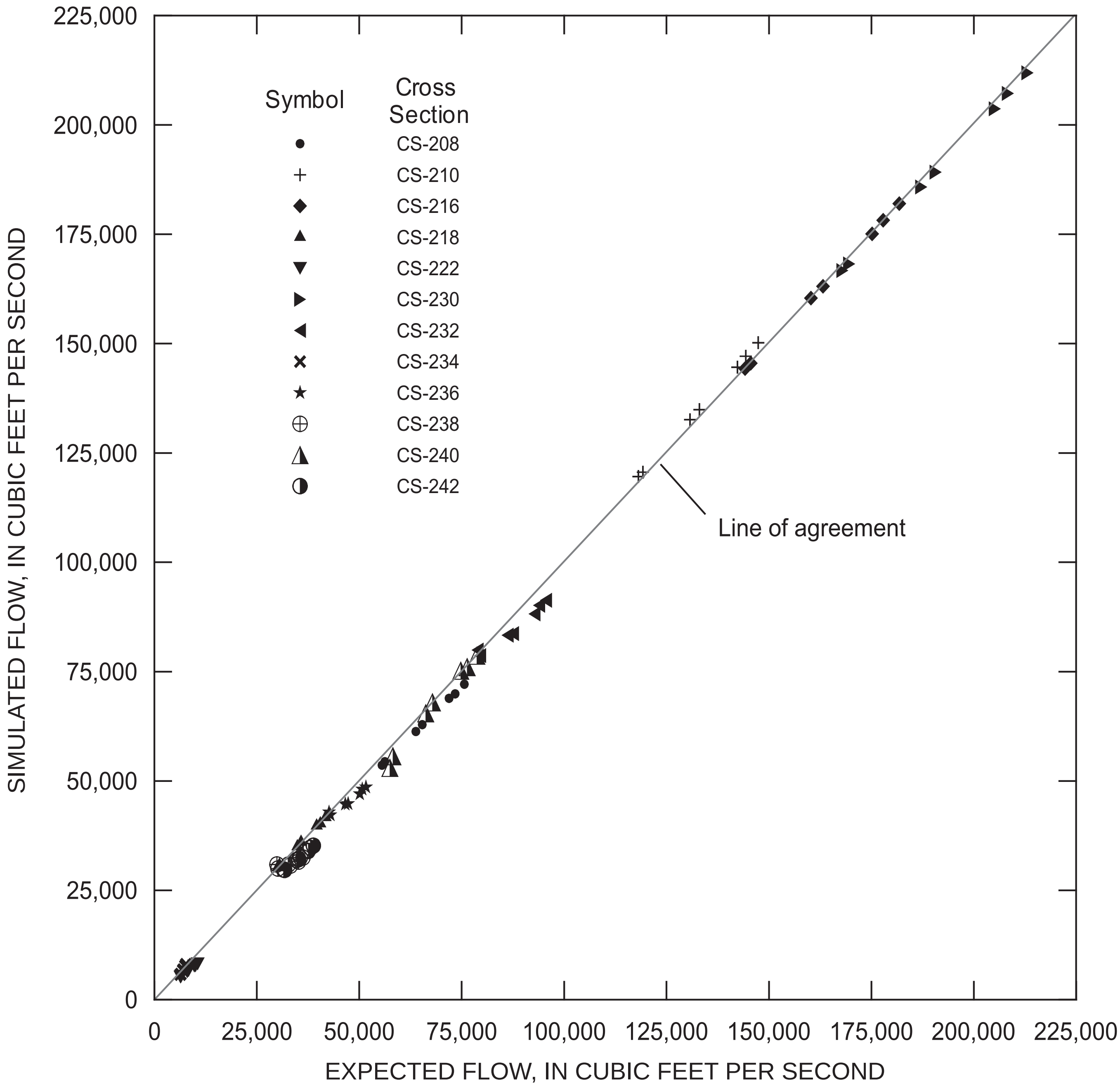


Figure 10. Relation between expected and simulated flows on St. Clair River for seven calibration scenarios.

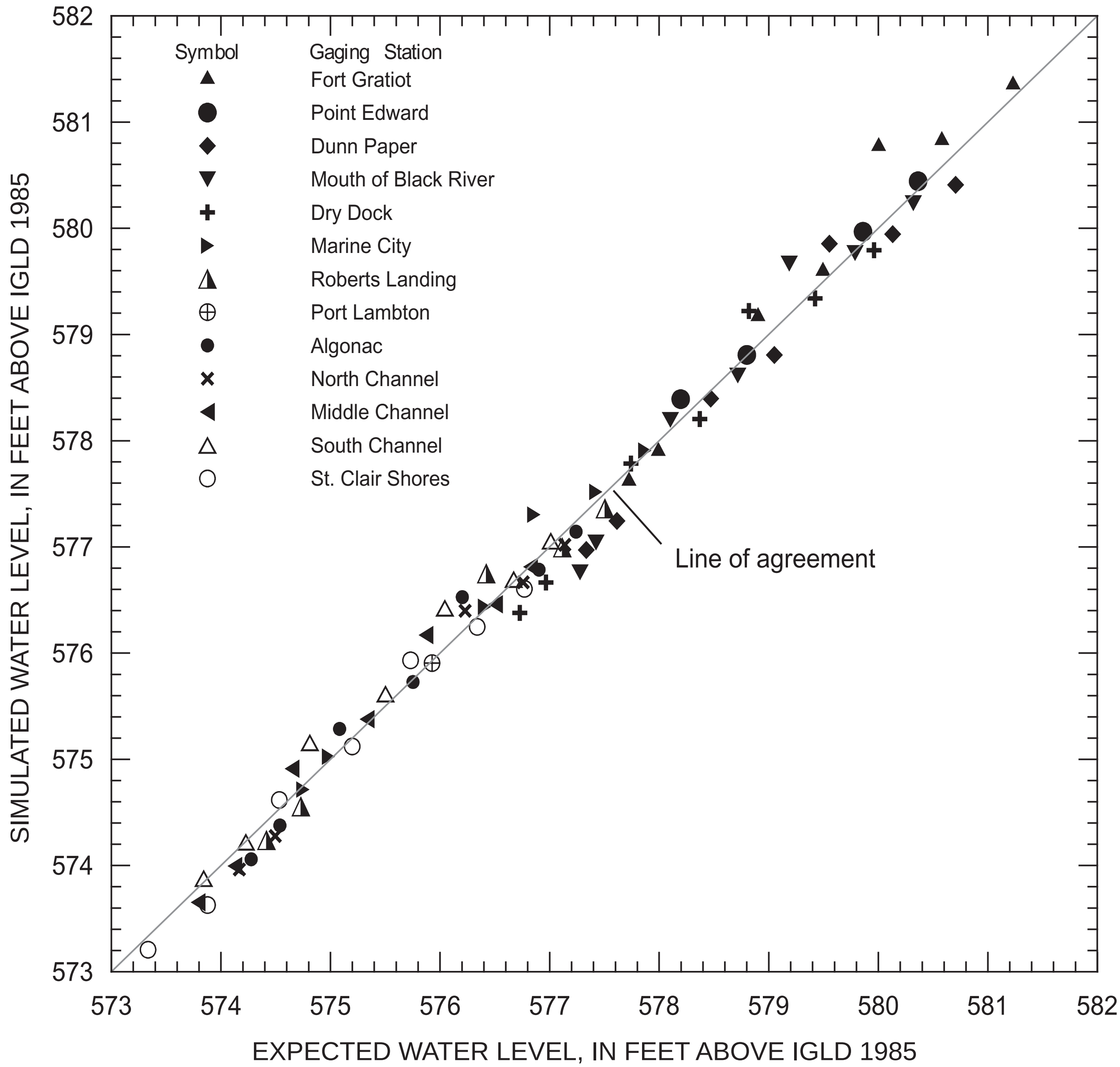


Figure 11. Relation between expected and simulated water levels on St. Clair River and Lake St. Clair for seven calibration scenarios.

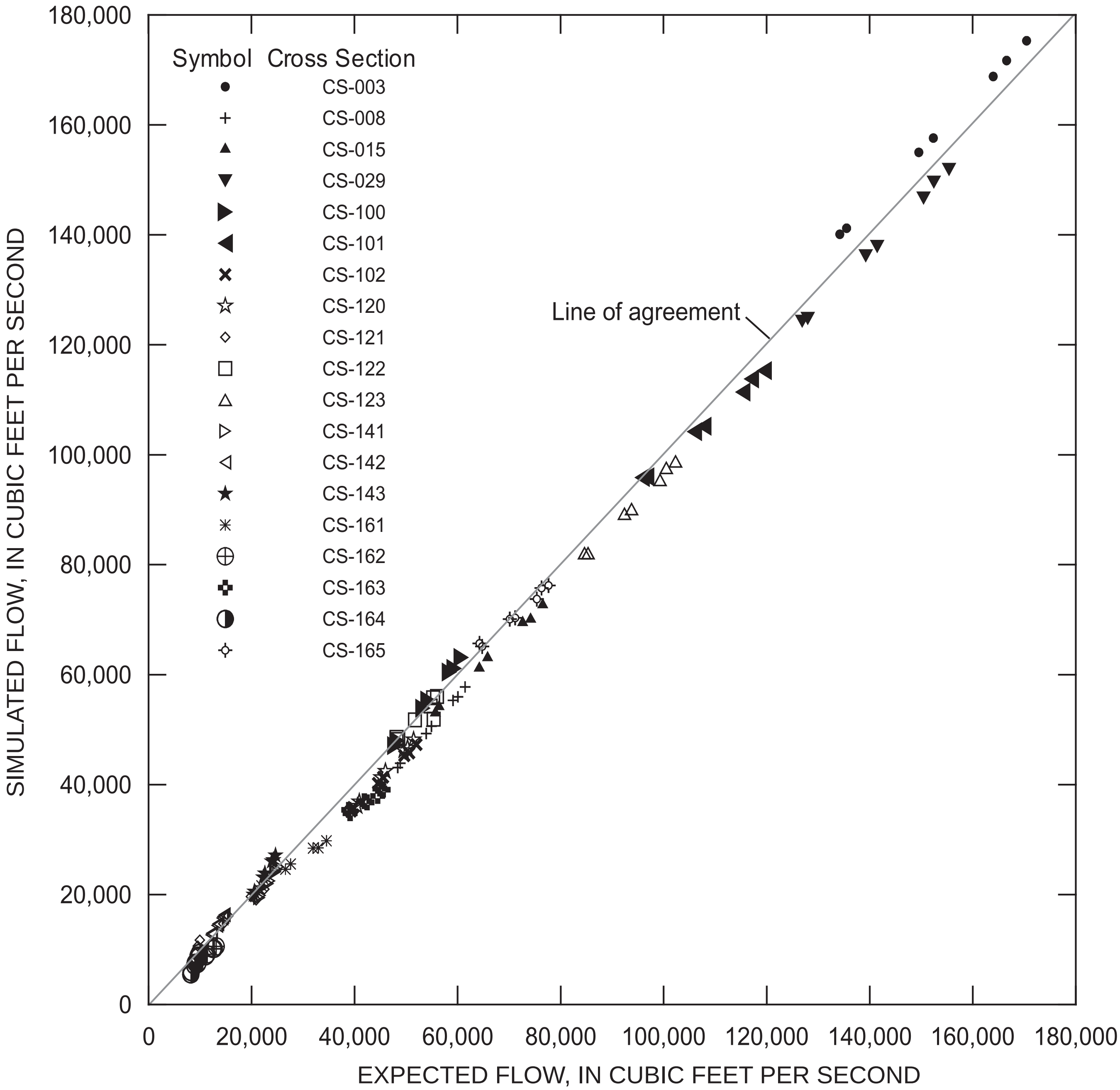


Figure 12. Relation between expected and simulated flows on Detroit River for seven calibration scenarios.

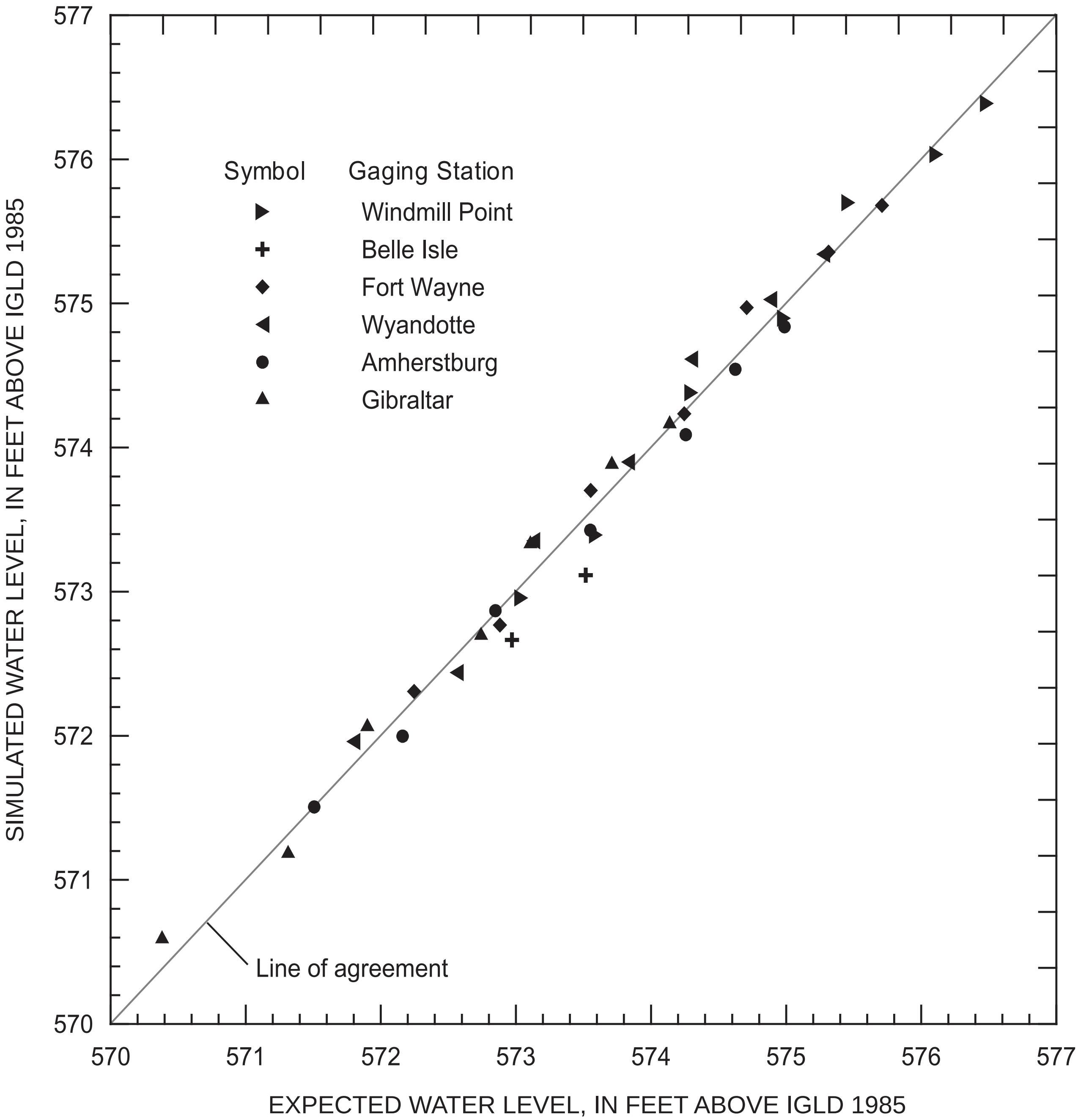


Figure 13. Relation between expected and simulated water levels on Detroit River for seven calibration scenarios.

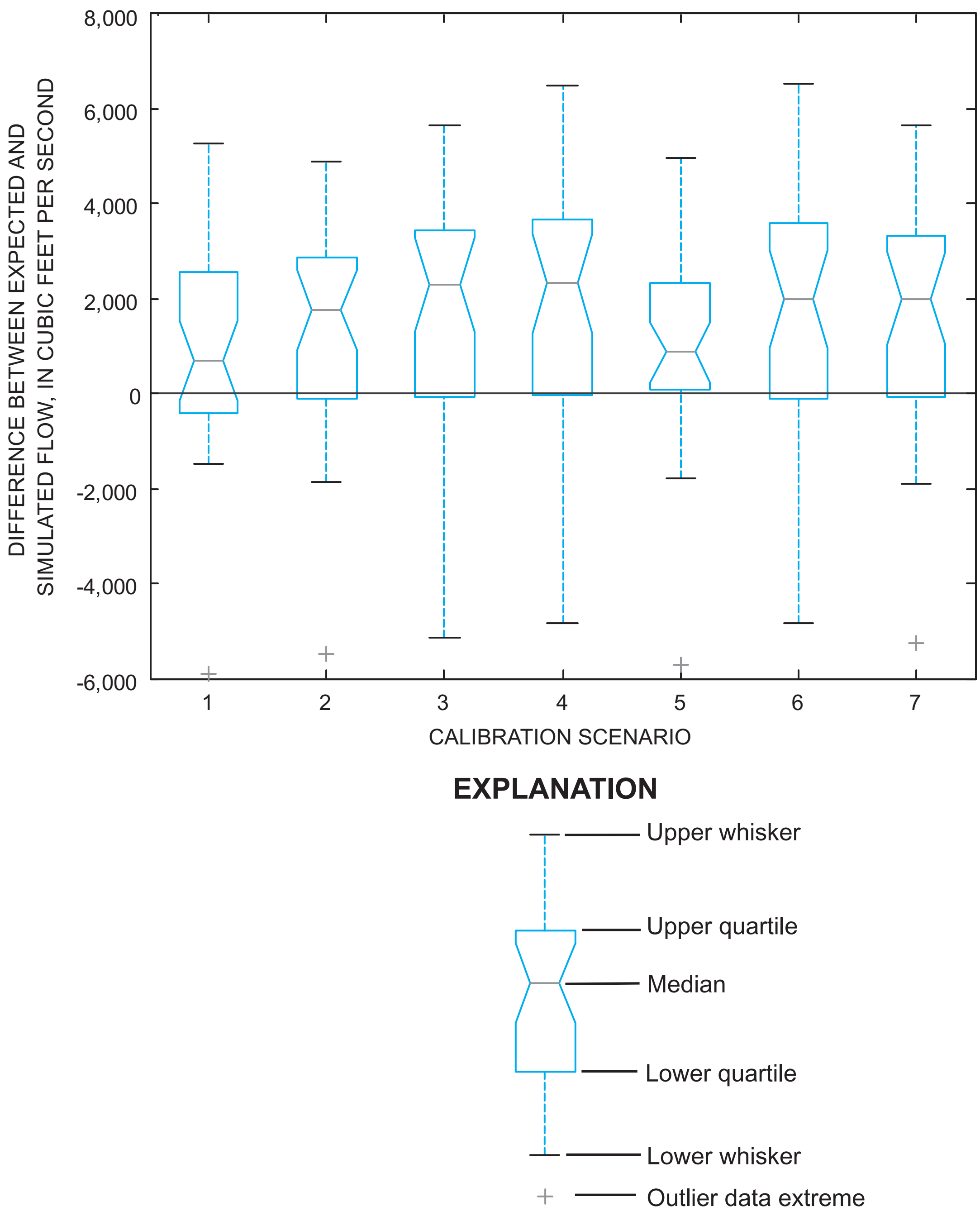


Figure 14. Distribution of flow residuals by calibration scenario.

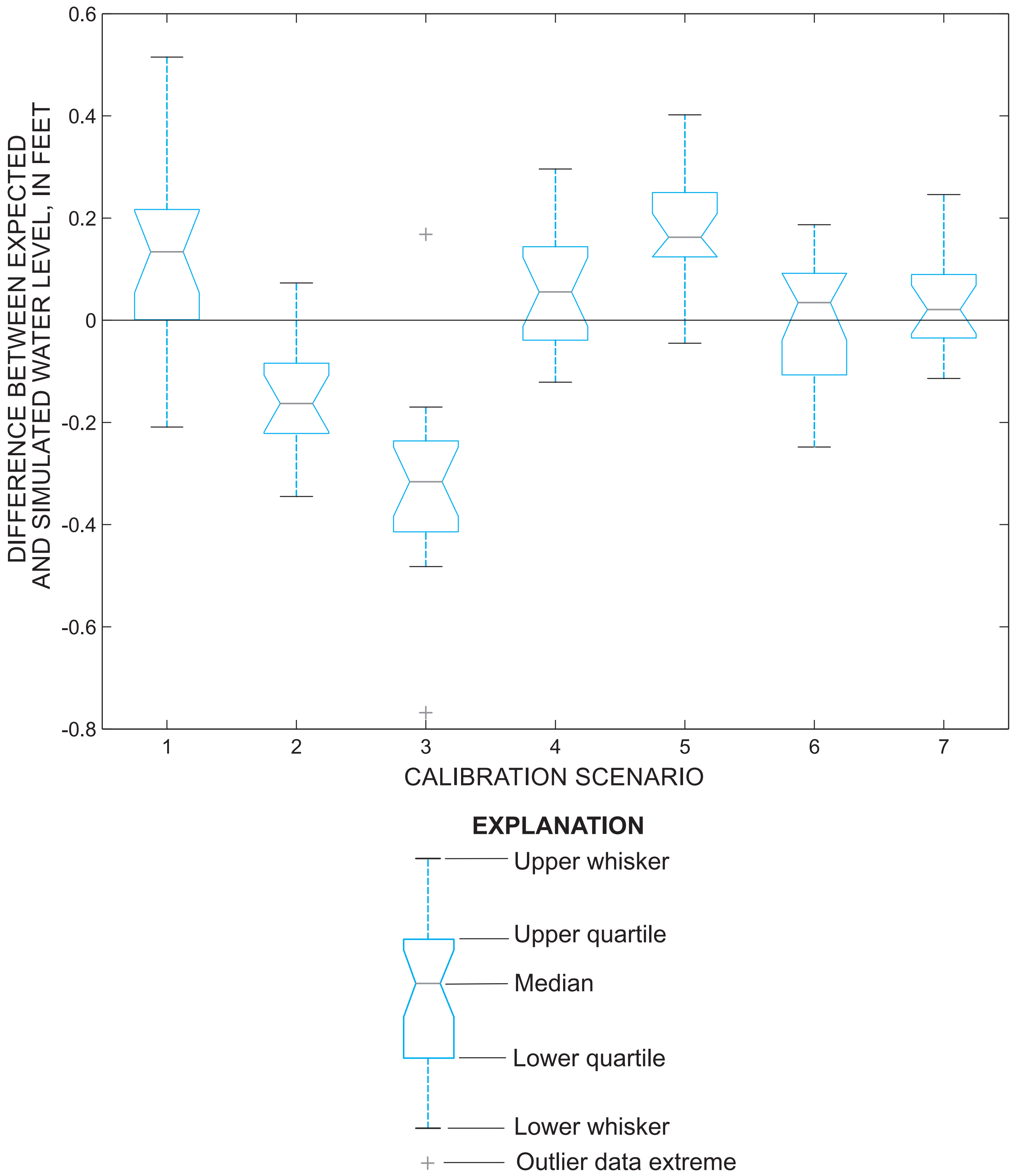


Figure 15. Distribution of water-level residuals by calibration scenario.

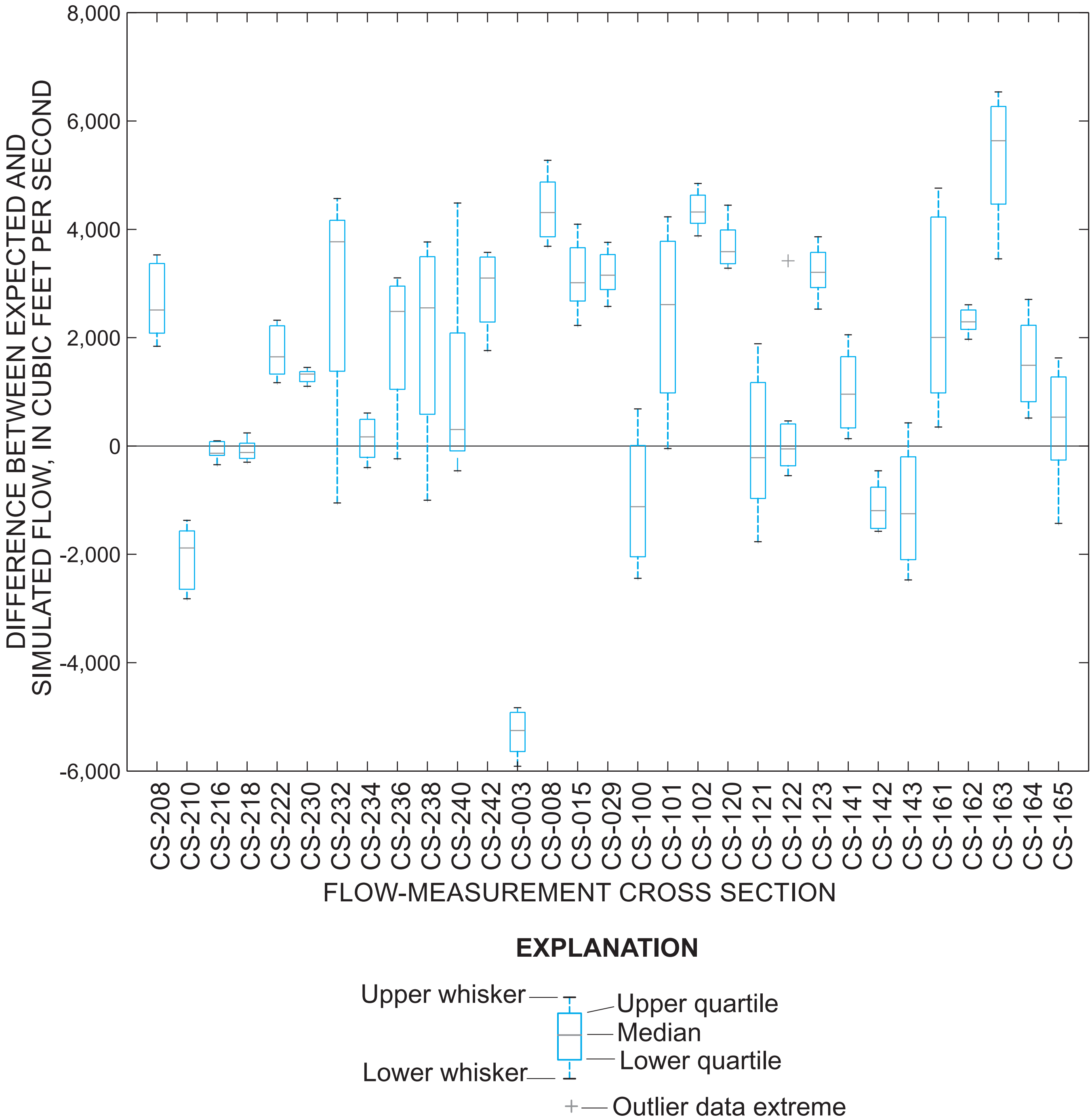


Figure 16. Distribution of flow residuals by flow-measurement cross section.

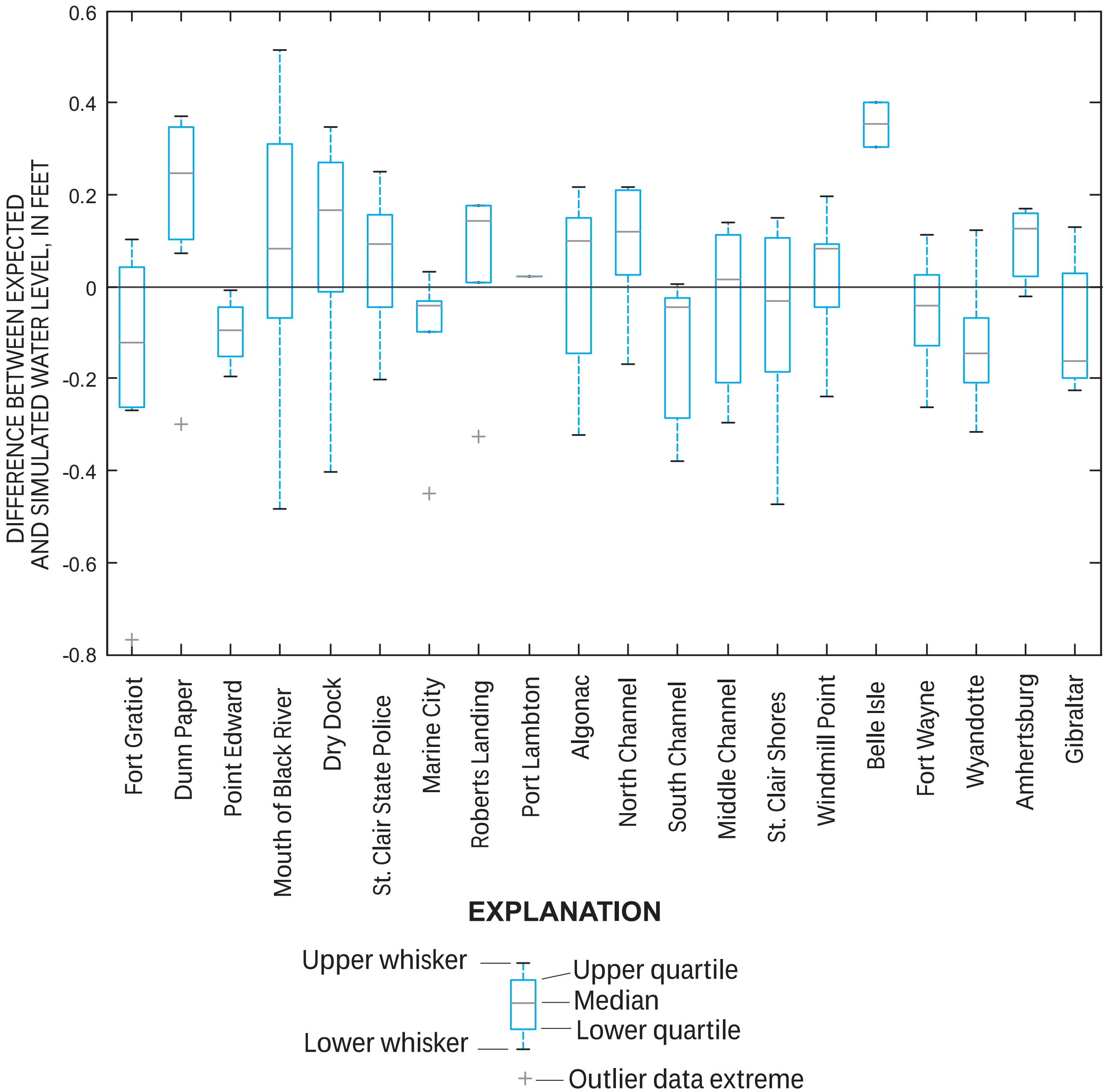


Figure 17. Distribution of water-level residuals by gaging station, St. Clair–Detroit River Waterway.

MODEL DEVELOPMENT NEEDS AND LIMITATIONS

The implementation and calibration of the hydrodynamic model of the St. Clair–Detroit River Waterway described in this report focuses on correctly distributing flows throughout the many branches of the waterway formed by islands, and on matching water levels near gaging stations. Although quantifying the accuracy of this type of simulation is a necessary component of calibration, additional model development is needed to conduct source-water assessments and to enhance emergency preparedness. In particular, more information is needed on velocity distributions, particularly near public water intakes, and on wind effects. Velocity distributions, indicated by point velocity data, can affect the time of constituent travel through the waterway, and the mixing characteristics of the flow. In addition, restrictions imposed by the model formulation, constraints on data acquisition, and limitations of computing resources need to be recognized in order to properly interpret simulation results and document the status of model development.

The model documented in this report simulates horizontal (two-dimensional, vertically averaged) velocity components and water levels at 42,936 nodes throughout the waterway. Quadratic interpolation can be used to compute velocities and water levels anywhere within the 13,783 elements formed by these nodes. Simulated flows were computed by integrating simulated (point) velocities and water levels at geometry, continuity-check lines (GCLs). The simulated flows and water levels were compared to corresponding measured values in an iterative calibration procedure that determined appropriate values of Manning's *n* (the effective channel roughness) in 25 designated material zones within the waterway. The calibrated model provides a basis for simulating flows and water levels over the range of data measured between 1996 and 2000. Faster computer processors will help determine whether changes in material zones designations can be used to reduce the number of parameters or increase the accuracy of the simulations.

The calibration procedure did not compare simulated point velocities with measured point velocities obtained during ADCP measurements. Thus, the accuracy of simulated point velocities has not been assessed. Point velocity data were not included in initial calibration efforts because the persistence and uncertainty of measured point velocity values has not been evaluated. Statistical analyses of point velocity fields are needed to determine their spatial structure, and to identify possible covariates, such as flows and water levels, that may influence their characteristics. Further calibration using point velocity data is planned.

Several model parameters can be adjusted to improve the match between simulated and measured point velocity data. Eddy viscosity and Manning's *n* control the horizontal variability of simulated velocities. In particular, lower eddy viscosity values allow greater variability in simulated velocities within a channel cross section. Lower eddy viscosity values, however, also can decrease the numerical stability of the simulations. Because eddy viscosities vary with element size and flow velocities, eddy viscosity assignments for individual elements are commonly based on either the Peclet number or Smagorinski coefficient (Donnell and others, 2000, p. 48). Future calibration efforts are planned to determine the preferred method for assigning eddy viscosities based on accuracy and stability criteria, and their appropriate parameterizations, which may vary spatially.

Horizontal velocity distributions also may be affected by local variability in channel roughness characteristics described by Manning's n. Light penetration in shallow areas may enhance vegetative growth and effectively increase Manning's *n*, thereby decreasing local velocities. Thus, future calibration efforts will attempt to determine parameters describing the depth, and perhaps seasonal, dependence of Manning's *n*.

According to Donnell and others (2000, p. 93), conventional RMA2 depth-averaged calculations of flow around a bend tends to over predict streamwise velocities on the inside bank of a river. When water flows around bend, a radial acceleration is developed that forces the surface water to the outside of the curve and the water near the bed to the inside of the curve, a phenomena that is commonly referred to as a secondary or helical flow pattern. RMA2 cannot adequately predict the effect of this behavior on the depth-averaged velocities. To improve predictions of depth-averaged velocities around curves, a secondary flow corrector, referred to as the bendway correction, was added to RMA2 in version 4.5 (Donnell and others, 2000, p. 93). The computational effectiveness of this option for improving the match between simulated and measured point velocities will be assessed as part of the future calibration efforts.

The governing equations in RMA2 (equations 1 and 2) include an empirical wind shear coefficient, ζ, and eight alternative wind shear stress formulations that provide considerable flexibility for simulating the effect of wind on flow. Wind effects are extremely difficult to implement in a two-dimensional model, however, because wind-driven currents are three-dimensional in nature (Donnell and others, 2000, p. 111). Signell, List, and Farris (2000) report that bottom wind-driven currents flow downwind along the shallow margins of the basin, but flow against the wind in the deeper regions. In this report, no assessments of wind effects on flow or water levels in the connecting channels or Lake St. Clair were made because of limited data on winds and associated current over Lake St. Clair. A planned installation of a wind station on Lake St. Clair in 2001, anticipated drifting buoy deployments in 2002, and existing water-level monitoring stations will provide a basis for selecting an appropriate wind-shear stress formulation, estimating associated parameters, and assessing the adequacy of the simulations.

In addition to calibration improvements, mesh refinements will be applied near selected public water intakes and perhaps GCLs to increase the density of nodes and improve the local accuracy of flow simulations. In addition, boundary elements will be created at selected intakes to facilitate simulation of pumping withdrawals. These refinements will provide additional detail on local two-dimensional velocity characteristics to more effectively quantify the susceptibility of public water intakes by use of particle-tracking analysis. Similarly, refinements in the model mesh at possible points of contaminant release may provide additional information to aid preparation of emergency responses.

In addition to model limitations discussed in the "Applications and Capabilities" section of this report, other constraints on model applications are likely to persist. In particular, ice commonly forms on the connecting channels and Lake St. Clair during prolonged periods of cold weather. Ice formation in the connecting channels restricts the flow area and reduces flow velocities. Although this effect might be approximated by increasing Manning's *n* values describing flow resistance, the uncertainty of simulated flows and water-levels during ice-affected periods is likely to remain high for the foreseeable future. Furthermore, there are no plans to routinely obtain flow information during ice-affected periods to provide a basis for improvements. Such flow information is needed to describe the nonlinear, highly time-dependent nature of ice-affected flow (Holtschlag and Grewal, 1998). In addition, application of flow simulation results are restricted to constituents that move with the depth-averaged water velocity; a situation that is unlikely with immiscible fluids or those having a density different from water.

SUMMARY AND CONCLUSIONS

St. Clair–Detroit River Waterway connects Lake Huron with Lake Erie in the Great Lakes basin and forms part of the international boundary between the United States and Canada. Public intakes within the waterway provide a water supply for about 6.2 million people. Michigan Department of Environmental Quality and Detroit Water and Sewerage Department, with the cooperation of U.S. Geological Survey and Detroit District of the U.S. Army Corps of Engineers, are developing a two-dimensional hydrodynamic model of the waterway to help assess the vulnerability of this water supply to contamination.

The waterway model is based on RMA2, a generalized finite-element hydrodynamic numerical model for two-dimensional (depth averaged) simulation. RMA2 is designed for far-field problems in which vertical accelerations are negligible and velocity vectors generally point in the same direction over the entire depth of the water column at any instant of time. RMA2 computations are based on a free surface (no ice conditions) and a vertically homogeneous fluid (no temperature stratification). The Surface Water Modeling System (SMS) was used to facilitate the implementation of data input files needed to describe the geometry, bathymetry, and hydraulic characteristics of the waterway for simulation with RMA2.

The model discretizes the waterway into a finite-element mesh containing 13,783 quadratic elements defined by 42,936 nodes. Flow and water-level boundary conditions are defined at the limits of the waterway to allow simulation of steady-state and transient hydrodynamic conditions. The primary flow boundary specification is at the headwaters of St. Clair River near the Fort Gratiot gaging station operated by NOAA. Additional flow boundaries are located on selected tributaries and on Lake St. Clair. A stage boundary is located at the mouth of Detroit River at the CHS gaging station near Bar Point, Ontario. Adjoining finite elements are grouped into 25 material zones. Each zone was assigned an initial value of Manning's *n*, a parameter associated with channel roughness, and eddy viscosity, a parameter that controls the numerical stability of the solution and the simulated velocity distribution. Bathymetry data defining channel and lakebed elevations were obtained from various field surveys, including a survey of the connecting channels by NOAA in 2000, and data shown on NOAA charts. The mesh was edited to meet mesh-quality criteria needed for efficient and accurate simulations.

The model was calibrated by systematically adjusting values of Manning's *n* in 25 material zones to improve the match between simulated and expected flows in major channels and water levels at gaging stations. Seven steady-state calibration scenarios were developed from among 18 flow-measurement events on St. Clair River from 1996 to 2000. The scenarios effectively spanned the available flow and water-level data. Expected flows in major channels were determined on the basis of average measured flow on St. Clair River during the calibration scenario, and on regression equations developed using data from all flow-measurement events. Expected water levels were based on the average of hourly water-level measurements during the scenario corresponding to a flow-measurement event. The universal parameter estimation code, UCODE, was used to systematically adjust model parameters, and to describe their associated uncertainty and correlation. Sensitivity analysis was used to describe the amount of information available to estimate individual parameters and to quantify the utility of information available on flows at individual cross sections and water levels at selected gaging station.

Overall, there is close agreement between simulated and expected flows and water levels. Expected flows were somewhat higher, however, than simulated flows in all scenarios because of an apparent under accounting of flows at GCLs, where simulated flow is accumulated. Other minor discrepancies between simulated and expected flows and water levels may be reduced by future changes in the material zone configurations.

Additional data collection, model calibration analysis, and grid refinements are needed to assess and enhance two-dimensional flow simulation capabilities describing the horizontal flow distributions in St. Clair and Detroit Rivers and circulation patterns in Lake St. Clair. Two-dimensional flow simulations results will be used with particle tracking analysis to assess the susceptibility of public water intakes to contaminants.

REFERENCES CITED

Deering, M.K., 1990, Practical Applications of 2-D Hydrodynamic Modeling—Proceedings of the 1990 National Conference: New York, Hydraulic Engineering, American Society of Civil Engineers, p 755–760.

Donnell B.P., Finnie, J.I., Letter, J.V., Jr., McAnally, W.H., Roig, L.C., and Thomas, W.A., 1997, Users guide to RMA2 WES Version 4.3: U.S. Army Corps of Engineers Waterway Experiment Station, 227 p.

Donnell B.P., Letter, J.V., Jr., McAnally, W.H., and Thomas, W.A., 2000, Users guide to RMA2 WES Version 4.5: U.S. Army Corps of Engineers Waterway Experiment Station, 264 p.

Environmental Modeling Research Laboratory, 1999, SMS Surface-water modeling system reference manual (version 7): Provo, Utah, Environmental Modeling Systems, Inc., 342 p.

Hauck, L.M., 1992, Hydrodynamics at mouth of Colorado River, Texas: U.S. Army Corps of Engineers Waterway Experiment Station Technical Report WES/TR/HL-92-11, 103 p.

Hill, M.C., 1998, Methods and guidelines for effective model calibration: U.S. Geological Survey Water-Resources Investigations Report 98-4005, 90 p.

Holtschlag, D.J., and Aichele, S.A., 2001, Visualization of drifting buoy deployments on St. Clair River near Public Water Intakes—October 3–5, 2000, U.S. Geological Survey Open-File Report 01-17, http://mi.water.usgs.gov/splan2/sp08903/SCRIndex.html.

Holtschlag, D.J., and Grewal, M.S., 1998, Estimating ice-affected streamflow by extended Kalman filtering: Journal of Hydrologic Engineering, July, p. 174–181.

Holtschlag, D.J., and Koschik, J.A., 2001, Steady-state flow distribution and monthly flow duration in selected branches of St. Clair and Detroit Rivers, two connecting channels of the Great Lakes: U.S. Geological Survey Water-Resources Investigations Report 01-4135, 58 p.

National Oceanic and Atmospheric Administration, 1999, Recreational chart 14853—Detroit River, Lake St. Clair, and St. Clair River: U.S. Department of Commerce, National Ocean Service, 1:15000 scale.

Poeter, E.P., and Hill, M.C., 1998, Documentation of UCODE, A computer code for universal inverse modeling: U.S. Geological Survey Water-Resources Investigations Report 98-4080, 116 p.

Schwab, D.J., Clites, A.H., Murthy, C.R., Sandall, J.E., Meadows, L.A., and Meadows, G.A., 1989, The effect of wind on transport and circulation in Lake St. Clair: Journal of Geophysical Research, v. 94, no. C4, April, p. 4947–4958.

Sellinger, C.E., and Quinn, F.H., 2001, Assessment of impacts of increased weed growth on Detroit River flows: National Oceanic and Atmospheric Administration Technical Memorandum GLERL-119, 12 p.

Signell, R.P., List, J.H., and Farris, A.S., 2000, Bottom currents and sediment transport in Long Island Sound—A Modeling Study: Journal of Coastal Research, v. 16, no. 3, p. 551–566.

Soong, T.W., and Bhowmik, N.G., 1993, Two-dimensional hydrodynamic modeling of a reach of the Mississippi River in Pool 19: Champaign, Illinois State Water Survey Division Report no. EMTC93R003, 14 p.

Tsanis, I.K., Shen, Huihua, and Venkatesh, S., 1996, Water currents in the St. Clair and Detroit Rivers: Journal of Great Lakes Research, v. 22, no. 2, p. 213–223.

U.S. Army Corps of Engineers, 2000, Corpscon for Windows (v. 5.11.08): U.S. Army Corps of Engineers Topographic Engineering Center, Alexandria, Va.

Williamson, D.C., Scott R.D., and Lord, Stephen, 1997, Numerical modeling of the St. Clair/Detroit River system and seasonal variations in head loss, *in* Proceedings of the 1997 Canadian Coastal Conference, Guelph, Ontario, May 21–24, 1997: Canadian Coastal Science and Engineering Association, p. 176–184.

Appendix A.
UNI File used in UCODE Parameter Estimation Analysis of the St. Clair–Detroit River Model

UCODE Files

```
#   UNI file for SCD8.
3       # Phase 1 provides parameter substitution and forward modeling
#         using the starting parameter values specified in the prepare file
### Sensitivity and regression control
1       # Differencing for sensitivity calculations: (1-> forward; 2-> central)
0.02    # Tolerance, convergence criterion based on changes in estimated parameter values
0.02    # SOSR, convergence criterion based on changes in model fit
0       # Do not apply quasi-Newton updating
5       # Maximum number of iterations
0.5     # Maximum fractional parameter changes
d:\usgs\wrdapp\ucode3.02\bin\mrdrive       # Path and name of inverse code
#
21      # Number of application models (one for each steady-state simulation)
d:\usgs\sms\models\rma2v435.exe < SCD8.SS1.bat
del SCD8.SS1.ihot
ren SCD8.SS1.ohot SCD8.SS1.ihot
d:\usgs\sms\models\rma2v435.exe < SCD8.SS2.bat
del SCD8.SS2.ihot
ren SCD8.SS2.ohot SCD8.SS2.ihot
d:\usgs\sms\models\rma2v435.exe < SCD8.SS3.bat
del SCD8.SS3.ihot
ren SCD8.SS3.ohot SCD8.SS3.ihot
d:\usgs\sms\models\rma2v435.exe < SCD8.SS4.bat
del SCD8.SS4.ihot
ren SCD8.SS4.ohot SCD8.SS4.ihot
d:\usgs\sms\models\rma2v435.exe < SCD8.SS5.bat
del SCD8.SS5.ihot
ren SCD8.SS5.ohot SCD8.SS5.ihot
d:\usgs\sms\models\rma2v435.exe < SCD8.SS6.bat
del SCD8.SS6.ihot
ren SCD8.SS6.ohot SCD8.SS6.ihot
d:\usgs\sms\models\rma2v435.exe < SCD8.SS7.bat
del SCD8.SS7.ihot
ren SCD8.SS7.ohot SCD8.SS7.ihot
#
#       Printing options
1       # Scale sensitivity: (0, none; 1, dimensionless; 1% scaled; 3, 1 and 2);
0       # Print-intermediate (0, no print; 1, print);
1       # Print graphing files (0, no; 1, yes);
3       # Number of sets of normally distributed random numbers to generate
#
#       OBSERVATIONS
# Obsname   value   statistic    stat-flag   plot-sym
# Scenario 1: Steady-state flow simulation for Nov. 3-5, 1999
# St. Clair River Flow
SS1QCS208    55557     1236         1           1        # CG 04
SS1QCS210   118133     1236         1           1        # CG 05
SS1QCS216   144166      889         1           1        # CG 08
SS1QCS218    30121      889         1           1        # CG 09
SS1QCS222     6399      625         1           1        # CG 11
SS1QCS230   167888      625         1           1        # CG 12
SS1QCS232    78880     2225         1           1        # CG 13
SS1QCS240    57495     1673         1           1        # CG 17
SS1QCS242    31513     1833         1           1        # CG 18
SS1QCS234     6356      832         1           1        # CG 14
SS1QCS236    42615     2217         1           1        # CG 15
SS1QCS238    29909     2414         1           1        # CG 16
```

```
# Detroit River Flows
SS1QCS003   134187     1770         1           1        # CG 21
SS1QCS008    48373     1770         1           1        # CG 22
SS1QCS015    55684     1460         1           1        # CG 24
SS1QCS029   126876     1460         1           1        # CG 25
SS1QCS100    47784     1179         1           1        # CG 29
SS1QCS101    95824     1110         1           1        # CG 30
SS1QCS102    39264      929         1           1        # CG 31
SS1QCS120    40517     1776         1           1        # CG 32
SS1QCS121     9572     2050         1           1        # CG 33
SS1QCS122    48136     1764         1           1        # CG 34
SS1QCS123    84647     2197         1           1        # CG 35
SS1QCS143    20396     1701         1           1        # CG 37
SS1QCS165    64252     2269         1           1        # CG 42
SS1QCS142    12201     2146         1           1        # CG 36
SS1QCS164     8195     2009         1           1        # CG 41
SS1QCS141    21484     2431         1           1        # CG 54
SS1QCS163    38854     2886         1           1        # CG 40
SS1QCS161    21531     2017         1           1        # CG 38
SS1QCS162     9524     1027         1           1        # CG 39
# Stages                                                   Gage     Node
SS1SFG      577.724    0.396        1           1        # NOAA 9014098  42935
SS1SDP      577.335    0.325        1           1        # NOAA 9014096  42839
SS1SMBR     577.277    0.233        1           1        # NOAA 9014090  41658
SS1SDD      576.727    0.330        1           1        # NOAA 9014087  40852
SS1SSCT     575.550    0.183        1           1        # NOAA 9014080  37154
SS1SMC      574.747    0.100        1           1        # USACE SCR at Marine City; Node 35169
SS1SRL      574.415    0.093        1           1        # USACE SCR at Roberts Landing; Node 32920
SS1SALG     574.276    0.063        1           1        # NOAA 9014070  31568
SS1SNorC    574.169    0.051        1           1        # USACE North Channel of St. Clair River; Node
29956
SS1SSouC    573.842    0.060        1           1        # USACE South Channel of St. Clair River; 29239
SS1SMidC    573.793    0.046        1           1        # USACE Middle Channel of St. Clair River; 25939
SS1SSCS     573.335    0.119        1           1        # NOAA 9034052  18594
SS1SWP      573.039    0.119        1           1        # NOAA 9044049  16127
SS1SBelle   572.970    0.149        1           1        # USACE Detroit River at Belle Isle; 15300
SS1SFW      572.247    0.238        1           1        # NOAA 9044036  12815
SS1SWYN     571.797    0.304        1           1        # NOAA 9044030   8923
SS1SAmher   571.507    0.334        1           1        # CHS on Detroit River at Amherstburg; Node 6141
SS1SGIB     570.381    0.641        1           1        # NOAA 9044020   2803
#
# Scenario 2: Steady-state flow simulation for Oct. 26-29, 1998
# St. Clair River Flow
SS2QCS208    63820     1282         1           1        # CG 04
SS2QCS210   130733     1282         1           1        # CG 05
SS2QCS216   160258      946         1           1        # CG 08
SS2QCS218    34893      946         1           1        # CG 09
SS2QCS222     8023      654         1           1        # CG 11
SS2QCS230   187128      654         1           1        # CG 12
SS2QCS232    86231     2310         1           1        # CG 13
SS2QCS240    66226     1744         1           1        # CG 17
SS2QCS242    34671     1944         1           1        # CG 18
SS2QCS234     6948      907         1           1        # CG 14
SS2QCS236    46586     2388         1           1        # CG 15
SS2QCS238    32696     2624         1           1        # CG 16
# Detroit River Flows
SS2QCS003   149522     1973         1           1        # CG 21
SS2QCS008    53901     1973         1           1        # CG 22
SS2QCS015    64196     1503         1           1        # CG 24
```

```
SS2QCS029   139228     1503         1           1        # CG 25
SS2QCS100    53236     1313         1           1        # CG 29
SS2QCS101   105960     1185         1           1        # CG 30
SS2QCS102    44540      987         1           1        # CG 31
SS2QCS120    45140     1979         1           1        # CG 32
SS2QCS121    14495     2283         1           1        # CG 33
SS2QCS122    51722     1870         1           1        # CG 34
SS2QCS123    92379     2277         1           1        # CG 35
SS2QCS143    22259     1858         1           1        # CG 37
SS2QCS165    70120     2502         1           1        # CG 42
SS2QCS142    13316     2342         1           1        # CG 36
SS2QCS164     8943     2192         1           1        # CG 41
SS2QCS141    23157     2623         1           1        # CG 54
SS2QCS163    41880     3116         1           1        # CG 40
SS2QCS161    26574     2216         1           1        # CG 38
SS2QCS162    11078     1105         1           1        # CG 39
# Stages
SS2SFG      578.902    0.207        1           1        # 9014098
SS2SDP      578.470    0.189        1           1        # 9014096
SS2SPE      578.196    0.159        1           1        # CHS Point Edward
SS2SMBR     578.102    0.163        1           1        # 9014090
SS2SDD      577.742    0.147        1           1        # 9014087
SS2SSCT     576.537    0.096        1           1        # 9014080
SS2SALG     575.083    0.025        1           1        # 9014070
SS2SSouC    574.812    0.031        1           1        # USACE South Channel of St. Clair River; 29239
SS2SMidC    574.650    0.022        1           1        # USACE Middle Channel of St. Clair River; 25939
SS2SSCS     574.533    0.036        1           1        # 9034052
SS2SWP      574.297    0.050        1           1        # 9044049
SS2SFW      573.553    0.064        1           1        # 9044036
SS2SWYN     573.129    0.085        1           1        # 9044030
SS2SAmher   572.848    0.097        1           1        # CHS on Detroit River at Amherstburg; Node 6141
SS2SGIB     571.900    0.161        1           1        # 9044020
#
# Scenario 3: Steady-state flow simulation for July 8-10, 1996
# St. Clair River Flow
SS3QCS208    73406     1449         1           1        # CG 04
SS3QCS210   144342     1449         1           1        # CG 05
SS3QCS216   177855     1083         1           1        # CG 08
SS3QCS218    40490     1083         1           1        # CG 09
SS3QCS222    10043      741         1           1        # CG 11
SS3QCS230   208302      741         1           1        # CG 12
SS3QCS232    93919     2663         1           1        # CG 13
SS3QCS240    76344     2015         1           1        # CG 17
SS3QCS242    38040     2218         1           1        # CG 18
SS3QCS234     7568      991         1           1        # CG 14
SS3QCS236    50740     2646         1           1        # CG 15
SS3QCS238    35611     2877         1           1        # CG 16
# Detroit River Flows
SS3QCS003   166571     2197         1           1        # CG 21
SS3QCS008    60047     2197         1           1        # CG 22
SS3QCS015    74176     1675         1           1        # CG 24
SS3QCS029   152442     1675         1           1        # CG 25
SS3QCS100    59296     1463         1           1        # CG 29
SS3QCS101   117038     1331         1           1        # CG 30
SS3QCS102    50596     1109         1           1        # CG 31
SS3QCS120    50278     2204         1           1        # CG 32
SS3QCS121    20889     2543         1           1        # CG 33
SS3QCS122    55251     2113         1           1        # CG 34
```

```
SS3QCS123   100512     2594         1           1        # CG 35
SS3QCS143    24218     2027         1           1        # CG 37
SS3QCS165    76294     2750         1           1        # CG 42
SS3QCS142    14488     2548         1           1        # CG 36
SS3QCS164     9730     2385         1           1        # CG 41
SS3QCS141    24831     2829         1           1        # CG 54
SS3QCS163    44907     3386         1           1        # CG 40
SS3QCS161    32964     2500         1           1        # CG 38
SS3QCS162    12756     1225         1           1        # CG 39
# Stages
SS3SFG      580.003    0.156        1           1        # 9014098
SS3SDP      579.554    0.134        1           1        # 9014096
SS3SMBR     579.187    0.131        1           1        # 9014090
SS3SDD      578.819    0.122        1           1        # 9014087
SS3SSCT     577.647    0.100        1           1        # 9014080
SS3SMC      576.854    0.071        1           1        # USACE at Marine City
SS3SRL      576.422    0.021        1           1        # USACE at Roberts Landing
SS3SALG     576.203    0.071        1           1        # 9014070
SS3SNorC    576.229    0.051        1           1        # USACE North Channel of St. Clair River; Node
29956
SS3SSouC    576.044    0.069        1           1        # USACE South Channel of St. Clair River; 29239
SS3SMidC    575.873    0.044        1           1        # USACE Middle Channel of St. Clair River; 25939
SS3SSCS     575.731    0.053        1           1        # 9034052
SS3SWP      575.459    0.059        1           1        # 9044049
SS3SFW      574.708    0.111        1           1        # 9044036
SS3SWYN     574.297    0.148        1           1        # 9044030
SS3SAmher   574.257    0.170        1           1        # CHS on Detroit River at Amherstburg; Node 6141
SS3SGIB     573.107    0.293        1           1        # 9044020
#
# Scenario 4: Steady-state flow simulation for August 4-6, 1997
# St. Clair River Flow
SS4QCS208    75647     1511         1           1        # CG 04
SS4QCS210   147380     1511         1           1        # CG 05
SS4QCS216   181818     1127         1           1        # CG 08
SS4QCS218    41807     1127         1           1        # CG 09
SS4QCS222    10535      773         1           1        # CG 11
SS4QCS230   213090      773         1           1        # CG 12
SS4QCS232    95599     2783         1           1        # CG 13
SS4QCS240    78706     2113         1           1        # CG 17
SS4QCS242    38786     2304         1           1        # CG 18
SS4QCS234     7703     1010         1           1        # CG 14
SS4QCS236    51647     2715         1           1        # CG 15
SS4QCS238    36248     2938         1           1        # CG 16
# Detroit River Flows
SS4QCS003   170452     2248         1           1        # CG 21
SS4QCS008    61446     2248         1           1        # CG 22
SS4QCS015    76523     1740         1           1        # CG 24
SS4QCS029   155374     1740         1           1        # CG 25
SS4QCS100    60676     1497         1           1        # CG 29
SS4QCS101   119531     1375         1           1        # CG 30
SS4QCS102    52003     1148         1           1        # CG 31
SS4QCS120    51448     2255         1           1        # CG 32
SS4QCS121    22480     2602         1           1        # CG 33
SS4QCS122    55987     2185         1           1        # CG 34
SS4QCS123   102295     2703         1           1        # CG 35
SS4QCS143    24648     2065         1           1        # CG 37
SS4QCS165    77647     2805         1           1        # CG 42
SS4QCS142    14745     2593         1           1        # CG 36
SS4QCS164     9903     2427         1           1        # CG 41
```

```
SS4QCS141    25185     2874         1           1        # CG 54
SS4QCS163    45547     3448         1           1        # CG 40
SS4QCS161    34541     2581         1           1        # CG 38
SS4QCS162    13123     1257         1           1        # CG 39
# Stages
SS4SFG      581.230    0.135        1           1        # 9014098
SS4SDP      580.705    0.110        1           1        # 9014096
SS4SPE      580.363    0.120        1           1        # CHS Point Edward
SS4SMBR     580.320    0.099        1           1        # 9014090
SS4SDD      579.961    0.093        1           1        # 9014087
SS4SSCT     578.682    0.064        1           1        # 9014080
SS4SMC      577.867    0.052        1           1        # USACE at Marine City
SS4SRL      577.505    0.040        1           1        # USACE at Roberts Landing
SS4SALG     577.241    0.025        1           1        # 9014070
SS4SNorC    577.138    0.038        1           1        # USACE North Channel of St. Clair River; Node
29956
SS4SSouC    577.010    0.036        1           1        # USACE South Channel of St. Clair River; 29239
SS4SMidC    576.827    0.030        1           1        # USACE Middle Channel of St. Clair River; 25939
SS4SSCS     576.770    0.033        1           1        # 9034052
SS4SWP      576.485    0.054        1           1        # 9044049
SS4SFW      575.709    0.051        1           1        # 9044036
SS4SWYN     575.275    0.060        1           1        # 9044030
SS4SAmher   574.988    0.069        1           1        # CHS on Detroit River at Amherstburg; Node 6141
SS4SGIB     574.138    0.117        1           1        # 9044020
#
# Scenario 5: Steady-state flow simulation for Sep. 23-24, 1999
# St. Clair River Flow
SS5QCS208    56253     1238         1           1        # CG 04
SS5QCS210   119228     1238         1           1        # CG 05
SS5QCS216   145557      892         1           1        # CG 08
SS5QCS218    30521      892         1           1        # CG 09
SS5QCS222     6531      627         1           1        # CG 11
SS5QCS230   169547      627         1           1        # CG 12
SS5QCS232    79527     2225         1           1        # CG 13
SS5QCS240    58231     1675         1           1        # CG 17
SS5QCS242    31789     1838         1           1        # CG 18
SS5QCS234     6408      838         1           1        # CG 14
SS5QCS236    42965     2229         1           1        # CG 15
SS5QCS238    30154     2432         1           1        # CG 16
# Detroit River Flows
SS5QCS003   135504     1788         1           1        # CG 21
SS5QCS008    48848     1788         1           1        # CG 22
SS5QCS015    56397     1462         1           1        # CG 24
SS5QCS029   127954     1462         1           1        # CG 25
SS5QCS100    48252     1190         1           1        # CG 29
SS5QCS101    96700     1115         1           1        # CG 30
SS5QCS102    39711      933         1           1        # CG 31
SS5QCS120    40914     1794         1           1        # CG 32
SS5QCS121     9964     2070         1           1        # CG 33
SS5QCS122    48459     1769         1           1        # CG 34
SS5QCS123    85327     2197         1           1        # CG 35
SS5QCS143    20559     1714         1           1        # CG 37
SS5QCS165    64767     2289         1           1        # CG 42
SS5QCS142    12299     2163         1           1        # CG 36
SS5QCS164     8260     2025         1           1        # CG 41
SS5QCS141    21634     2448         1           1        # CG 54
SS5QCS163    39125     2905         1           1        # CG 40
SS5QCS161    21939     2034         1           1        # CG 38
SS5QCS162     9658     1033         1           1        # CG 39
```

```
# Stages                                                    Gage     Node
SS5SFG      577.992    0.191        1           1         # NOAA 9014098  42935
SS5SDP      577.615    0.161        1           1         # NOAA 9014096  42839
SS5SMBR     577.423    0.144        1           1         # NOAA 9014090  41658
SS5SDD      576.967    0.107        1           1         # NOAA 9014087  40852
SS5SSCT     575.843    0.075        1           1         # NOAA 9014080  37154
SS5SMC      574.980    0.068        1           1         # USACE SCR at Marine City; Node 35169
SS5SRL      574.730    0.064        1           1         # USACE SCR at Roberts Landing; Node 32920
SS5SALG     574.538    0.059        1           1         # NOAA 9014070  31568
SS5SNorC    574.496    0.067        1           1         # USACE North Channel of St. Clair River; Node
29956
SS5SSouC    574.227    0.115        1           1         # USACE South Channel of St. Clair River; 29239
SS5SMidC    574.128    0.065        1           1         # USACE Middle Channel of St. Clair River; 25939
SS5SSCS     573.878    0.060        1           1         # NOAA 9034052  18594
SS5SWP      573.591    0.102        1           1         # NOAA 9044049  16127
SS5SBelle   573.516    0.105        1           1         # USACE Detroit River at Belle Isle; 15300
SS5SFW      572.881    0.130        1           1         # NOAA 9044036  12815
SS5SWYN     572.562    0.120        1           1         # NOAA 9044030   8923
SS5SAmher   572.161    0.194        1           1         # CHS on Detroit River at Amherstburg; Node 6141
SS5SGIB     571.314    0.304        1           1         # NOAA 9044020   2803
#
#
# Scenario 6: Steady-state flow simulation for May 5-7, 1997
# St. Clair River Flow
SS6QCS208    71916     1413         1           1         # CG 04
SS6QCS210   142292     1413         1           1         # CG 05
SS6QCS216   175189     1056         1           1         # CG 08
SS6QCS218    39616     1056         1           1         # CG 09
SS6QCS222     9720      722         1           1         # CG 11
SS6QCS230   205085      722         1           1         # CG 12
SS6QCS232    92778     2590         1           1         # CG 13
SS6QCS240    74772     1957         1           1         # CG 17
SS6QCS242    37535     2165         1           1         # CG 18
SS6QCS234     7476      978         1           1         # CG 14
SS6QCS236    50123     2602         1           1         # CG 15
SS6QCS238    35179     2837         1           1         # CG 16
# Detroit River Flows
SS6QCS003   163969     2163         1           1         # CG 21
SS6QCS008    59109     2163         1           1         # CG 22
SS6QCS015    72617     1637         1           1         # CG 24
SS6QCS029   150461     1637         1           1         # CG 25
SS6QCS100    58371     1440         1           1         # CG 29
SS6QCS101   115360     1304         1           1         # CG 30
SS6QCS102    49658     1086         1           1         # CG 31
SS6QCS120    49494     2170         1           1         # CG 32
SS6QCS121    19850     2504         1           1         # CG 33
SS6QCS122    54743     2068         1           1         # CG 34
SS6QCS123    99302     2529         1           1         # CG 35
SS6QCS143    23927     2002         1           1         # CG 37
SS6QCS165    75375     2713         1           1         # CG 42
SS6QCS142    14313     2517         1           1         # CG 36
SS6QCS164     9613     2356         1           1         # CG 41
SS6QCS141    24588     2798         1           1         # CG 54
SS6QCS163    44468     3344         1           1         # CG 40
SS6QCS161    31933     2450         1           1         # CG 38
SS6QCS162    12506     1204         1           1         # CG 39
# Stages                                                    Gage     Node
SS6SFG      580.580    0.274        1           1         # NOAA 9014098  42935
SS6SDP      580.131    0.220        1           1         # NOAA 9014096  42839
```

```
SS6SPE      579.860    0.214        1           1        # CHS Point Edward 42476
SS6SMBR     579.788    0.202        1           1        # NOAA 9014090  41658
SS6SDD      579.423    0.172        1           1        # NOAA 9014087  40852
SS6SSCT     578.182    0.099        1           1        # NOAA 9014080  37154
SS6SMC      577.420    0.089        1           1        # USACE SCR at Marine City; Node 35169
SS6SRL      577.115    0.102        1           1        # USACE SCR at Roberts Landing; Node 32920
SS6SALG     576.903    0.070        1           1        # NOAA 9014070  31568
SS6SNorC    576.759    0.104        1           1        # USACE North Channel of St. Clair River; Node
29956
SS6SSouC    576.672    0.089        1           1        # USACE South Channel of St. Clair River; 29239
SS6SMidC    576.508    0.076        1           1        # USACE Middle Channel of St. Clair River; 25939
SS6SSCS     576.339    0.087        1           1        # NOAA 9034052  18594
SS6SWP      576.111    0.124        1           1        # NOAA 9044049  16127
SS6SFW      575.314    0.140        1           1        # NOAA 9044036  12815
SS6SWYN     574.882    0.176        1           1        # NOAA 9044030   8923
SS6SAmher   574.624    0.198        1           1        # CHS on Detroit River at Amherstburg; Node 6141
SS6SGIB     573.710    0.351        1           1        # NOAA 9044020   2803
#
#
# Scenario 7: Steady-state flow simulation for Sep. 21-24, 1998
# St. Clair River Flow
SS7QCS208    65379     1299         1           1        # CG 04
SS7QCS210   133017     1299         1           1        # CG 05
SS7QCS216   163195      963         1           1        # CG 08
SS7QCS218    35799      963         1           1        # CG 09
SS7QCS222     8342      663         1           1        # CG 11
SS7QCS230   190652      663         1           1        # CG 12
SS7QCS232    87539     2348         1           1        # CG 13
SS7QCS240    67873     1772         1           1        # CG 17
SS7QCS242    35240     1977         1           1        # CG 18
SS7QCS234     7054      921         1           1        # CG 14
SS7QCS236    47293     2425         1           1        # CG 15
SS7QCS238    33192     2664         1           1        # CG 16
# Detroit River Flows
SS7QCS003   152347     2010         1           1        # CG 21
SS7QCS008    54919     2010         1           1        # CG 22
SS7QCS015    65811     1520         1           1        # CG 24
SS7QCS029   141455     1520         1           1        # CG 25
SS7QCS100    54240     1338         1           1        # CG 29
SS7QCS101   107809     1204         1           1        # CG 30
SS7QCS102    45529     1002         1           1        # CG 31
SS7QCS120    45991     2016         1           1        # CG 32
SS7QCS121    15487     2327         1           1        # CG 33
SS7QCS122    55340     1902         1           1        # CG 34
SS7QCS123    93760     2312         1           1        # CG 35
SS7QCS143    22591     1886         1           1        # CG 37
SS7QCS165    71169     2543         1           1        # CG 42
SS7QCS142    13515     2377         1           1        # CG 36
SS7QCS164     9077     2225         1           1        # CG 41
SS7QCS141    23448     2658         1           1        # CG 54
SS7QCS163    42407     3160         1           1        # CG 40
SS7QCS161    27574     2257         1           1        # CG 38
SS7QCS162    11362     1123         1           1        # CG 39
# Stages                                                   Gage      Node
SS7SFG      579.495    0.191        1           1        # NOAA 9014098  42935
SS7SDP      579.052    0.168        1           1        # NOAA 9014096  42839
SS7SPE      578.800    0.148        1           1        # CHS Point Edward 42476
SS7SMBR     578.718    0.153        1           1        # NOAA 9014090  41658
SS7SDD      578.370    0.135        1           1        # NOAA 9014087  40852
```

```
SS7SSCT     577.176    0.086        1           1        # NOAA 9014080  37154
SS7SMC      576.405    0.065        1           1        # USACE SCR at Marine City; Node 35169
SS7SPL      575.927    0.049        1           1        # CHS at Port Lambton
SS7SALG     575.753    0.046        1           1        # NOAA 9014070  31568
SS7SSouC    575.502    0.055        1           1        # USACE South Channel of St. Clair River; 29239
SS7SMidC    575.335    0.048        1           1        # USACE Middle Channel of St. Clair River; 25939
SS7SSCS     575.198    0.050        1           1        # NOAA 9034052  18594
SS7SWP      574.983    0.096        1           1        # NOAA 9044049  16127
SS7SFW      574.246    0.111        1           1        # NOAA 9044036  12815
SS7SWYN     573.830    0.142        1           1        # NOAA 9044030   8923
SS7SAmher   573.551    0.160        1           1        # CHS on Detroit River at Amherstburg; Node 6141
SS7SGIB     572.742    0.224        1           1        # NOAA 9044020   2803
#
END
```

Appendix B.
PREPARE Input File used in UCODE Parameter Estimation Analysis of the St. Clair–Detroit River Model

```
# Prepare Input File for the St. Clair - Detroit River System
#
# No function file
F no
#
# List of template files and associated model input files
<SCD8.SS1.tpl
>SCD8.SS1.bc
<SCD8.SS2.tpl
>SCD8.SS2.bc
<SCD8.SS3.tpl
>SCD8.SS3.bc
<SCD8.SS4.tpl
>SCD8.SS4.bc
<SCD8.SS5.tpl
>SCD8.SS5.bc
<SCD8.SS6.tpl
>SCD8.SS6.bc
<SCD8.SS7.tpl
>SCD8.SS7.bc
#
# Parameter
/!SCRUpper,,!  0.0286721 0.01  0.05  0.01  %12.9f  1  1
/!SCRDryDock!  0.0253656 0.01  0.05  0.01  %12.9f  1  1
/!SCRInterIs!  0.0233593 0.01  0.05  0.01  %12.9f  1  1
/!SCRAlgonac!  0.0216357 0.01  0.05  0.01  %12.9f  1  1
/!SCRFlats,,!  0.0390826 0.01  0.05  0.01  %12.9f  1  1
/!SCRFawnIsE!  0.0211818 0.01  0.05  0.01  %12.9f  1  1
/!ChenalEcar!  0.0153055 0.01  0.05  0.01  %12.9f  1  1
/!SCRNorth,,!  0.0252233 0.01  0.05  0.01  %12.9f  1  1
/!SCRMiddle,!  0.0199496 0.01  0.05  0.01  %12.9f  1  1
/!SCRCutoff,!  0.0293515 0.01  0.05  0.01  %12.9f  1  1
/!BassettCh,!  0.0227179 0.01  0.05  0.01  %12.9f  1  1
/!LakStClair!  0.0238171 0.01  0.05  0.01  %12.9f  1  1
/!DETUpper,,!  0.0198704 0.01  0.05  0.01  %12.9f  1  1
/!DETBelleIN!  0.0214061 0.01  0.05  0.01  %12.9f  1  1
/!DETRRouge,!  0.0184265 0.01  0.05  0.01  %12.9f  1  1
/!DETFightIs!  0.0312344 0.01  0.05  0.01  %12.9f  1  1
/!DETStonyIs!  0.0490775 0.01  0.05  0.01  %12.9f  1  1
/!DETTrenton!  0.0365092 0.01  0.05  0.01  %12.9f  1  1
/!DETSugarW,!  0.0472579 0.01  0.05  0.01  %12.9f  1  1
/!DETBobloIs!  0.0677871 0.01  0.10  0.01  %12.9f  1  1
/!DETLivChLo!  0.0315868 0.01  0.05  0.01  %12.9f  1  1
/!DETLivChUp!  0.0172790 0.01  0.05  0.01  %12.9f  1  1
/!DETAmhChUp!  0.0250071 0.01  0.05  0.01  %12.9f  1  1
/!DETAmhChLo!  0.0339551 0.01  0.05  0.01  %12.9f  1  1
/!DETSugarE,!  0.0318956 0.01  0.05  0.01  %12.9f  1  1
#
END
```

Appendix C.
Example of TEMPLATE Files used to Generate Control Files in the UCODE Parameter Estimation Analysis of the St. Clair–Detroit River Model

```
T1 St. Clair–Detroit River Waterway
T2 SCD8 - SCD7 after applying fixslope
T3 Steady State Low-Flow Run for Nov. 3-5, 1999
SI  0
$L  63  62  60  0  0  3  0
$M  1
TR  0 -1 1 0
GCL    1      1      3      5      7      9     11
GCL          13     15     17     19     21     23
GCL          25     27     29     31     33     35
GCL          37     39     41     43     45     47
GCL          49     51     53     55     57     59
GCL          61     63     65     67     69     71
GCL          73     75  -1
GCL    2  41588  41585  41582  41579  41576  41573
GCL       41567  41561  41559  41564  41570  -1
GCL    3  39811  39808  39805  39799  39757  39748
GCL       39742  39739  39733  39731  39736  39745
GCL       39751  -1
GCL    4  39224  39222  39227  39230  39233  39236  -1
GCL    5  39265  39262  39259  39256  39253  39250
GCL       39247  39244  39241  39239  -1
GCL    6  37154  37151  37148  37145  37142  37139
GCL       37133  37127  37125  37130  37136  -1
GCL    7  34754  34751  34748  34745  34742  34739
GCL       34733  34727  34725  34730  34736  -1
GCL    8  34241  34238  34235  34232  34229  34226
GCL       34223  34220  34218  -1
GCL    9  34166  34164  34169  34172  34180  -1
GCL   10  33077  33074  33071  33068  33065  33062
GCL       33056  33050  33048  33053  33059  -1
GCL   11  32176  32178  32181  -1
GCL   12  31582  31471  31372  31281  31204  31189
GCL       31186  31183  31177  31171  31169  31174
GCL       31180  -1
GCL   13  29065  29062  29056  29050  29048  29053
GCL       29059  -1
GCL   14  27674  27676  -1
GCL   15  24097  24094  24091  24089  -1
GCL   16  25491  25177  24886  24888  -1
GCL   17  29903  29901  29906  29909  29912  -1
GCL   18  30101  30098  30095  30093  -1
GCL   19  25945  25942  25939  25937  -1
GCL   20  27780  27778  27783  -1
GCL   21  16080  16078  16043  16041  16046  16049
GCL       16052  16055  16058  16061  -1
GCL   22  16066  16064  16069  16072  16075  -1
GCL   23  15824  15821  15790  15766  15702  15646
GCL       15649  15652  15661  15664  15667  15670
GCL       15673  15676  15679  15682  -1
GCL   24  15593  15590  15587  15584  15581  15579  -1
GCL   25  14971  14969  14974  14977  14980  14983
GCL       14986  14989  14992  14995  -1
GCL   26  14097  14091  14084  14082  14076  14070
GCL       14068  14073  14079  14088  14094  14100
GCL       14103  14106  14109  14112  -1
GCL   27  12813  12807  12801  12795  12789  12787
GCL       12792  12798  12804  12810  12816  12819
```

```
GCL       12822  -1
GCL   28  11864  11858  11852  11846  11837  11835
GCL       11842  11902  11911  11917  11923  11929
GCL       11980  -1
GCL   29   9785   9779   9773   9767   9765  -1
GCL   30  10113  10111  10116  10119  10123  10126
GCL       10129  -1
GCL   31  10957  10955  10960  10963  10966  -1
GCL   32   8199   8196   8193   8190   8188  -1
GCL   33   4833   4827   4821   4819   4824  -1
GCL   34   4260   4258   4263   4266   4269  -1
GCL   35   5394   5391   5388   5382   5376   5374
GCL        5379   5385  -1
GCL   36   4057   4051   4046   4044   3955  -1
GCL   37   4057   4168   4275   4376   4396  -1
GCL   38   2331   2334   2338   2342   2345   2464  -1
GCL   39   2225   2228  -1
GCL   40   3929   3931   3934   3937   3944  -1
GCL   41   3453   3447   3445   3450   3456   3459  -1
GCL   42   2556   2554   2559   2562   2565   2568
GCL        2571  -1
GCL   43   3033   3030   2899   2766   2733   2730
GCL        2727   2724   2721   2719  -1
GCL   44   2139   2137   1989   1987   1992   1995  -1
GCL   45   1880   1878   1883   2018   2021  -1
GCL   46  42932  42926  42920  42914  42908  42906
GCL       42911  42917  42923  42929  42935  -1
GCL   47  41694  41692  -1
GCL   48  37385  37383  -1
GCL   49  34594  34592  -1
GCL   50  32251  32254  -1
GCL   51  25520  25518  -1
GCL   52  28471  28469  -1
GCL   53  12277  12275  -1
GCL   54   3903   3775   3656   3546  -1
TZ  0  0  0  0  0
DE  0  0  4
TI  10  4  0.00010  0.00000
FT  15
IC  575.   0  0.25
CO   RD  1  1   0.030683920     3.0305200   0.030971330    0.05552626
HNT   1 !SCRUpper,,!
HNT  38 !SCRUpper,,!
HNT   2 !SCRUpper,,!
HNT  39 !SCRDryDock!
HNT   3 !SCRDryDock!
HNT   4 !SCRDryDock!
HNT   5 !SCRInterIs!
HNT   6 !SCRInterIs!
HNT   8 !SCRAlgonac!
HNT  11 !SCRAlgonac!
HNT  14 !SCRFlats,,!
HNT   7 !SCRFawnIsE!
HNT  40 !ChenalEcar!
HNT  12 !SCRNorth,,!
HNT  13 !SCRMiddle,!
HNT  15 !SCRCutoff,!
HNT  16 !BassettCh,!
```

```
HNT  17 !LakStClair!
HNT  18 !LakStClair!
HNT  19 !LakStClair!
HNT  20 !DETUpper,,!
HNT  41 !DETUpper,,!
HNT  22 !DETBelleIN!
HNT  42 !DETRRouge,!
HNT  25 !DETRRouge,!
HNT  26 !DETFightIs!
HNT  29 !DETFightIs!
HNT  27 !DETFightIs!
HNT  28 !DETFightIs!
HNT  43 !DETStonyIs!
HNT  35 !DETTrenton!
HNT  36 !DETSugarW,!
HNT  37 !DETSugarW,!
HNT  46 !DETBobloIs!
HNT  48 !DETBobloIs!
HNT  32 !DETLivChLo!
HNT  44 !DETLivChUp!
HNT  33 !DETAmhChUp!
HNT  45 !DETAmhChLo!
HNT  47 !DETSugarE,!
PE   1  15      1.000      1.000      1.000      1.000      1.000
BHL   1  570.052
BQL  46  173201  4.29014  0.5
BQL  47  489  5.43537  0.5
BQL  48  119  6.18352  0.5
BQL  49  478  4.45179  0.5
BQL  50  1861  4.22988  0.5
BQL  51  928  6.18352  0.5
BQL  52  4857  3.19418  0.5
BQL  53  312  5.47077  0.5
RAT  17  0.001448
RAT  18  0.001448
RAT  19  0.001448
END  Simulation at time =  0.00
STOP
```

Appendix D.
Excerpt from EXTRACT File used to Process Output Files from UCODE Parameters Estimation Analysis of the St. Clair–Detroit River Model

```
# Extract file for St. Clair - Detroit Simulation Model
#
# Scenario 1: Nov. 3-5, 1999
<SCD8.SS1.OUT
o SS1SSouC
+300
/NODAL VELOCITY, DEPTH AND ELEVATION..../
/ 29239 /
c114_120
o SS1SBelle
/ 15300 /
c74_80
o SS1SNorC
/ 29958 /
c114_120
o SS1SWP
/ 16127 /
c74_80
o SS1SGIB
/  2803 /
c34_40
o SS1SALG
/ 31568 /
c114_120
o SS1SSCS
/ 18594 /
c74_80
o SS1SRL
/ 32920 /
c114_120
o SS1SAmher
/  6141 /
c34_40
o SS1SMC
/ 35169 /
c114_120
o SS1SSCT
/ 37154 /
c114_120
o SS1SWYN
/  8923 /
c34_40
o SS1SMidC
/ 25939 /
c74_80
o SS1SDD
/ 40852 /
c114_120
o SS1SFW
/ 12815 /
c34_40
o SS1SMBR
/ 41658 /
c114_120
o SS1SDP
/ 42839 /
c114_120
o SS1SFG
```

```
/ 42935 /
c114_120
#
# St. Clair River Flows
o SS1QCS208 # 55004     1234         1           1         CG 04
/ CONTINUITY CHECKS ... TIME STEP =/
# /          4 /
+6
c20_30
o SS1QCS210 #  117258     1234         1           1         CG 05
/          5 /
c20_30
o SS1QCS216 #  143055      887         1           1         CG 08
/          8 /
c20_30
o SS1QCS218 #   29804      887         1           1         CG 09
/          9 /
c20_30
o SS1QCS222 #    6295      624         1           1         CG 11
/         11 /
c20_30
o SS1QCS230 #  166564      624         1           1         CG 12
/         12 /
c20_30
o SS1QCS232 #   78361     2225         1           1         CG 13
/         13 /
c20_30
o SS1QCS234 #    6314      827         1           1         CG 14
/         14 /
c20_30
o SS1QCS236 #   42335     2207         1           1         CG 15
/         15/
c20_30
o SS1QCS238 #   29712     2400         1           1         CG 16
/         16 /
c20_30
o SS1QCS240 #   56911     1671         1           1         CG 17
/         17 /
c20_30
o SS1QCS242 #   31292     1829         1           1         CG 18
/         18 /
# Detroit River Flows
c20_30
o SS1QCS003 #  133137     1756         1           1         CG 21
/         21 /
c20_30
o SS1QCS008 #   47994     1756         1           1         CG 22
/         22 /
c20_30
o SS1QCS015 #   55117     1459         1           1         CG 24
/         24 /
c20_30
o SS1QCS029 #  126014     1459         1           1         CG 25
/         25 /
c20_30
o SS1QCS100 #   47411     1170         1           1         CG 29
/         29 /
c20_30
```

```
o SS1QCS101 #   95124     1106         1           1         CG 30
/         30 /
c20_30
o SS1QCS102 #   38909      926         1           1         CG 31
/         31 /
c20_30
o SS1QCS120 #   40201     1762         1           1         CG 32
/         32 /
c20_30
o SS1QCS121 #    9263     2034         1           1         CG 33
/         33 /
c20_30
o SS1QCS122 #   47876     1760         1           1         CG 34
/         34 /
c20_30
o SS1QCS123 #   84103     2197         1           1         CG 35
/         35 /
c20_30
o SS1QCS142 #   12123     2132         1           1         CG 36
/         36 /
c20_30
o SS1QCS143 #   20265     1690         1           1         CG 37
/         37 /
c20_30
o SS1QCS161 #   21209     2004         1           1         CG 38
/         38 /
c20_30
o SS1QCS162 #    9418     1023         1           1         CG 39
/         39 /
c20_30
o SS1QCS163 #   38636     2871         1           1         CG 40
/         40 /
c20_30
o SS1QCS164 #    8142     1996         1           1         CG 41
/         41 /
c20_30
o SS1QCS165 #   63839     2253         1           1         CG 42
/         42 /
c20_30
o SS1QCS141 #   21363     2418         1           1         CG 54
/         54 /
c20_30
#
```