Institute of Water Research
Annual Technical Report
FY 2010

Introduction

The Institute of Water Research (IWR) at Michigan State University (MSU) continuously provides timely information for addressing contemporary land and water resource issues through coordinated multidisciplinary efforts using advanced information and networking systems. The IWR endeavors to strengthen MSU's efforts in nontraditional education, outreach, and interdisciplinary studies utilizing available advanced technology, and partnerships with local, state, regional, and federal organizations and individuals. Activities include coordinating education and training programs on surface and ground water protection, land use and watershed management, and many others. We also encourage accessing our web site which offers a more comprehensive resource on IWR activities, goals, and accomplishments: http://www.iwr.msu.edu.

The Institute has increasingly recognized the acute need and effort for multi-disciplinary research to achieve better water management and improved water quality. This effort involves the integration of research data and knowledge with the application of models and geographic information systems (GIS) to produce spatial decision support systems (SDSS). These geospatial decision support systems provide an analytical framework and research data via the web to assist individuals and local and state government agencies make wise resource decisions. The Institute has also increasingly become a catalyst for region wide decision-making support in partnership with other states in EPA Region 5 using state-of-the-art decision support systems.

The Institute works closely with the MSU Cooperative Extension Service to conduct outreach and education. USGS support of this Institute as well as others in the region enhances the Institute credibility and facilitates partnerships with other federal agencies, universities, and local and state government agencies. The Institute also provides important support to MSU-WATER, a major university initiative dealing with urban storm water issues with funding from the university Vice President for Finance. A member of the Institute s staff works half-time in facilitating MSU-WATER activities so the Institute enjoys a close linkage with this project. The following provides a more detailed explanation of the Institute s general philosophy and approach in defining its program areas and responsibilities.

General Statement

To deal successfully with the emergence of water resource issues unique to the 21st century, transformation of our knowledge and understanding of water for the protection, conservation, and management of water resources is imperative. Radically innovative approaches involving our best scientific knowledge, extensive spatial databases, and intelligent tools that visualize wise resource management and conservation in a single holistic system are likewise imperative. Finally, holistic system analysis and understanding requires a strong and integrated multi-disciplinary framework.

Research Program Introduction

Research Program Introduction
The management of water resources, appropriate policies, and data acquisition and modeling continue to be at the forefront of the State Legislatures agenda and numerous environmental and agricultural organizations. Our contribution to informing the debate involved numerous meetings, personal discussions, and most importantly, the enhancement of web-based information to aid in the informed decision-making process.

Unique Capabilities: Decision Support Systems as the Nexus
IWR, with its "extended research family," is exceptionally well-positioned to integrate research conducted within each of the three principal water research domains: hydrologic sciences, water resources, and aquatic ecosystems. Integrated decision support both reflects and forms the nexus of these three research domains. Expanding web accessibility to the decision support system nexus (formed by the intersection of the three research domains) will facilitate broad distribution of science-based research produced in these domains. A special emphasis is being placed on facilitation of science-based natural resource state and national policy evolution.

The Institute's extensive experience in regional and national networking provides exceptional opportunities for assembling multi-agency funding to support interdisciplinary water research projects and multi-university partnerships.

Using a Multi-Disciplinary Framework
Using a multi-disciplinary framework facilitates dynamic applications of information to create geospatial, place-based strategies, including watershed management tools, to optimize economic benefits and assure long-term sustainability of valuable water resources. New information technologies including GIS and computational analysis, enhanced human/machine interfaces that drive better information distribution, and access to extensive real-time environmental datasets make a new "intelligent reality" possible.

Effective watershed management requires integration of theory, data, simulation models, and expert judgment to solve practical problems. Geospatial decision support systems meet these requirements with the capacity to assess and present information geographically, or spatially, through an interface with a geographic information system (GIS). Through the integration of databases, simulation models, and user interfaces, these systems are designed to assist decision makers in evaluating the economic and environmental impacts of various watershed management alternatives.

The ultimate goal of these new imperatives is to secure and protect the future of water quality and supplies in the Great Lakes Basin and across the country and the world with management strategies based on an understanding of the uniqueness of each watershed.

Award No. G09AC00161 Developing the Water Withdrawal Assessment Tool

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Prepared in cooperation with the
Michigan Department of Natural Resources

Ground-Water-Withdrawal Component of the Michigan Water-Withdrawal Screening Tool

Scientific Investigations Report 2009–5003

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

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

U.S. Department of the Interior
KEN SALAZAR, Secretary

U.S. Geological Survey
Suzette M. Kimball, Acting Director

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Contents

Abstract 1
Introduction 1
Assessment Process and Screening Tool 1
Streamflow Depletion by Pumping Wells 2
Purpose and Scope 2
Study Approach 2
Ground-Water-Withdrawal Component of Screening Tool 3
Input of Constant and Time-Varying Pumping Rates 4
Aquifer Properties Required for the Water-Withdrawal Screening Tool 4
Definition of Valley Segments 5
Assignment of Bedrock Aquifer Properties to Valley Segments 7
Definition of Great Lake Shoreline Catchments 8
Distribution of Streamflow Depletion Among Valley Segments in Neighboring Catchments 8
Demonstration of Analytical Model and Distribution Approach 9
Limitations of Testing 12
Summary of the Ground-Water Component of the Water-Withdrawal Screening Tool 12
Example Screening and Confirmation of Water-Withdrawal Screening-Tool Results 13
References Cited 15
Appendix 1. Background and Literature Review on Streamflow Depletion Modeling 17
Appendix 2. Distribution of Withdrawal Between Neighboring Watersheds 27

Figures

1. Graph showing reported aquifer storage coefficients for wells completed in glacial deposits from aquifer tests reviewed by the State of Michigan as a function of depth; arithmetic, geometric, and harmonic means also are shown 6
2. Map showing four bedrock categories used in the water-withdrawal screening tool for Michigan 7
3. Graph showing recharge and pumping rates used in the base simulations with the Kalamazoo regional ground-water-flow model 9
4–6. Maps showing:
4. A grid of points used to compare the analytical model and different distribution methods to MODFLOW results from the Kalamazoo regional ground-water-flow model 10
5. Estimated streamflow depletion from valley segment 3544 as a percentage of pumping rate after 5 years of pumping. *A*, results from a sequential introduction of test wells in the MODFLOW ground-water-flow model for Kalamazoo County, Mich. *B*, results from analytical model with inverse distance to stream distribution of streamflow depletion 11
6. Example test point, valley-segment catchment containing the point, and neighboring valley-segment catchments 13

1–1 – 2–1. Diagrams showing:

1–1. Alternate conceptual models for streamflow depletion by a pumping well. *A*, Fully penetrating stream with no streambed resistance. *B*, Fully penetrating stream with streambed resistance. *C*, Partially penetrating stream with streambed resistance. *D*, Partially penetrating stream in semiconfining layer with pumping from underlying semiconfined aquifer 17

1–2. Alternate sources of water for capture by a well near a stream. *A*, Stream in an aquifer that overlies a regional aquifer with potentially different hydraulic properties. *B*, Stream in an aquifer system where pumping may interact with plants and change evapotranspiration losses from the system 21

2–1. Pumping well between two parallel streams with notation used in an equation for steady-state streamflow depletion 27

2–2 – 2–5. Maps showing:

2–2. A grid of points used to compare the analytical model and different distribution methods to MODFLOW results from the Kalamazoo regional ground-water-flow model 31

2–3. Estimated streamflow depletion from valley segment 3544 resulting from a sequential introduction of test wells in the MODFLOW ground-water-flow model for Kalamazoo County, Mich., as a percentage of pumping rate after 5 years of pumping 32

2–4. Estimated streamflow depletion from valley segment 3544 resulting from a sequential application of the analytical model to test wells with no weighting approach between adjacent valley segments as a percentage of pumping rate after 5 years of pumping 33

2–5. Estimated streamflow depletion from valley segment 3544 as a percentage of pumping rate after 5 years of pumping. *A*, results from a sequential application MODFLOW. Results from sequential application of the analytical model with *B*, the inverse distance to the stream, *C*, inverse distance to the stream squared, and *D*, natural neighbor distribution methods 35

Tables

1. Bedrock categories and response by water-withdrawal screening tool to proposed bedrock well in each category 8

2. Compilation of estimates for an example test point using the Michigan water-withdrawal screening tool and the set of batch programs used in screening-tool development and testing 14

Conversion Factors and Datum

Multiply	By	To obtain
	Length	
foot (ft)	0.3048	meter (m)
meter (m)	3.281	foot (ft)
mile (mi)	1.609	kilometer (km)
kilometer (km)	0.6214	mile (mi)
	Area	
square mile (mi^2)	259.0	hectare (ha)
square mile (mi^2)	2.590	square kilometer (km^2)
	Flow rate	
gallon per minute (gal/min)	3.785	liter per minute (L/min)
gallon per day (gal/d)	4.3×10^{-8}	cubic meter per second (m^3/s)
million gallons per day (Mgal/d)	0.04381	cubic meter per second (m^3/s)

Horizontal coordinate information is referenced to the North American Datum of 1983 (NAD 83).

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Ground-Water-Withdrawal Component of the Michigan Water-Withdrawal Screening Tool

By Howard W. Reeves[1], David A. Hamilton[2], Paul W. Seelbach[3], and A. Jeremiah Asher[4]

Abstract

A water-withdrawal assessment process and Internet-based screening tool have been developed to evaluate proposed new or increased high-capacity water withdrawals in Michigan. Michigan legislation defines high capacity withdrawals as those capable of removing an average of 100,000 gallons per day for a consecutive 30-day period. This report describes the ground-water component of the screening tool, provides background information used to develop the screening tool, and documents how this component of the screening tool is implemented. The screening tool is based on application of an analytical model to estimate streamflow depletion by a proposed pumping well. The screening tool is designed to evaluate intermittent pumping, to account for the dynamics of stream-aquifer interaction, and to apportion streamflow depletion among neighboring streams. The tool is to be used for an initial screening of a proposed new or increased high-capacity withdrawal in order to identify withdrawals that may cause adverse resource impacts. The screening tool is not intended to be a site-specific design tool. Results of an example application of the screening tool in Kalamazoo County, Mich., are compared to streamflow depletion estimated by use of a regional ground-water-flow model to demonstrate its performance.

Introduction

The water-withdrawal assessment process mandated by State of Michigan Public Act 34 of 2006 (2006 PA 34) (Michigan State Legislature, 2006a) was proposed to "assist in determining whether the proposed [water] withdrawal may cause an adverse impact to the waters of the state or to the water-dependent natural resources of the state." The water-withdrawal assessment process was developed under the auspices of the Michigan Ground Water Conservation Advisory Council (GWCAC), which was formed though Public Act 148 of 2003 (2003 PA 148) (Michigan State Legislature, 2003) and revised by 2006 PA 34. In response to 2006 PA 34, the U.S. Geological Survey (USGS) entered into a cooperative agreement in 2006 with the Michigan Department of Natural Resources; the Michigan Department of Environmental Quality; the Institute for Fisheries Research, University of Michigan; and the Institute for Water Research, Michigan State University, to assist in developing the technical aspects of the water-withdrawal assessment process.

The 2006 PA 34 legislation presumed that, for the first 2 years of the act, wells deeper than 150 ft or further away than ¼-mi from trout streams did not create an adverse resource impact on a trout stream (Michigan State Legislature, 2006a). Wells within ¼-mi of a trout stream and less than 150 ft deep may have posed an adverse resource impact on the stream, but the legislation did not specify how this potential should be analyzed. This presumption expired in 2008, and the legislature replaced it with the water-withdrawal assessment process including an Internet-based screening tool (Public Act 185 of 2008 (2008 PA 184), Michigan State Legislature, 2008a). The water-withdrawal process identifies withdrawals likely to cause an adverse environmental impact on the waters of the State by assessing whether the withdrawal will affect the ability of a stream to support the characteristic fish population at a site (State of Michigan Ground Water Conservation Advisory Council, 2007).

Assessment Process and Screening Tool

The legislature and GWCAC envisioned a screening tool as part of the water-withdrawal assessment process. In this report, the term "assessment process" refers to the entire process used to assess a new or increased high-capacity withdrawal from surface water or ground water, including initial screening, site-specific review, and agency procedures. High capacity withdrawals are defined through legislation as those capable of removing an average of 100,000 gal/d for a

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consecutive 30-day period (as defined in section 32701 of Public Act 33 of 2006 (2006 PA 33), Michigan State Legislature, 2006b). The screening tool is an Internet-accessible program used for an initial screening of a proposed new or increased high-capacity withdrawal. This screening tool identifies withdrawals that are not likely to cause an adverse resource impact upon any type of stream in the State and allows users proposing such withdrawals to proceed with the withdrawal after registering the use. Withdrawals identified as having potential to cause an adverse resource impact are expected to require additional agency review to determine their disposition (State of Michigan Ground Water Conservation Advisory Council, 2007). This tool is designed to focus regulatory resources on withdrawals that have greater potential to cause environmental harm. The screening tool uses a statewide database of aquifer types and properties in conjunction with a robust analytical equation to identify withdrawals not likely to cause an adverse environmental impact.

In this report, the component of the screening tool used to estimate the amount of streamflow reduction caused by a given ground-water withdrawal is presented and discussed. The complete screening tool, including ground-water and surface-water withdrawals and the decision rules used to evaluate withdrawals, will be documented in a separate report.

Streamflow Depletion by Pumping Wells

The key to understanding the potential impact of a pumping well on streamflow is to recognize the source of water to wells as described, for example, by Theis (1940), Bredehoeft and others (1982), Sophocleous (1997), Alley and others (1999), and Bredehoeft (2002). When a well is pumped, water is removed initially from storage in the aquifer, and the potentiometric level, or head, near the well is reduced. Once the head near the well is reduced, then flow is induced towards the well. Water is removed from storage, and the potentiometric level declines away from the pumping well, thereby creating a cone of depression around the well. This cone of depression continues to expand until the pumping can be balanced by (a) *an increase in recharge* to the system, induced by the lowering of the potentiometric level in the aquifer; (b) *a decrease in the discharge* from the system, resulting from the lowered potentiometric level in the system and decreased gradients in discharge areas; or (c) *a combination of increased recharge and decreased discharge* (Bredehoeft, 2002). The sum of increased recharge and decreased discharge is called capture (Lohman and others, 1972). If the well cannot capture enough water to balance pumping, water levels will continue to decline until pumping cannot continue at the initial rate. The capture of a pumping well does not depend on the initial recharge rate; rather, it depends on the change in recharge induced by the pumping well (Bredehoeft and others, 1982; Bredehoeft, 2002).

Ground-water pumping can capture streamflow in two ways for an initially gaining stream: (1) decreased discharge from the aquifer to the stream because of the lowered potentiometric gradient, and (2) induced infiltration from the stream to the aquifer because of a reversal in potentiometric gradient. In the second instance, the flow is from the stream toward the well, and the affected segment of the stream becomes a losing segment. The source of water to a pumping well changes with time from water released from storage to water captured because of decreased discharge or increased recharge, and this shift depends on the geometry of the system and aquifer properties (Bredehoeft, 2002). Appendix 1 offers an analysis of the various ways that the interaction between a pumping well and a stream have been quantified.

Purpose and Scope

The purpose of this report is to document the ground-water-withdrawal component of the Michigan water-withdrawal screening tool. In practice, the impact of wells on streams may not be limited to the ¼-mi buffer and 150 ft cutoff depth used in the original legislation so the ground-water component of the statewide assessment tool is designed to estimate streamflow depletion resulting from pumping a well without imposing arbitrary spatial constraints. The final screening tool also is designed to evaluate intermittent pumping and to account for the dynamics of stream-aquifer interaction so that ground-water withdrawals are not considered to be immediate from the stream at the pumping rate. Finally, the screening tool was designed to estimate the depletion from neighboring streams, not just from the stream closest to the proposed well.

In this report, the methods used to evaluate the impact of a new or increased ground-water withdrawal upon streamflow are described. Types of data required for the evaluation and the sources of data are provided. The distribution of streamflow depletion between neighboring streams is discussed in detail because the method used for this distribution was developed in this project. The screening tool was tested by comparison of results from it to streamflow depletion estimates generated with a numerical ground-water-flow model of Kalamazoo County, Mich. (Luukkonen and others, 2004), and these results are presented and discussed.

Study Approach

The ground-water component of the water-withdrawal screening tool was designed to account for the removal of water from storage and the resulting delay in the impact of new or increased pumping on streamflow. As a conservative approach, the only sources of water to the well in the screening tool are storage and streamflow depletion. For

the screening tool, recharge to the aquifer is assumed to be unaffected by the addition of a high-capacity well. Several other potential sources of water to the well are omitted in this approach, including decreased loss of ground water to vegetation capable of using shallow ground water, and changes in water exchange between adjacent aquifers through semiconfining layers. The pumping well also is assumed to not significantly affect the water level in the stream. Because stream elevation and recharge are assumed to be unaffected by the additional pumping, natural seasonal variation in the system (including variations in stream elevation and recharge) does not influence the estimation of streamflow depletion.

As stated by Bredehoeft (2002) and described in appendix 1, the only way to assess capture by a pumping well is by using either analytical or numerical approaches to model the system. In general, analytical models are applicable for simple geometries and uniform aquifer properties, whereas numerical models allow for more complicated systems. For simple systems, both approaches yield similar estimates. For more complicated systems, analytical solutions may not capture the complexity of the system. Numerical models can describe a more complicated system, but these models require more extensive site-specific data and analysis. The goal of this project was to devise a procedure applicable for statewide screening; therefore, an analytical model was selected to estimate streamflow depletion by a pumping well. Use of an analytical model yields a screening tool that is sufficiently accurate but requires minimal input data and user training.

Ground-Water-Withdrawal Component of Screening Tool

Upon review of the literature related to modeling streamflow depletion by pumping wells, the analytical model selected for the ground-water component of the water-withdrawal screening tool is an equation derived by Hunt (1999). This analytical model describes streamflow depletion by a pumping well for a partially penetrating stream in an infinite aquifer with streambed resistance between the stream and the aquifer. This analytical model is appropriate for Michigan streams, which typically do not fully penetrate the aquifers used for water supply, and it is sufficiently simple for statewide screening. This analytical model was implemented in a Fortran computer code (Reeves, 2008). In the final implementation of the screening tool, an Internet-accessible version of the analytical model was required. The essential elements of the analytical model were programmed in VBScript (Microsoft Corporation, 2007) for implementation in the Internet version. This report includes verification that the VBScript version of the analytical model yields solutions similar to those from the Fortran version documented by Reeves (2008).

To illustrate the aquifer properties required by the analytical model, the form of the model is a useful summary. Hunt (1999) derives the analytical model as

$$Q_s = Q_w \left[\operatorname{erfc}\left(\sqrt{\frac{Sd^2}{4Tt}} \right) - \exp\left(\frac{\lambda^2 t}{4ST} + \frac{\lambda d}{2T} \right) \operatorname{erfc}\left(\sqrt{\frac{\lambda^2 t}{4ST}} + \sqrt{\frac{Sd^2}{4Tt}} \right) \right], \qquad (1)$$

where

Q_s	is the rate of streamflow depletion (length cubed per unit time),
Q_w	is the pumping rate (length cubed per unit time),
erfc()	is the complementary error function (dimensionless),
exp()	is the exponential function (dimensionless),
d	is the distance from the well to the stream (length),
S	is the storage coefficient, or storativity, of the aquifer (dimensionless),
T	is the transmissivity of the aquifer (length squared per unit time),
t	is the time from the start of pumping, and
λ	is the streambed conductance term (length per unit time).

The major assumptions used to derive equation 1 (Hunt, 1999) are the following:

- Horizontal flow dominates any potential vertical flow; the Dupuit assumption is valid.
- The aquifer is homogeneous and isotropic and has constant saturated thickness.
- The aquifer is either confined or, if unconfined, change in hydraulic head in the aquifer is small compared to the saturated thickness.
- The stream is straight, infinitely long, and remains in hydraulic connection with the aquifer.
- The pumping does not change the stage of the stream.
- Recharge to the system is unchanged by pumping.
- The streambed may offer resistance to ground-water flow.
- There is no streambank storage.
- The pumping rate is constant.
- The aquifer extends to infinity.

Examination of equation 1 reveals that streamflow depletion depends on aquifer and streambed properties, the distance from the well to the stream, and time. In this model, streamflow depletion is described by a Darcy expression describing the flux between the stream and the aquifer (Hunt, 1999). The aquifer is assumed to remain in hydraulic contact with the stream, which means that the pumping well does not cause the hydraulic head in the aquifer to be lower than the streambed. See appendix 1 for more discussion of this assumption. To examine the sensitivity of streamflow depletion results on variations of input parameters, see Hunt (1999) and Reeves (2008).

The aquifer is assumed to be infinite, and, therefore, no additional data regarding the aquifer geometry are required by the model beyond the distance between the well and the stream. The remaining model input includes transmissivity, streambed conductance, storage coefficient, pumping rate, and time desired for the evaluation. As described in Reeves (2008), the analytical model was implemented in the computer code STRMDEPL08, which was used for development of the screening tool, with the option to simulate time-varying pumping rates.

Input of Constant and Time-Varying Pumping Rates

The impact of time-varying pumping is estimated in the screening tool because removal of water from storage may reduce the streamflow depletion. The streamflow depletion caused by time-varying pumping may be much lower than the pumping rate, and the estimated depletion caused by time-varying pumping often continues in time even while the pump is off. For analysis of streamflow depletion resulting from a constant pumping rate, the user must input the pumping rate. The duration of pumping in the screening tool is set to 1,825 days (5 years). For time-varying pumping, the user must not only provide the pumping rate but also a pumping schedule. Appendix 1 provides more discussion regarding the affect of time-varying pumping rates.

The interface to the screening tool prompts the user for more information if the user indicates a ground-water withdrawal with time-varying pumping. The user must enter the months when the well will be pumped, the well capacity, the days per week that the well will be pumped during those months, and the hours per day pumped. If the hours pumped per day are less than 24, the well capacity is prorated to yield a daily pumping rate. The days per week and months of pumping are then evaluated to determine the number of times that the pumping rate is changed. A superposition in time technique is used to account for time-varying pumping in the screening tool. Assuming that only streamflow depletion caused by a new or increased use is of interest, the equation for superposition used to evaluate time-varying pumping may be written as

$$Q_s(t_i) = \sum_{k=1}^{i} \Delta Q_k(t_k) R(\Delta t_k) \,, \qquad (2)$$

where

$Q_s(t_i)$ is the streamflow depletion at time interval i (length cubed per unit time),

$\Delta Q_k(t_k)$ is the change in pumping rate during the interval k (length cubed per unit time),

$R(\Delta t_k)$ is the ratio of streamflow depletion to pumping rate given by equation 1 for time interval k (length cubed per unit time),

t_i is the length of time from the beginning of the pumping analysis to the time of interest,

Δt_k is $t_i - t_k$, the difference in time between the time of interest and the time when the pumping rate changed for interval k,

i is the number of times when the pumping rate changes (dimensionless), and

k is the time interval number (dimensionless).

Streamflow depletion is estimated for every time when the pumping rate changes and at the end of the 5-year evaluation period. The maximum streamflow depletion from each of these estimations is identified in the screening tool and used to evaluate the potential impact of the proposed pumping.

Aquifer Properties Required for the Water-Withdrawal Screening Tool

The analytical model used for the water-withdrawal screening tool, equation 1, requires aquifer transmissivity, streambed conductance, and aquifer storage coefficient. One of the assumptions is that the aquifer is homogeneous. Aquifers in Michigan, however, are typically heterogeneous. For the screening-level evaluation, an estimated transmissivity and storage coefficient were assigned to watersheds and used in the screening tool. A safety factor was assigned in the screening tool to allow for more site-specific evaluation of withdrawals that may lead to adverse environmental impact. The procedures used to assign aquifer properties to watersheds for the water-withdrawal screening tool are presented in this section.

For the statewide water-withdrawal screening tool, the most consistent source of aquifer properties was assembled recently into the Michigan Ground Water Inventory and Map (GWIM) database (Michigan Department of Environmental Quality, 2005). The GWIM database includes estimates for aquifer transmissivity mapped to a 1-km by 1-km (3,281 ft by 3,281 ft) grid across the State for glacial deposits and bedrock aquifers. Constant values for aquifer storage coefficient were assumed in the GWIM analysis for illustration of potential well-to-well impacts. These values were different for the glacial deposits and bedrock aquifers, but the values for both types were indicative of leaky (semiconfined) systems.

The range of storage coefficients observed in aquifer tests in Michigan is discussed later in this report. The GWIM database information was used to assign transmissivity, streambed conductance, and storage coefficient in the screening tool.

Definition of Valley Segments

The surface-water spatial framework used for the ground-water component of the water-withdrawal screening tool was built on the classification of Michigan stream arcs into ecological valley segments (Seelbach and others, 2006; Brenden and others, 2008; Zorn and others, 2009). Each valley segment is a contiguous length of stream with relatively homogeneous hydraulic, hydrologic, and ecologic characteristics. The catchment area, which is the surface watershed drainage area, for each valley segment was defined by combining the surface catchments of the approximately 30,000 individual stream arcs in the 1:100,000-scale National Hydrography Dataset (NHD) as processed in the Great Lakes Regional Aquatic Gap project (Morrison and others, 2003; Brenden and others, 2006). The final framework consists of approximately 10,000 valley segments. The reduction in streamflow caused by a ground-water withdrawal is assigned to the downstream point of the valley-segment catchment. To apply the water-withdrawal screening tool, aquifer properties were required for each unique valley segment.

Assignment of Aquifer Properties for Glacial Deposits to Valley Segments

Three aquifer properties are required by the analytical model: transmissivity, streambed conductance, and storage coefficient. Values for these properties were estimated from information in the GWIM database (Michigan Department of Environmental Quality, 2005). In this database, transmissivity of glacial deposits is mapped to a grid for the entire State of Michigan. The median transmissivity for the grid cells within each valley segment catchment is assigned to the valley segment and used in the screening model. The median was selected as the representative statistic instead of the arithmetic mean because the median is less influenced by extremely low or high transmissivity estimates in the database and therefore may be the more reasonable statistic for screening-level estimation.

The streambed conductance used in equation 1 may be written as

$$\lambda = \frac{(K_v w)}{b}, \qquad (3)$$

where

K_v is the vertical hydraulic conductivity of the aquifer (length per unit time),

w is the stream width (length), and

b is the distance from the bottom of the stream to the top of the well screen or open interval of a bedrock well (length).

The distance from the bottom of the stream to the top of the well screen or open interval, b, is provided as the well depth by the user. For the statewide screening, the stream width was estimated by use of a regression equation developed to relate stream width to drainage area of a stream segment (T.G. Zorn, Michigan Department of Natural Resources, written commun., 2007):

$$w = 3.28 * (10 \hat{} ((0.522358 * \log(da * 1.6093 \hat{} 2)) - 0.18786)), \qquad (4)$$

where

da is the drainage area of the catchment (square miles) and

w is width (feet).

An estimate of the vertical hydraulic conductivity of the aquifer was computed by dividing the median transmissivity by the average thickness of aquifer material for each valley-segment catchment. This thickness was estimated by interpolating the thickness used for the wells in the GWIM transmissivity-estimation procedure to a 3,281 ft by 3,281 ft grid over the State and then computing the mean estimated thickness for the grid cells within each valley-segment catchment. To avoid dividing by zero in areas where glacial deposits are thin, a minimum value of 5 ft was assigned.

Equation 2 allows the streambed conductance used in the screening tool to vary with the depth to the top of the well screen entered by the user. A factor of 1/10 is included in the estimated streambed conductance to account for the anticipated anisotropy of aquifers in Michigan. This factor is reasonable for aquifers without clay units and probably underestimates the anisotropy in areas where clay layers are present (Todd and Mays, 2005). Anisotropy in hydraulic conductivity describes the tendency for the aquifer material to have less resistance to flow in the horizontal direction than the vertical direction primarily because of layering of the system: underestimation of this factor is conservative in the estimate of streamflow depletion by a pumping well. Because the user may request site-specific review of a proposed withdrawal if the screening tool identifies it as having greater potential for causing adverse environmental impact, this conservative factor was appropriate. The final expression for streambed conductance used in the screening tool is

$$\lambda = \frac{\left((T / B')w / 10\right)}{b}, \qquad (5)$$

where

B' is the estimated mean thickness of glacial deposits for the valley-segment catchment (length) and

b is the input value of depth to the top of the well screen or open interval of the well (length).

The final aquifer property is storage coefficient. In the analysis for the GWIM, constant values for storage coefficient were used: 0.0016 for glacial deposits and 0.0004 for bedrock aquifers. These values were determined by use of the geometric means of reported storage coefficients from aquifer tests reviewed by the State. For the screening tool, the value for the glacial deposits was believed to be too small, resulting in overprediction of the streamflow depletion from wells in unconfined or leaky aquifers. The storage coefficients reported for aquifer tests in glacial deposits vary over four orders of magnitude and do not correlate well with location in the State, surficial geology, or depth. Relation of storage coefficient with depth is illustrated in figure 1. On the statewide scale, it has not been possible to reliably identify areas of Michigan dominated by confined, leaky, or unconfined conditions. Use of the geometric mean, or a smaller value typical of a confined aquifer, may lead to a potentially contradictory situation where the assumption is made in the screening tool that the aquifer behaves as confined but also in good hydraulic contact with headwater streams. Conversely, assuming that an unconfined specific yield represents statewide conditions is not conservative, especially for time-varying pumping estimates. To give a conservative estimate that is consistent with the observed uncertainty in the estimated storage coefficients across the state, a constant value of 0.01, which is representative of a leaky aquifer, was used in the screening tool.

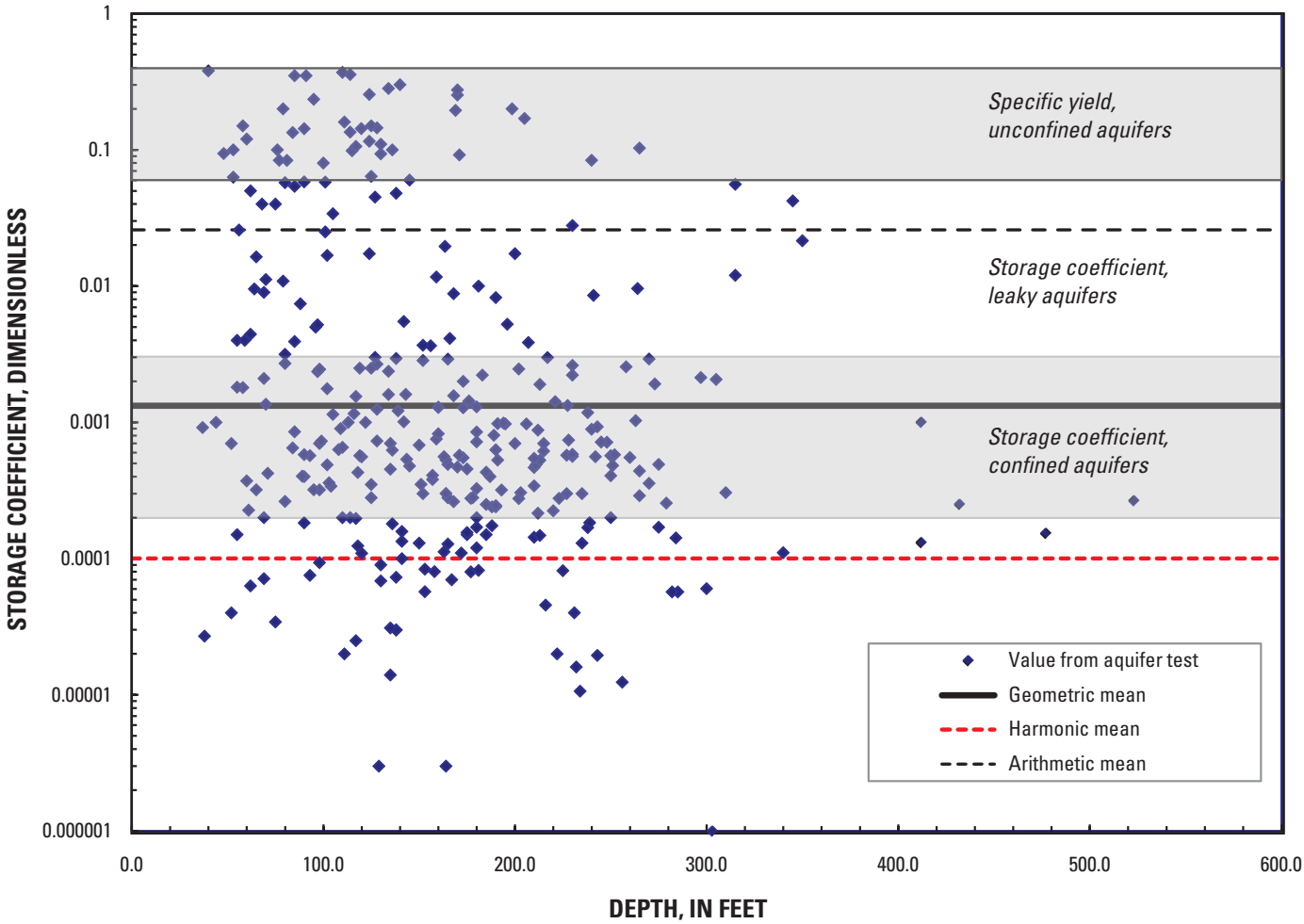
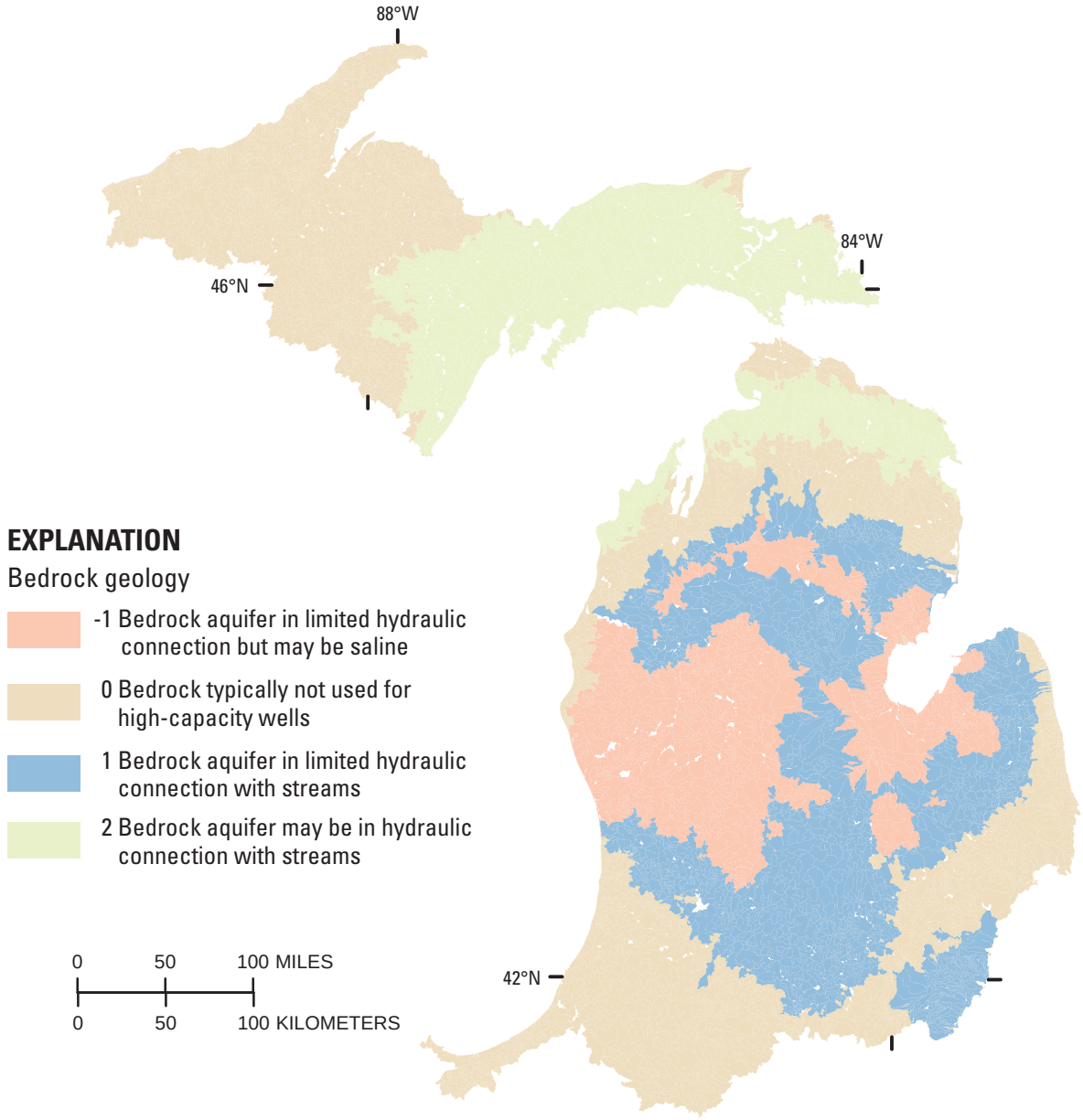


Figure 1. Reported aquifer storage coefficients for wells completed in glacial deposits from aquifer tests reviewed by the State of Michigan as a function of depth; arithmetic, geometric, and harmonic means also are shown. Shaded zones show typical ranges of specific yield and storage coefficient (for a 100 foot aquifer) for unconsolidated materials (Domenico and Schwartz, 1990).

Assignment of Bedrock Aquifer Properties to Valley Segments

Bedrock aquifers are used in parts of Michigan, and in some areas of the State these bedrock aquifers are separated from overlying streams by thick glacial deposits containing layers of material with low hydraulic conductivity, such as silt or clay. In these areas, the hydraulic connection between these aquifers and nearby streams is limited. In other areas, there may be a greater hydraulic connection between the bedrock aquifer and overlying streams. Saline water may be present in some areas of the major bedrock aquifers, and it may occur at depth under a freshwater zone or through the entire thickness of the bedrock aquifer. Finally, in some areas of the State, bedrock aquifers are not suitable for high-capacity wells. To account for these different potential conditions in the screening tool, the bedrock aquifers were grouped into four categories (fig. 2). The categories and response given by the water-withdrawal screening tool are summarized in table 1.



Bedrock geology from Michigan Department of Environmental Quality, 1987

Figure 2. Four bedrock categories used in the water-withdrawal screening tool for Michigan.

Table 1. Bedrock categories and response by water-withdrawal screening tool to proposed bedrock well in each category.

Bedrock category	Description of bedrock hydraulic conditions	Response from water-withdrawal screening tool
-1	Bedrock aquifers typically in only limited hydraulic connection with streams but in areas where ground water in the bedrock aquifer is potentially saline based on a regional assessment (Westjohn and Weaver, 1996). Note that in some areas, saline water may occur at depth below a freshwater zone, and in other areas, saline water may be present throughout the entire bedrock thickness.	The proposed well passes the screen and the user is informed to register the use as required by statues. Because in some areas identified as saline (Westjohn and Weaver, 1996) bedrock wells may produce potable water and saline water becomes an issue only for deeper bedrock wells, this flag is not used in the current version (January 2008) of the screening tool. The information is retained in the underlying database in case this information is desired in future versions. The user is warned in all uses of the screening tool that the tool is not intended as a design tool and that the evaluation does not guarantee ground-water quantity or quality.
0	Bedrock typically not used for high-capacity wells because the dominant bedrock unit in the area is not a productive aquifer. For example, this category is used for areas in the state underlain by the Coldwater Shale.	The user is informed through a pop-up message that bedrock aquifers in this area are generally not used for high-capacity wells. The screening tool uses aquifer properties from the glacial deposits to evaluate the potential streamflow depletion for the proposed well.
1	Bedrock aquifers typically in only limited hydraulic connection with streams, especially smaller streams.	The proposed well passes the screen, and the user is informed to register the use as required by statues.
2	Bedrock aquifer may have hydraulic connection with streams.	The proposed withdrawal is evaluated by use of bedrock properties from the Ground-Water Inventory and Map database that were processed in the same way as the properties for the glacial deposits. The streambed conductance between the bedrock aquifer and the stream is estimated by use of the properties of the glacial deposits overlying the bedrock. The assigned storage coefficient is 0.0004, as used in the Ground-Water Inventory and Map.

Definition of Great Lake Shoreline Catchments

Many small valley-segment catchments were defined adjacent to one of the Great Lakes. If the valley segment in a catchment adjacent to a Great Lake did not contain a stream or was smaller than approximately 3 to 6 mi^2, then the valley-segment catchment was designated as a shoreline catchment. No limitation on depletion was set from these shoreline catchments because pumping was assumed to come from the lake and not adversely impact a stream. Entities proposing withdrawals greater than 2 Mgal/d, however, are required to obtain a water-withdrawal permit (Public Act 180 of 2008 (2008 PA 180), Michigan State Legislature, 2008b), and the potential ecological impact of such withdrawals may be assessed in the permitting process.

Distribution of Streamflow Depletion Among Valley Segments in Neighboring Catchments

Unlike direct surface-water withdrawal, ground-water withdrawals are thought to potentially affect valley segments in neighboring catchments. The analytical solution, however, estimates streamflow depletion only between the well and a single stream. Nine different methods to apportion streamflow depletion among neighboring valley segments were evaluated. Details regarding this evalution are presented in appendix 2. The simplest approach is to estimate streamflow depletion only for the valley segment draining the catchment containing the well. This simple approach, however, performed the worst compared to the results from a numerical ground-water-flow model. On the basis of the analysis, an inverse distance method was selected for the screening tool because (1) it produces a reasonable overall pattern of streamflow depletion compared to a numerical ground-water-flow model, (2) it is the most straightforward to implement in the Internet-based screening tool, and (3) it has some theoretical basis in steady-state analysis (Wilson, 1993). The weighting used for this distribution method may be written as

$$f_i = \frac{\frac{1}{d_i}}{\sum_{j=1,n} \frac{1}{d_j}}, \tag{6}$$

where

f_i is the fraction of the captured water attributed to valley segment i,

n is the number of adjacent valley-segment catchments, and

d_i is the distance from the proposed well to the closest point on the valley segment within catchment *i*.

Demonstration of Analytical Model and Distribution Approach

The ground-water-flow model for the area around Kalamazoo County, Mich. (Luukkonen and others, 2004) was used to test the nine distribution methods discussed in appendix 2 and to demonstrate the performance of the analytical model used in the screening tool. The ground-water-flow model is a finite-difference (MODFLOW) simulation model with 6 layers, 154 rows, and 162 columns. The smallest grid spacing in the model is 660 ft by 660 ft. Valley-segment catchments in the interior of the model that have this finest grid spacing were used in the methods testing. The model used for the test case includes approximately 90 existing wells, and streamflow depletion caused by the addition of a new well to different parts of the model is examined. To illustrate the applicability of the analytical model and distribution approach to field problems, a transient simulation with seasonally varying recharge and pumping rates was used as the test case. Luukkonen and others (2004) presented the results for a 9-year transient simulation; but, in this work, the length of the simulation was reduced to 5 years to reduce computer run time (fig. 3). The simulation illustrates seasonal pumping and recharge. This simulation is used in the demonstration to illustrate that the analytical model given by equation 1 is not affected by time-varying areal recharge as long as the areal recharge is independent of the imposed pumping. Because areal recharge in the numerical model is specified and does not depend on the pumping imposed on the system, the numerical model is consistent with the assumptions made in the analytical model. For many cases in Michigan, pumping will not induce increased recharge, and this assumption is valid at least on a screening level.

A method to illustrate streamflow capture by pumping wells (Leake and Reeves, 2008) was used to examine the spatial distribution of streamflow capture from the valley segments. In this method, hypothetical wells are added to the MODFLOW model sequentially on a grid of cells (fig. 4).

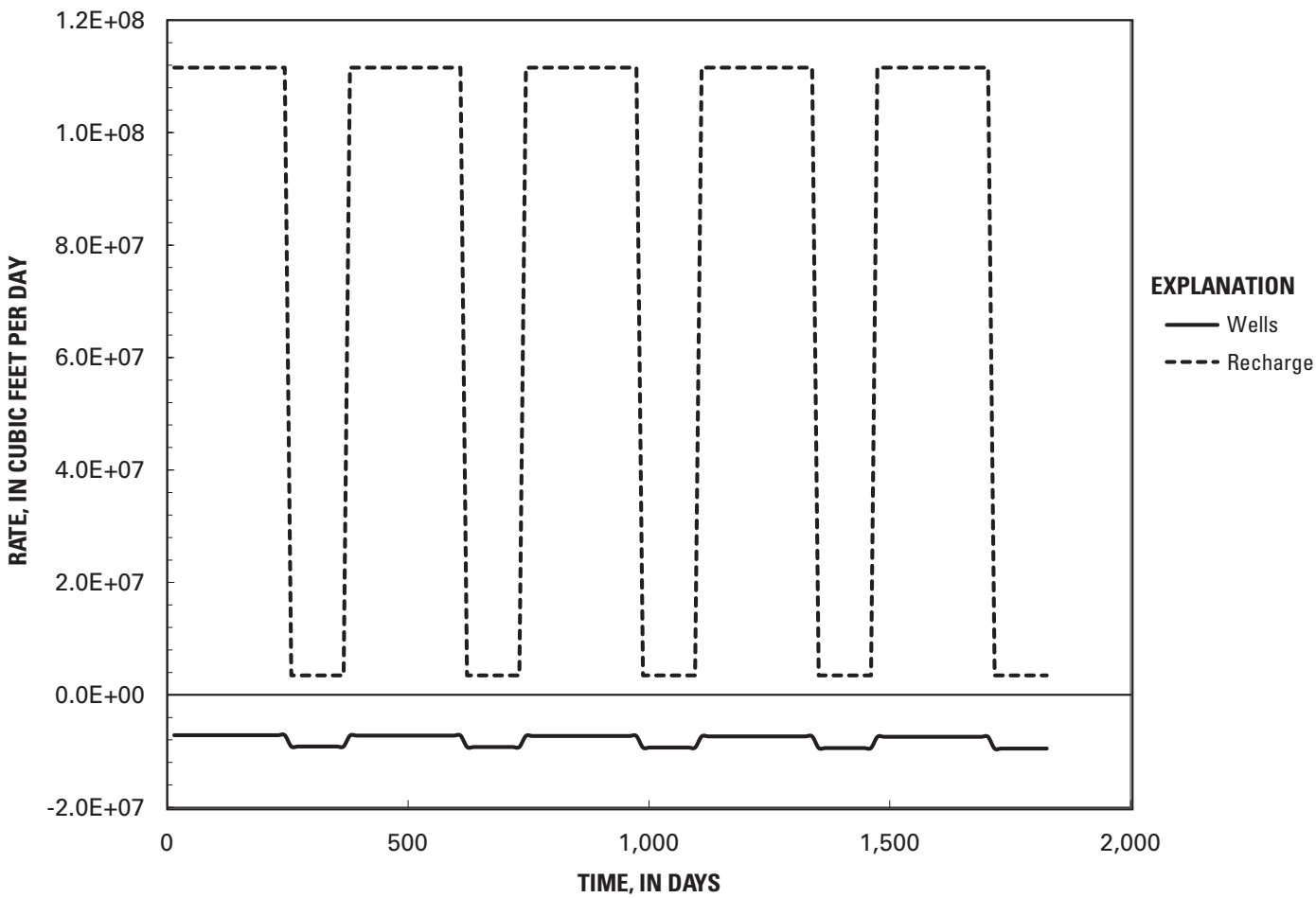


Figure 3. Recharge and pumping rates used in the base simulations with the Kalamazoo regional ground-water-flow model (Luukkonen and others, 2004).

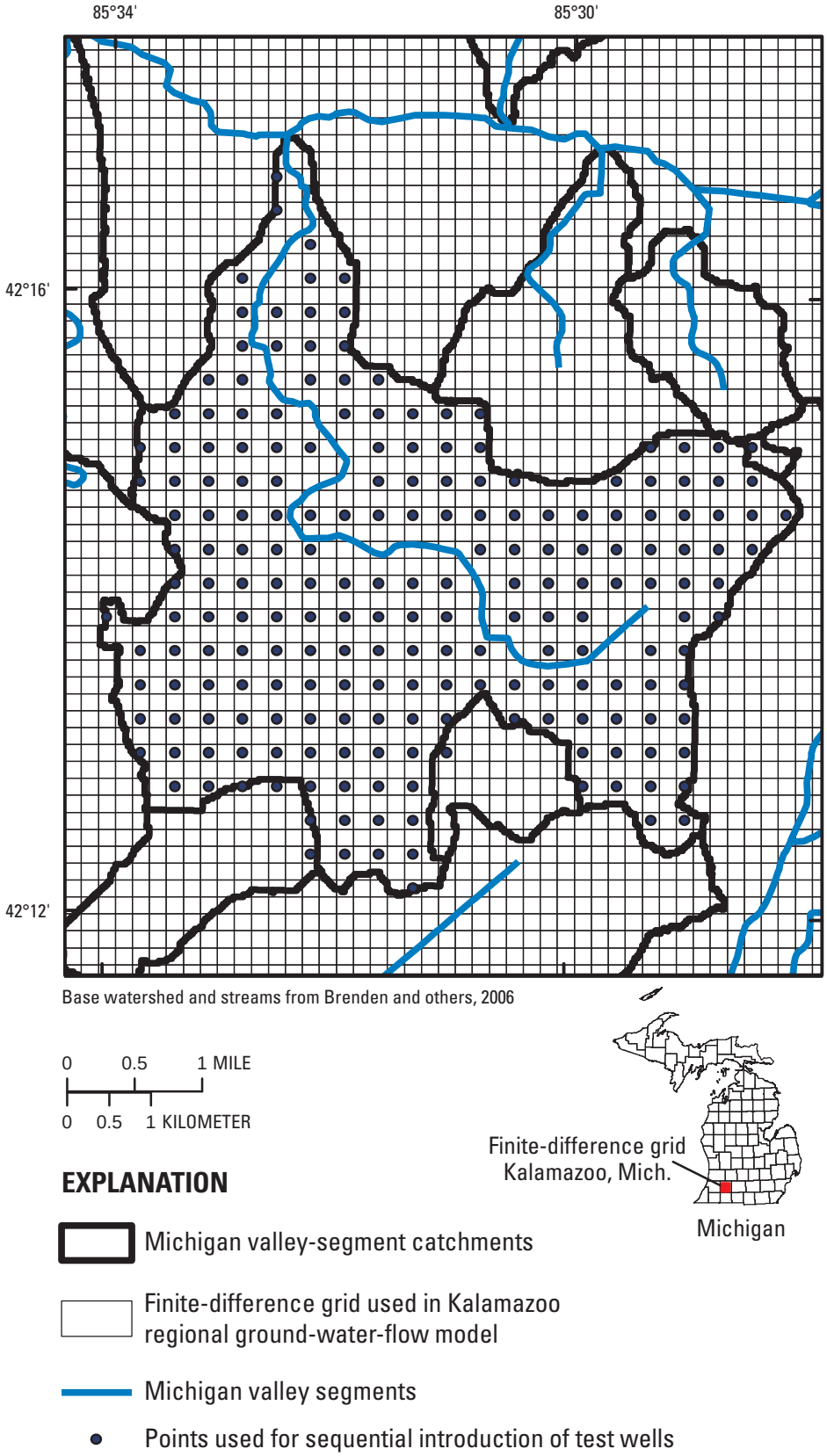


Figure 4. A grid of points used to compare the analytical model and different distribution methods to MODFLOW results from the Kalamazoo regional ground-water-flow model (Luukkonen and others, 2004).

One well is added to a specified cell, and the new simulation is computed. The results from this new simulation are subtracted from base-model results to determine the capture and change in storage caused by the new well. The process is repeated with one new well at a time, generating a grid of results that may be mapped. The fluxes to individual river cells representing the valley segments from the statewide data framework were computed. These fluxes were recorded by use of a river observation file (Hill and others, 2000) to designate the finite-difference cells assigned as river cells to the appropriate valley segments. The river flux output from the system with the new well for each designated valley segment was subtracted from the valley-segment flux computed with the original model to yield the streamflow depletion due to the new well as simulated with the MODFLOW model. Values for streamflow depletion as a percentage of pumping rate for the grid of wells shown in figure 4, which were placed in layer 3 of the model, are shown in figure 5. The two methods, MODFLOW and the analytical model, produce similar results for wells introduced into the test valley-segment catchment. The maximum depletion for wells introduced near the valley segment within the catchment is between 70 and 80 percent, and the minimum depletion near the boundary of the catchment is less than 10 percent (See appendix 2 for more detailed discussion of the methods to distribute streamflow depletion among neighboring valley segments).

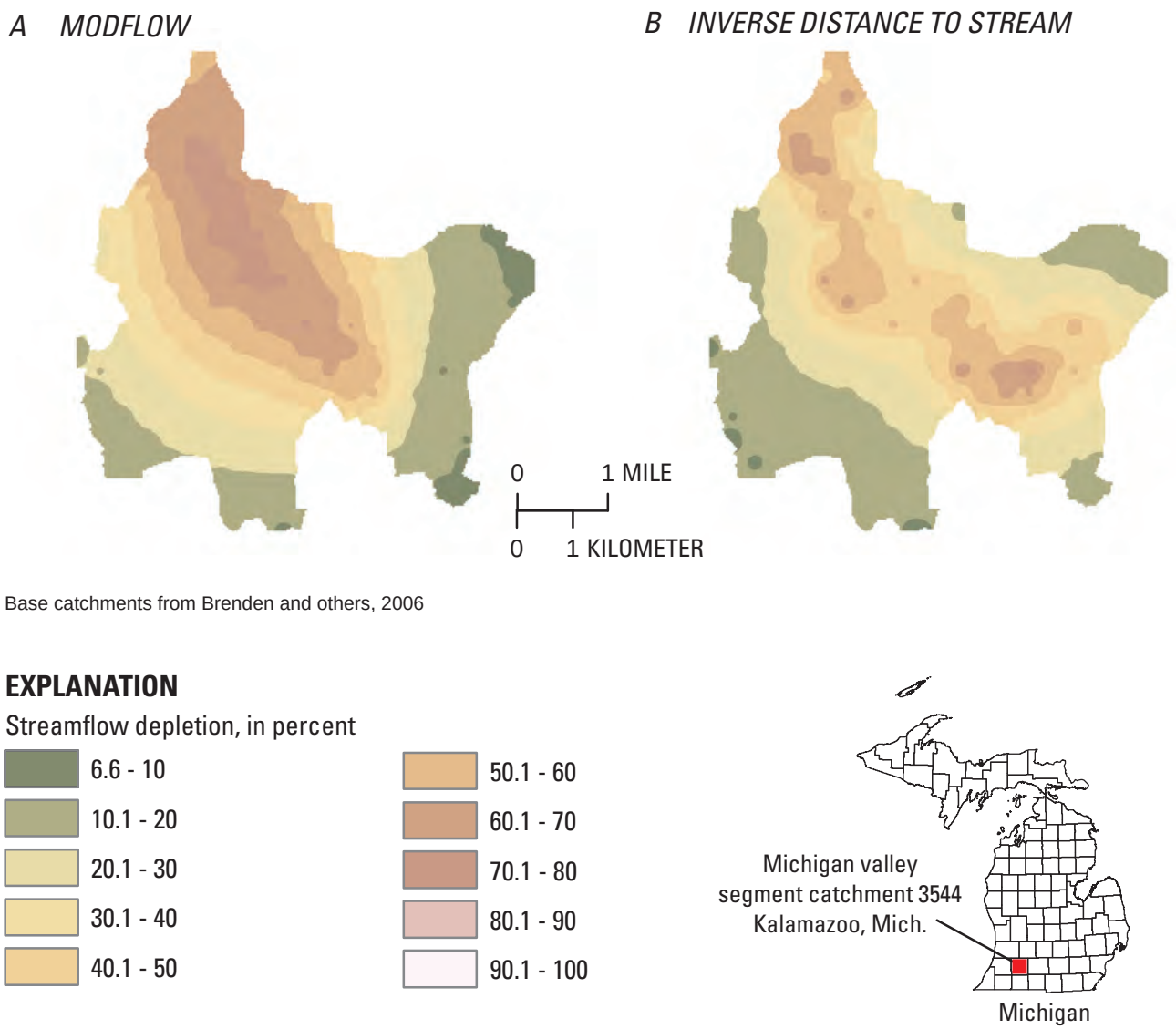


Figure 5. Estimated streamflow depletion from valley segment 3544 as a percentage of pumping rate after 5 years of pumping. *A*, results from a sequential introduction of test wells in the MODFLOW ground-water-flow model for Kalamazoo County, Mich. *B*, results from analytical model with inverse distance to stream distribution of streamflow depletion.

Limitations of Testing

The MODFLOW simulation model for the Kalamazoo area provides a convenient way to test the analytical model and distribution methods. The ground-water-flow model, however, is a regional simplification of the flow system, and neither the MODFLOW model nor the analytical model may accurately estimate the true impact of a specific well on a specific stream in the area. Site-specific investigation would be required for such an estimate. The MODFLOW model resolution of the stream network and well distribution also affects the estimates. The smallest grid size in the ground-water-flow model is 660 ft by 660 ft, and this becomes the shortest distance between the well and the stream that can be tested with the MODFLOW model. If a test point is placed in the same cell as a valley segment, the effective distance between the well and the stream is zero in the MODFLOW model. For the test grid (fig. 4), no wells were placed in valley-segment cells. The distances used for the analytical model are from geoprocessing of the data-framework files. These distances are more accurate than those used in the MODFLOW model, and some mismatch between MODFLOW results and the analytical estimates is expected because of these distance differences. In addition, the aquifer characteristics used in the MODFLOW model are different from those used in the analytical model. The transmissivity, storage coefficient, and streamflow-conductance values used in the analytical model in the test were estimated from the statewide databases, as described earlier in this report. The values used in the MODFLOW model, however, were the calibrated values from Luukkonen and others (2004). Different input values were used to more fully test the approach for the screening tool described previously. The reasonable match between the MODFLOW results and the analytical-model results supports the use of the analytical model, the use of the estimated aquifer properties derived from the GWIM database, and the use of the inverse-distance weighting scheme to distribute streamflow depletion among neighboring valley-segment catchments.

The aquifer and surface-water network in Kalamazoo County is not necessarily representative of conditions across all of Michigan. In addition to this quantitative test, a series of qualitative ad hoc tests were performed by applying the analytical model to locations of high-capacity wells in every county of the state. The ad hoc tests relied on the experience of the testing team to assess whether the results appeared to be reasonable, and no major problems were identified through this testing.

Summary of the Ground-Water Component of the Water-Withdrawal Screening Tool

The water-withdrawal screening tool was designed to be accessed through the Internet. This access required the integration of several technologies. The screening tool essentially implements the analytical model and inverse-distance weighting distribution method described in the previous sections but with different computer software than used in the testing and development. A brief list of steps may help illustrate the ground-water component of the screening tool. The overarching technology is an ArcIMS Web site (Environmental Systems Research Institute, Inc. (ESRI), 2004) that provides a map interface to the screening tool for the user. The following is the sequence of steps for a typical screening-tool session:

1. When the user enters the location for a new withdrawal, a server running ArcView with Avenue Scripts (for example, Razavi and Warwick, 1999) determines the valley segment containing the proposed well.

2. The user specifies whether the proposed well is in glacial deposits or bedrock. If bedrock, then the bedrock type for the valley-segment catchment is identified.

3. A GIS data file is accessed to gather the aquifer properties assigned to the valley-segment catchment and to determine whether the valley-segment catchment is identified as a Great Lake shoreline catchment.

4. The neighboring valley segments are identified.

5. The distances from the proposed well to the nearest valley segment in each of the valley-segment catchments are computed.

6. VBScripts are used to run the Hunt (1999) analytical model (equation 1) for each of the valley segments using the aquifer properties for the valley-segment catchment containing the well and the distances computed in step 5. If the user specifies time-varying pumping, then superposition (equation 2) is used to compute the maximum streamflow depletion during the 5-year evaluation period. For steady pumping, the solution is evaluated after 5 years of pumping.

7. VBScripts are used to distribute the streamflow depletion between the neighboring valley segments using inverse distance weighting (equation 6).

8. Additional scripts are used to collect this information, compare the results to streamflow estimates, and apply screening rules to provide feedback to the user.

Example Screening and Confirmation of Water-Withdrawal Screening-Tool Results

The tests of the analytical model presented in this report were generated by use of Python scripts and the Fortran-based STRMDEPL08 program (Reeves, 2008). The STRMDEPL08 program was used to evaluate the Hunt (1999) analytical model (equation 1). Examples were run in this manner as batch tests for the technical subcommittee of the GWCAC. Because the STRMDEPL08 program has been documented by Reeves (2008), it serves as a standard for comparison of the Internet-based water-withdrawal screening tool. In this final section, results from the water-withdrawal screening tool using the sequence of ArcIMS, VBScript, and Avenue scripts listed above are shown to match results from STRMDEPL08 with inverse-distance weighting applied to distribute withdrawal among neighboring valley segments.

For this demonstration, an example in the northern part of the Lower Peninsula of Michigan (fig. 6) was evaluated with the water-withdrawal screening tool. The latitude and

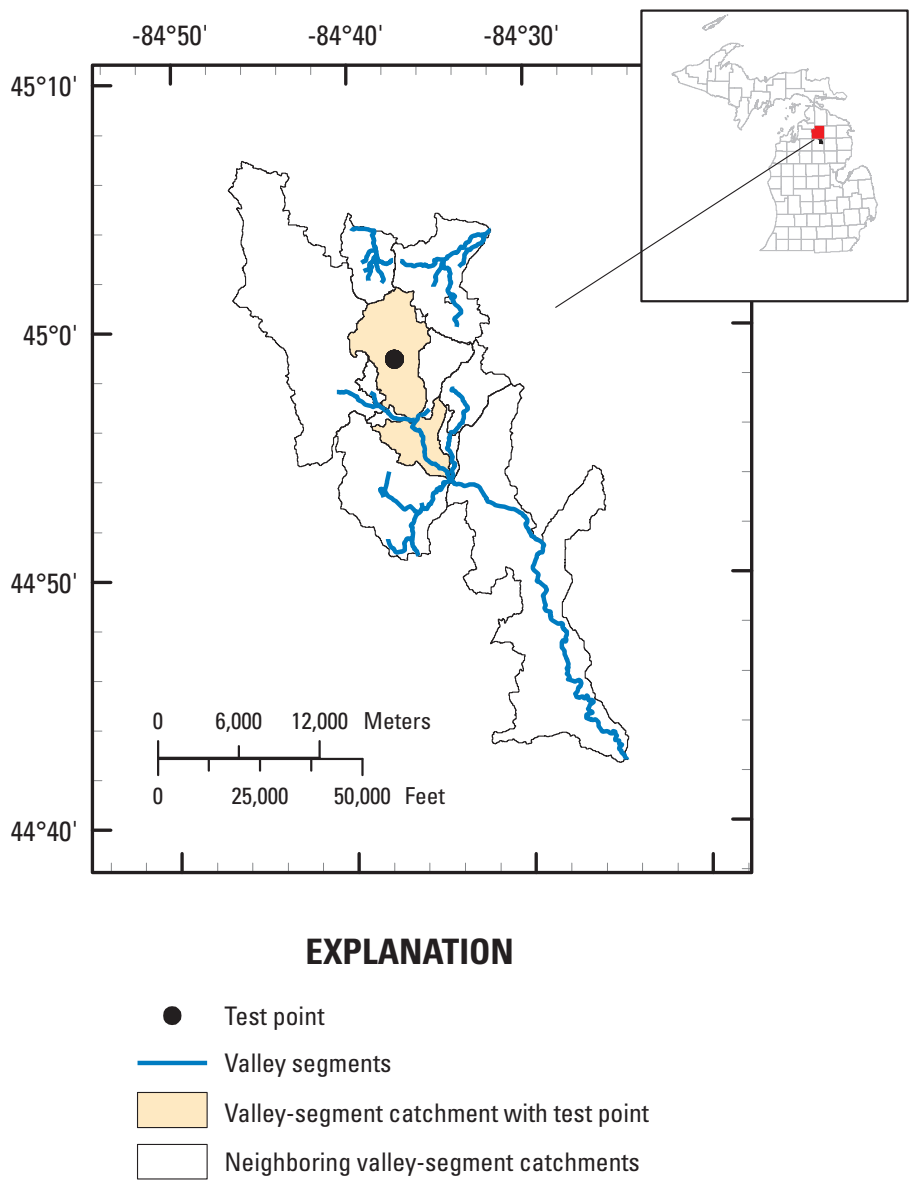


Figure 6. Example test point, valley-segment catchment containing the point, and neighboring valley-segment catchments.

longitude of the point were input to the Python scripts used for the screening-tool development. The point, the valley-segment catchment containing the point, the neighboring valley-segment catchments, and the neighboring valley segments identified by the Internet-based suite of programs and the Python scripts were identical. The percent removal from each of the valley segments and the total removal given a well at a depth of 80 ft and a continuous pumping rate of 70 gal/min generated by the STRMDEPL08 program (Reeves, 2008) and the water-withdrawal screening tool were nearly identical (table 2). The differences between the STRMDEPL08 and water-withdrawal screening tool may be attributed to slight differences in the estimated distances between the proposed well and valley segments, most likely caused by round-off in the latitudes and longitudes used to locate the point.

Table 2. Compilation of estimates for an example test point using the Michigan water-withdrawal screening tool and the set of batch programs used in screening-tool development and testing.

[The number of digits used does not signify precision of estimates but is reported to show the difference between the two sets of calculations]

Valley segment identification	Distance to example well, feet		Removal from valley segment, percent		Analytical removal, gallons per minute		Estimated removal from valley segment, gallons per minute	
	Screening tool	Batch	Screening tool	Batch	Screening tool	Batch	Screening tool	Batch
8	14,802	14,798.9	9.89	9.89	52.02	52.02	5.15	5.15
9	12,609.2	12,609.6	11.61	11.61	54.30	54.30	6.31	6.30
11	15,750.5	15,745.0	9.30	9.30	51.05	51.03	4.75	4.74
27	22,567.6	22,562.4	6.49	6.49	44.24	44.25	2.87	2.87
9741	27,565.2	27,561.4	5.31	5.31	39.52	39.49	2.10	2.10
10532	33,059.5	33,052.5	4.43	4.43	34.62	34.60	1.53	1.53
11967	14,846.3	14,844.0	9.86	9.86	51.98	51.97	5.13	5.13
12515	17,042.5	17,033.9	8.59	8.59	49.73	49.73	4.27	4.27
12573	11,959.5	11,960.4	12.24	12.24	54.98	54.98	6.73	6.73
12941	19,070.8	19,063.4	7.68	7.68	47.69	47.71	3.66	3.66
13925	10,028.9	10,030.6	14.60	14.59	57.01	57.00	8.32	8.32

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Appendix 1. Background and Literature Review on Streamflow Depletion Modeling

Streamflow depletion has been modeled with various analytical and numerical models. The conceptual model underlying each approach may be used to distinguish and classify the analytical and numerical models. Five conceptual models and extensions are discussed to provide an overview of the relevant literature on streamflow depletion by wells.

Fully Penetrating Stream With No Streambed Resistance

The first conceptual model discussed in this report was used to derive a solution by Theis (1941) that was later recast in the now more familiar form by Glover and Balmer (1954). This model is for a stream that fully penetrates the aquifer. There is no resistance to flow offered by the streambed. The domain is homogeneous and extends to infinity away from the stream. The stream is infinite, and the interaction between the pumped aquifer and the entire stream length is considered. There is no flow across the bottom of the aquifer. Flow is horizontal (Dupuit approximation) and, if the aquifer is unconfined, then drawdown in the aquifer is small compared to the saturated thickness such that the system may be modeled with constant transmissivity (fig. 1–1*A*). Glover (1974) presents a solution to the problem that provides an estimate of streamflow depletion for an arbitrary length of the stream.

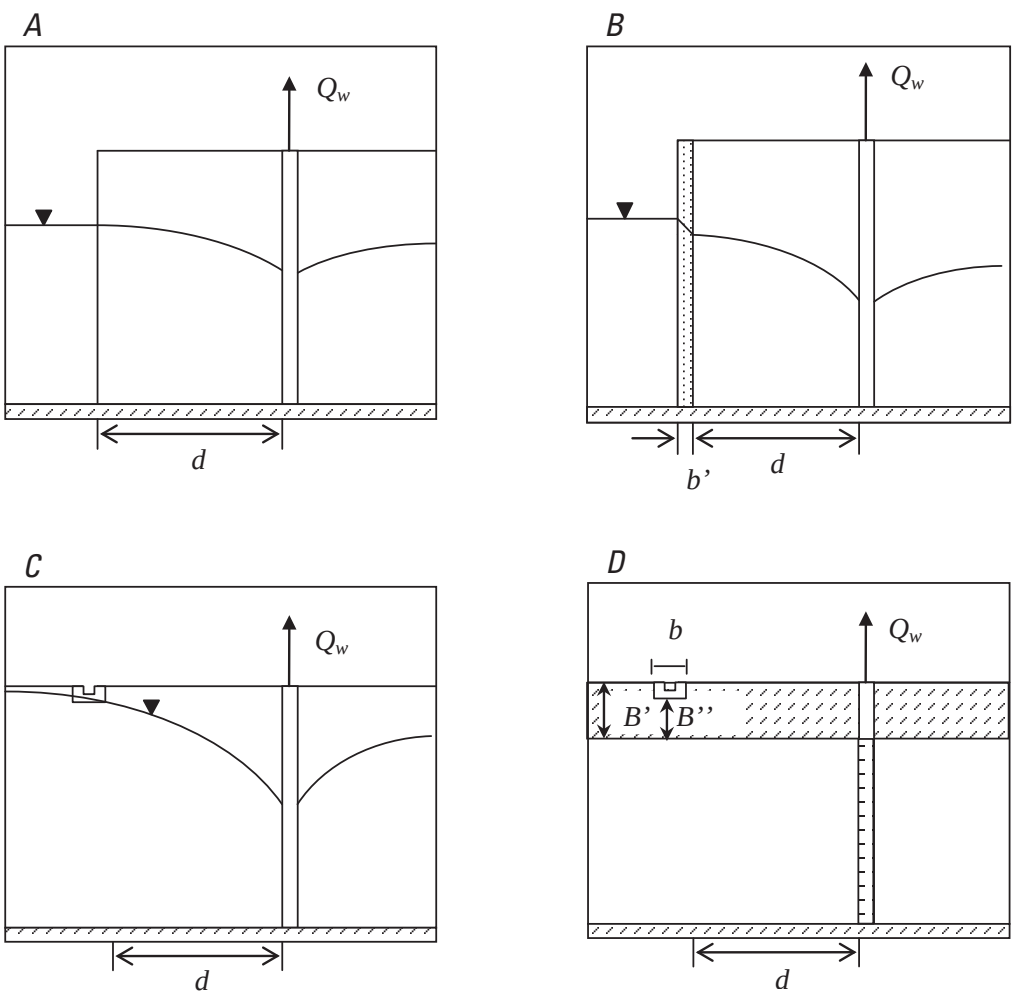

Figure 1–1. Alternate conceptual models for streamflow depletion by a pumping well. (*A*, Fully penetrating stream with no streambed resistance. *B*, Fully penetrating stream with streambed resistance. *C*, Partially penetrating stream with streambed resistance. *D*, Partially penetrating stream in semiconfining layer with pumping from underlying semiconfined aquifer. In the figure, d is the distance from the well to the stream, Q_w is the pumping rate from the well, b' is the thickness of the streambed, B' is the distance from the land surface to the top of the leaky aquifer, B'' is the distance from the bottom of the stream to the top of the leaky aquifer, and b is the width of the stream (Modified from Reeves, 2008)).

The Theis (1941) and Glover and Balmer (1954) solutions are transient but consider only a constant pumping rate. Jenkins (1968) and Wallace and others (1990) describe how to use superposition to extend the Glover and Balmer (1954) solution for intermittent or cyclic pumping rates. Jenkins (1968) introduces the concept of the streamflow depletion factor (*sdf*) that is used by several subsequent authors (for example, Burns, 1983). Jenkins (1968) focuses on the use of superposition to solve intermittent pumping problems and demonstrates that streamflow depletion continues for some time even after pumping has been stopped. Wallace and others (1990) examine the time required for the system to attain a dynamic steady state and the conditions under which a cycle-average pumping rate could be used in the estimation of streamflow depletion by cyclic pumping. Under certain conditions, discussed in the paper, the use of the cycle-average pumping rate to analyze streamflow depletion severely underestimates the peak depletion rates; therefore, an analysis with the true cyclic pumping rates is preferable. Barlow (2000) wrote a computer program to compute the Glover and Balmer (1954) solution for intermittent pumping, using the techniques described by Jenkins (1968).

In contrast to the transient solutions, Newsom and Wilson (1988) and Wilson (1993) present steady-state solutions to this problem. For all the solutions discussed for this conceptual model, the total streamflow depletion is the pumping rate because there are no other sources of water to allow the system to reach steady state other than capture from the stream. The Glover (1974) solution and the Newsom and Wilson (1988) or Wilson (1993) solutions can be used to estimate the amount of streamflow depletion in a prescribed length of the stream reach. As this length becomes large, the streamflow depletion from the specified stream reach approaches the pumping rate. The papers by Newsom and Wilson (1988) and Wilson (1993) illustrate the importance of regional ground-water flow on the solution. The analysis in the papers also distinguishes between streamflow capture by interception of ground water that would have been discharged from the aquifer as base flow and streamflow capture by induction of stream water into the aquifer. Wilson (1993) also provides analysis for a well between two streams with vertical recharge and for an aquifer with both a stream and a barrier boundary.

Distinguishing between capture from decreased base flow to the stream and induced infiltration from the stream may be important for water-quality analysis if the water-quality characteristics of the stream and the aquifer are different. The steady-state solutions may be used to analyze the infiltration rate of poor-quality surface water to a supply well or the discharge rate of contaminated ground water to a stream despite the installation of an extraction well. The critical pumping rate required to induce infiltration from the stream is shown to be a function of the angle between the ambient flow direction and the stream (Newsom and Wilson, 1988). If the ambient flow rate is perpendicular to the streambed, which is the typical situation, the critical flow rate is calculated as follows (Newsom and Wilson, 1988; Wilson, 1993):

$$Q_c = \pi d q_a , \qquad (1\text{–}1)$$

where

Q_c is the critical pumping rate, d is the distance between the well and the stream, and

q_a is the ambient flow rate of ground water to the stream per unit length of stream.

This last term is the specific discharge from the aquifer to the stream integrated by the thickness of the aquifer, and it has units of length squared per unit time (Newsom and Wilson, 1988). Newsom and Wilson (1988) present results that show that this critical pumping rate increases by approximately 10 percent at an approximate angle between the ambient flow and the streambed of 29 degrees. The critical pumping rate is increased for angles between 0 and approximately 55 degrees and decreases between 55 degrees and 90 degrees. For flow parallel to the streambed (90-degree angle between ambient flow and the streambed), the critical pumping rate is approximately 40 percent of the value given above.

Chen (2003) combines transient analysis and the questions posed by Newsom and Wilson (1988) and Wilson (1993) to present a transient investigation of induced infiltration from the stream and decreased base flow to the stream. In particular, Chen (2003) derives the critical time required to induce infiltration from the stream as

$$t_c = -\frac{d^2 S}{4T \ln(\pi q_a d / Q)} , \qquad (1\text{-}2)$$

where

t_c is the critical time when infiltration from the stream to the aquifer is induced,

T is the aquifer transmissivity (length squared per unit time),

S is the aquifer storage coefficient (dimensionless), and

Q is the pumping rate of the well (length cubed per unit time).

Chen (2003) also discusses the residual impact of pumping on streamflow after pumping has ceased. As noted by other transient analysis (for example, Jenkins, 1968; Wallace and others, 1990), streamflow depletion continues after pumping has stopped until, under this conceptual model, the total volume removed as streamflow depletion is the same as the volume of water removed from the aquifer by the intermittent pumping.

Fully Penetrating Stream With Streambed Resistance

Hantush (1965) presented the solution for the second conceptual model that includes streambed resistance as illustrated in figure 1–1*B*. The resistance in the streambed is described by

a streambed leakance or retardation coefficient, $L = (Kb'/K')$, where K is the hydraulic conductivity of the aquifer, K' is the hydraulic conductivity of the streambed, and b' is the thickness of the streambed[1]. The streambed leakance term causes the interaction between the pumping well and the stream to be delayed. As discussed for the previous conceptual model, because there are no other sources of water for the well to capture, the streamflow depletion is the pumping rate at steady state. The Hantush (1965) solution is a transient solution for a constant pumping rate, and the superposition techniques described by Jenkins (1968) can be applied to this solution. Barlow (2000) includes the Hantush (1965) solution in the computer program cited above as an input option selected by the user.

Many solutions that consider streambed resistance also incorporate partial penetration of the streambed into the aquifer, and these solutions will be discussed in the next section. Three papers that evaluated analytical solutions and identified shortcomings with various conceptual models are now reviewed to emphasize the difference between the conceptual models and associated analytical solutions. Spaulding and Khaleel (1991) and Sophocleous and others (1995) analyzed the analytical solutions by Glover and Balmer (1954), Jacob (1950) (discussed in the next section), Hantush (1965), and Glover (1974) and provide results illustrating the importance of streambed resistance and partial penetration of the streambed into the aquifer. See figure 1–1*C* for an illustration of a partially penetrating streambed. Spaulding and Khaleel (1991) used a finite-element ground-water-flow model from the literature and Sophocleous and others (1995) used the finite-difference-based model MODFLOW (Harbaugh and others, 2000) to test the various analytical solutions for different conceptual models. Both papers conclude that streambed resistance and partial penetration of the streambed into the aquifer are important to the solution and that conceptual models that do not account for these factors may severely overestimate the streamflow depletion rate at a given time. Conrad and Beljin (1996) also used MODFLOW to investigate various assumptions inherent in the Wilson (1993) solution. These authors also investigated the impact of streambed resistance and partial penetration by the stream. In addition, they present tests exploring the impact of vertical anisotropy in the aquifer and of considering typical variations in stream levels on the simulation of the aquifer system. All of these papers show that partial penetration of the streambed into the aquifer and incorporation of streambed resistance are important features that should be included in the analysis of streamflow depletion.

Partially Penetrating Stream With Streambed Resistance

Hunt (1999) generalizes the problem more by considering a partially penetrating stream in a fully confined or unconfined aquifer. The rest of the assumptions used for the previous cases still hold: horizontal flow following the Dupuit approximation, small changes in saturated thickness for the unconfined case, and a homogeneous aquifer. In this case, the aquifer has infinite extent and the stream width and depth are small compared to the aquifer thickness, such that the stream may be modeled as a line (zero width). Hunt (1999) includes the resistance through a streambed using Darcy's Law, $Q = \lambda (H-h)$, where λ is a streambed-conductance term that must incorporate the hydraulic conductivity of the streambed, geometry of the streambed, and streambed thickness; H is the elevation of the water level in the stream; and h is the head in the aquifer at the streambed. As discussed by Hunt (1999), and emphasized by Rushton (1999), the head in the aquifer is assumed to remain in the streambed in this solution. (Solutions considering the case where the head in the aquifer drops below the streambed are discussed later.) This solution considers the impact of pumping on the head in the aquifer on the opposite side of the stream from the pumping well (fig. 1–1*C*). The solution yields the time-dependent response of the aquifer and for streamflow depletion to steady pumping from a well. Hunt (1999) shows how the solution presented approaches the Glover and Balmer (1954) solution as λ approaches infinity and the Hantush (1965) solution if λ is replaced by $2T/L$. Hunt (1999) points out that Hantush (1965) suggested that the distance from the stream to the well, d, in the solution may be varied to account for partial penetration of the stream (see also Jacob, 1950; and Spaulding and Khaleel, 1991) and that this suggestion appears to be incorrect. Evidently, the Hantush (1965) solution for the semi-infinite domain and fully penetrating stream may be used for the infinite domain and partially penetrating stream by appropriate correction to the retardation coefficient, L, using $L = 2T/\lambda$.

The notion that partial penetration of the streambed into the aquifer may be modeled by varying the distance from the well to the stream in the solution is not unique to Hantush (1965). Jacob (1950) suggested that the distance from the well to the stream may be varied in the Glover and Balmer (1954) solution to account for both streambed resistance and partial penetration of the streambed (Spaulding and Khaleel, 1991). To facilitate comparison of the analytical solutions, Spaulding and Khaleel (1991) used a three-dimensional analytical solution to derive a set of curves defining the effective distance from the well to the stream for different degrees of partial penetration for use in either the Glover and Balmer (1954) or Hantush (1965) solutions. Darama (2001) used this set of curves along with techniques from Wallace and others (1990) to examine cyclic pumping in the case of partially penetrating streambed with streambed resistance. Darama (2001) echoed the conclusions of Spaulding and Khaleel (1991) and Sophocleous and others (1995) that partial penetration of the streambed and streambed resistance are important factors in the solution that should be considered in the conceptual model.

Singh (2003) presents an alternate solution for a partially penetrating stream by adding an equivalent resistance length to the Hantush (1965) retardation coefficient to account for

[1] Streambed resistance in the paper by Hunt (1999) is L, but Hantush (1965) denotes this coefficient by a.

partial penetration. In this way the solution addresses both streambed resistance and partial penetration. An expression to approximate the additional resistance length that depends on the thickness of the aquifer and the stream width is provided. Singh (2003) also discusses the use of superposition to account for intermittent pumping. The geometry of the conceptual model is not discussed by Singh (2003), and the Hunt (1999) solution is not cited. Because of the relation between the Hantush (1965) and Hunt (1999) solutions, and because the Singh (2003) solution is an extension of the Hantush (1965) solution, there must be a relation between the Singh (2003) and Hunt (1999) solutions. This relation implies that the Singh (2003) solution could be used for the conceptual model shown in figures 1–1*B* or 1–1*C*. An analysis to relate the Hantush (1965) retardation coefficient, the streambed-conductance term used by Hunt (1999), and the resistance length added due to partial penetration in the Singh (2003) would be interesting but beyond the scope of this review.

Another approach to this conceptual model was offered by Zlotnik and Huang (1999), who derived an analytical solution by breaking the problem domain into two regions. The first region is the aquifer below the partially penetrating stream, and the second region is the adjacent semi-infinite aquifer. The solution is derived by simultaneously solving the equations for the two regions that are coupled by the boundary condition at the interface between the two regions. The solution is given as a Laplace Transform and is awkward to evaluate. A simplified version of the solution in which the storage coefficient in the region below the streambed is ignored yields a simpler solution that has a similar form to many of the other analytical solutions discussed. One advantage of this solution is that the stream has finite width in contrast to the solution presented by Hunt (1999) that models the stream as a line.

Butler and others (2001) extend the earlier work by Zlotnik and Huang (1999) and compare results of this analytical model to results from the solution presented by Hunt (1999) and to numerical results generated from MODFLOW. This analysis again emphasizes the importance of considering both partially penetrating streambed and streambed resistance when simulating the interaction between a pumping well and a stream. The authors noted that the model by Hunt (1999), which does not account for stream width, yields essentially the same result as a finite-width solution if the well is more than five stream-widths away from the stream. Comparison with the numerical model allowed the evaluation of the assumption that the aquifer is infinite in extent away from the stream. This analysis suggested that the aquifer width has to be hundreds of stream widths in extent before the analytical solution yields similar results as the numerical solution.

A solution for a finite-width stream also was given by Fox and others (2002). The nature of the solution and an alternate explanation for convergence problems identified by Fox and others (2002) is presented in the discussion by Hunt (2004). The difference between the finite-width solution (Fox and others, 2002) and line-width solution (Hunt, 1999) was investigated for a range of conditions. The difference depends on the distance from the well to the stream and the simulation time. When the well is more than 50 stream widths from the stream, the difference between the two solutions is less than 1 percent. In contrast to the findings of Butler and others (2001), the lower limit reported by Fox and others (2002) for agreement between the solutions is 25 stream widths. When the well is closer than 15 stream widths away from the stream, the maximum error between the solutions under the worst-case conditions is stated to be as great as 10 percent.

Di Matteo and Dragoni (2005a, 2005b) used MODFLOW to investigate partial penetration of the streambed into the aquifer and the impact of regional gradients on the solution. The importance of regional gradients for fully penetrating streams also was illustrated by Newsom and Wilson (1988), Wilson (1993), and Chen (2003). Di Matteo and Dragoni (2005a) present an interesting approach wherein MODFLOW was used to generate streamflow-depletion estimates, and then these estimates were fit by a nonlinear function in terms of the aquifer parameters and stream geometry. This empirical relation was then tested for a variety of conditions to illustrate the importance of anisotropy, partial penetration of the streambed, and the overlap between the bottom of the streambed and top of the well casing. This is the only paper that explicitly considers this overlap in the analysis.

Steady-state solutions to the partially penetrating streambed are presented by Ernst (1979) and Bakker and Anderson (2003). Ernst (1979) uses image-well theory to derive expressions for drawdown and streamflow depletion, but this paper appears to be largely forgotten because it is not often cited in the literature. Bakker and Anderson (2003) also use image-well theory and allow for a hydraulic gradient in the stream and for ambient flow in the aquifer at an arbitrary angle to the streambed. The solution is very interesting in that it illustrates the impact of pumping a well on the opposite side of the stream as solved by Hunt (1999) and schematically illustrated in figure 1–1*C*. In the special case of no hydraulic gradient in either the stream or in the aquifer (no ambient flow), the solution reduces to a steady-state evaluation of the solution by Hunt (1999). The Bakker and Anderson (2003) solution is similar in concept to that of Newsom and Wilson (1988) and Wilson (1993) except that it considers partial penetration of the streambed. The partial penetration of the streambed into the aquifer complicates matters and leads to a solution written in terms of complex potentials. As in the case of the earlier steady-state solutions, this solution is useful to delineate ultimate capture zones for wells and to distinguish between captured base flow and induced infiltration from the stream to the aquifer.

Partially Penetrating Stream With Drawdown in the Aquifer Below the Streambed

Several papers in the literature have discussed the importance of unsaturated flow in the analysis of the interaction of a stream and an aquifer when the head in the aquifer falls below

the streambed and the stream becomes disconnected from the water table (perched). In all of the solutions presented earlier in this review, the head in the aquifer must remain within the streambed. In cases where the resistance to flow in either the aquifer or the streambed is large enough, the head in the aquifer may drop below the streambed in response to pumping. Classically, when the head in the aquifer falls below the streambed, the rate of streamflow depletion becomes constant and independent of the pumping rate. The rate of streamflow depletion depends on the water level in the stream, the elevation of the streambed, and the hydraulic characteristics of the streambed (as modeled in MODFLOW, for example (Harbaugh and others, 2000); see also the discussion by Rushton, 1999). Soil properties under unsaturated flow conditions, however, lead to more complicated behavior, and the rate of streamflow depletion also depends on the degree of saturation of the aquifer material below the streambed, the saturation-capillary pressure characteristics of the aquifer material, and the distance between the streambed and the water table.

Peterson and Zhang (2000) use a numerical model for unsaturated flow to demonstrate that the capillary pressure that develops below a perched stream may become an important consideration to the estimate of streamflow depletion. Solutions that use the classic approach described above may significantly underestimate the streamflow-depletion rate because they do not consider the flow from the stream to the aquifer caused by capillary-pressure differences and described by unsaturated flow theory.

Osman and Bruen (2002) recognized this problem and proposed a modified algorithm for losing streams for MODFLOW that includes a term to account for unsaturated flow. These authors compared the results of the modified MODFLOW model to a full unsaturated-flow model. They report that the modified approach performed much better than the classic MODFLOW approach compared to the unsaturated-flow model for the water-table configuration under a perched stream and for the estimated streamflow depletion. Bruen and Osman (2004) used Monte Carlo experiments to investigate the importance of unsaturated flow below perched streams and the heterogeneity of the underlying aquifer. They report that explicit consideration of aquifer heterogeneity compared to modeling with average properties increases in importance in the estimate of streamflow depletion when the water table is well below the streambed.

Fox and Durnford (2003) modify the Hunt (1999) solution to allow part of the stream to become perched. The segment of the stream that is perched delivers water to the unsaturated zone at a rate determined by the unsaturated properties of the aquifer, as described by the previous papers. Empirical testing allowed Fox and Durnford (2003) to generate an analytical-solution procedure. The authors showed that if the stream becomes perched, the drawdown is greater and streamflow depletion is less than that predicted by use of the Hunt (1999) solution, which does not allow the stream to become perched.

Streamflow Depletion in the Presence of Other Water Sources

The only water source for capture by the well to attain a steady state for all of the solutions presented thus far is the stream. The capture is either captured discharge from the aquifer that would have reached the stream or induced infiltration from the stream to the aquifer. The differences between the solutions are the rate that the system reaches steady state and the configuration of drawdown in the aquifer, such as whether the solution predicts drawdown on the side of the stream opposite from the pumping well. Other sources of water, however, may exist in some practical situations, and the estimate that ultimately streamflow depletion equals the pumping rate will not hold in these situations. Several papers present and analyze various other water sources (figs. 1–1*D* and 1–2).

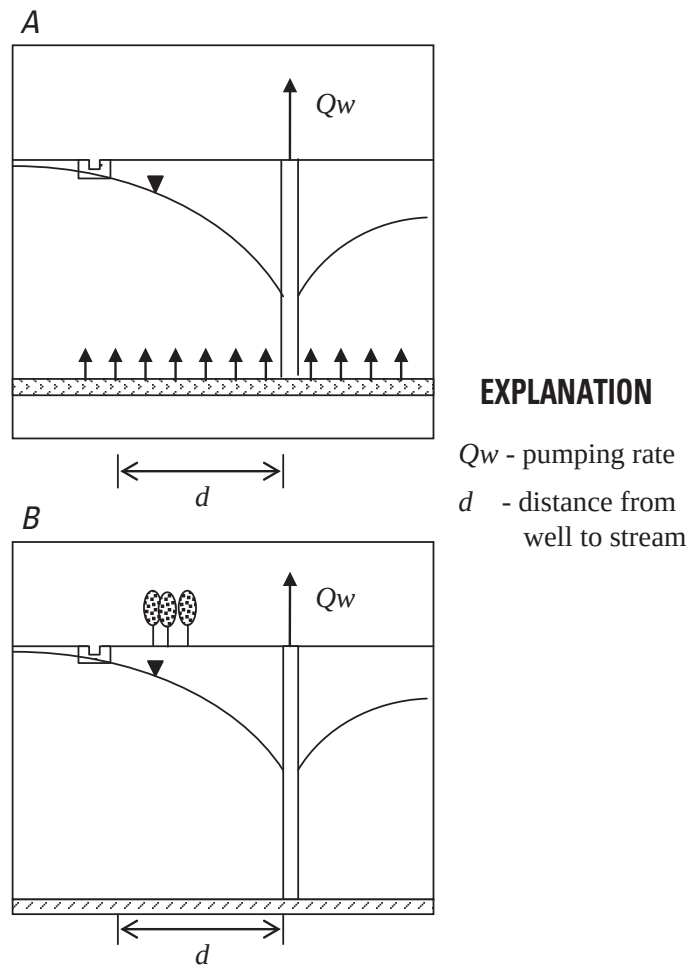

Figure 1–2. Alternate sources of water for capture by a well near a stream. *A*, Stream in an aquifer that overlies a regional aquifer with potentially different hydraulic properties. *B*, Stream in an aquifer system where pumping may interact with plants and change evapotranspiration losses from the system.

Hunt (2003a) presents an analysis for a stream in an semiconfining unit that overlies a leaky aquifer with a well (fig. 1–1*D*). Water may be released from storage from both the leaky aquifer and the semiconfining unit. The water released from storage from the semiconfining unit is the additional water source in this solution. The solution exhibits delayed-yield behavior: after an initial fairly rapid response to pumping, usually considered the result of the expansion of water and compression of the matrix, the response curve flattens for a time and then sharpens once again. The flattening of the response curve in this case is a result of the additional water source yielding water to the well without requiring additional drawdown in the aquifer. It is the only analytical solution to pumping a well near a stream that can fit this type of response by an aquifer. After long periods of time, as the system approaches a steady state, and the streamflow depletion will again equal the pumping rate. Release of water from storage from the semiconfining unit further delays the steady state such that the streamflow depletion may be less than the pumping rate for practical problems and time frames. In this conceptual model, the water in storage in the semiconfining unit is not recharged; therefore, the semiconfining unit cannot provide a long-term source of water to allow the system to reach steady state. This solution is used by several authors to analyze field data that exhibit delayed yield (Hunt, 2003b; Kollet and Zlotnik, 2003, 2005; Fox, 2004; and Lough, 2005).

Zlotnik (2004) solves a conceptual model that provides for a long-term source of water and generates a solution where the streamflow depletion rate is not necessarily the pumping rate at steady state. The conceptual model describes a stream in a shallow aquifer that overlies a deeper regional aquifer (fig. 1–2*A*). The shallow and regional aquifers may be separated by a confining or semiconfining unit. The regional aquifer presumably receives recharge that is independent of the stream and shallow aquifer and is modeled as maintaining a constant peizometric head. The conceptual model used for this analytical solution does not consider streambed resistance or partial penetration of the streambed into the shallow aquifer. The key result is that the streamflow depletion rate is dependent on the hydraulic properties of the shallow aquifer and the unit separating the shallow and regional aquifers. The paper also presents analysis of different boundary conditions for the shallow aquifer and summarizes test cases illustrating this type of behavior in the field.

Two papers investigated in interaction between pumping a well near a stream and changes in evapotranspiration losses from the aquifer (fig. 1–2*B*). Darama (2004) used analytical models, and Chen and Shu (2006) used the numerical model MODFLOW. Both of these papers illustrate how ground water may be captured by a reduction of evapotranspiration loss as the head in the aquifer is lowered by pumping. This evapotranspiration capture decreases the streamflow capture required for the system to reach steady state. Chen and Shu (2006) summarize two important points regarding this situation that depend on whether the issue is streamflow depletion in response to pumping or streamflow recovery in response to reductions in pumping. The first point is that the water captured by a reduction in evapotranspiration rate causes the streamflow depletion to be less than the pumping rate. The second point is that if pumping rates are reduced to help maintain streamflow, then the potential increase in evapotranspiration rates as the head in the aquifer is increased causes the increase in streamflow to be less than the reduction in pumping rate.

Application and Analysis of Streamflow-Depletion Models

Several articles and reports have been written that apply or analyze streamflow-depletion models. For this review, they are classified into two areas: application of the techniques to field problems and use of streamflow-depletion models for water-resources management. Most of the papers already cited provide application of the methods and discussion of the results. The papers in this section use the previous solutions or numerical methods that have already been summarized.

Application to Field Problems

Christensen (2000) demonstrated how the Hunt (1999) solution could be used to estimate streamflow-depletion parameters from aquifer-test data. This paper provides a detailed derivation of the inverse method and a discussion of the uncertainties associated with this type of analysis. The paper does not give an example of an application of the techniques to field data but refers to work that was later published by Nyholm and others (2002, 2003). Nyholm and others (2002) analyze two aquifer tests for wells located 60 m (200 ft) from a stream in a glacial outwash plain in Denmark. As discussed, the authors state that the conditions required to use the analytical solution by Hunt (1999) do not hold for these particular aquifer tests and use MODFLOW to simulate the tests. The inverse modeling code MODFLOWP (Hill, 1992) was used in this case (although MODFLOW–2000 should be able to produce similar results). The paper is notable in the analysis of the MODFLOWP information and related statistical tools and in the detailed discussion of this analysis. More detail regarding the tests and analysis of the test results, including the analysis of application of the Hunt (1999) solution, is offered by Nyholm and others (2003).

Hunt and others (2001) present an analysis of a field experiment that estimated the aquifer transmissivity and storage coefficient and the streambed-conductance factor by application of the Hunt (1999) solution to field data. (See also the discussion of the paper by Kollet and Zlotnik, 2002.) Hunt and others (2001) demonstrate the techniques used to estimate the aquifer and streambed properties.

Hunt (2003b) presents a short paper comparing application his 1999 model and his 2003 model to data from a field experiment. The brief paper demonstrates that the newer solution exhibiting delayed yield fits the field data better than the

earlier solution, which does not include semiconfined conditions (Hunt, 1999). The newer solution fits over the entire time of the test and yields reasonable values for the aquifer characteristics.

Kollet and Zlotnik (2003) describe a detailed aquifer test near a stream with clusters of piezometers between a pumping well and a stream. They analyzed the data with both the Hunt (1999) and the Butler and others (2001) approaches. The authors argue that Butler and others' approach (2001) allows for a better fit of model parameters to the measured data because this model was better able to capture different hydrogeology at the site. Lough (2005) offers a different analysis of the data using the Hunt (2003a) model for a leaky aquifer exhibiting delayed yield and states that this approach better fits the entire response at the observation wells than does the late-time portion used by Kollet and Zlotnik (2003). Kollet and Zlonik (2005) reply that the aquifer is not leaky and suggest that the Hunt (1999; 2003a) analytical solutions do not fit the experimental data well because the assumption of horizontal flow (Dupuit assumption) is violated near the stream, as shown in the observation well data.

Chen and Chen (2003a) present another case study applying the Hunt (1999) solution to field data to estimate streamflow depletion parameters. The authors also present an ad hoc sensitivity analysis of the Hunt (1999) solution and an evaluation of the reliability of estimates for hypothetical cases. This paper received two comments in the literature stating that it did not recognize earlier work by Christensen (2000) or the application by Nyholm and others (2002). (See Christensen, 2005; Chen and Chen, 2005a.) Kollet (2005) argues that the Hunt (1999) solution was inappropriate for this field test and that Chen and Chen (2003a) did not adequately discuss the differences between their results and previously published work (see Chen and Chen, 2005b).

Fox (2004) presents another case study and compares the result of fitting the Hunt (1999), Butler and others (2001), Fox and others (2002), and Hunt (2003a) solutions to field data. In this case, the data again show a delayed-yield response, and the solution by Hunt (2003a) is claimed to fit the drawdown data the best (other fits are not shown). All of the methods were stated to adequately fit the late-time data obtained in the field, and the transmissivity values reported using each of the solutions were reasonable.

Use of Streamflow-Depletion Models for Water-Resources Management

The STRMDEPL program was first documented in a report describing the application of a precipitation-runoff model for the impact of water withdrawals on streamflow by Zarriello and Ries (2000). This implementation of the analytical solutions for streamflow depletion from wells was subsequently used in several other USGS studies in New England. Representative of these are two other precipitation-runoff models (Zarriello and Bent, 2004; Barbaro and Zarriello, 2007) and a detailed water-use and water-availability analysis (Barlow, 2003). In all four of these studies, STRMDEPL (Barlow, 2000) was used to estimate daily streamflow depletion based on daily pumping records from municipal wells. Streamflow depletion is delayed in time and attenuated compared with pumping records, and the analytical solution allowed the precipitation-runoff models to be appropriately calibrated to the pumping records.

A series of papers analyzed the proportion of streamflow depletion from induced infiltration from the stream to the aquifer and from captured discharge that would have reached the stream as base flow under different pumping or aquifer conditions (Chen, 2001; Chen and Yin, 2001; Chen and Shu, 2002; Chen and Chen, 2003b; and Chen and Yin, 2004). These papers, in addition to those by Newsom and Wilson (1988), Wilson (1993), and Bakker and Anderson (2003), may be used to assess water-quality issues arising from induced infiltration from the stream to an aquifer.

Chen and Yin (2001) and Chen and Shu (2002) use MODFLOW to study induced infiltration of stream water to an aquifer stressed by seasonally pumped wells. Chen and Shu (2002) emphasize streamflow depletion and the analysis of the depletion that continues after pumping is stopped. Chen (2001) uses particle tracking and a simple analytical model (Theis solution with an image well) to examine the capture zone of a well. Chen and Chen (2003b) use MODFLOW and particle tracking to assess the impact of anisotropy on the induced infiltration of stream water. Chen and Yin (2004) use the Hunt (1999) solution and apply the concepts illustrated by Wilson (1993) to identify the reach of stream where induced infiltration from the stream to the aquifer occurs. The ratio of capture by induced infiltration to total capture is presented for various conditions, and comparison of the analytical model results to numerical results generated with MODFLOW are presented. As discussed, distinguishing between induced infiltration and base-flow reduction is more important in water-quality analysis than in streamflow-depletion analysis because the total streamflow depletion is the same regardless of the partitioning between these mechanisms.

The Environment Agency, which manages water resources in England and Wales, evaluated potential ways to assess ground-water pumping on streamflow. The "Impact of Groundwater Abstractions on River Flows (IGARF I)" program was discussed by Kirk and Herbert (2002) and in technical reports by the Environment Agency (for example, Parkin and others, 2002).

Case studies examining whether reductions in pumping will change river flows form the core of a paper by Rushton (2002). The major message of this paper is that natural systems are more complicated than those described by most models and that careful hydrogeologic investigation and data collection are required to estimate whether ground-water pumping affects river flow at a given site. Rushton (2002) shows how the timing of recharge events, high and low flows, and seasonal changes in ground-water levels determine the response of the river to reductions in pumping when the river

is at low flow. In some cases, Rushton argues, the pumping wells are virtually disconnected from the river during low flow and reductions in pumping may have only a marginal benefit on river flows.

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Appendix 2. Distribution of Withdrawal Between Neighboring Watersheds

A major aspect of the screening tool is the distribution of pumping between several neighboring valley segments. The simplest approach to estimate the impact of a proposed well on the stream network is to treat the withdrawal as a surface-water withdrawal and assume that the streamflow depletion due to pumping is immediate in time and entirely on the valley segment that drains the catchment containing the well. Use of the Hunt (1999) analytical model relaxes one of these assumptions and accounts for the delay in streamflow depletion due to removal of water from storage in the aquifer. All of the removal may be assigned to the valley segment in the catchment containing the well with no removal from other valley segments, but this approach is not physically realistic because a real well may capture water from adjacent valley segments. Because of the potentially complex geometry of the stream network, numerical ground-water-flow modeling would be required to rigorously estimate the capture from each valley segment. Keeping with the screening nature of the analysis; however, an approach to use an analytical solution was sought.

Wilson (1993) presented an analysis of streamflow depletion by pumping wells considering ambient flow to the stream. This analysis focused on steady-state solutions of induced infiltration from the stream to identify whether a well induced flow from the stream to the aquifer or whether the stream remained a gaining stream. In the latter case, pumping lowers the potentiometric level in the aquifer and reduces discharge to the stream but does not induce flow from the stream. This situation also may be described as capturing recharge that would have reached the stream in the absence of pumping. A solution is presented for a well between two parallel gaining streams (fig. 2–1).

The solution (Wilson, 1993) can be written as

$$Q_s = -2x'q_a + \frac{Q_w}{\pi}\cos^{-1}\left(\frac{1-\cosh\left(\frac{\pi x'}{L}\right)\cos\left(\frac{\pi d}{L}\right)}{\cosh\left(\frac{\pi x'}{L}\right)-\cos\left(\frac{\pi d}{L}\right)}\right), \quad (2\text{–}1)$$

where

- d is the distance from the well to one of two streams (length),
- x' is the distance along the stream from the point opposite the pumping well to the end of the zone of induced infiltration from the stream (length),
- cosh () is the hyperbolic cosine function (dimensionless),
- q_a is the ambient flow between the two streams per unit length of stream (length squared per unit time), and
- L is the distance between the two parallel streams (length).

Points x_s' and x_s are known as the stagnation points, and induced infiltration from the stream occurs along the distance *-x' to x'* (fig. 2–1).

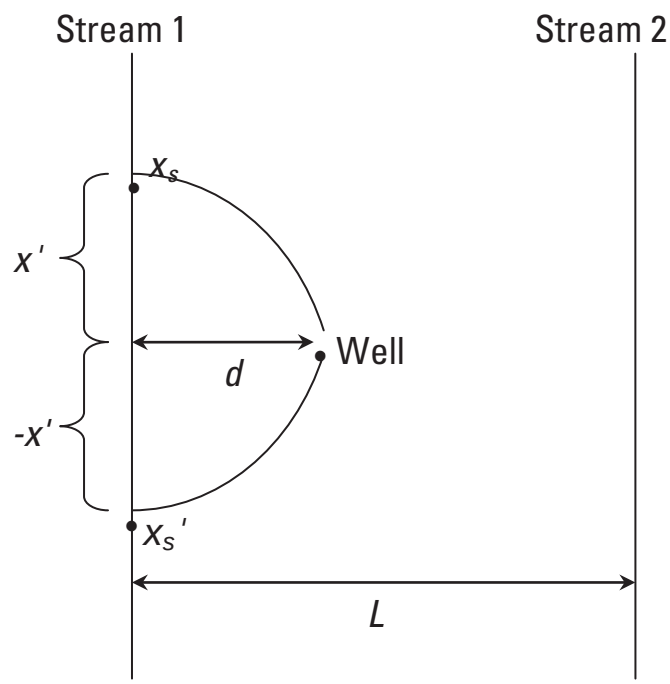

Figure 2–1. Pumping well between two parallel streams with notation used in the Wilson (1993) equation for steady-state streamflow depletion.

The ambient flow per unit length of stream, q_a, may be written as

$$q_a = \frac{NL}{2} + \frac{\Phi_2 - \Phi_1}{L}, \quad (2\text{–}2)$$

where

- N is the recharge rate (length per unit time),
- Φ_i is the state variable (length cubed per unit time) at stream i defined by,
- $\Phi_i = Th_i$ for a confined aquifer, or
- $\Phi = Kh_i^2$ for an unconfined aquifer,
- T is the transmissivity of the aquifer (length squared per unit time), and
- K is the hydraulic conductivity of the aquifer (length per unit time).

The stagnation point, x_s, is found by solving

$$\frac{Q_w}{2Lq_a} = \frac{\cosh\left(\frac{\pi x_S}{L}\right) - \cos(2\delta)}{\sin(2\delta)}, \qquad (2\text{–}3)$$

where

$$\delta = \frac{\pi d}{2L}. \qquad (2\text{–}4)$$

Details regarding the results from this solution are given by Wilson (1993). In summary, at low pumping rates, the well does not induce flow from either stream, and all of the well capture at steady state is from intercepted recharge. Determination of the percentage of this capture from recharge as diminishment of streamflow for each stream can be determined only through numerical ground-water-flow modeling (Wilson, 1993). As the pumping rate is increased, the well induces flow from the nearer stream and then from the second stream. At even higher pumping rates, as defined by the distance between the streams and the ambient flow between the streams controlled by recharge and aquifer conditions as shown in equation 2–3, the source of water to the well is dominated by induced flow from the two streams. At these higher pumping rates, the proportion of water induced by the pumping well from each stream depends only on the inverse of the distance from the well to each stream (Wilson, 1993). This last observation is used to guide the analysis for application of the analytical solution to multiple streams.

Distribution Methods Tested

Several methods based on either distances between a proposed well and the streams in the network or on the areas of the surface-water catchments associated with a proposed well, as approximations to the ground-water catchments, were tested to determine the most appropriate method to distribute water withdrawals between adjacent catchments in the screening tool. The methods distribute streamflow capture among adjacent or neighboring catchments defined as the valley-segment catchments that touch the boundary of the valley-segment catchment containing the proposed pumping well. Nine distribution methods were tested, and each method was computed by means of Python scripts that use geoprocessing commands (Tucker, 2005; van Rossum and Drake, 2006). The methods were inverse distance from valley segment, inverse distance from valley segment squared, inverse distance from catchment center, inverse distance from catchment center squared, transmissivity weighted, transmissivity weighted squared, natural neighbor, buffer around well, and no weighting. No weighting is the solution when all the streamflow depletion is assigned to the valley segment associated with the catchment containing the well.

Inverse Distance From Valley Segment

One distribution method, which is a direct extension of the analysis by Wilson (1993), is to assume that the distribution is directly proportional to the inverse distance from the pumping well to each stream. The contribution of any valley-segment catchment, *i*, is described by

$$f_i = \frac{\frac{1}{d_i^m}}{\sum_{j=1,n} \frac{1}{d_j^m}}, \qquad (2\text{–}5)$$

where

- f_i is the fraction of the pumping attributed to valley segment *i*,
- m is a factor to adjust weighting,
- n is the number of adjacent valley-segment catchments, and
- d_i is the distance from the proposed well to the closest point on the valley segment within catchment *i*.

To allow for close points to have greater influence on the contribution percentages, the factor *m* was included in the algorithm. Two methods of inverse distance weighting were tested: linear, *m*=1; and squared, *m*=2. Inverse distance squared weighting gives greater contribution to close valley segments compared to valley segments further from the proposed well than the linear inverse distance weighting.

Inverse Distance From Catchment Center

The philosophy of the Michigan statewide valley-segment framework is to group short arcs identified in the NHD dataset by hydrology and ecology into larger units. These larger units are the valley segments. Often, catchments associated with the valley segments contain several arcs for the same stream or arcs from different similar streams that join within the catchment. A second weighting scheme is based on this philosophy in that it uses the distance from the well to the adjacent valley-segment catchment centers to compute the contribution for each valley segment:

$$f_i = \frac{\frac{1}{l_i^m}}{\sum_{j=1,n} \frac{1}{l_j^m}}, \qquad (2\text{–}6)$$

where

- l_i is the distance from the proposed well to the center of the valley-segment catchment *i*.

As in the previous case, inverse distance squared weighting also is implemented.

Transmissivity Weighted

The final distance-based weighting scheme uses the approach for computing the equivalent vertical hydraulic conductivity in a layered system. In this case, the transmissivity assigned to each valley-segment catchment also is used to weight the contribution from the catchment in combination with the inverse distance between the pumping well and the valley segment. Valley-segment catchments with low transmissivity will contribute less than adjacent catchments with higher transmissivity. The contribution for valley-segment catchment *i* is given by

$$f_i = \frac{\frac{T_i}{d_i^m}}{\sum_{j=1,n} \frac{T_j}{d_j^m}}, \qquad (2\text{–}7)$$

where

T_i is the transmissivity assigned to valley-segment catchment *i*.

Again, inverse distance squared weighting is implemented for the testing.

Buffer Around Well

In contrast to the distance-based weighting schemes, two area-based schemes were developed. These methods were tested as options that may reproduce the interception of recharge by the pumping well better than the distance-based weightings. The first uses a circular buffer around the well to identify the potentially contributing valley-segment catchments. The fraction of the buffer area attributed to each catchment is used to determine the contribution for each valley-segment catchment. For this method, the size of the buffer is important. If the buffer is very small, then all the weight is assigned to the valley-segment catchment containing the well unless the well is quite close to the catchment boundary. If the buffer is too large, too many neighboring valley segments are assigned a fraction of the streamflow depletion, and the contribution from the catchment containing the well may be too low. To be consistent with the statewide screening, and to allow the hydrogeology of the setting to influence the estimate, a simple well drawdown computation with ad hoc values for drawdown, time, pumping, and storage coefficient was done to determine the buffer radius used in the computations. The Theis solution was used:

$$s = \frac{Q}{4\pi T} W(u) \quad , \quad u = \frac{Sr^2}{4Tt} \cdot \qquad (2\text{–}8)$$

The equation was solved by bisection for each valley-segment catchment to determine the radius, *r*, for a drawdown, *s*, of 0.1 ft after 5 years of pumping, *t*, at 70 gal/min, *Q*, given the transmissivity, *T*, assigned to the valley-segment catchment in the screening tool, and a storage coefficient, *S*, of 0.1.

The contribution for each valley-segment catchment is given by

$$f_i = \frac{a_i}{\sum_{j=1,n} a_j}, \qquad (2\text{-}9)$$

where

n is the number of adjacent valley-segment catchments, and

a_i is the area of the buffer enclosed by valley-segment catchment *i*.

Natural Neighbor

The final method uses natural neighbor weighting to compute the contribution from the adjacent valley-segment catchments. Natural neighbor weighting uses Theissen polygons to define the natural neighbors of the proposed well and to compute areal weighting for the well (Sibson, 1980, 1981). The points defining the Theissen polygons are the closest points from the well to the valley segments that are used in the analytical solution. Natural neighbor weighting is computed by first generating a set of Theissen polygons for these points. A second set of Theissen polygons is then created with the closest valley-segment points and the well location. The overlap between these two sets of polygons is used to estimate the weighting assigned to each of the valley-segment points. If the new polygon generated around the well does not overlap with some of the original Theissen polygons, then the weight assigned to the points in these polygons is zero. If the well falls exactly on one of the valley-segment points, which means that the well is placed on a valley segment, the polygon generated in the second step exactly overlaps one polygon from the first set and the weight assigned to this point is 1. The contribution for each valley-segment catchment is given by

$$f_i = \frac{a_i}{\sum_{j=1,n} a_j}, \qquad (2\text{–}10)$$

where

a_i is the area of influence determined by means of the overlapping areas of the Thiessen polygons for each of the natural neighbors.

The analytical model by Hunt (1999) was used to compute the time-dependent streamflow depletion due to a pumping well. This model provides the fraction of the pumping rate attributed to removal from storage and to streamflow capture. The pumping from a proposed well is distributed between adjacent valley segments by estimating a contribution for each valley-segment catchment. These contributions are assumed to be valid for the entire pumping time for the well. To estimate streamflow depletion for each of the valley segments, the analytical solution is computed for the well and each valley segment independently. These solutions are multiplied by a fraction representing the contribution to the pumping well for

each valley-segment catchment. The sum of the contributions from each valley segment must equal 1 so that the sum of the streamflow depletions for all the contributing valley-segment catchments is equal to the pumping rate as the system reaches steady state. To compute the analytical solution for each valley segment, the distance between the closest point on the valley segment and the proposed well is determined. This distance is used along with the aquifer properties of the catchment containing the well to compute the streamflow depletion with time.

Testing Procedure

The ground-water-flow model for the area around Kalamazoo County, Mich. (Luukkonen and others, 2004) was used to test the distribution methods. The ground-water-flow model is a finite-difference (MODFLOW) simulation model with 6 layers, 154 rows, and 162 columns. MODFLOW is documented by Harbaugh and others (2000). The smallest grid spacing in the model is 660 ft by 660 ft. Valley-segment catchments in the interior of the model that have this finest grid spacing were used in the methods testing. To illustrate the applicability of the analytical model to field problems, a transient simulation with seasonally varying recharge and pumping rates was used as the test case. Luukkonen and others (2004) presented the results for a 9-year transient simulation; but, in this work, the length of the simulation was reduced to 5 years to reduce computer run time.

A method to illustrate streamflow capture by pumping wells (Leake and Reeves, 2008) was used to examine the spatial distribution of streamflow capture from the valley segments. In this method, hypothetical wells are added to the MODFLOW model sequentially on a grid of cells (fig. 2–2). One well is added to a specified cell, and the new simulation is computed. The results from this new simulation are subtracted from base-model results to determine the capture and change in storage caused by the new well. The process is repeated with one new well at a time, generating a grid of results that may be mapped. The fluxes to individual river cells representing the valley segments from the statewide data framework were computed. These fluxes were recorded by use of a river observation file (Hill and others, 2000) to designate the finite-difference cells assigned as river cells to the appropriate valley segments. The river flux output from the system with the new well for each designated valley segment was subtracted from the valley-segment flux computed with the original model to yield the streamflow depletion due to the new well as simulated with the MODFLOW model. Values for streamflow depletion as a percentage of pumping rate for the grid of wells shown in figure 2–2 placed in layer 3 of the model were interpolated by means of inverse distance weighing to produce the map shown in figure 2–3. These streamflow depletions and the spatial pattern produced through this technique are used to access the distribution schemes applied with the analytical model.

The analytical model was solved for the same grid of points as the MODFLOW model illustrated in figure 2–2. Python scripts for the distribution methods used geoprocessing commands (Tucker, 2005; van Rossum and Drake, 2006) to identify the catchment containing the well, to identify the neighboring catchments, and to compute the different weightings. The analytical solution was computed for the well and each of the nearby valley segments sequentially by use of the transmissivity assigned to the valley-segment catchment containing the test point, which for these trials was always valley-segment catchment 3544. The storage coefficient and streamflow-conductance terms for this catchment from the water-withdrawal screening tool also were used.

The streamflow depletion for each valley segment and each distribution method was estimated by multiplying the analytical solution for that valley segment-test point combination by the computed percent contribution for the valley-segment catchment. The resulting streamflow depletions were compared to the depletions computed with the MODFLOW model through the river observation file (Hill and others, 2000) for each valley segment. The results from the ground-water-flow model and the analytical solutions after 5 years were compared to ensure that differences in the solutions resulting from differences in the storage coefficient used in the screening tool and the MODFLOW model do not dominate the analysis. To avoid problems with differences between small estimates of streamflow depletion biasing the analysis, the difference between the MODFLOW results and the analytical model was computed only if either the MODFLOW or the analytical model estimated a streamflow depletion of 5 percent of the pumping rate or greater.

The simplest approach for the screening procedure would be the no-weighting approach. The capture caused by a proposed well would be assigned to the valley segment in the catchment containing the well. In essence, use of this approach assumes that the ground-water divides are coincident with surface-water divides and that the divides do not change in response to pumping. Because ground-water divides will respond to pumping, this should be a poor assumption. Testing reveals that streamflow depletion was overestimated in this approach compared to the MODFLOW model results (figs. 2–3 and 2–4). The minimum streamflow depletion estimated by way of this approach is approximately 63 percent, and the estimated streamflow depletion is greater than 80 percent for much of the valley-segment catchment. These results do not compare well with results generated using the MODFLOW model. For the MODFLOW model, the maximum estimated streamflow depletion for the valley segment was less than 80 percent for most of the catchment and it was less than 20 percent for parts of the valley-segment catchment near the most distant surface-water divides defining the catchment. On the basis of this comparison, the no-weighting approach—although computationally the most straightforward method—was rejected as an option for the screening model.

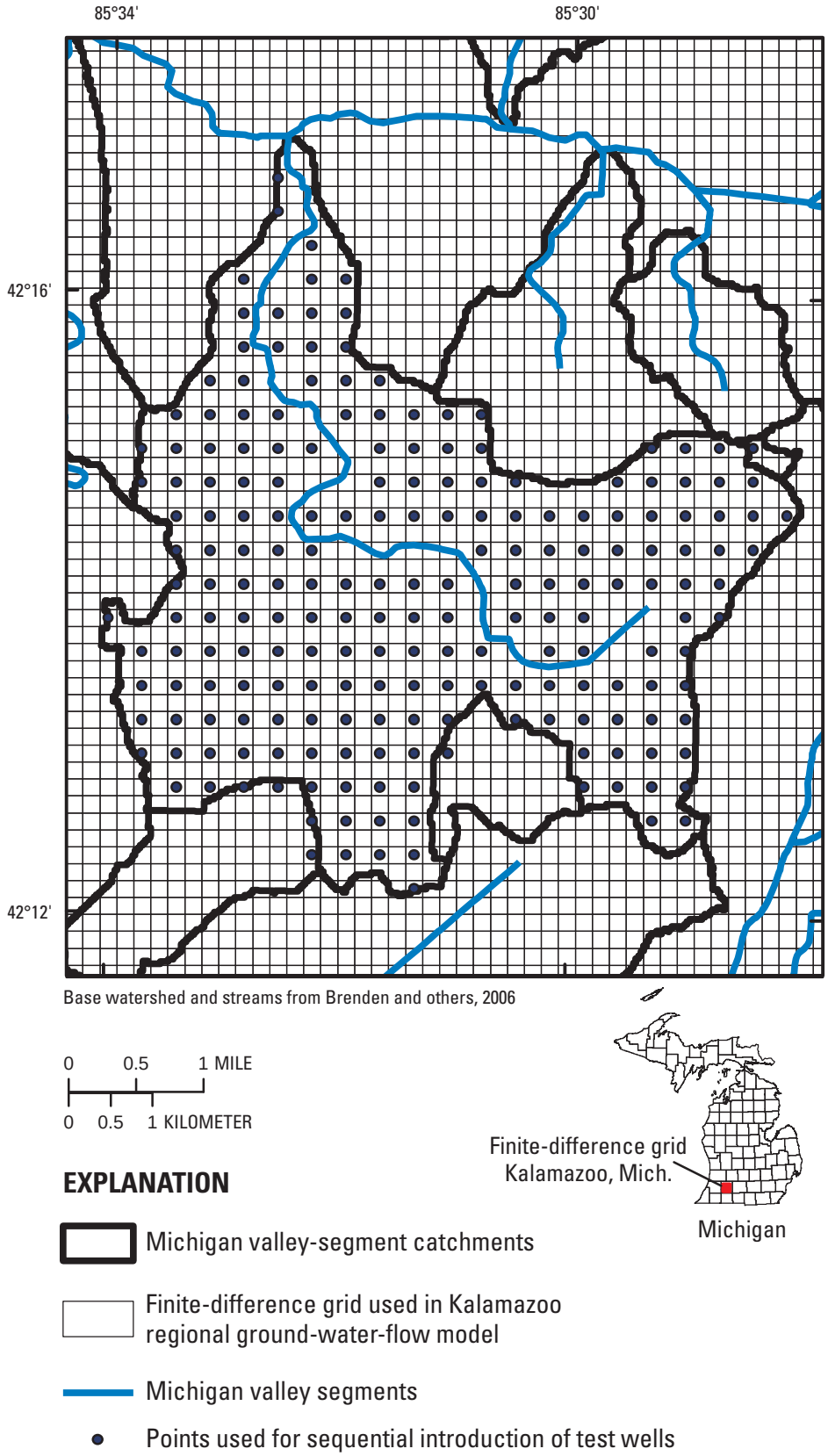

Figure 2–2. A grid of points used to compare the analytical model and different distribution methods to MODFLOW results from the Kalamazoo regional ground-water-flow model.

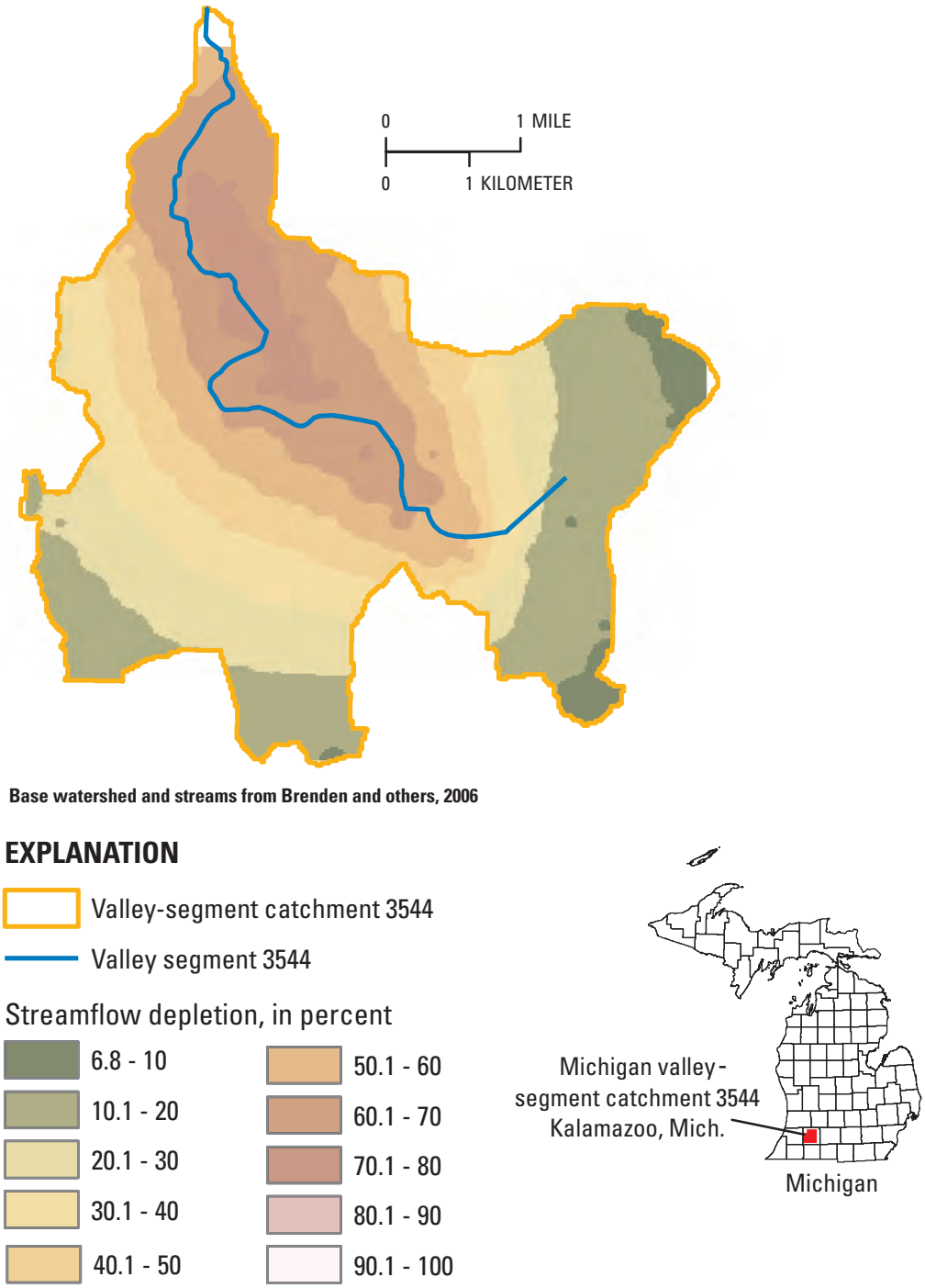

Figure 2–3. Estimated streamflow depletion from valley segment 3544 resulting from a sequential introduction of test wells in the MODFLOW ground-water-flow model for Kalamazoo County, Mich., as a percentage of pumping rate after 5 years of pumping.

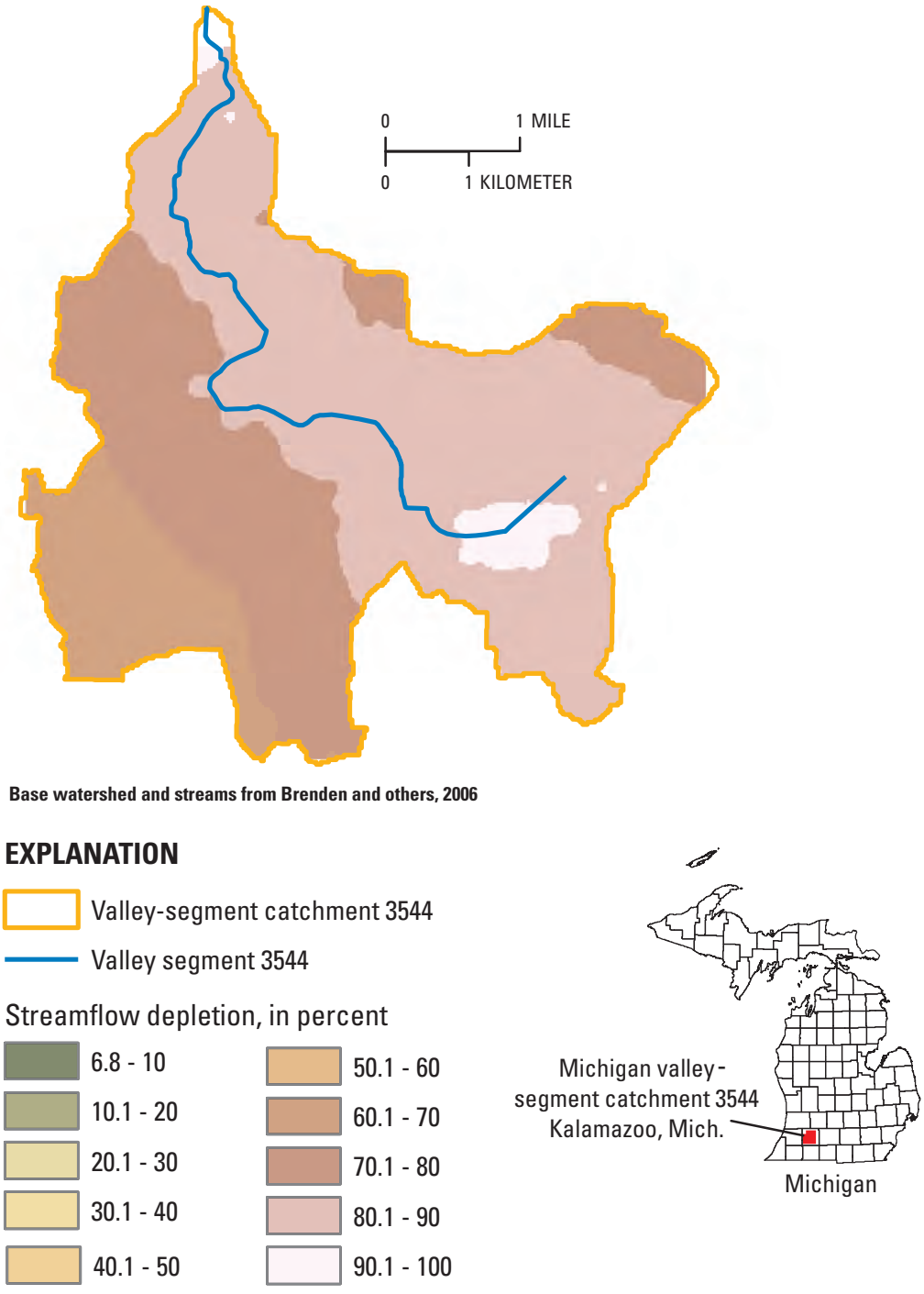

Figure 2–4. Estimated streamflow depletion from valley segment 3544 resulting from a sequential application of the analytical model to test wells with no weighting approach between adjacent valley segments as a percentage of pumping rate after 5 years of pumping.

The distribution approaches that matched the MODFLOW results the best were the inverse distance to valley segment, inverse distance to valley segment squared, and natural neighbor weightings (fig. 2–5). The inverse distance to valley segment squared and natural neighbor approaches overestimate streamflow depletion compared to the MODFLOW results, and the inverse distance to valley segment weighting tends to underestimate the depletion near the stream compared to the MODFLOW results. The transmissivity-weighted approaches (not shown) are not significantly better than the inverse distance to valley segment weightings and require slightly more computational effort and more book-keeping to gather and use the transmissivity of each neighboring valley-segment catchment. The buffer weighting and distance to center weighting (also not shown) did not produce interpolated maps that were reasonable matches to the MODFLOW results, and these methods were rejected. Statistical and ranked comparisons of the weighting methods based on the differences between each method and the MODFLOW results showed that each of the methods performed the best for some of the hypothetical well points and were outperformed at others. None of the methods produced a statistically significant difference in error characteristics compared with the MODFLOW results to help guide the decision. As a result of this testing, the inverse distance to the valley segment method was selected for the screening tool because it produces a reasonable overall pattern of streamflow depletion compared with the MODFLOW tests, it is the most straightforward to implement in the Web application, and it has some theoretical basis in Wilson's analysis (1993).

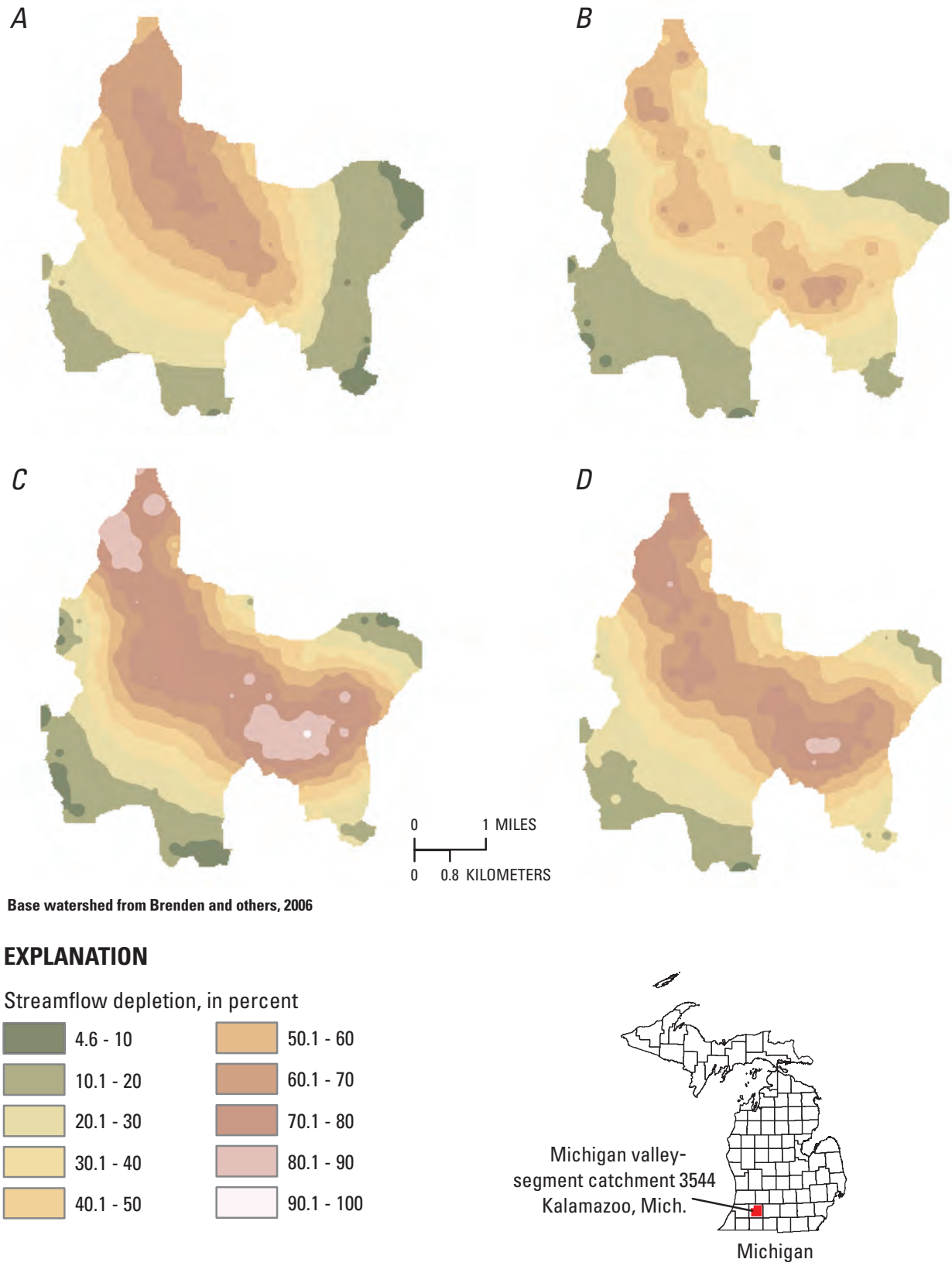

Figure 2–5. Estimated streamflow depletion from valley segment 3544 as a percentage of pumping rate after 5 years of pumping. ***A***, results from a sequential application MODFLOW. Results from sequential application of the analytical model with ***B***, the inverse distance to the stream, ***C***, inverse distance to the stream squared, and ***D***, natural neighbor distribution methods.

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USGS Award No. G09AP00153: Economic Expert, International Upper Great Lakes Study

Basic Information

Title:	USGS Award No. G09AP00153: Economic Expert, International Upper Great Lakes Study
Project Number:	2009MI162S
Start Date:	8/7/2009
End Date:	3/31/2011
Funding Source:	Supplemental
Congressional District:	8
Research Category:	Social Sciences
Focus Category:	Management and Planning, None, None
Descriptors:	Upper Great Lakes, Economic Growth Scenarios, Climate Change, Water Regulation
Principal Investigators:	Jon Bartholic

Publications

There are no publications.

Title: Economic Expert, International Upper Great Lakes Study
Project Number: 2009MI162S (extended to FY2009)
Start: 08/07/2009(actual)
End: 03/31/2011(actual)
Funding Source: USGS ("104S")
Congressional District: eighth
Research Category: Social Sciences
Focus Categories: Management and Planning
Descriptors: Upper Great Lakes, Economic Growth Scenarios, Climate Change, Water Regulation
Primary PI: John Hoehn, Professor, Agricultural, Food, and Resource Economics, Michigan State University, 301A Agriculture Hall, East Lansing, MI 48824-1039, PH: 517.353.6735, hoehn@msu.edu
Project Class: Research

Introduction

The plan of work calls for the development of six of economic growth scenarios for the upper Great Lakes region over the next 20 to 40 years. The scenarios develop possible trajectories for economic growth in population and gross regional product. As these scenarios are develop, the research will examine how regional economic growth may influence the way society may choose to regulate water levels in the future through adaptive management.

General Statement

Problem/Demand

The researcher has reviewed the economic and scientific literature to assess current and projected trends and has reviewed the interests and vulnerabilities represented in the work of the technical working groups (TWGs). The researcher is in the process of finalizing the six growth scenarios and writing a final report.

Methodology

The research reviews the literature regard economic growth prospects for the upper Great Lakes in the next 30 to 40 years and summarizes the best economic and scientific analysis in the form of six economic growth scenarios.

Problem and Research Objectives

Six growth scenarios are developed that are consistent with the specifications described in the project plan of work. The first three scenarios are:

1. The current economy going forward 30 to 40 years with no change in population, gross regional product, and other economic factors

2. The current economy going forward 30 to 40 years and growth consistent with current trends.

3. A high growth scenario going forward 30 to 40 years.

The first three scenarios are developed assuming no climate change. The second set of three scenarios are developed incorporated climate change. Climate change considerations are incorporated from the research and summaries of the U.S. Global Change Research Program.

Principle Findings and Significance

The researcher is finalizing the six growth scenarios and writing the final report. The summary and review of literature revealed different prospects for sub-regions with Canada and the United States. The Canadian upper Great Lakes sub-region is the southwestern section of Ontario. Statistics Canada anticipates higher growth in the working population in this sub-region than analysts expect for the U.S. upper Great Lakes sub-region. Since the working population is linked directly with the growth potential of a region, the Canadian sub-region can expect higher rates of economic growth than can the U.S. sub-region of the upper Great Lakes.

Table 1 displays the different levels of growth expected by U.S. and Canadian sub-region for each of the three scenarios with no climate change. In the high scenario, population in the U.S. sub-region grows by 32% by 2050 and in the Canadian sub-region it grows by 52%. The disparity between sub-regions also show up in the gross regional products (GRPs). Under the high scenario, GRP in the U.S. sub-region more than doubles, but GRP in the Canadian sub-region more than triples by 2050. In the U.S. region, growth in the economy paces growth in the working age population so the number of jobs per capita remains constant under the high growth scenario. In the Canadian sub-region, jobs per capita grows by 32%.

Table 1. Total and Percent Growth by Scenario, 2010 to 2050, Upper Great Lakes Region

Three Scenarios, No Climate Change	Population (Thousands or %)	GRP ($Millions or %)	Jobs (Thousands or %)	Jobs per Capita (Number or %)	Personal Income per Job ($)
United States Sub-region					
No Change	10,542	413,005	6,084	0.58	56,759
Low Scenario	7%	97%	13%	6%	54%
High Scenario	32%	114%	32%	0%	62%
Canadian Sub-region					
No Change	12,610	553,016	6,985	0.55	--
Low Scenario	46%	141%	55%	9%	55%
High Scenario	52%	219%	84%	32%	92%

Publications

Not at this time.

Natural Resources Integrated Information System

Basic Information

Title:	Natural Resources Integrated Information System
Project Number:	2010MI163B
Start Date:	3/1/2010
End Date:	2/28/2011
Funding Source:	104B
Congressional District:	8
Research Category:	Water Quality
Focus Category:	Management and Planning, Water Quality, Water Use
Descriptors:	Management and Planning, Water Quality, Water Use
Principal Investigators:	Jon Bartholic

Publications

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Title: Natural Resources Integrated Information System
Project Number: 2010MI163B
Start: 03/01/10(actual)
End: 02/28/11 (actual)
Funding Source: USGS 104(B)
Congressional District: eighth
Research Category: Water Quality
Focus Categories: Management and Planning, Water Quality, Water Use
Descriptors: Management and Planning, Water Quality, Water Use
Primary PI: Jon F. Bartholic, Director, Institute of Water Research, Michigan State University, East Lansing, MI 48823, bartholi@msu.edu
Project Class: Research

Problem and Research Objectives

Nature and Importance to the Problem and Relevance to the Mission

Water is replacing oil as one of the single most important resources upon which policy and, in fact, human existence in many portions of the globe will depend. Political power, economics, and civilization's development will be critically impacted by our ability to sustainably manage and optimally utilize the planet's water resources. Because of the United States' relative advantage from a water resource standpoint, this country's role will be increasingly significant in food production and industrial production requiring significant quantities of water, and in developing sustainable approaches to maintain waters' ecological services. Specifically, the Great Lakes region will have tremendous opportunities to capitalize in numerous ways on the potential of its vast water resources. But water resources management always occurs in a social context involving multiple stakeholders. Stakeholders can have radically different perceptions of the problems and potential trade-offs associated with finding solutions because of dynamic social, economic, and political factors as well as biophysical complexities of water resources issues. This complex nature of water resource management and other related issues, such as global climate change and health care, is often referred to in the scientific community as "wicked." Research on wicked-type problems suggests that a comprehensive knowledge system sustained by a boundary organization is essential. Boundary organizations act as intermediaries between science and policy because they fulfill or possess (see Figure 1): 1) specialized roles within the organization for managing the boundary; 2) clear lines of responsibility and accountability to distinct social arenas on opposite sides of the boundary; and 3) a forum in which information can be co-created by research and interested parties. Since its very beginning and long history of existence, the Institute of Water Research (IWR) has been functioning as a boundary organization to tackle wicked water resources management issues. Through a history of extensive knowledge generation, engagement and facilitation, and working experience with local, state, and basin-wide organizations, IWR has a solid base of success to build upon in creating innovative knowledge systems for sustainable management of water resources.

Previous Work and Present Outlook

Three current IWR projects illustrate approaches to solving wicked problems. The first project involves a nearly six-year experience in the co-creation, facilitation, and support for the State of

Michigan's Water Withdrawal Assessment Process to meet the requirements of the Great Lakes Basin Water Resources Compact (Steinman, et al. 2010) The assessment process integrates surface and groundwater hydrology and fisheries resource models to predict potential adverse resource impacts from water withdrawals. The role of IWR was to provide key input to state legislators and convene a science advisory committee. Also, IWR was assigned the task of developing the legislatively-designated web-based tool that is currently being used to assess potential water withdrawals. The second example, in place for the last seven years encompasses work with non-point source pollution reduction with the support of numerous agencies including the U.S. Army Corps of Engineers, EPA, MDA, USDA_NRCS, MAES, MSUE, and several foundations including the Frey and the Grand Rapids Community Foundation. As part of this large effort, IWR developed a model to evaluate sediment contributions to the tributaries of the Great Lakes and its harbors. The model was used by IWR to identify and map the agricultural areas contributing the greatest sediment loadings. This enabled the Corps to begin targeting its sediment reduction efforts at a macro scale. More recently, IWR worked with MDA and USDA NRCS to refine this targeting approach at the local level in three Michigan watersheds. These watershed projects allowed IWR to complete development of a more refined High Impact Targeting (HIT) decision support system.

The HIT system is designed to aid federal, state, and local decision makers with prioritizing their sediment reduction efforts (O'Neil, Bartholic and Shi 2010; O'Neil, Theller, et.al. 2010). A third example involves IWR collaborating internationally with three Borlaug Fellows from India and the MSU Institute of International Agriculture (Bartholic, Shi, Maredia, et.al. 2010). The joint international effort included an Indo-U.S. Workshop on "Emerging Issues in Water Management for Sustainable Agriculture in South Asia Region" in Tamil Nadu, India. This event was jointly organized by the Central Soil & Water Conservation Research & Training Institute (Indian Council of Agricultural Research) and Michigan State University. MSU was represented by the Institute of International Agriculture and IWR. The workshop was attended by top level representatives from over ten major water management programs. As a result of this workshop, a South Asia Water Knowledge and Innovation Network was formed, and IWR will be a major player in the expansive new efforts initiated at this workshop.

Our vision is to create an institute that effectively links science and technology for the sustainable management of water resources. There is a great need for local, state, national and international water resources management decisions and policies to be based on thorough scientific research and multidisciplinary expertise. IWR works across multiple units within the University and with numerous external partners. As water resources issues become more complex, IWR will embrace and strive to enhance its service as a boundary organization by advancing the understanding of wicked problems related to water issues among academia, state partners, NGOs, citizens of Michigan, and the global community and through the research and development of new decision support systems that help address these complex problems.

Methodology

Research Methods/Experimental Procedures

The manner in which we have engaged in team efforts with the scientific community from across campus, the state and region has been effective and provides an approach upon which we can build. As previously mentioned, we have an evolving process which will help us to transform our

institute to more effectively address “wicked” problems. The advisory body will be critical in guiding the re-creation of our activities, which will lead to more holistic and effective approaches to addressing “wicked” problems. This transformation may be aided through support and input from various internal individuals and entities, including departments and units within CANR such as the proposed new Department of Natural Resources Ecology and Management, Department or focal area of Sustainable Studies and Biosystems Engineering. In addition, Dr. Hiram Fitzgerald, Director of University Outreach and Engagement, and colleagues, are refining a community-based systems approach for affecting change in social systems, which IWR may incorporate as a component of this new strategy. These various inputs will guide our initial activities. In addition to its staff members who have expertise in a broad array of water resources management topics, including database development and information systems, GIS, aquatic ecology and community-based water management programming, IWR has historically worked with many diverse faculty members representing a broad cross section of water resources expertise across MSU colleges. A listing of the faculty members and students who have recently worked with and received support from IWR on various water resources management projects was included in a recent report compiled for the Water Resources Partnership, a jointly funded agreement between the Michigan Department of Natural Resources and Environment (formerly the MDEQ) and MSU.

Our first achievement strategy is to build on and transform current IWR strengths, partnerships, and reputation. By working in a co-creative framework with individuals, policymakers and organizations to integrate the science and knowledge base, IWR is generating adaptive and dynamic systems for management of critical water resources that includes ecological, social and economic components.

(1) Reorganize IWR to more effectively link knowledge with action, i.e., connecting knowledge generation and local applications by becoming an appropriately structured boundary organization. The structure depicted in Figure 1 shows that IWR will not only serve as a critical link between the research and knowledge generated by the scientific community (i.e., entities at the University) and the user community, but will also serve to facilitate the co-creation of knowledge (middle column, Figure 1) by working with the end users (right column) and the scientific community (left column).

(2) Actively be involved in facilitating, leading, demonstrating and evaluating the co-creation process through numerous specific activities involving “wicked” problems. Water resources management with consideration for economic development is a complex or "wicked" problem because it often demands organizations/stakeholders at all levels to come together and find acceptable solutions to issues. Such solutions may also evolve over time when agreed upon by the parties involved. Integrating sciences into this dynamic social process and utilize modern technologies to facilitate communications and problem solving is the grand challenge we face as university researchers and technology transfer professionals. As a boundary organization, our objective is to be uniquely positioned to work across disciplinary boundaries and bring advanced sciences and technologies into decision makers' hands. Since there is a large gap between academic research and real world operational applications, bridging this gap and streamlining research and the technology transfer process is a major task for IWR as a boundary organization. The efficient and effective utilization of modern technologies such as

advanced Information and Communication Technology (ICT), GIS and numerical modeling is the key to achieve this objective.

(3) Develop decision support systems that provide support for knowledge users to make more informed decisions based on input from the knowledge generators. As we move from traditional PC-based computing era to a new Internet-based cloud computing age with millions of mobile computing devices coming online at an accelerated rate, we need to conduct further detailed research on how we can develop a new generation of water resources decision support and knowledge systems that can take advantage of recent advances in cyber infrastructure, social networking, geospatial technologies and numerical modeling and associated scientific visualization technologies. To implement this new generation of systems, we need to analyze the needs of different target audiences such as federal, state and local government agencies, NGOs, various environmental organizations and the general public. As a boundary organization, it's critically important that we bring environmental knowledge producers and consumers together under the same overarching umbrella and provide tools for them to work together in a mutually beneficial manner. We need to understand their needs and concerns and address them appropriately.

(4) Guide development of this new bridging structure through an external advisory body, representing a cross-section of users and scientific groups. This advisory body will have integrative and dynamic roles in providing guidance and ideas to communities of users. The scientists involved will provide connections to clusters of water expertise from the following: multiple units within CANR, such as the Center for Water Sciences and Department of Biosystems and Ag Engineering; other colleges, such as Natural Science and Civil and Environmental Engineering; and, external partners including the USGS Great Lakes Science Center, the Nature Conservancy and others.

(5) Provide an inclusive environment to facilitate a sense of trust among the knowledge users so they can effectively interact with the knowledge generators, creating an atmosphere and functionality where there is successful communication, translation, mediation, and adaptive process outcomes.

(6) Actively inform and partner with NGOs and other funding agencies such as EPA, GLPF (Great Lakes Protection Fund), US Army Corps of Engineers, etc., to aid in acquiring support of IWR activities. These partnerships will help to add new funding sources to IWR's existing broad portfolio of funders to facilitate an expanding base of fiscal support.

Literature Review

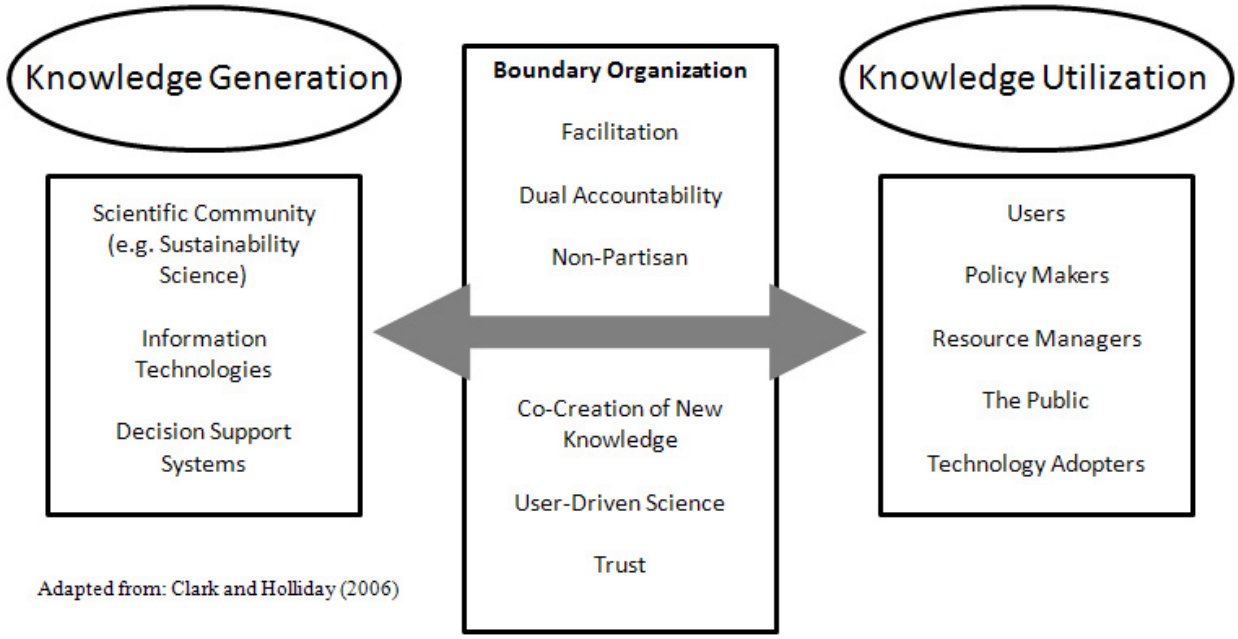

Figure 1. Boundary organization: Linking knowledge with action

All social, economic and environmental factors in a watershed need to be considered in a holistic approach to determine proper actions to manage water resources (Heathcote 1998; Gregersen et al., 2008). Watershed management often involves multiple stakeholders with conflicting interests. These stakeholders can have radically different perceptions of the problems and potential trade-offs associated with finding solutions because of dynamic social, economic, and political factors as well as biophysical complexities of water resources issues. This complex nature of water resource management and other related issues, such as global climate change or health issues, is often referred to in the scientific community as wicked problems (Batie 2008). These types of problems are so named because they are usually difficult to solve due to their complexities and changing nature and often may create other problems as the initial ones are being addressed.

Research on wicked-type problems suggests that a comprehensive knowledge system sustained by a boundary organization is essential (Cash et al., 2003). Boundary organizations act as intermediaries between science and policy because they fulfill or possess: 1) specialized roles within the organization for managing the boundary; 2) clear lines of responsibility and accountability to distinct social arenas on opposite sides of the boundary; and 3) a forum in which information can be co-created by interested parties (Cash et al., 2003). Ingram and Bradley (2006) define boundary organizations as those situated between different social and organizational worlds, such as science and policy. Guston (2001) list three conditions often attributed to successful boundary organizations. "First, they must provide incentives to produce boundary objects, such as decisions or products that reflect the input of different perspectives. Second, they involve participation from actors across boundaries. Third, they have lines of accountability to the various organizations spanned by the boundary organization." According

to Batie (2008), adaptive and inclusive management practices are essential to the functioning of boundary organizations, and Ruttan et al. (1991) suggests that boundary organizations serve as a bridging institution and help to link suppliers and users of knowledge.

One way to further the efforts of boundary organizations, particularly with wicked problems, is to provide tools to assist with good decision-making using science-based data. Spatial Decision Support Systems (SDSS) are a type of computer system that combine the technologies of Geographic Information Systems (GIS) and DSS to assist decision-makers with problems that have spatial dimensions (Walsh 1993). SDSS are developed to integrate data, knowledge, and modeling results to identify, evaluate, and recommend alternative solutions to spatially distributed problems (Djokic, 1996; Prato and Hajkowicz, 1999). A SDSS focuses on a limited problem domain, utilizes a variety of data, and brings analytical and statistical modeling capabilities to solve the problems. It further depends on graphical displays to convey information to the users. It can be adapted to decision-maker's style of problem solving, and can easily be extended to include new capabilities as needed (Densham et al. 1989, Armstrong et al. 1990).

In natural resource management, SDSS have proven to be effective in a variety of applications such as flood prediction (Al-Sabhan et al., 2003) and conservation program management and best management practices assessment (Rao et al., 2007). Al-Sabhan et al. (2003) argued that a web-based hydrologic modeling SDSS can help solve problems such as limited accessibility by non-experts and the public; lack of collaboration support; and costly data acquisition and communications. They further indicated such system can offer openness, user friendly interface, transparency, interactivity, flexibility, and fast communication and be directly accessible to a broad audience including decision makers, stakeholders and the general public.

Objectives

(1) Reorganize IWR to more effectively link knowledge with action, i.e., connecting knowledge generation and local applications by becoming an appropriately structured boundary organization.
(2) Actively be involved in leading, demonstrating and evaluating the co-creation process through numerous specific activities involving "wicked" problems.
(3) Develop decision support systems that provide support for knowledge users to make more informed decisions based on input from the knowledge generators.
(4) Guide development of this new bridging structure through an external advisory body, representing a cross-section of users and scientific groups.
(5) Provide an inclusive environment to facilitate a sense of trust among the knowledge users so they can effectively interact with the knowledge generators, creating an atmosphere and functionality where there is successful communication, translation, mediation, and adaptive process outcomes.
(6) Actively inform and partner with NGOs and other funding agencies to aid in acquiring support of IWR activities. These partnerships will help to add new funding sources to IWR's existing broad portfolio of funders to facilitate an expanding base of fiscal support.

Plans to Disseminate Information from Stated Research

IWR has effectively worked with a variety of organizations and audiences. This has allowed IWR to build a diverse network of partners. As a complicated and wicked problem, effective water resource management requires solutions from the broad economic sectors it affects. With partners from the university, government, non-government, and private sectors, IWR will receive the input needed to reorganize itself as a boundary organization, bridging the gaps between each of the sectors. IWR will work with its partners and internally to co-create solutions to the complex problems posed by water resource management and disseminate this information through its well established technology transfer program, as well as through its decision support systems, regional networking, social networks and facilitation capabilities. Advisory body inputs will be critically important in defining targets, timelines, and expected impacts. This reorganization can evolve largely within our existing financial and personnel structures.

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Principle Findings and Significance

Extensive investigation and research is needed to achieve effective coupling of human management needs with geospatial databases and decision support systems to assist better decision-making. Multiple research funding opportunities exist to support linking understanding of various phases of the hydrologic cycle with impacts on water use, management, and conservation. As a result, outstanding opportunities to develop scientific water management skills and techniques for the 21st Century are clearly within reach.

Research and Development: The *Water Resources Partnership* is a major effort with support and involvement from units across the University campus with the Michigan Department of Environmental Quality as the key external funding partner. At this time the project is a four year effort funded at 1.5 million dollars. [This project is inclusive in nature relative to Michigan's Department of Environmental Quality (MDEQ) partners and clients interested in the products.] Campus partners provide fundamental inputs relative to new frontiers such as computational thinking which is dependent on new computational capabilities, web technologies, and advanced GIS web-based delivery systems. Also, MSU's Extension and Outreach and Engagement units are involved. Fundamentally this project facilitates the discovery of new approaches for integrating advanced multi-scale modeling with intuitive visual and interactively enhanced outputs. Products from this activity are also used in other active projects, with those projects in turn providing general feedback into the Water Resources Partnership.

Our strong research base is enhanced by our involvement in regional/national USDA Hatch multi-state research projects. One such project, MICLO4064/W2190 entitled *Water Policy and Management Challenges in the West* (from W1190), addresses water policy and economic research and involves researchers across the U.S. Another research project, MICLO4052/S1042 *Modeling for TMDL Development and Watershed Based Planning and Management and Assessment*, involves hydrologic and non-point source (NPS) modelers with a specific focus on total maximum daily loading (TMDL's) and general NPS reduction strategies.

Specific Projects Conducted

1. "Decision Support System to Produce Impact-Based Solutions and more Efficient Allocation of Resources" – Final Report provides outputs and outcomes/impacts from this broad 5-year umbrella project.
2. "Water Policy and Management Challenges in the West" for IWR's part contrasts Water Law/Management between the Eastern and Western United States. This is a annual report of progress.
3. "Modeling for TMDL Development and Watershed Based Planning, Management and Assessment" Research Report incorporates recent progress on a variety of IWR's research projects.
4. "Web-based Networked Neighborhoods for Eco-Conservation" funded by the Great Lakes Protection Fund.

1. Decision Support System to Produce Impact-Based Solutions and more Efficient Allocation of Resources

Outputs

Basin-wide Activities: (a) Regionally, IWR provided leadership for development with EPA Region 5 of the Midwest Spatial Decision Support System Partnership (http://www.epa.gov/waterspace/). (b) Personnel from the Institute of Water Research (IWR) were designated by MSUE as State Extension Water Quality Coordinators. Web-based Water Resource Planning and Management Tools: Utilizing evolving information technologies we advanced the concepts of spatial decision support systems to guide and inform decision-makers with web accessible analysis tools to improve their environmental related decisions. These include Digital Watershed (DW) (http://www.iwr.msu.edu/dw), IWR website (http://www.iwr.msu.edu), Revised Universal Soil Loss Equation (RUSLE) (http://www.iwr.msu.edu/rusle/). Expansion of the DW web tool (a dynamic real-time system) was funded for $200,000 by EPA Region 5 to interface EPA Las Vegas Labs ATtILA and EPA ORD ReVA system. Subsequently, with funding from the Wisconsin DNR NEIEN grant DW was modified to acquire data on-the-fly from STORET.

Major Multi-Partner Projects: Partnership capabilities with additional IWR components were woven into larger projects. Examples include: (a) A suite of activities to reduce non-point source pollution was initially supported by the Army Corps of Engineers (ACOE) and then by both the ACOE and the USDA (NRCS) with a $900,000 project. This grant has allowed us to evaluate, enhance, and fine-tune the High Impact Targeting (HIT) tool for use across the basin for more effective (BMPs). (b) Key projects were supported by the Great Lake Protection Fund (GLPF) ($700,000) and subsequently the Michigan Department of Environmental Quality (MDEQ) to aid with planning, development and evolution of Michigans Water Withdrawal Assessment Tool (WWAT) which IWR presently hosts for the State of Michigan. (c) As part of the Social Indicators Data Management and Analysis System (SIDMA) for EPA Region 5, IWR received over $275,000 through EPA and USDA to develop the web-based interface for (SIDMA) for a multi-state team comprised of land-grant universities. (d) Source Water Assessment and Protection: Michigan has more than 12,000 public drinking water supplies covering both highly urbanized and rural areas. That program has transitioned to source water protection for which IWR provides training programs and direct assistance. More than $3.5 million has been awarded to the IWR to support source water assessment and protection activities. (e) MSU Water: IWR provides support to MSU-WATER, a major university initiative dealing with urban stormwater issues. IWR staff facilitates the program which integrates research, education and outreach activities that focus on managing stormwater through low impact design techniques in both highly urbanized and urbanizing watersheds. The project includes a working partnership with 20 governmental entities and organizations.

Outcomes/Impacts

Water Withdrawal Assessment Tool (WWAT): The IWR played a key role in several steps of the legislation process and developed the interface for the WWAT. The IWR is continuing with modifications of the WWAT. The IWR assisted with the development of the concepts incorporated in the legislation, providing testimony to the state Senate Natural Resources and

Environmental Policy Committee, convened an experts review panel to ensure that the Assessment Process was scientifically valid, and created the web based tool that is currently being used to keep track of new or increased large capacity water withdrawals in the state. The WWAT recently received two national awards; one for Outstanding Achievement Award for 2010 from the Renewable Natural Resources Foundation, and one from the Environmental Council of States for State Program Innovation. HIT: The success of the NRCS Conservation Innovation Grant that funded HITs development motivated Michigan NRCS to evaluate the incorporation of HIT prioritizations as a factor in EQIP application scoring. The integration of HIT into this process helps target EQIP conservation practices in the sub-watersheds where they are likely to have the greatest impact on water quality per dollar spent. IWR outcomes and impacts were recognized as one of two projects sited in the national announcement by the USDA. WASHINGTON, Nov. 30, 2010, Agriculture Secretary Tom Vilsack today announced that USDA is seeking proposals for grants to improve water quality, air quality and promote energy conservation. USDAs Natural Resources Conservation Service (NRCS) is making available $25 million through the Conservation Innovation Grants (CIG). Now in its eighth year, the CIG program offers funding dedicated to the adoption of technologies to address a broad range of agricultural issues.

For example, the Michigan Department of Agriculture worked with Michigan State University and agricultural landowners to establish conservation practices for high-risk erosion areas, with a goal of reducing sediment and nutrient runoff. Paw Paw River Watershed Groundwater Recharge Calculator: Though the outputs of this project are still new, TNC has been able to utilize them to estimate the maximum groundwater recharge potential for the Paw Paw River Watershed. TNC and Coca-Cola are reviewing these findings and utilizing the on-line tool to coordinate conservation strategies. Networked Neighborhoods for Eco-conservation Online (NECO): IWR held three user evaluation sessions for the NECO tool in pilot communities. In April 2010, the system was evaluated by citizens of Holland, MI. In May the system was evaluated by potential users in East Lansing. A final evaluation was held in Toledo, OH in June. The results of these evaluations led to significant system refinements, making the system roll-out events at MSUs Ag Expo (July) and Holland, MI (October) all the more successful.

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Asher, A.J. 2010. Networked Neighborhoods for Eco-Conservation (NEC) Online presented to the Holland Community Energy Advisory Group by Jeremiah Asher of MSU-Institute of Water Research's Web-based Mapping Project; October 7 at City Flats Hotel-Theater Room downtown Holland, MI.

2. Water Policy and Management Challenges in the West

Outputs

(1) Three outputs were completed and listed during the reporting period. They are being disseminated through publications, manuscripts, and working papers. The first publication was published by the Emerald Group Publishing Limited, in the Agricultural Finance Review (Evidence of Land Hoarding Behavior in US Agriculture). The other two were presented at professional water conferences and are in preparation for submission to peer-reviewed journals (Using Bio-Physical Information to Structure a Ground Water Conservation Credit Program; The Role of Water Conservation Technology, Economics, and Institutions for Reducing water Use Conflicts). (2) The Water Withdrawal Assessment Tool (WWAT) has been developed to estimate the likely impact of a water withdrawal on nearby streams and rivers.

The WWAT is available on-line (http://www.miwwat.org/) for anyone proposing to make a new or increased large quantity withdrawal (over 70 gallons per minute) from the waters of the state, including all groundwater and surface water sources. The proposed project must use the WWAT to determine if the withdrawal is likely to cause an Adverse Resource Impact. If there is no adverse impact the withdrawal may be registered on-line using the WWAT. The results page provides a quick link to submitting a registration with the state. For example, the WWAT has been used by The Nature Conservancy (TNC) to protect and improve water quantity and quality in the Paw Paw River watershed, helping Coca-Cola with water sustainability practices for a commercial bottling operation.

Outcomes/Impacts

(1) Market-like Policy for Groundwater: We developed a framework for market-like trading, Conservation Credit Offset Trading (CCOT), to be used as an alternative policy for regulating groundwater use in a sensitive watershed in order to protect stream fish habitats in Michigan. The premise of this policy design was tested using integrated bio-physical modeling with a hypothetical case study and applied data from an actual watershed. A bio-physical model was used to capture the resource impacts and helped in designing the policy. The framework of the CCOT could provide a road map for Michigan and Great Lakes Basin (GLB) states to implement new water policies and regulations to meet objectives of water resource management as stated in the GLB compact. Of key importance for the success of policy development is the need to recognize the challenges in policy development and implementation. This type of market-like approach might meet the needs of community-based, legally enforceable and long-term approaches to protect special ecological places, [those dependent upon groundwater flow] (Seedang, S. et al 2010/manuscript paper). (2) Land Hoarding Behavior in US Agriculture: A theoretical framework is developed to understand the demand for agricultural land retention with and without speculation in U.S. Agriculture. Our research introduces the land hoarding hypothesis.

High rates of land appreciation can be expected to signal that holding land may yield better returns than selling, suggesting that if rates of land appreciation become significantly high enough, farmers may begin to hoard land, to maximize long-term returns. This concept can be valuable to market-based agricultural land retention programs at the urban fringe. By linking

speculative behavior, land demand and the existence of hoarding behavior under some conditions, this paper adds value and originality to the literature (Adelaja, A.et al 2010). (3) Water Conservation Technology Adoption: Lessons Learned. We explored the potential implementation of a water conservation policy in Michigan where water use conflicts may arise as a result of new legislation. We reviewed the experiences of other regions (US South West-Eastern states/Canada) related to agricultural water conservation implementation. We explored the important role of agricultural water conservation technology, economic incentive policies and institutional governance to support and encourage the implementation of a policy for minimizing water use conflicts. Although we used SW Michigan for our discussion context, it can be applied to other areas in the Great Lakes Basin as long as resource managers/policy makers have a clear understanding of what underlines water use conflicts and of key institutional support and existing policies (Seedang et al 2010/working paper). (4) The impact of the Water Withdrawal Assessment Tool has been recognized nationally via the Outstanding Achievement Award for 2010 from the Renewable Natural Resources Foundation, and was one of four innovations to receive the State Program Innovation Award from the Environmental Council of States.

Publications

Bartholic, J., W. Northcott, S. Miller, J. Asher, S. Seedang, S. Gasteyer, and J. Andresen. 2010. Refining the Water Needs and Availability for Michigans Agriculture from a Spatial and Temporal Perspective (working paper).

Isely, E, P. Isely, S. Seedang, K. Mulder, A. Steinman, and K. Thompson. 2010. Addressing the Information Gaps Associated with Valuing Green Infrastructure in West Michigan: Integrated Valuation of Ecosystem Services Tool (INVEST). Journal of Great Lakes Research 36(3):448-457.

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3. Modeling for TMDL Development and Watershed Based Planning, Management and Assessment

Outputs

(1) HIT: HIT is an interactive system where users can visualize GIS data on high-risk erosion areas that are of the greatest interest to them. The use of HIT supports important NRCS, MDA, and other state agency conservation goals such as the reduction of soil erosion and sedimentation, improvement of water quality, and enhancement of wildlife habitat. Conservation districts and farmers can use this targeted approach to realize the maximum impact of conservation programs. With HITs availability expanding to the entire Great Lakes Basin in late 2009, IWR began promoting the tool to decision makers in the basin. IWR performed demonstrations in NRCS state offices in Michigan and Wisconsin, at local conservation district offices in Michigan, and at U.S. Army Corps of Engineer sediment workshops in Buffalo and Milwaukee (with another workshop scheduled for January in Cleveland). Michigan NRCS has agreed to evaluate the tools output as a ranking for EQIP application scoring across the state. (www.iwr.msu.edu/hit2)Paw Paw River Watershed Groundwater Recharge Calculator: IWR collaborated with The Nature Conservancy (TNC) to develop an online tool allowing users to spatially evaluate the impacts of land cover change and agricultural conservation practices on groundwater recharge in the Paw Paw River Watershed of southwest Michigan. IWR developed field-scale priority maps weighting recharge potential and erosion/sedimentation risk. TNC is using the tool and maps to coordinate conservation strategies with local conservation districts in the watershed. The project was funded by the Coca-Cola Foundation, who has expressed an interest in making its bottling plant in the watershed water neutral. This project provides a means by which that goal could be coordinated and evaluated. (http://35.9.116.206/tnc). (2) Networked Neighborhoods for Eco-conservation Online (NECO): IWR collaborated with local environmental groups and digital media / communication researchers at MSU to develop an online tool allowing users to document, map, and view urban conservation practices in their communities. For example, users can view the locations of existing rain barrels and rain gardens in their neighborhood, document their own, quantify their hydrological impact, and share information with other users. IWR conducted user testing and rollout workshops throughout 2010. This project was funded by the Great Lakes Protection Fund. (www.networkedneighbors.org). (3) Red Cedar River Watershed Planning Project: IWR is collaborating with Civil and Environmental Engineering professors from MSU and local conservation district staff to develop a management plan for the Red Cedar River Watershed of south central Michigan. The team will utilize HIT and the Process Adaptive Watershed Simulator (PAWS) to prioritize sub-watersheds by sediment, nutrients, and E. coli, and estimate load reductions. This project is funded through EPAs 319 program.

Outcomes/Impacts:

(1) HIT: The success of the NRCS Conservation Innovation Grant that funded HIT's development motivated Michigan NRCS to evaluate the incorporation of HIT prioritizations as a factor in EQIP application scoring. Currently, watershed sediment loading rates are not factored into EQIP applications. The integration of HIT into this process helps target EQIP conservation practices in the sub-watersheds where they are likely to have the greatest impact on water quality

per dollar spent. (2) Paw Paw River Watershed Groundwater Recharge Calculator: Though the outputs of this project are still new, TNC has been able to utilize them to estimate the maximum groundwater recharge potential for the Paw Paw River Watershed. TNC and Coca-Cola are reviewing these findings and utilizing the on-line tool to coordinate conservation strategies. (3) Networked Neighborhoods for Eco-conservation Online (NECO): IWR held three user evaluation sessions for the NECO tool in pilot communities. In April 2010 the system was evaluated by citizens of Holland, MI. In May the system was evaluated by potential users in East Lansing, MI. A final evaluation was held in Toledo, OH in June. The results of these evaluations led to significant system refinements, making the system roll-out events at MSUs Ag Expo (July) and Holland, MI (October) all the more successful. (4) Red Cedar River Watershed Planning Project: This project has just begun. There are no outcomes to report.

Publications

O'Neil, G. 2010. Conservation Innovation Grant final report, Impact Targeting: applying conservation tools to the worst areas for maximum sediment/nutrient reductions. Submitted to Michigan Department of Agriculture.

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4. Web-based Networked Neighborhoods for Eco-Conservation"

What is NECO

NECO is a new and innovative web-based system being developed by the Institute of Water Research at Michigan State University to help individuals map and share environmental practices they have put in place or are interested in implementing. The goals of the system in the Great Lakes region are to:

- Motivate individuals to adopt environmentally beneficial practices;
- Increase effectiveness of existing environmental groups and organizations;
- Improve the health of the Great Lakes through the adoption of environmental stewardship practices

NECO uses the concept of social networking and mapping technology to link people together with common goals of improving the environment in the Great Lakes Basin or in their own back yard. Simple installations of rain barrels, rain gardens, porous pavement, and many other green practices can add up to significant improvements in your watershed or neighborhood.

NECO Features

Real-time mapping of low impact developments and environmental stewardship practices in your community;

- Photographs, how-to's, and examples of environmental practices;
- Tools to inform individuals of environmental practices they could adopt and their benefits to the environment and Great Lakes health;
- Integration of Facebook and Flickr to network environmental groups and neighborhoods;
- Automated notification for weather alerts during ecologically sensitive days and actions they can take.

NECO Partners

- Michigan State University
- Institute of Water Research
- West Michigan Environmental Action Council
- Decision Support Professionals
- West Michigan Strategic Alliance
- Toledo Rain Garden Initiative
- American Rivers

Learn More

To learn more about NECO and how you or your organization can participate, visit http://www.iwr.msu.edu/neco. A more detailed report on NECO follows:

Progress Summary

The NECO project is moving forward as planned, and the development team at IWR along with project partners are excited to have the system available this spring for data collection and system reporting. The development team recently created a set of features that greatly increases the value of the system to communities, watershed groups, and other organizations. We are looking forward to moving these features to the production server in the next two weeks for public access.

Over the past 5 months IWR has divided its time into two major efforts: 1) modifications and enhancements of the system as a result of evaluation workshops; and 2) rollout of the application. We are on par with our overall project objectives and timeline, with slight modifications to some task durations and order of execution.

Our progress to date can be summarized by the following tasks and activities:

1. Adding new tools and features to the website
2. Coordinating rollout events
3. Producing print material
4. Planning an overall system evaluation after rollout

1) Since the last progress report IWR has developed several new tools and features to be added to NECO; they include: 1) an interface with charts and graphs to compare groups of users with each other, 2) new calculations and charts to calculate and display sediment, nitrogen, phosphorus, and fecal coliform reduction's, and 3) survey tools to collect information regarding the system and users perceptions.
2) During the late winter and early spring, IWR has been coordinating site advertisement with existing rain barrel sale events and scheduling demonstrations.
3) IWR has generated several additional print handouts for advertising NECO and has drafted press releases to use in different locations during the rollout.
4) One of the ways IWR will track success of the project is through data collection on NECO in the form of survey instruments and practices logged. The social networking team has developed a set of four questionnaires to be utilized on the site to help better understand the impacts of NECO.

Project Planning and Scheduling Sheet

Task No.	Task/Action Step	Start Time	End Time	% Complete
1.0	Identify pilot study areas and stakeholder groups	10/1/08	12/1/08	100%
1.1	Meet with groups to raise awareness of activities regarding the prototype system and coordinate efforts	10/15/08	1/15/09	100%
1.2	Begin collaboration process with partners	11/1/08	9/30/11	
1.3	Coordinate event planning and scheduling with partners	12/1/08	3/1/09	Ongoing
1.4	Identify or establish networked neighborhoods	1/15/09	3/1/09	Ongoing
1.5	Map networked neighborhoods	3/1/09	3/15/09	100%
2.0	Research and identify ecosystem health issues/concerns	12/1/08	3/1/09	100%
2.1	Research and identify behaviors and impacts related task 2.1	1/15/09	4/15/09	100%
2.2	Build and Populate SQL database for GLE Behavior-Impact Matrix	4/15/09	6/1/09	100%
2.3	Testing, Modification, Evaluation	6/1/09	6/15/09	100%
3.0	Inventory Existing Tools	11/1/08	6/1/09	100%
3.1	Collect GIS data for study areas and across the region	1/15/09	6/15/09	100%
3.2	Build geographic database	2/1/09	7/1/09	100%
3.3	Develop Interactive Mapping Interface	7/1/09	1/15/10	100%~
3.4	Testing, Modification, Evaluation	1/15/10	2/15/10	100%
4.0	Plan Social Networking System Design	1/15/10	6/1/10	100%
4.1	Evaluate User Groups and Technical Skills	1/15/10	4/15/10	100%
4.2	Develop Content and Appropriate Media	1/15/10	4/1/10	100%
5.0	Initiate Focus groups and interviews to assist in site design criteria	11/1/09	3/15/09	100%
5.1	Design Layout	2/15/09	5/15/09	100%
5.2	Develop System Interface ProtoType1	4/1/09	9/1/09	100%~
5.3	Connect User Interface to Behavior-Impact Matrix	5/1/09	7/1/09	100%
5.4	Connect User Interface to Interactive Mapping Interface	5/1/09	7/1/09	100%
5.5	Develop Alert System	2/1/09	11/1/09	100%
5.6	Develop user incentive tools, including gifts	1/15/09	5/15/09	100%
5.7	Testing, Modification, Evaluation from Users Groups	9/1/09	12/1/09	100%
6.0	Develop and adapt dynamic modeling functions	4/15/09	9/1/09	100%
6.1	Develop Final System Interface	12/1/09	4/1/09	99%~
6.2	Print marketing Material	9/1/09	3/1/10	99%~
6.3	~~Develop introductory and training videos for site~~	~~9/1/09~~	~~3/1/10~~	~~0%~~
6.4	Rollout Prototype Application and Distribute Paper and Digital Media	3/15/10	4/30/10	70%
6.5	Host hands on workshops for the new system	3/15/10	6/15/10	90%~
7.0	Installations of Green Infrastructures	9/30/08	7/1/11	Ongoing
8.0	Monitor, Evaluate, and Test Effectiveness	3/15/10	7/1/11	0%
8.1	Track and map improvements via indicators and volunteer groups	3/15/10	7/1/11	0%
9.0	Evaluate Project Success and Write Final Report	7/1/11	9/30/11	0%
10.0	Begin Long-Term Hosting and Maintenance			0%

~ Indicates additional useful features may continue to be added to benefit the overall system

Progress by Tasks

The following section provides a brief description of the tasks and progress since the last report. Although some tasks have been completed we may continue to spend some time modifying and adding features that are requested by partners, citizens, and other project stakeholders that lend to the overall success and increased adoption of the system. Tasks that have been completed are identified as such; detailed information about their progress can be found in previous reports.

Task 1.0 – Identify Pilot Study Areas and Stakeholder Groups

Completed

Task 1.2 and 1.3 – Partner Collaboration and Event Planning

We view the collaboration process as an ongoing effort that is crucial to the successful implementation of NECO and extends through the life of the project. A variety of objectives such as coordinating activities and events, identifying user needs, understanding key players, and knowledge sharing in addition to many others will be accomplished through this process. We are on schedule with these tasks and are meeting with our partners and project team as needed.

Since our previous report we have coordinated with our partners and local communities to conduct NECO demonstrations and advertisement in their areas through the spring and summer of 2011. Locally, we will be advertising at a May 21st Rain Barrel and Compost Bin Sale conducted by the Capital Area Recycling and Trash program.

Task 1.4 and 1.5 – Identify Networked Neighborhoods

In the previous report the development team at IWR added some additional features to the NECO website to help people connect and attach themselves to a neighborhood. This action included a new definition of neighbors in relation to NECO and an automated connection to local 8 digit watersheds. In an effort to expand this neighborhood concept the development team also created a “group” function that allows users to add themselves to existing groups or create new ones.

Task 2.0 – 2.3 – Research and Develop Behavior Impact Matrix

Completed

Task 3.0, 5.0 – Inventory Existing Tools and Conduct Interviews

Completed

Task 3.1 and 3.2 – Collect GIS Data

Completed

Task 3.3 – Develop Interactive Mapping Interface

Completed

Task 4.0 and 4.2 – Social Networking Design

Completed

Tasks 4.1, 5.7, and 6.5 – User Evaluations and Workshops

Completed

Task 5.2, 5.3, and 5.4 – Develop Prototype Interface

The development team recently completed the last round of major enhancements to the system. These enhancements are still located on the development server and will be transferred in the coming weeks to the production server where they will be accessible to the public. The enhancements and screen captures are as follows.

The report function now has new interactive charts and graphs that allow the user to move their mouse over the graphs and view data points and information in a more user-friendly manner (Figure 1).

In addition, three new interactive charts have been added to the reporting system to display estimates on nitrogen, phosphorus, sediment, and fecal coliform reductions from practices installed on NECO (Figure 2).

As part of our attempt to foster friendly competitive rivalry among neighborhoods or communities, the social networking team proposed a plan to develop an interface to allow users to join groups that can be compared to one another. The concept could utilize existing rivalries. For example, users belonging to the Michigan State University group could compare their total water managed, number of practices, or environmental benefits against the University of Michigan group, and likewise neighboring cities or communities could do the same. The interface uses a set of dials near the top of the page to compare the user with others in four categories: 1) number of practices installed, 2) amount of water managed, 3) activity on the website, and 4) environmental benefits (Figure 3).

The group comparison interface also provides bar charts for the same previously mentioned categories plus one additional category for percent of practices with photos entered into NECO. Users can select any number of groups on the right hand side of the page to compare (Figure 4).

The user can join these existing groups or create new ones under the account tab. Groups are divided into three categories for easy filtering; 1) place based groups [cities states, neighborhoods, etc], 2) establishment based groups [schools, churches, stores, organizations, etc.], and 3) natural boundary groups [rivers, watersheds, and lakes] (Figure 5).

Lastly, the social networking team has developed a set of four questionnaires to be utilized on the site to help better understand the impacts of NECO (Figure 6). The first survey is titled "General Survey", it examines user's opinions about the NECO website specifically and green practices in general. The second is titled "Value Survey", which examines the user's values related to green practices. The third is titled "Demographics Survey", and it examines common demographics information about NECO users. The fourth is titled "Environment Survey". This final survey examines the user's belief and understanding of green practices and how they affect the environment.

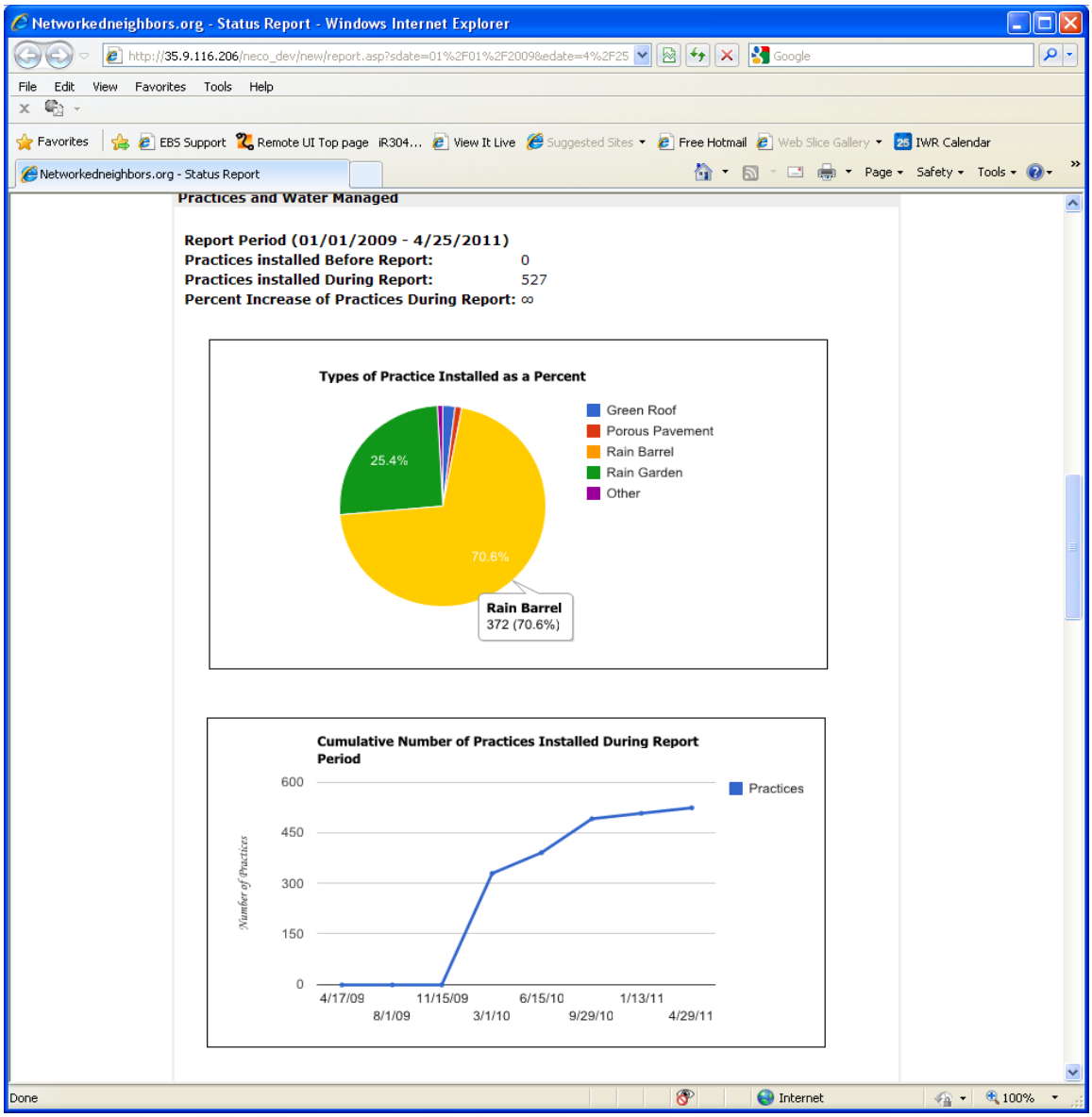


Figure 1
Interactive charts and graphs make reading information easier.

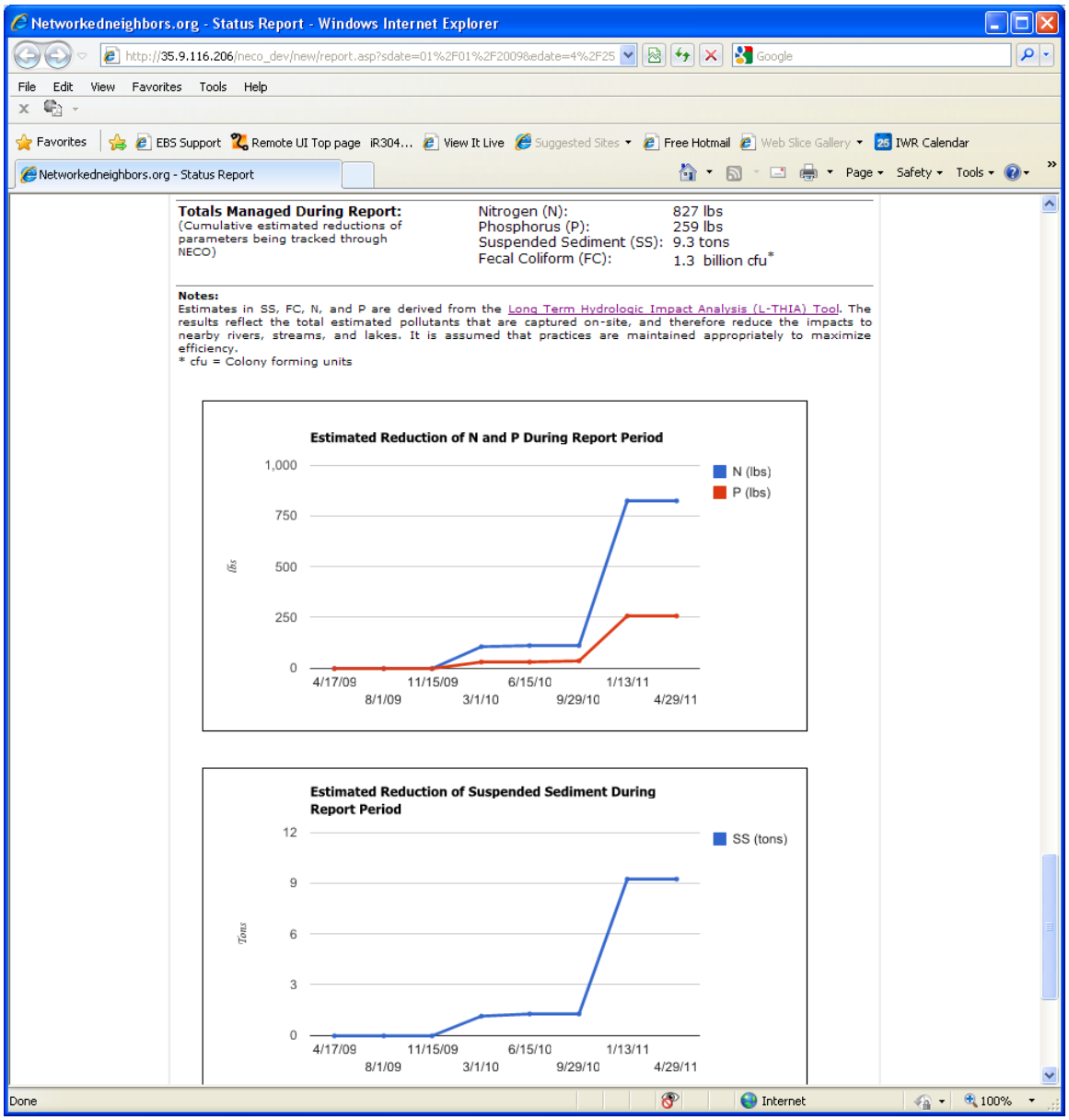


Figure 2
New interactive charts for nitrogen, phosphorus, sediment, and fecal coliform reductions.

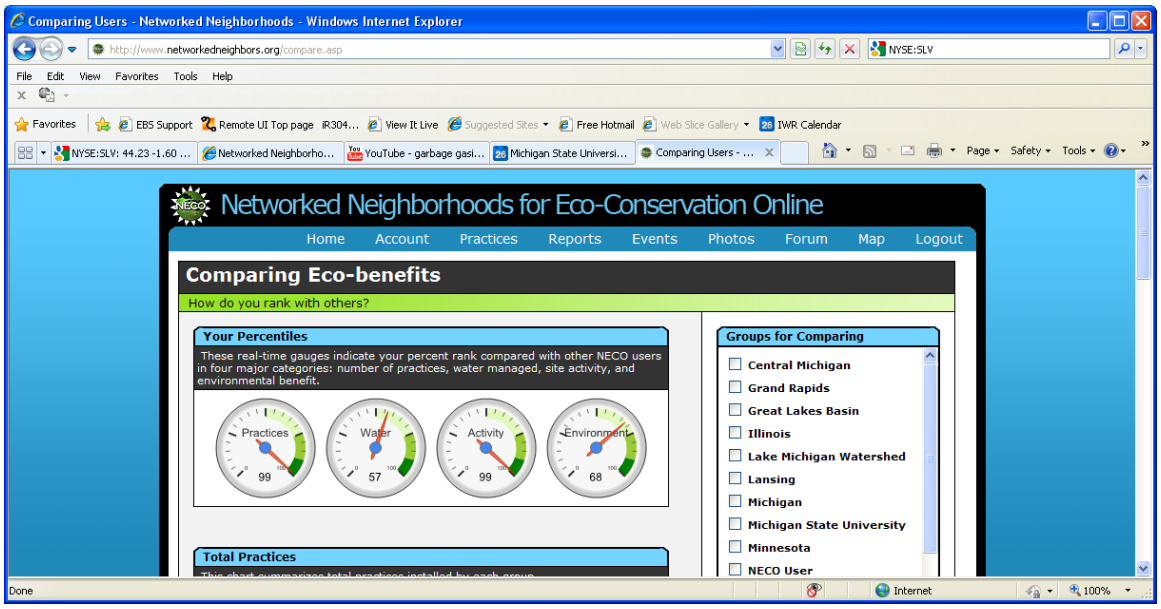


Figure 3
Real-time dials for comparing users with others

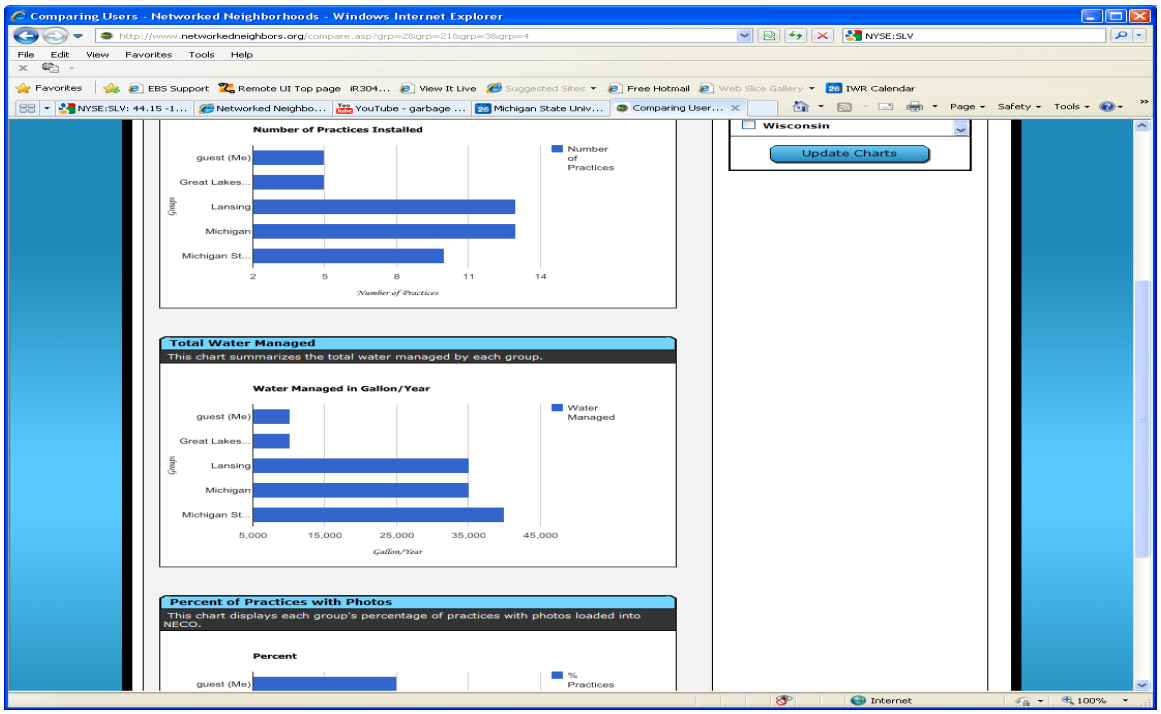


Figure 4
Bar charts for comparing groups with each other

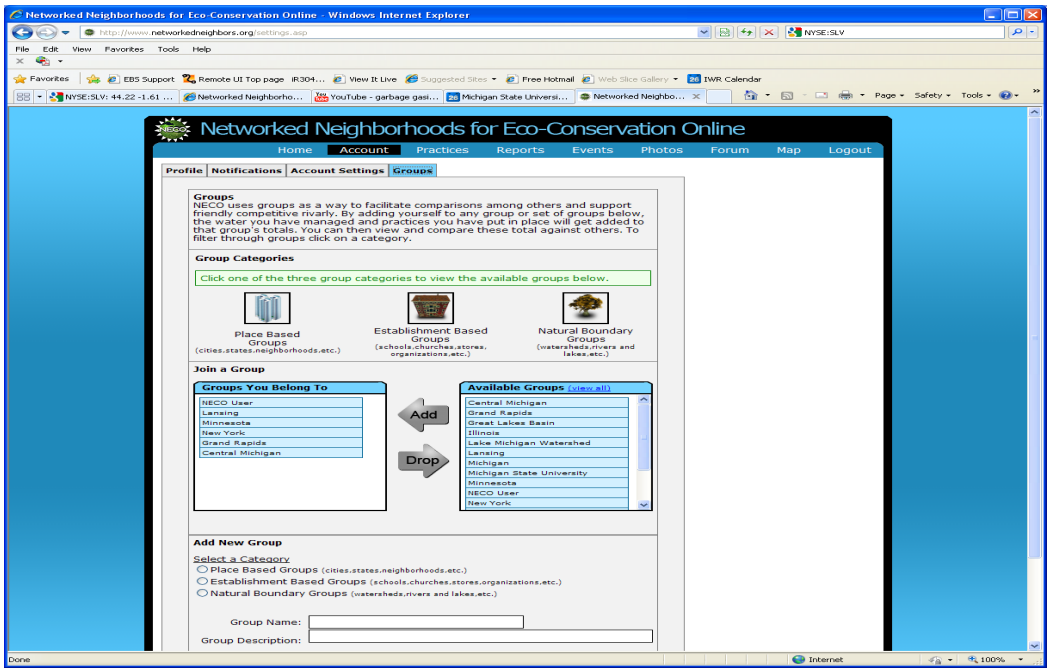


Figure 5
Interface for users to join existing groups or create new ones

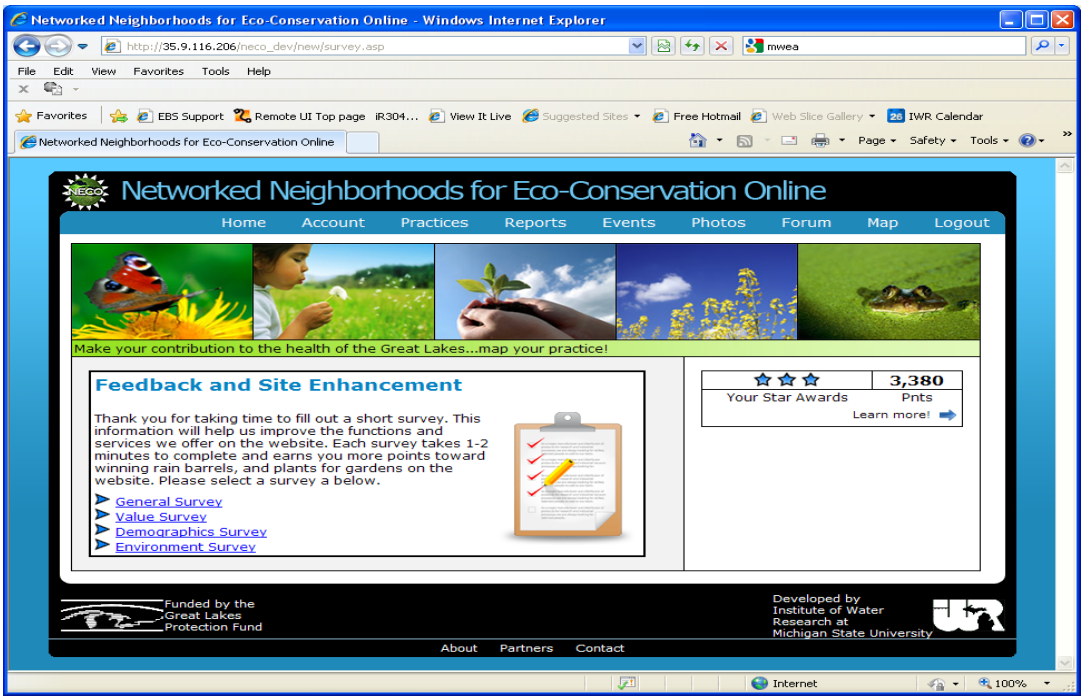


Figure 6
Interface to capture valuable information about user's beliefs and values about green practices

Task 5.5 – Develop Alert System

Completed

Task 5.6 – Develop User Incentive Tools

Completed

Task 6.0 – Develop Dynamic Modeling Functions

One of the most challenging aspects of implementing low impact developments or green practices is demonstrating environmental benefits and total water managed. Task 6.0 was created for this very purpose. The dynamic modeling functions take green practices that are being mapped and collects information regarding size, geographic location, and other parameters to calculate how much water is being managed and estimates some environmental improvements.

In our previous report we had finished developing the calculators to determine the amount of water that each practice was managing, and had anticipated finishing the pollutant calculations. Since them the development team worked with Purdue University using the Long Term Hydrologic Impact Analysis (L-THIA) tool to estimate reductions in four parameters: 1) nitrogen, 2) phosphorus, 3) sediment, and 4) fecal coliform. L-THIA uses land use and runoff curve numbers to estimate pollutant reductions. A more detailed description of the L-THIA tool will be provided on the NECO website. The estimates are calculated dynamically based on the water managed at each property and are displayed in the report section of NECO. These pollutant calculators are now completed and available on the development site and will be transferred to the public site next week.

Task 6.2 – Develop Marketing Material

Since much of the initial success of a project is heavily tied to marketing, IWR has been creating a variety of outreach materials to be passed out at workshops and distributed by our partners. We have drafted most of our marketing material and will make it available on the NECO website.

Task 6.3 – Develop Introductory and Training Videos

This task has been removed. For more details please refer to progress report IV.

Task 6.4 and 6.5 – Rollout of the System

The primary purpose of this task is to expose the NECO system to the general public and begin developing an active user community. We have decided to break this task into two phases and extend its overall time frame. Phase one is the soft rollout and phase two is the hard rollout.

The purpose of the soft rollout is to determine how users are reacting to the system allowing time to modify or change rollout strategies for the hard rollout. The hard rollout will occur just before the height of green practice installations in the spring and we anticipate that with fresh exposure to the NECO site, people will remember and be more likely to participate.

During the past several months IWR has been rolling out the current version of the application at a variety of venues. These demonstrations, poster sessions, webinars, and hand outs will continue

through April, May, and June to facilitate distributing information about the system. Following are a few of the events where the NECO project was recently presented.

- National Water Program in Washington D.C., January 31st - February 2nd, 2011
- Michigan State University ANR Week Presidential Luncheon, March 8th, 2011
- Michigan State University Specialist Forum, February 23rd, 2011
- Michigan Water Environment Association, March 22, 2011

Locally, NECO will be advertised at the May 21st Rain Barrel and Compost Bin Sale conducted by the Capital Area Recycling and Trash program covering a three county area near Lansing.

We are currently scheduling several outreach efforts in Wisconsin that will take place May.

Task 7.0 – Installation of Green Infrastructures

This task will be primarily carried out by our partners in pilot study areas over the course of the project. As these practices are mapped we can begin to examine where activities are happening around the Great Lakes region. Our partners will be utilizing funds provided through the NECO project to install both rain gardens and rain barrels in the pilot areas across the Great Lakes. Our partners are currently estimating project costs for the 2011 season. These projects will be similar to projects described in the fifth Interim Report.

Publications

Bartholic, J., Y. Shi, K. Maredia, S. Seedang, J. MacDonagh-Dumler.. 2010. Institute of Water Research and Institute of International Agriculture, Michigan State University, "Characteristics of an Action Plan for Addressing Emerging Issues in Water Management for Sustainable Agriculture in South Asia Region." Submitted to the Central Soil & Water Conservation Research & Training Institute Research Centre, India for inclusion in Proceedings from the Indo-US Workshop on Emerging Issues in Water Management for Sustainable Agriculture in South Asia Region, December 10-12, 2009, in Udhagamandalam, Tamil Nadu, India. In Press.

O'Neil, G., J. Bartholic, Y. Shi. 2010. Institute of Water Research, Michigan State University. "High Impact Targeting Decision Support System for BMPs to Most Effectively Reduce NPS Pollution" presented at the 18th National Nonpoint Source Monitoring Workshop held in Milwaukee, Wisconsin November 16-18. Nov. 17, Session 5-03, In Proceedings on CD, 33 pp.

O'Neil, G., L. Theller, Y. Shi, J. Bartholic, B. Engel. 2010. The Swan Creek Watershed Management System," presented by O'Neil at the TMDL 2010: Watershed Management to Improve Water Quality ASABE Conference, Nov. 14-17 in Baltimore, MD. In Press

Bartholic, Jon, William Northcott, Steve Miller, Jeremiah Asher, Saichon Seedang, Steve Gasteyer, and Jeff Andresen. 2010. Refining the Water Needs and Availability for Michigan's Agriculture from a Spatial and Temporal Perspective, Institute of Water Research, Michigan State University, 5pgs.

Bartholic, J., O'Neil, G., Shi, Y. 2009. A Web-Accessible Watershed-Based System Targets Land Areas at Highest Risk for Sediment Loss to Streams. On Line Proceedings 2009 at http://www.benthos.org/Other-Publications /NABStracts/2009/4406.aspx, North American Benthological Society, Grand Rapids, MI.

Shi, Y., 2009. Midwest Spatial Decision Support System Partnership, Exchange Network Grant Program Semi-Annual Progress Report for Grant OS-83320901-0, submitted to Wisconsin DNR to Environmental Protection Agency. 21 pages.

Seedang, S., Fernald, A., Adams, R., Landers, D. 2008. Economic Analysis of Water Temperature Reduction Practices in a Large River Floodplain: an Exploratory Study of the Willamette River, Oregon, Wiley InterScience on line at www.interscience.wiley.com, 19 pages.

O'Neil, G., Y. Shi, J. Bartholic, R. Fanelli, B. Engel, J. Hunter. 2008. Swan Creek Watershed Project Final Report submitted to U.S. Army Corps of Engineers in fulfillment of funding requirements. 17 Pages.

Runoff Reduction Credits for Low Impact Development Facilities

Basic Information

Title:	Runoff Reduction Credits for Low Impact Development Facilities
Project Number:	2010MI165B
Start Date:	3/1/2010
End Date:	2/28/2011
Funding Source:	104B
Congressional District:	8
Research Category:	Water Quality
Focus Category:	Water Quantity, Water Quality, Models
Descriptors:	None
Principal Investigators:	Amirpouyan Nejadhashemi

Publications

There are no publications.

Final Report

Runoff Reduction Credits for Low Impact Development Facilities

Project Number: 2010MI165B
Project PI: Amirpouyan Nejadhashemi

Statement of the Problem:
Rapid growth of the urban sector has led to significant environmental and social changes in this environment. To manage stormwater and control pollution from developed areas naturally, urban best management practices (BMPs) have been developed. Effective BMP selection in the urban environment is a key challenge to address when trying to protect water quality.

Project Objectives:
The following project objectives were proposed to address these problems:

1. Synthesize current literature and databases related to the runoff prediction capabilities for various urban BMPs.
2. Develop a user-friendly assessment tool to estimate BMP effectiveness on runoff reduction capacity, performance under different influent qualities, and total pollutant load mitigation based on site-specific factors.

Model Description:
A user-friendly assessment tool called "Runoff Reduction Credits for Low Impact Development Facilities-RRCLIDF" was developed using Microsoft Visual Studio 2008 Version 9.0.30729.1 with .NET Framework Version 3.5. The program code is presented in appendix A. The program assists users in:

• Selecting BMP(s) based on up to 137 contaminants

• Estimating BMP Runoff Reduction Capacity

• Estimating BMP Performance under Different Influent Quantities

• Estimating Total Pollutant Load Mitigation for BMPs

• Comparing Contaminant Removal Performance of Different BMPs

The RRCLIDF program includes three modules: 1) BMP Runoff Reduction Performance Module 2) BMP Influent/Effluent Quality Module, and 3) Total Pollution Load Mitigation Module.

1. *BMP Runoff Reduction Performance Module*

The runoff reduction performance dataset was developed through a comprehensive literature review. The collected dataset was analyzed to determine the mean, median, range, and standard deviation of individual BMP effectiveness on mitigating runoff. This

module can aid in assigning runoff reduction rate to various BMPs and estimate runoff reduction volume on an annual average basis.

2. *BMP Influent/Effluent Quality Module*

The BMP influent/effluent quality concentrations data was obtained through literature review and incorporated in this module. The collected dataset was analyzed to provide a range of expected influent and effluent quality concentrations for different BMPs.

3. *Total Pollution Load Mitigation Module*

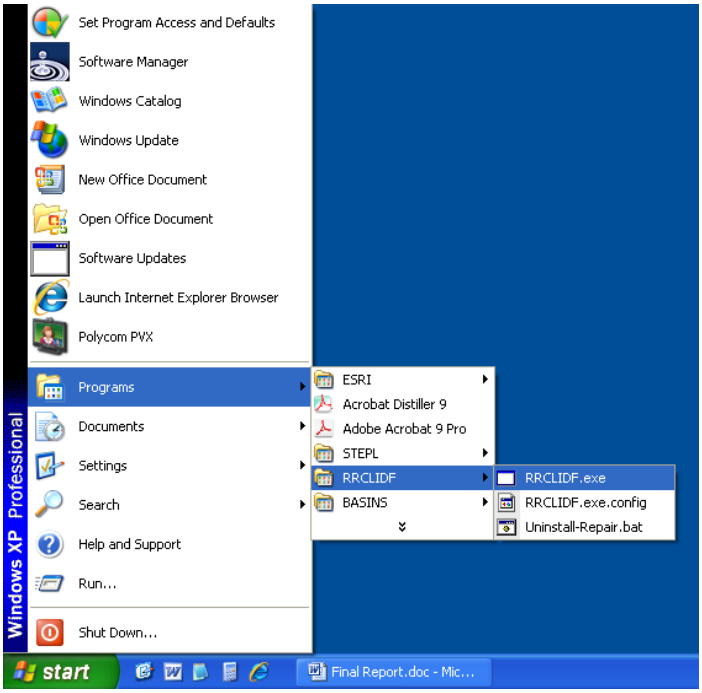
To calculate the total load reduction, data obtained from the *BMP Runoff Reduction Performance Module* and the *BMP Influent/Effluent Quality Module* were used. The total volume of water that is treated by a BMP (treatment volume) is estimated from the *Runoff Reduction Performance Module*. This value is multiplied by average concentration of the pollutant, which is estimated from influent and effluent quality concentrations differences.

Acknowledgment:

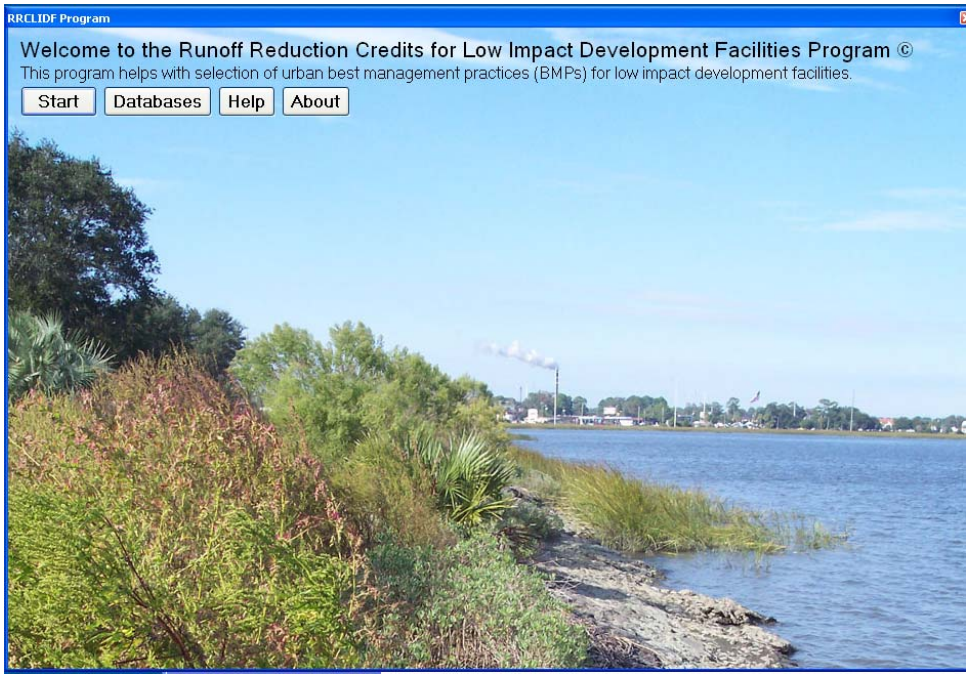
The author gratefully acknowledges the assistance of Michael Prohaska (Department of Civil and Environmental Engineering, Michigan State University), who helped with the development of the program and data organization; Matt Einheuser, Brad Wardynski, Sean Woznicki, and Brad Love (Department of Biosystems and Agricultural Engineering, Michigan State University) for assistance with data collection. Funding for this project was provided by the United States Geological Survey (Project Number: 2010MI165B).

RRCLIDF Program Tutorial:

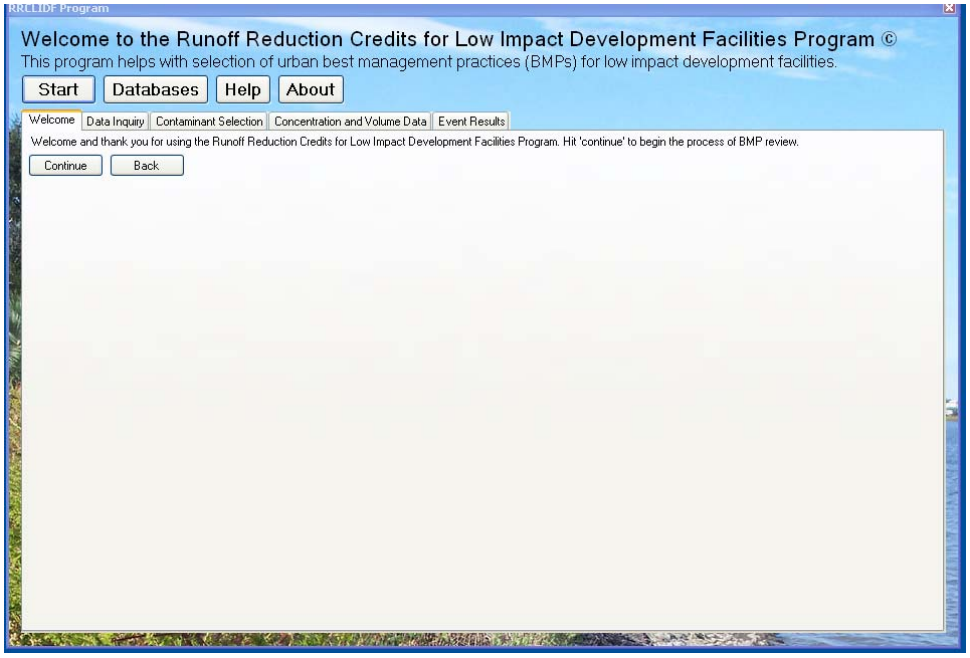
1. From the windows® taskbar, click ***Start***, ***Programs, PRCLIDF, RRCLIDF.EXE***



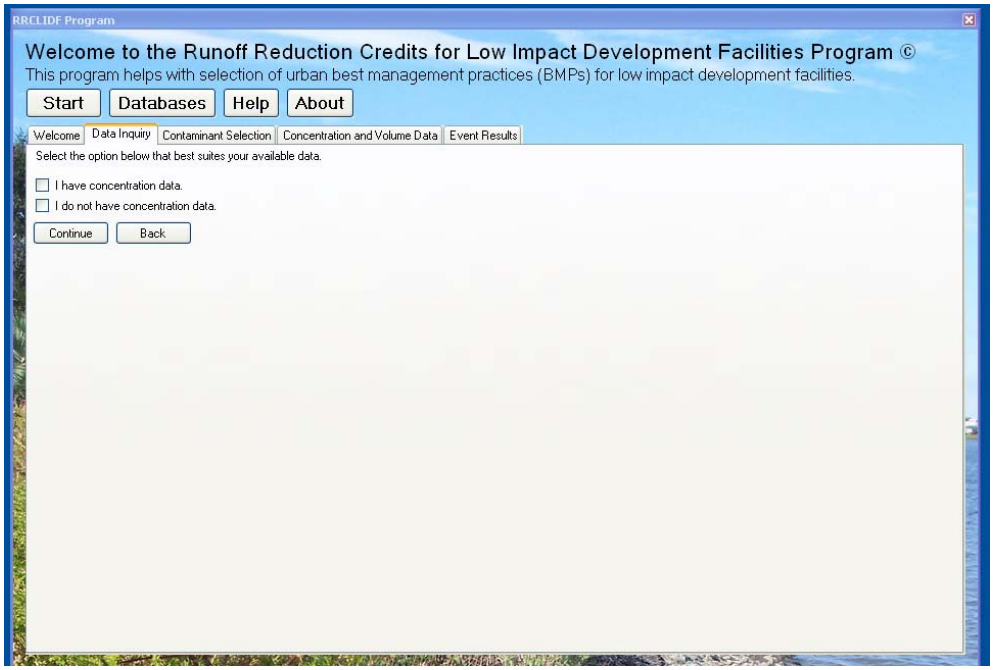
2. In the resulting RRCLIDF window, click the ***Start*** button.



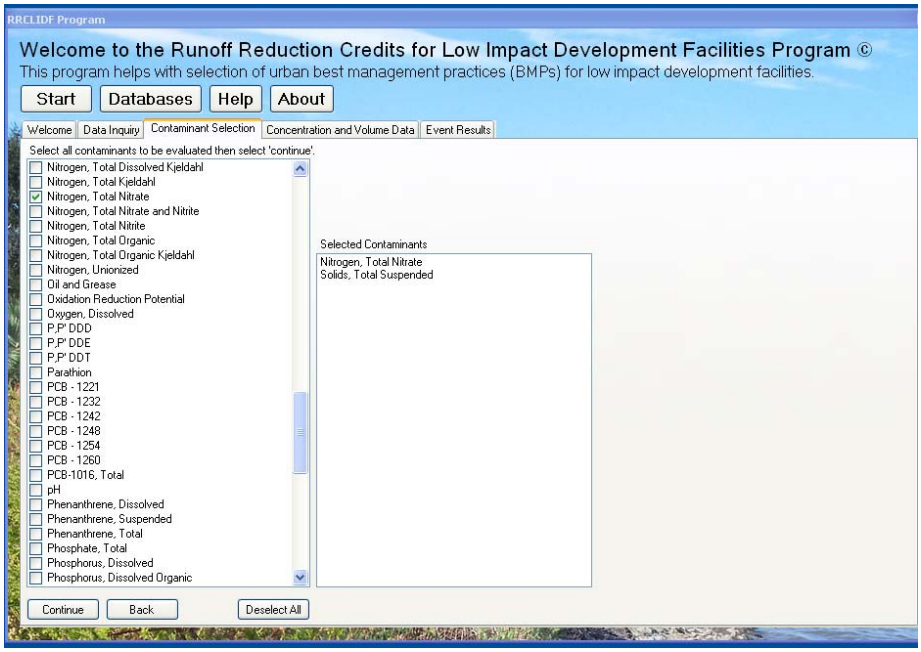
3. Click on the ***Continue*** button to start the process.



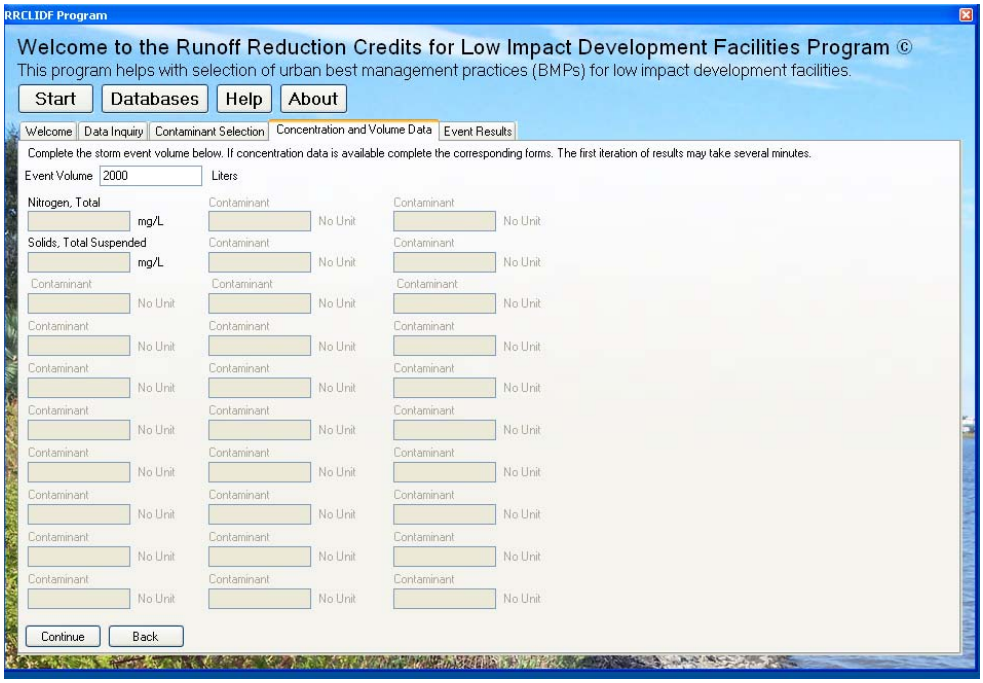
4. In the next window, the user is asked to select between two options. In the case that the user has pollutant concentration for the study area, they will select first option, otherwise, program default values will be used.



5. In the next window, the user has the option to select one or multiple contaminants of concern and then click the ***Continue*** button.

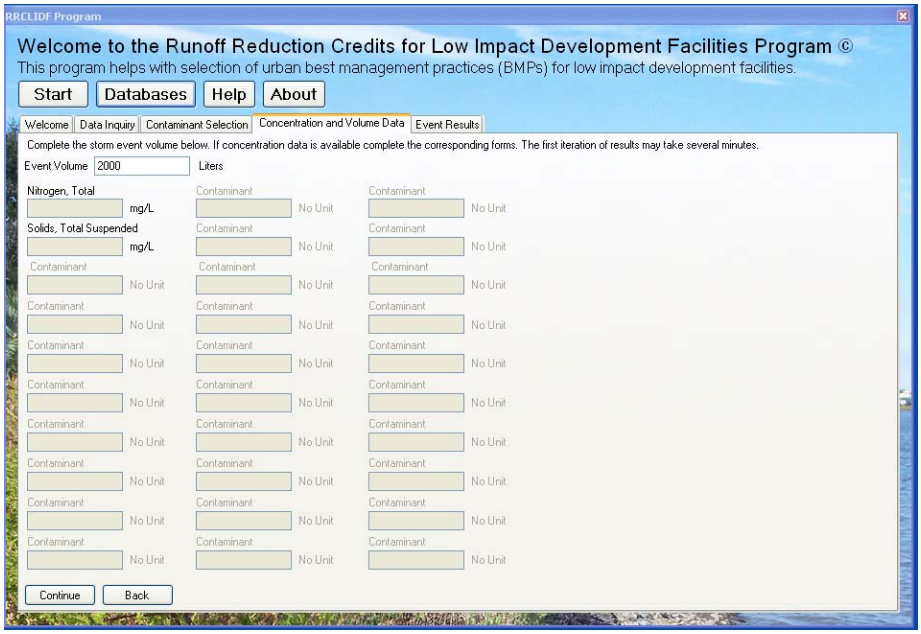


6. In the next window, enter the volume of the storm event in liters and then click on the ***Continue*** button.



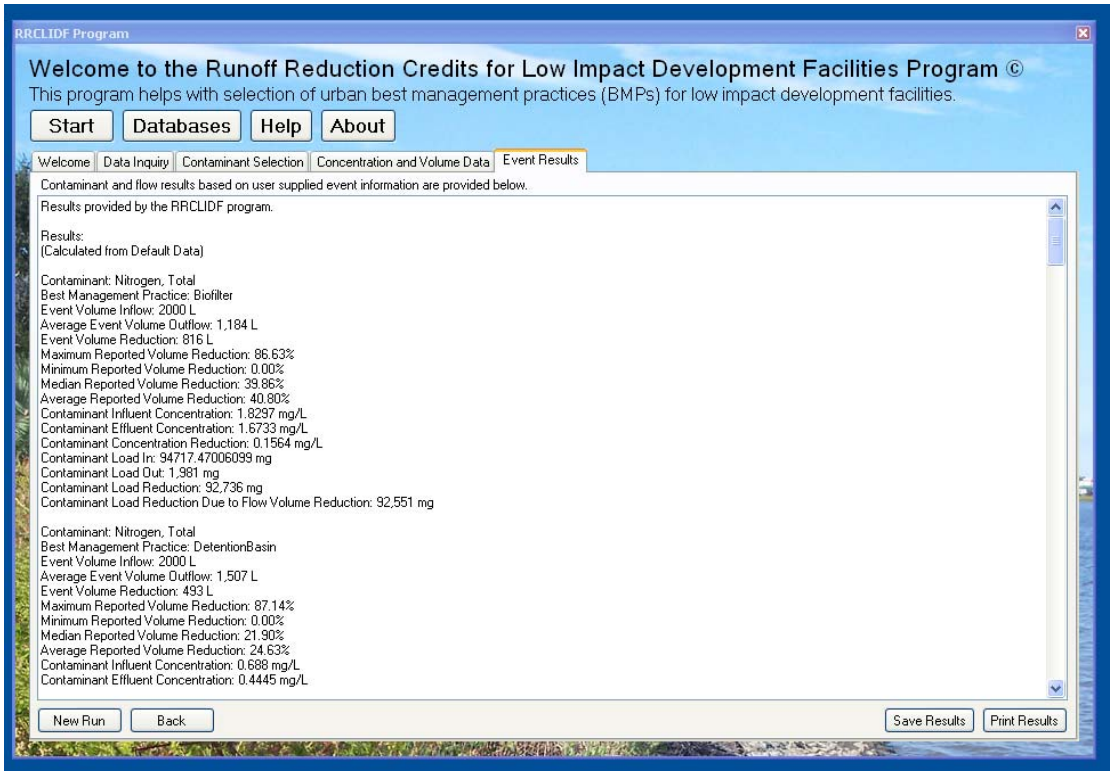
7. Based on the type of contaminant, the program will identify the possible BMP(s) options that can be used. The list of BMPs that were considered include:

- Biofilter
- Detention Basin
- Hydrodynamic Device
- Infiltration Basin
- Media Filter
- Percolation Trench-Well
- Porous Pavement
- Retention Pond
- Wetland Basin
- Wetland Channel



8. After analysis was performed, a window will be opened that includes information on:

- Name of contaminant
- Suggested BMP(s)
- Event volume inflow to the BMP (L)
- Average event flow outflow (L)
- Event flow runoff reduction (L)
- Minimum reported volume reduction (%)
- Median reported volume reduction (%)
- Average reported volume reduction (%)
- Contaminant influent concentration (mg/L)
- Contaminant effluent concentration (mg/L)
- Contaminant concentration reduction (mg/L)
- Contaminant load in (mg)
- Contaminant load out (mg)
- Contaminant load reduction (mg)
- Contaminant load reduction due to flow volume reduction (mg)



Appendix A: Program Code

Form 1

```
Public Class Main

   Private Sub Message(ByVal sender As System.Object, ByVal e As System.EventArgs) Handles
MyBase.Load



   End Sub

   Dim StringToPrint As String

   '=========================================

   'INPUT BIOFILTER ARRAY AND HASH

   '=========================================

   'Column Reference Info

   Public columnBiofilter() As String = {"Conc_In", "Conc_Out", "Flow_In", "Flow_Out", "Vol_Red", "
Min_Vol_Red", "Max_Vol_Red", "Med_Vol_Red", "Ave_Vol_Red"}

   'Row Reference Info

   Public rowBiofilter() As String = {"Ammonia, Total Nitrogen", "Arsenic, Dissolved", "Arsenic, Total",
"Biochemical Oxygen Demand-5", "Cadmium, Dissolved", "Cadmium, Total", "Carbon, Dissolved Organic",
"Carbon, Organic", "Carbon, Total Dissolved Organic", "Carbon, Total Organic", "Chemical Oxygen
Demand", "Chloride, Total", "Chlorpyrifos, Total Recoverable", "Chromium, Dissolved", "Chromium, Total",
"Copper, Dissolved", "Copper, Total", "Diazinon", "Escherichia Coli", "Fecal Coliforms", "Fecal
Streptococcus", "Hardness (Ca-Mg), Total", "Hardness (Ca-Mg), Total", "Hydrocarbon, Total Recoverable
Petroleum", "Iron, Dissolved", "Iron, Total", "Lead, Dissolved", "Lead, Total", "Nickel, Dissolved", "Nickel,
Total", "Nitrogen, Ammonia", "Nitrogen, Total", "Nitrogen, Total Kjeldahl", "Nitrogen, Total Kjeldahl",
"Nitrogen, Total Nitrate", "Nitrogen, Total Nitrate", "Nitrogen, Total Nitrate and Nitrite", "Oil and Grease",
"Oxygen, Dissolved", "pH", "Phosphorus, Dissolved", "Phosphorus, Dissolved Organic", "Phosphorus,
Dissolved Ortho Phosphate", "Phosphorus, Ortho Phosphate", "Phosphorus, Total", "Residue, Total",
"Silver, Dissolved", "Silver, Total", "Solids, Total", "Solids, Total Dissolved", "Solids, Total Suspended",
"Solids, Total Volatile", "Specific Conductance", "Temperature, Water", "Turbidity", "Zinc, Dissolved",
"Zinc, Total"}

   'Table Info

   Public Biofilter(,) As String = {{0.535, 0.018, 232850.0, 72150.0, 69.01, 0.0, 86.63, 39.86, 40.8}, {0.003,
0.0022, 45502.8571, 25360.3429, 44.27, 0.0, 86.63, 39.86, 40.8}, {0.0055, 0.0044, 45502.8571,
25360.3429, 44.27, 0.0, 86.63, 39.86, 40.8}, {8.2906, 6.0586, 104220.0, 38960.0, 62.62, 0.0, 86.63, 39.86,
40.8}, {0.0004, 0.0002, 54071.0526, 32318.7368, 40.23, 0.0, 86.63, 39.86, 40.8}, {0.0009, 0.0009,
```

53166.6667, 31972.1026, 39.86, 0.0, 86.63, 39.86, 40.8}, {24.24, 15.9683, 77533.3333, 44616.6667, 42.45, 0.0, 86.63, 39.86, 40.8}, {14.2, 12.21, 18800.0, 18800.0, 0.0, 0.0, 86.63, 39.86, 40.8}, {23.0, 11.5977, 98433.3333, 60566.6667, 38.47, 0.0, 86.63, 39.86, 40.8}, {27.4096, 16.8314, 81450.0, 49340.0, 39.42, 0.0, 86.63, 39.86, 40.8}, {89.8055, 50.0556, 67950.0, 25275.0, 62.8, 0.0, 86.63, 39.86, 40.8}, {0.0, 0.0, 55900.0, 55900.0, 0.0, 0.0, 86.63, 39.86, 40.8}, {0.0, "NA", 81500.0, 10900.0, 86.63, 0.0, 86.63, 39.86, 40.8}, {0.0043, 0.0047, 46473.5294, 25797.4118, 44.49, 0.0, 86.63, 39.86, 40.8}, {0.0078, 0.0081, 47181.8182, 26173.0909, 44.53, 0.0, 86.63, 39.86, 40.8}, {0.0175, 0.0102, 53276.9231, 31833.641, 40.25, 0.0, 86.63, 39.86, 40.8}, {0.0381, 0.0174, 54800.0, 31969.5385, 41.66, 0.0, 86.63, 39.86, 40.8}, {0.0, "NA", 81500.0, 10900.0, 86.63, 0.0, 86.63, 39.86, 40.8}, {153545.424, 14857.064, 28320.0, 11560.0, 59.18, 0.0, 86.63, 39.86, 40.8}, {1225.0, 375.0, 67133.3333, 42983.3333, 35.97, 0.0, 86.63, 39.86, 40.8}, {322591.59, 1999082.25, 18800.0, 18800.0, 0.0, 0.0, 86.63, 39.86, 40.8}, {34.8226, 38.85, 45878.9474, 29947.3684, 34.73, 0.0, 86.63, 39.86, 40.8}, {34.9553, 39.0435, 62263.1579, 34690.1053, 44.28, 0.0, 86.63, 39.86, 40.8}, {2.5, "NA", 81500.0, 10900.0, 86.63, 0.0, 86.63, 39.86, 40.8}, {0.133, 0.1631, 12280.0, 8580.0, 30.13, 0.0, 86.63, 39.86, 40.8}, {0.9372, 1.0178, 82600.0, 56042.8571, 32.15, 0.0, 86.63, 39.86, 40.8}, {0.0079, 0.0043, 53276.9231, 31833.641, 40.25, 0.0, 86.63, 39.86, 40.8}, {0.0429, 0.014, 53900.0, 31640.3, 41.3, 0.0, 86.63, 39.86, 40.8}, {0.0057, 0.0032, 36650.0, 22822.25, 37.73, 0.0, 86.63, 39.86, 40.8}, {0.0096, 0.0054, 36650.0, 22822.25, 37.73, 0.0, 86.63, 39.86, 40.8}, {0.2133, 0.0933, 39366.6667, 14200.0, 63.93, 0.0, 86.63, 39.86, 40.8}, {1.8297, 1.6733, 51766.6667, 27166.6667, 47.52, 0.0, 86.63, 39.86, 40.8}, {2.4588, 2.3029, 49894.1176, 32576.4706, 34.71, 0.0, 86.63, 39.86, 40.8}, {2.6826, 2.4302, 40495.2381, 17510.0952, 56.76, 0.0, 86.63, 39.86, 40.8}, {0.8111, 0.9328, 50227.7778, 33872.2222, 32.56, 0.0, 86.63, 39.86, 40.8}, {1.2672, 0.793, 39138.0952, 18714.8571, 52.18, 0.0, 86.63, 39.86, 40.8}, {0.75, 0.6433, 179966.6667, 120933.3333, 32.8, 0.0, 86.63, 39.86, 40.8}, {3.17, 0.89, 82950.0, 60733.3333, 26.78, 0.0, 86.63, 39.86, 40.8}, {0.0, 0.0, 14775.0, 9775.0, 33.84, 0.0, 86.63, 39.86, 40.8}, {0.0, 0.0, 70430.0, 47830.0, 32.09, 0.0, 86.63, 39.86, 40.8}, {0.1307, 0.5697, 78360.0, 46280.0, 40.94, 0.0, 86.63, 39.86, 40.8}, {0.1216, 0.2685, 19303.8462, 13415.8462, 30.5, 0.0, 86.63, 39.86, 40.8}, {0.0, 0.0, 23100.0, 13400.0, 41.99, 0.0, 86.63, 39.86, 40.8}, {0.09, 0.145, 11750.0, 7600.0, 35.32, 0.0, 86.63, 39.86, 40.8}, {0.3282, 0.4934, 52695.3488, 31756.093, 39.74, 0.0, 86.63, 39.86, 40.8}, {119.1757, 75.6467, 139933.3333, 52433.3333, 62.53, 0.0, 86.63, 39.86, 40.8}, {0.0001, 0.0001, 17800.0, 11950.0, 32.87, 0.0, 86.63, 39.86, 40.8}, {0.05, 0.05, 17800.0, 11950.0, 32.87, 0.0, 86.63, 39.86, 40.8}, {192.72, 97.485, 11750.0, 7600.0, 35.32, 0.0, 86.63, 39.86, 40.8}, {95.3832, 91.0886, 43864.8649, 24724.6486, 43.63, 0.0, 86.63, 39.86, 40.8}, {84.4325, 67.6596, 51768.1818, 31188.9091, 39.75, 0.0, 86.63, 39.86, 40.8}, {20.87, 27.48, 18800.0, 18800.0, 0.0, 0.0, 86.63, 39.86, 40.8}, {75.7219, 84.4188, 27558.3333, 17622.5556, 36.05, 0.0, 86.63, 39.86, 40.8}, {2.332, 2.386, 99540.0, 72880.0, 26.78, 0.0, 86.63, 39.86, 40.8}, {0.0, 0.0, 438600.0, 325300.0, 25.83, 0.0, 86.63, 39.86, 40.8}, {0.0992, 0.0313, 53276.9231, 31833.641, 40.25, 0.0, 86.63, 39.86, 40.8}, {0.212, 0.0726, 53948.7805, 32232.0, 40.25, 0.0, 86.63, 39.86, 40.8}}

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'INPUT DETENTION BASIN ARRAY AND HASH

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'Column Reference Info

Public columnDetentionBasin() As String = {"Conc_In", "Conc_Out", "Flow_In", "Flow_Out", "Vol_Red", "
Min_Vol_Red", "Max_Vol_Red", "Med_Vol_Red", "Ave_Vol_Red"}
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'Row Reference Info

Public rowDetentionBasin() As String = {"Alkalinity, as Cabonate Total", "Ammonia Nitrogen, Total",
"Ammonia, Total", "Arsenic, Dissolved", "Arsenic, Total", "Biochemical Oxygen Demand-5", "Cadmium,
Dissolved", "Cadmium, Total", "Cadmium, Total Recoverable in Water", "Carbon, Dissolved Organic",
"Carbon, Total Dissolved Organic", "Carbon, Total Organic", "Chemical Oxygen Demand", "Chloride, Total",
"Chromium, Dissolved", "Chromium, Total", "Copper, Dissolved", "Copper, Total", "Di(N)Butyl Phthalate",
"Fecal Coliforms", "Fluoride, Total", "Hardness (Ca-Mg), Total", "Iron, Total", "Lead, Dissolved", "Lead,
Total", "Mercury, Total", "Nickel, Dissolved", "Nickel, Total", "Nitrogen, Ammonia Dissolved", "Nitrogen,
Dissolved Kjeldahl", "Nitrogen, Dissolved Nitrate", "Nitrogen, Total", "Nitrogen, Total Dissolved Kjeldahl",
"Nitrogen, Total Kjeldahl", "Nitrogen, Total Nitrate", "Nitrogen, Total Nitrate", "Nitrogen, Total Nitrate
and Nitrite", "Nitrogen, Total Nitrite", "Nitrogen, Total Organic", "Nitrogen, Total Organic Kjeldahl", "Oil
and Grease", "pH", "Phosphorus, Dissolved", "Phosphorus, Dissolved Ortho Phosphate", "Phosphorus,
Ortho Phosphate", "Phosphorus, Total", "Phosphorus, Total Suspended", "Residue, Total", "Silver, Total",
"Solids, Total", "Solids, Total Dissolved", "Solids, Total Suspended", "Specific Conductance", "Turbidity",
"Zinc, Dissolved", "Zinc, Total", "Escherichia Coli"}

'Table Info

Public DetentionBasin(,) As String = {{98.0, 0.0, 1299800.0, 1299800.0, 0.0, 0.0, 87.14, 21.9, 24.63},
{0.162, 0.0475, 835000.0, 728000.0, 12.81, 0.0, 87.14, 21.9, 24.63}, {0.187, 0.183, 551100.0, 432300.0,
21.56, 0.0, 87.14, 21.9, 24.63}, {0.0009, 0.1809, 345971.4286, 251228.5714, 27.38, 0.0, 87.14, 21.9, 24.63},
{0.0019, 0.2992, 465200.0, 382300.0, 17.82, 0.0, 87.14, 21.9, 24.63}, {6.56, 6.1678, 588775.0, 497025.0,
15.58, 0.0, 87.14, 21.9, 24.63}, {0.0002, 0.0218, 311783.3333, 221050.0, 29.1, 0.0, 87.14, 21.9, 24.63},
{0.0016, 0.0523, 1531877.7778, 1015944.4444, 33.68, 0.0, 87.14, 21.9, 24.63}, {0.279, 0.2, 146500.0,
146500.0, 0.0, 0.0, 87.14, 21.9, 24.63}, {5.015, 5.655, 770600.0, 757050.0, 1.76, 0.0, 87.14, 21.9, 24.63},
{14.982, 16.3183, 314775.0, 238950.0, 24.09, 0.0, 87.14, 21.9, 24.63}, {13.9015, 13.3664, 1678650.0,
1129250.0, 32.73, 0.0, 87.14, 21.9, 24.63}, {19.074, 16.7457, 3533400.0, 719816.6667, 79.63, 0.0, 87.14,
21.9, 24.63}, {103.76, 0.0, 1299800.0, 1299800.0, 0.0, 0.0, 87.14, 21.9, 24.63}, {0.0019, 0.4373, 346880.0,
267740.0, 22.81, 0.0, 87.14, 21.9, 24.63}, {0.0223, "NA", 1729225.0, 1164975.0, 32.63, 0.0, 87.14, 21.9,
24.63}, {0.009, 1.3957, 345971.4286, 251228.5714, 27.38, 0.0, 87.14, 21.9, 24.63}, {0.0268, 2.3239,
2771508.3333, 1001575.0, 63.86, 0.0, 87.14, 21.9, 24.63}, {0.0002, 0.0002, 146500.0, 146500.0, 0.0, 0.0,
87.14, 21.9, 24.63}, {3326.25, 13062.5, 219950.0, 173500.0, 21.12, 0.0, 87.14, 21.9, 24.63}, {0.0, 0.0,
1299800.0, 1299800.0, 0.0, 0.0, 87.14, 21.9, 24.63}, {41.1506, 45.9124, 345971.4286, 251228.5714, 27.38,
0.0, 87.14, 21.9, 24.63}, {0.8011, 0.0, 1299800.0, 1299800.0, 0.0, 0.0, 87.14, 21.9, 24.63}, {0.0031, 0.2805,
345971.4286, 251228.5714, 27.38, 0.0, 87.14, 21.9, 24.63}, {0.0478, 2.4191, 2771508.3333, 1001575.0,
63.86, 0.0, 87.14, 21.9, 24.63}, {0.0, 0.0, 1299800.0, 1299800.0, 0.0, 0.0, 87.14, 21.9, 24.63}, {0.0026,
0.2823, 341933.3333, 267066.6667, 21.9, 0.0, 87.14, 21.9, 24.63}, {0.0097, 0.4734, 1729225.0, 1164975.0,
32.63, 0.0, 87.14, 21.9, 24.63}, {0.083, 0.11, 146500.0, 146500.0, 0.0, 0.0, 87.14, 21.9, 24.63}, {0.0, 0.0,
1299800.0, 1299800.0, 0.0, 0.0, 87.14, 21.9, 24.63}, {0.271, 0.276, 146500.0, 146500.0, 0.0, 0.0, 87.14,
21.9, 24.63}, {0.688, 0.4445, 14628000.0, 4357100.0, 70.21, 0.0, 87.14, 21.9, 24.63}, {1.35, 0.0, 1299800.0,
1299800.0, 0.0, 0.0, 87.14, 21.9, 24.63}, {1.6306, 1.583, 319475.0, 232300.0, 27.29, 0.0, 87.14, 21.9,
24.63}, {0.0, 0.59, 241400.0, 214300.0, 11.23, 0.0, 87.14, 21.9, 24.63}, {0.8411, 0.721, 1808971.4286,
1137414.2857, 37.12, 0.0, 87.14, 21.9, 24.63}, {0.992, 0.597, 134000.0, 99800.0, 25.52, 0.0, 87.14, 21.9,
24.63}, {0.58, 0.0, 1299800.0, 1299800.0, 0.0, 0.0, 87.14, 21.9, 24.63}, {0.86, 0.38, 10482400.0, 6417600.0,
38.78, 0.0, 87.14, 21.9, 24.63}, {0.472, 0.51, 146500.0, 146500.0, 0.0, 0.0, 87.14, 21.9, 24.63}, {1.9607,
0.7777, 6739966.6667, 1247633.3333, 81.49, 0.0, 87.14, 21.9, 24.63}, {0.0, 0.0, 770600.0, 757050.0, 1.76,
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0.0, 87.14, 21.9, 24.63}, {0.108, 0.1096, 419185.7143, 367100.0, 12.43, 0.0, 87.14, 21.9, 24.63}, {0.157, 0.151, 10482400.0, 6417600.0, 38.78, 0.0, 87.14, 21.9, 24.63}, {0.0383, 0.03, 9515975.0, 1223975.0, 87.14, 0.0, 87.14, 21.9, 24.63}, {0.3167, 0.2574, 1152684.6154, 774338.4615, 32.82, 0.0, 87.14, 21.9, 24.63}, {0.251, 0.145, 10482400.0, 6417600.0, 38.78, 0.0, 87.14, 21.9, 24.63}, {441.57, 263.3335, 925450.0, 866050.0, 6.42, 0.0, 87.14, 21.9, 24.63}, {0.0001, 0.0001, 370200.0, 156200.0, 57.81, 0.0, 87.14, 21.9, 24.63}, {0.0, 0.0, 1299800.0, 1299800.0, 0.0, 0.0, 87.14, 21.9, 24.63}, {63.8038, 59.4761, 413062.5, 340737.5, 17.51, 0.0, 87.14, 21.9, 24.63}, {96.153, 65.5115, 2411321.4286, 883071.4286, 63.38, 0.0, 87.14, 21.9, 24.63}, {84.5423, 127.632, 466716.6667, 411650.0, 11.8, 0.0, 87.14, 21.9, 24.63}, {0.0, 0.0, 1299800.0, 1299800.0, 0.0, 0.0, 87.14, 21.9, 24.63}, {0.057, 3.5699, 345971.4286, 251228.5714, 27.38, 0.0, 87.14, 21.9, 24.63}, {0.1785, 11.3999, 2411321.4286, 883071.4286, 63.38, 0.0, 87.14, 21.9, 24.63}, {15652.5, 455, 3590550, 30280000, 15.67, 0.0, 87.14, 21.9, 24.63}}

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'INPUT HYDRODYNAMIC DEVICE ARRAY AND HASH

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'Column Reference Info

Public columnHydrodynamicDevice() As String = {"Conc_In", "Conc_Out", "Flow_In", "Flow_Out",
"Vol_Red", " Min_Vol_Red", "Max_Vol_Red", "Med_Vol_Red", "Ave_Vol_Red"}

'Row Reference Info

Public rowHydrodynamicDevice() As String = {"1,2,5,6-Dibenzanthracene, Total", "1,2,5,6-
Dibenzanthracene, Total", "Acenaphthene, Dissolved", "Acenaphthene, Total", "Acenaphthylene,
Suspended", "Acenaphthylene, Total", "Alkalinity, Total", "Ammonia Nitrogen, Total", "Ammonia, Total
Nitrogen", "Anthracene, Suspended", "Anthracene, Total", "Arsenic, Dissolved", "Arsenic, Total",
"Benzo(A)anthracene1,2-Benzanthracene, Total", "Benzo(A)Pyrene, Suspended", "Benzo(A)Pyrene, Total",
"Benzo(B)Fluoranthene", "Benzo(B)Fluoranthene, Suspended", "Benzo(B)Fluorine",
"Benzo(G,H,I)perylene1,12-Benzoperylene, Total", "Benzo(K)Fluoranthene, Suspended",
"Benzo(K)Fluoranthene, Total", "Biochemical Oxygen Demand-5", "Cadmium, Dissolved", "Cadmium,
Total", "Calcium, Dissolved", "Calcium, Total", "Carbon, Total Dissolved Organic", "Carbon, Total Organic",
"Chemical Oxygen Demand", "Chloride, Dissolved", "Chromium, Dissolved", "Chromium, Total", "Chrysene,
Suspended", "Chrysene, Total", "Copper, Dissolved", "Copper, Total", "Dibenzo(A,H)Anthracene,
Dissolved", "Fecal Coliforms", "Fluoranthene, Suspended", "Fluoranthene, Total", "Fluorene, Suspended",
"Fluorene, Total", "Fluorine, Total", "Hardness (Ca-Mg), Total", "Hardness, Noncarbonate", "Hydrocarbon,
Total", "Hydrocarbon, Total Petroleum", "Hydrocarbon, Total Polycyclic Aromatic", "Indeno (1,2,3-Cd)
Pyrene, Suspended", "Indeno (1,2,3-Cd) Pyrene, Total", "Indeno (1,2,3-Cd) Pyrene, Total", "Lead,
Dissolved", "Lead, Total", "Magnesium, Dissolved", "Magnesium, Total", "Mercury, Total", "Naphthalene,
Dissolved", "Naphthalene, Suspended", "Naphthalene, Total", "Naphthalene, Total", "Nickel, Dissolved",
"Nickel, Total", "Nitrogen, Ammonia", "Nitrogen, Total", "Nitrogen, Total Kjeldahl", "Nitrogen, Total
Nitrate", "Nitrogen, Total Nitrate and Nitrite", "Oil and Grease", "Phenanthrene, Dissolved",
"Phenanthrene, Suspended", "Phenanthrene, Total", "Phosphorus, Dissolved", "Phosphorus, Total",
"Pyrene, Suspended", "Pyrene, Total", "Selenium, Total", "Silver, Total", "Solids, Total Dissolved", "Solids,
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Total Suspended", "Solids, Volatile Dissolved", "Specific Conductance", "Sulfate, Dissolved", "Zinc, Dissolved", "Zinc, Total"}

'Table Info

Public HydrodynamicDevice(,) As String = {{0.0003, 0.0002, 209700.0, 209700.0, 0.0, 0.0, 80.2, 0.0, 8.58}, {0.0001, 0.0, 58200.0, 58200.0, 0.0, 0.0, 80.2, 0.0, 8.58}, {0.0001, 0.0001, 58200.0, 58200.0, 0.0, 0.0, 80.2, 0.0, 8.58}, {0.0006, 0.0006, 108700.0, 108700.0, 0.0, 0.0, 80.2, 0.0, 8.58}, {0.0, 0.0, 4500.0, 4500.0, 0.0, 0.0, 80.2, 0.0, 8.58}, {0.0007, 0.0007, 107100.0, 107100.0, 0.0, 0.0, 80.2, 0.0, 8.58}, {52.2715, 69.4755, 58200.0, 58200.0, 0.0, 0.0, 80.2, 0.0, 8.58}, {0.601, 0.525, 111900.0, 111900.0, 0.0, 0.0, 80.2, 0.0, 8.58}, {0.086, 0.054, 4500.0, 4500.0, 0.0, 0.0, 80.2, 0.0, 8.58}, {0.0, 0.0, 4500.0, 4500.0, 0.0, 0.0, 80.2, 0.0, 8.58}, {0.0003, 0.0002, 108700.0, 108700.0, 0.0, 0.0, 80.2, 0.0, 8.58}, {0.0008, 0.0005, 138050.0, 138050.0, 0.0, 0.0, 80.2, 0.0, 8.58}, {0.0016, 0.0013, 161933.3333, 161933.3333, 0.0, 0.0, 80.2, 0.0, 8.58}, {0.0005, 0.0002, 108700.0, 108700.0, 0.0, 0.0, 80.2, 0.0, 8.58}, {0.0001, 0.0, 4500.0, 4500.0, 0.0, 0.0, 80.2, 0.0, 8.58}, {0.0006, 0.0003, 108700.0, 108700.0, 0.0, 0.0, 80.2, 0.0, 8.58}, {0.0009, 0.0003, 58200.0, 58200.0, 0.0, 0.0, 80.2, 0.0, 8.58}, {0.0001, 0.0, 4500.0, 4500.0, 0.0, 0.0, 80.2, 0.0, 8.58}, {0.0006, 0.001, 209700.0, 209700.0, 0.0, 0.0, 80.2, 0.0, 8.58}, {0.0006, 0.0003, 108700.0, 108700.0, 0.0, 0.0, 80.2, 0.0, 8.58}, {0.0001, 0.0, 4500.0, 4500.0, 0.0, 0.0, 80.2, 0.0, 8.58}, {0.0004, 0.0002, 108700.0, 108700.0, 0.0, 0.0, 80.2, 0.0, 8.58}, {16.7072, 11.158, 36962466.6667, 7370083.3333, 80.06, 0.0, 80.2, 0.0, 8.58}, {0.0005, 0.0006, 149700.0, 78500.0, 47.56, 0.0, 80.2, 0.0, 8.58}, {0.0017, 0.0014, 159700.0, 100366.6667, 37.15, 0.0, 80.2, 0.0, 8.58}, {0.019, 0.0339, 4500.0, 4500.0, 0.0, 0.0, 80.2, 0.0, 8.58}, {0.0643, 0.0341, 4500.0, 4500.0, 0.0, 0.0, 80.2, 0.0, 8.58}, {21.626, 19.5488, 98125.0, 98125.0, 0.0, 0.0, 80.2, 0.0, 8.58}, {19.9774, 16.8989, 149357.1429, 98228.5714, 34.23, 0.0, 80.2, 0.0, 8.58}, {82.1489, 61.4014, 27621737.5, 5469425.0, 80.2, 0.0, 80.2, 0.0, 8.58}, {1742.8035, 1865.2325, 58200.0, 58200.0, 0.0, 0.0, 80.2, 0.0, 8.58}, {0.0014, 0.0015, 93533.3333, 93533.3333, 0.0, 0.0, 80.2, 0.0, 8.58}, {0.0047, 0.0035, 122575.0, 122575.0, 0.0, 0.0, 80.2, 0.0, 8.58}, {0.0001, 0.0, 4500.0, 4500.0, 0.0, 0.0, 80.2, 0.0, 8.58}, {0.0008, 0.0004, 108700.0, 108700.0, 0.0, 0.0, 80.2, 0.0, 8.58}, {0.0175, 0.0127, 139300.0, 79650.0, 42.82, 0.0, 80.2, 0.0, 8.58}, {0.0215, 0.0137, 138800.0, 87485.7143, 36.97, 0.0, 80.2, 0.0, 8.58}, {0.0, 0.0, 4500.0, 4500.0, 0.0, 0.0, 80.2, 0.0, 8.58}, {9549.9335, 18959.4875, 138050.0, 138050.0, 0.0, 0.0, 80.2, 0.0, 8.58}, {0.0002, 0.0, 4500.0, 4500.0, 0.0, 0.0, 80.2, 0.0, 8.58}, {0.0029, 0.0015, 108700.0, 108700.0, 0.0, 0.0, 80.2, 0.0, 8.58}, {0.0002, 0.0002, 58200.0, 58200.0, 0.0, 0.0, 80.2, 0.0, 8.58}, {0.001, 0.0007, 58200.0, 58200.0, 0.0, 0.0, 80.2, 0.0, 8.58}, {0.0002, 0.0002, 209700.0, 209700.0, 0.0, 0.0, 80.2, 0.0, 8.58}, {116.6282, 63.0482, 129833.3333, 70500.0, 45.7, 0.0, 80.2, 0.0, 8.58}, {50.8, 102.267, 4500.0, 4500.0, 0.0, 0.0, 80.2, 0.0, 8.58}, {0.46, 0.46, 209700.0, 209700.0, 0.0, 0.0, 80.2, 0.0, 8.58}, {1.155, 0.35, 87300.0, 85400.0, 2.18, 0.0, 80.2, 0.0, 8.58}, {0.0177, 0.0111, 111900.0, 111900.0, 0.0, 0.0, 80.2, 0.0, 8.58}, {0.0001, 0.0, 4500.0, 4500.0, 0.0, 0.0, 80.2, 0.0, 8.58}, {0.0007, 0.0006, 209700.0, 209700.0, 0.0, 0.0, 80.2, 0.0, 8.58}, {0.0006, 0.0002, 58200.0, 58200.0, 0.0, 0.0, 80.2, 0.0, 8.58}, {0.0039, 0.0027, 139300.0, 79650.0, 42.82, 0.0, 80.2, 0.0, 8.58}, {0.0231, 0.0107, 159700.0, 100366.6667, 37.15, 0.0, 80.2, 0.0, 8.58}, {0.782, 3.7803, 4500.0, 4500.0, 0.0, 0.0, 80.2, 0.0, 8.58}, {0.0222, 0.0043, 4500.0, 4500.0, 0.0, 0.0, 80.2, 0.0, 8.58}, {0.0, 0.0, 209700.0, 209700.0, 0.0, 0.0, 80.2, 0.0, 8.58}, {0.0005, 0.0007, 111900.0, 111900.0, 0.0, 0.0, 80.2, 0.0, 8.58}, {0.0, 0.0, 4500.0, 4500.0, 0.0, 0.0, 80.2, 0.0, 8.58}, {0.0003, 0.0003, 58200.0, 58200.0, 0.0, 0.0, 80.2, 0.0, 8.58}, {0.001, 0.0014, 209700.0, 209700.0, 0.0, 0.0, 80.2, 0.0, 8.58}, {0.0034, 0.0036, 138050.0, 138050.0, 0.0, 0.0, 80.2, 0.0, 8.58}, {0.0075, 0.0072, 161933.3333, 161933.3333, 0.0, 0.0, 80.2, 0.0, 8.58}, {1.68, 0.5, 209700.0, 209700.0, 0.0, 0.0, 80.2, 0.0, 8.58}, {2.5, 2.8425, 365000.0, 363400.0, 0.44, 0.0, 80.2, 0.0, 8.58}, {8.1188, 2.6498, 143275.0, 142800.0, 0.33, 0.0, 80.2, 0.0, 8.58}, {1.3935, 1.127, 138050.0, 138050.0, 0.0, 0.0, 80.2, 0.0, 8.58}, {0.792, 0.4, 108700.0, 108700.0, 0.0, 0.0, 80.2, 0.0, 8.58}, {19.443, 6.6706, 73300.0, 68880.0, 6.03, 0.0, 80.2, 0.0, 8.58},

{0.0006, 0.0006, 111900.0, 111900.0, 0.0, 0.0, 80.2, 0.0, 8.58}, {0.0001, 0.0, 4500.0, 4500.0, 0.0, 0.0, 80.2, 0.0, 8.58}, {0.0025, 0.0015, 108700.0, 108700.0, 0.0, 0.0, 80.2, 0.0, 8.58}, {0.088, 0.0708, 98125.0, 98125.0, 0.0, 0.0, 80.2, 0.0, 8.58}, {12.2361, 12.5287, 14800280.0, 2985586.6667, 79.83, 0.0, 80.2, 0.0, 8.58}, {0.0001, 0.0, 4500.0, 4500.0, 0.0, 0.0, 80.2, 0.0, 8.58}, {0.002, 0.001, 108700.0, 108700.0, 0.0, 0.0, 80.2, 0.0, 8.58}, {0.001, 0.001, 209700.0, 209700.0, 0.0, 0.0, 80.2, 0.0, 8.58}, {0.0017, 0.0014, 209700.0, 209700.0, 0.0, 0.0, 80.2, 0.0, 8.58}, {3541.2735, 4201.347, 98125.0, 98125.0, 0.0, 0.0, 80.2, 0.0, 8.58}, {218.3866, 110.2021, 13900518.75, 2803375.0, 79.83, 0.0, 80.2, 0.0, 8.58}, {59.267, 3.757, 4500.0, 4500.0, 0.0, 0.0, 80.2, 0.0, 8.58}, {857.917, 490.664, 77775.0, 77775.0, 0.0, 0.0, 80.2, 0.0, 8.58}, {24.133, 29.333, 4500.0, 4500.0, 0.0, 0.0, 80.2, 0.0, 8.58}, {0.0931, 0.0711, 139300.0, 79650.0, 42.82, 0.0, 80.2, 0.0, 8.58}, {19.6102, 15.0739, 83753.8462, 56123.0769, 32.99, 0.0, 80.2, 0.0, 8.58}}

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'INPUT INFILTRATION BASIN ARRAY AND HASH

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'Column Reference Info

Public columnInfiltrationBasin() As String = {"Conc_In", "Conc_Out", "Flow_In", "Flow_Out", "Vol_Red",
" Min_Vol_Red", "Max_Vol_Red", "Med_Vol_Red", "Ave_Vol_Red"}

'Row Reference Info

Public rowInfiltrationBasin() As String = {"Chloride, Dissolved", "Chromium, Dissolved", "Copper,
Dissolved", "Lead, Dissolved", "Nitrogen, Total", "Nitrogen, Total Nitrate", "Nitrogen, Total Nitrite",
"Phosphorus, Dissolved Organic", "Phosphorus, Total", "Solids, Total Dissolved", "Solids, Total Suspended",
"Specific Conductance", "Temperature, Water", "Zinc, Dissolved"}

'Table Info

Public InfiltrationBasin(,) As String = {{"NA", 0.0, 73100.0, 73100.0, 0.0, 0.0, 0.0, 0.0, 0.0}, {"NA", 0.0,
73100.0, 73100.0, 0.0, 0.0, 0.0, 0.0, 0.0}, {"NA", 0.0, 73100.0, 73100.0, 0.0, 0.0, 0.0, 0.0, 0.0}, {"NA", 0.0,
73100.0, 73100.0, 0.0, 0.0, 0.0, 0.0, 0.0}, {"NA", 0.0, 73100.0, 73100.0, 0.0, 0.0, 0.0, 0.0, 0.0}, {"NA", 0.0,
73100.0, 73100.0, 0.0, 0.0, 0.0, 0.0, 0.0}, {"NA", 0.0, 73100.0, 73100.0, 0.0, 0.0, 0.0, 0.0, 0.0}, {"NA", 0.0,
73100.0, 73100.0, 0.0, 0.0, 0.0, 0.0, 0.0}, {"NA", 0.0, 73100.0, 73100.0, 0.0, 0.0, 0.0, 0.0, 0.0}, {"NA", 0.0,
73100.0, 73100.0, 0.0, 0.0, 0.0, 0.0, 0.0}, {"NA", 0.0, 73100.0, 73100.0, 0.0, 0.0, 0.0, 0.0, 0.0}, {"NA", 0.0,
73100.0, 73100.0, 0.0, 0.0, 0.0, 0.0, 0.0}, {"NA", 0.0, 73100.0, 73100.0, 0.0, 0.0, 0.0, 0.0, 0.0}, {"NA", 0.0,
73100.0, 73100.0, 0.0, 0.0, 0.0, 0.0, 0.0}}

'==========================================

'INPUT MEDIA FILTER ARRAY AND HASH

'==========================================
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'Column Reference Info

Public columnMediaFilter() As String = {"Conc_In", "Conc_Out", "Flow_In", "Flow_Out", "Vol_Red", "
Min_Vol_Red", "Max_Vol_Red", "Med_Vol_Red", "Ave_Vol_Red"}

'Row Reference Info

Public rowMediaFilter() As String = {"Ammonia, Total", "Arsenic, Dissolved", "Arsenic, Total", "Cadmium,
Dissolved", "Cadmium, Total", "Carbon, Dissolved Organic", "Carbon, Total Dissolved Organic", "Carbon,
Total Organic", "Chemical Oxygen Demand", "Chlorpyrifos", "Chlorpyrifos, Total Recoverable", "Chromium,
Dissolved", "Chromium, Total", "Copper, Dissolved", "Copper, Total", "Diazinon", "Fecal Coliforms",
"Hardness (Ca-Mg), Total", "Hydrocarbon, Petroleum", "Hydrocarbon, Total Recoverable Petroleum",
"Iron, Total", "Lead, Dissolved", "Lead, Total", "Nickel, Dissolved", "Nickel, Total", "Nitrogen, Ammonia",
"Nitrogen, Total Kjeldahl", "Nitrogen, Total Kjeldahl", "Nitrogen, Total Nitrate", "Nitrogen, Total Nitrate",
"Nitrogen, Unionized", "Oil and Grease", "Oxygen, Dissolved", "pH", "Phosphorus, Dissolved",
"Phosphorus, Ortho Phosphate", "Phosphorus, Total", "Solids, Total Dissolved", "Solids, Total Suspended",
"Solids, Total Volatile", "Specific Conductance", "Zinc, Dissolved", "Zinc, Total"}

'Table Info

Public MediaFilter(,) As String = {{1.0328, 0.4576, 140955.5556, 140955.5556, 0.0, 0.0, 0.0, 0.0, 0.0},
{0.0065, 0.0065, 140955.5556, 140955.5556, 0.0, 0.0, 0.0, 0.0, 0.0}, {0.0092, 0.008, 140955.5556,
140955.5556, 0.0, 0.0, 0.0, 0.0, 0.0}, {0.0002, 0.0002, 140955.5556, 140955.5556, 0.0, 0.0, 0.0, 0.0, 0.0},
{0.0007, 0.0005, 115327.2727, 115327.2727, 0.0, 0.0, 0.0, 0.0, 0.0}, {20.445, 19.13, 120450.0, 120450.0,
0.0, 0.0, 0.0, 0.0, 0.0}, {15.6466, 17.8993, 146814.2857, 146814.2857, 0.0, 0.0, 0.0, 0.0, 0.0}, {17.7567,
19.2775, 115327.2727, 115327.2727, 0.0, 0.0, 0.0, 0.0, 0.0}, {65.311, 21.55, 62475.0, 62475.0, 0.0, 0.0, 0.0,
0.0, 0.0}, {0.0, "NA", 189600.0, 189600.0, 0.0, 0.0, 0.0, 0.0, 0.0}, {0.0, "NA", 60300.0, 60300.0, 0.0, 0.0, 0.0,
0.0, 0.0}, {0.0013, 0.0009, 140955.5556, 140955.5556, 0.0, 0.0, 0.0, 0.0, 0.0}, {0.0034, 0.0019,
115327.2727, 115327.2727, 0.0, 0.0, 0.0, 0.0, 0.0}, {0.011, 0.0087, 136318.1818, 136318.1818, 0.0, 0.0,
0.0, 0.0, 0.0}, {0.0312, 0.0128, 107330.7692, 107330.7692, 0.0, 0.0, 0.0, 0.0, 0.0}, {0.0003, "NA", 124950.0,
124950.0, 0.0, 0.0, 0.0, 0.0, 0.0}, {3198.9703, 23988.9898, 105960.0, 105960.0, 0.0, 0.0, 0.0, 0.0, 0.0},
{26.8923, 36.4141, 139110.0, 139110.0, 0.0, 0.0, 0.0, 0.0, 0.0}, {2.5, "NA", 189600.0, 189600.0, 0.0, 0.0,
0.0, 0.0, 0.0}, {2.5, "NA", 60300.0, 60300.0, 0.0, 0.0, 0.0, 0.0, 0.0}, {1.4494, 1.1058, 0.0, 0.0, "NA", 0.0, 0.0,
0.0, 0.0}, {0.002, 0.0011, 140955.5556, 140955.5556, 0.0, 0.0, 0.0, 0.0, 0.0}, {0.0178, 0.0073, 106246.1538,
106246.1538, 0.0, 0.0, 0.0, 0.0, 0.0}, {0.0034, 0.0035, 140955.5556, 140955.5556, 0.0, 0.0, 0.0, 0.0, 0.0},
{0.0059, 0.0042, 115327.2727, 115327.2727, 0.0, 0.0, 0.0, 0.0, 0.0}, {1.17, 1.97, 51300.0, 51300.0, 0.0, 0.0,
0.0, 0.0, 0.0}, {3.875, 2.55, 120450.0, 120450.0, 0.0, 0.0, 0.0, 0.0, 0.0}, {1.908, 1.4589, 146814.2857,
146814.2857, 0.0, 0.0, 0.0, 0.0, 0.0}, {0.865, 1.215, 120450.0, 120450.0, 0.0, 0.0, 0.0, 0.0, 0.0}, {0.4999,
0.7914, 114188.8889, 114188.8889, 0.0, 0.0, 0.0, 0.0, 0.0}, {0.0, 0.0, 120450.0, 120450.0, 0.0, 0.0, 0.0, 0.0,
0.0}, {5.0, "NA", 124950.0, 124950.0, 0.0, 0.0, 0.0, 0.0, 0.0}, {17.58, 12.51, 4200.0, 4200.0, 0.0, 0.0, 0.0, 0.0,
0.0}, {0.0, 0.0, 120450.0, 120450.0, 0.0, 0.0, 0.0, 0.0, 0.0}, {0.1396, 0.1331, 140955.5556, 140955.5556, 0.0,
0.0, 0.0, 0.0, 0.0}, {0.2495, "NA", 55800.0, 55800.0, 0.0, 0.0, 0.0, 0.0, 0.0}, {0.2324, 0.1501, 92188.8889,
92188.8889, 0.0, 0.0, 0.0, 0.0, 0.0}, {55.3531, 79.591, 140955.5556, 140955.5556, 0.0, 0.0, 0.0, 0.0, 0.0},
{84.7267, 25.5999, 103014.2857, 103014.2857, 0.0, 0.0, 0.0, 0.0, 0.0}, {9.432, 7.2667, 36133.3333,
36133.3333, 0.0, 0.0, 0.0, 0.0, 0.0}, {73.9741, 91.1106, 131462.5, 131462.5, 0.0, 0.0, 0.0, 0.0, 0.0}, {0.115,
0.0457, 136318.1818, 136318.1818, 0.0, 0.0, 0.0, 0.0, 0.0}, {4.0984, 2.7092, 92188.8889, 92188.8889, 0.0,
0.0, 0.0, 0.0, 0.0}}
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'INPUT PERCOLATION TRENCH - WELL ARRAY AND HASH

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'Column Reference Info

Public columnPercolationTrenchWell() As String = {"Conc_In", "Conc_Out", "Flow_In", "Flow_Out",
"Vol_Red", " Min_Vol_Red", "Max_Vol_Red", "Med_Vol_Red", "Ave_Vol_Red"}

'Row Reference Info

Public rowPercolationTrenchWell() As String = {"Cadmium, Dissolved", "Calcium, Dissolved", "Chemical
Oxygen Demand", "Copper, Dissolved", "Iron, Dissolved", "Lead, Dissolved", "Magnesium, Dissolved",
"Manganese, Dissolved", "Nickel, Dissolved", "Solids, Total Suspended", "Solids, Volatile Suspended",
"Zinc, Dissolved"}

'Table Info

Public PercolationTrenchWell(,) As String = {{0.0018, 0.0007, 315.67, 121.67, 61.46, 61.46, 61.46, 61.46,
61.46}, {16.7717, 17.9773, 315.67, 121.67, 61.46, 61.46, 61.46, 61.46, 61.46}, {254.2333, 112.7667, 315.67,
121.67, 61.46, 61.46, 61.46, 61.46, 61.46}, {0.0328, 0.0123, 315.67, 121.67, 61.46, 61.46, 61.46, 61.46,
61.46}, {0.1223, 0.0638, 315.67, 121.67, 61.46, 61.46, 61.46, 61.46, 61.46}, {0.0204, 0.0176, 315.67,
121.67, 61.46, 61.46, 61.46, 61.46, 61.46}, {1.6476, 1.9736, 315.67, 121.67, 61.46, 61.46, 61.46, 61.46,
61.46}, {0.1018, 0.0034, 315.67, 121.67, 61.46, 61.46, 61.46, 61.46, 61.46}, {0.0217, 0.0068, 315.67,
121.67, 61.46, 61.46, 61.46, 61.46, 61.46}, {141.1667, 34.4667, 315.67, 121.67, 61.46, 61.46, 61.46, 61.46,
61.46}, {49.0, 13.4, 315.67, 121.67, 61.46, 61.46, 61.46, 61.46, 61.46}, {0.7084, 0.042, 315.67, 121.67,
61.46, 61.46, 61.46, 61.46, 61.46}}


'==========================================

'INPUT POROUS PAVEMENT ARRAY AND HASH

'==========================================

'Column Reference Info

Public columnPorousPavement() As String = {"Conc_In", "Conc_Out", "Flow_In", "Flow_Out", "Vol_Red",
" Min_Vol_Red", "Max_Vol_Red", "Med_Vol_Red", "Ave_Vol_Red"}

'Row Reference Info

Public rowPorousPavement() As String = {"Cadmium, Total", "Calcium, Total", "Chemical Oxygen
Demand", "Copper, Total", "Hydrocarbon, Total", "Lead, Total", "Nitrogen, Ammonium", "Nitrogen,
Organic", "Nitrogen, Total", "Nitrogen, Total Kjeldahl", "Nitrogen, Total Nitrate", "Nitrogen, Total Nitrate
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and Nitrite", "Phosphate, Total", "Phosphorus, Ortho Phosphate", "Phosphorus, Partical Bound",
"Phosphorus, Total", "Runoff", "Silicon", "Solids, Total Suspended", "Turbidity", "Zinc, Total"}

    'Table Info

    Public PorousPavement(,) As String = {{0.00148, 0.00049, 455.2, 1.74, 99.61775044, 60.39782409, 100,
94.86306695, 91.93043808}, {8.29, 6.91, 19930, 1360, 93.17611641, 60.39782409, 100, 94.86306695,
91.93043808}, {23, 22, 455.2, 1.74, 99.61775044, 60.39782409, 100, 94.86306695, 91.93043808}, {0.015,
0.012333333, 907.7333333, 141.58, 84.40290834, 60.39782409, 100, 94.86306695, 91.93043808}, {0.02,
0.02, 455.2, 1.74, 99.61775044, 60.39782409, 100, 94.86306695, 91.93043808}, {0.012666667,
0.003466667, 907.7333333, 141.58, 84.40290834, 60.39782409, 100, 94.86306695, 91.93043808}, {0.12,
0.07, 17282.66667, 141, 99.18415368, 60.39782409, 100, 94.86306695, 91.93043808}, {0, 0.05, 49580, 0,
100, 60.39782409, 100, 94.86306695, 91.93043808}, {1.306, 2.732, 14822.42, 731.225, 95.06676373,
60.39782409, 100, 94.86306695, 91.93043808}, {3.116666667, 1.088333333, 9407.683333, 453.1875,
95.18279385, 60.39782409, 100, 94.86306695, 91.93043808}, {0.414, 0.926, 1373.22, 543.825,
60.39782409, 60.39782409, 100, 94.86306695, 91.93043808}, {0, 0.17, 49580, 0, 100, 60.39782409, 100,
94.86306695, 91.93043808}, {0.125, 0.094, 0, 0, "NA", 60.39782409, 100, 94.86306695, 91.93043808}, {0,
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    'INPUT RETENTION POND ARRAY AND HASH

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    'Column Reference Info

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    'Row Reference Info

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Total", "2,4-Dichlorophenoxypropionic Acid, Total", "2-Methyl-4-Chlorophenoxyacetic Acid",
"AceNAphthene, Total", "AceNAphthylene, Total", "Aldehyde, Total Endrin", "Aldrin", "Alkalinity,
CarboNAte", "Alkalinity, Fixed Endpoint", "Alkalinity, Total", "Alpha Benzene Hexachloride", "Alpha
Endosulfan, Total", "Aluminum, Total Recoverable in Water", "Ammonia Nitrogen, Total", "Ammonia,
Total", "Anthracene, Total", "Antimony, Total", "Antimony, Total", "Arsenic, Dissolved", "Arsenic, Total",
"Banvel (Dicamba)", "Barium, Total", "Benzo(A)anthracene1,2-Benzanthracene, Total", "Benzo(A)Pyrene,
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Total", "Benzo(B)Fluoranthene", "Benzo(G,H,I)perylene1,12-Benzoperylene, Total", "Benzo(K)Fluoranthene, Total", "Beta Endosulfan, Total", "Biochemical Oxygen Demand-5", "Cadmium, Dissolved", "Cadmium, Total", "Calcium, Total", "Calcium, Total Recoverable in Water", "Carbon, Dissolved Organic", "Carbon, Organic", "Carbon, Total Dissolved Organic", "Carbon, Total Organic", "Chemical Oxygen Demand", "Chlordane", "Chloride, Total", "Chloride, Total", "Chlorpyrifos, Total Recoverable", "Chromium, Dissolved", "Chromium, Total", "Chromium, Total Recoverable in Water", "Chrysene, Total", "Cobalt, Total", "Copper, Dissolved", "Copper, Total", "Dalapon, Total", "Delta Bezene Hexachloride, Total", "Demeton-O, Total", "Demeton-S, Total", "Diazinon", "Dieldrin", "Dinoseb", "Disulfoton", "Endrin", "Epn(C14H14NO4PS)", "Ethion", "Fecal Coliforms", "Fecal Streptococcus", "Fluoranthene, Total", "Fluorene, Total", "Fluoride, Total", "Gamma-Bhc (Lindane)", "Guthion", "Hardness (Ca-Mg), Total", "Heptachlor", "Heptachlor Epoxide", "Hydrocarbon, Total", "Indeno (1,2,3-Cd) Pyrene, Total", "Iron, Dissolved", "Iron, Total", "Lead, Dissolved", "Lead, Total", "Magnesium, Total", "Malathion", "Manganese, Total", "Mercury, Total", "Methoxychlor", "Methyl Parathion", "Methylchlorophenoxypropionic Acid , Total", "Molybdenum, Total", "NAphthalene, Total", "Nickel, Dissolved", "Nickel, Total", "Nitrogen, Ammonia", "Nitrogen, ammonia as N", "Nitrogen, Dissolved Kjeldahl", "Nitrogen, Dissolved Organic", "Nitrogen, Total", "Nitrogen, Total Kjeldahl", "Nitrogen, Total Kjeldahl", "Nitrogen, Total Nitrate", "Nitrogen, Total Nitrate", "Nitrogen, Total Nitrate and Nitrite", "Nitrogen, Total Nitrate and Nitrite", "Nitrogen, Total Nitrite", "Nitrogen, Total Organic", "Oil and Grease", "P,P' DDD", "P,P' DDE", "P,P' DDT", "Parathion", "PCB - 1221", "PCB - 1232", "PCB - 1242", "PCB - 1248", "PCB - 1254", "PCB - 1260", "PCB-1016, Total", "pH", "PheNAnthrene, Total", "Phosphorus, Dissolved", "Phosphorus, Dissolved Organic", "Phosphorus, Dissolved Ortho Phosphate", "Phosphorus, Ortho Phosphate", "Phosphorus, Total", "Phosphorus, Total Suspended", "Potassium, Total", "Pyrene, Total", "Selenium, Total", "Silver, Total", "Silvex", "Sodium, Total", "Solids, Total", "Solids, Total Dissolved", "Solids, Total Suspended", "Solids, Total Volatile", "Specific Conductance", "Sulfate, Total", "Sulfate, Total", "Sulfate, Total Endosulfan", "Sulfide, Total", "Toxaphene", "Turbidity", "Vanadium, Total", "Vanadium, Total", "Zinc, Dissolved", "Zinc, Total", "Escherichia Coli"}

'Table Info

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'INPUT WETLAND BASIN ARRAY AND HASH

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'Column Reference Info

Public columnWetlandBasin() As String = {"Conc_In", "Conc_Out", "Flow_In", "Flow_Out", "Vol_Red", "
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Demand", "Chloride, Total", "Copper, Dissolved", "Copper, Total", "Hardness (Ca-Mg), Total", "Iron, Total",
"Lead, Dissolved", "Lead, Total", "Magnesium, Total", "Manganese, Total", "Nitrogen, Total", "Nitrogen,
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Total Nitrate and Nitrite", "Nitrogen, Total Nitrite", "Nitrogen, Total Organic", "Phosphorus, Dissolved",
"Phosphorus, Dissolved Organic", "Phosphorus, Ortho Phosphate", "Phosphorus, Total", "Phosphorus,
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'Table Info

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6.038199635}, {0.013, 0.007, 651000, 651000, 0, 0, 38.43, 0, 6.038199635}, {0.76425, 0.76325, 1629625,
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```

```
{1.335333333, 0.698333333, 343633.3333, 343633.3333, 0, 0, 38.43, 0, 6.038199635}, {0.18, 0.1, 38699700, 38699700, 0, 0, 38.43, 0, 6.038199635}, {0.918545455, 0.657727273, 885854.5455, 737636.3636, 16.73166126, 0, 38.43, 0, 6.038199635}, {0.048, 0.0435, 2816700, 2056700, 38.43, 0, 38.43, 0, 6.038199635}, {0.177, 0.398, 234100, 234100, 0, 0, 38.43, 0, 6.038199635}, {0.348, 1.035, 234100, 234100, 0, 0, 38.43, 0, 6.038199635}, {89.87853846, 51.01215385, 3768092.308, 3642676.923, 3.328352237, 0, 38.43, 0, 6.038199635}, {5.302, 3.882, 234100, 234100, 0, 0, 38.43, 0, 6.038199635}, {0.029757, 0.016479, 541100, 541100, 0, 0, 38.43, 0, 6.038199635}, {0.166807, 0.103599286, 356200, 356200, 0, 0, 38.43, 0, 6.038199635}, {9848.7, 240.5, 1182200, 727900, 38.43, 0, 38.43, 0, 6.038199635}}


'==========

'INPUT WETLAND CHANNEL ARRAY AND HASH

'==========

'Column Reference Info

Public columnWetlandChannel() As String = {"Conc_In", "Conc_Out", "Flow_In", "Flow_Out", "Vol_Red", " Min_Vol_Red", "Max_Vol_Red", "Med_Vol_Red", "Ave_Vol_Red"}

'Row Reference Info

Public rowWetlandChannel() As String = {"Alkalinity, Carbonate", "Alkalinity, Fixed Endpoint", "Ammonia Nitrogen, Total", "Antimony, Total", "Arsenic, Total", "Beryllium, Total", "Biochemical Oxygen Demand-5", "Cadmium, Total", "Calcium as CaCO3", "Calcium, Total", "Carbon, Organic", "Carbon, Total Organic", "Chemical Oxygen Demand", "Chloride, Total", "Chromium, Dissolved", "Chromium, Total", "Copper, Dissolved", "Copper, Total", "Fecal Coliforms", "Iron, Dissolved", "Iron, Total", "Lead, Dissolved", "Lead, Total", "Magnesium, Total", "Manganese, Dissolved", "Manganese, Total", "Nickel, Dissolved", "Nickel, Total", "Nitrogen, Ammonia", "Nitrogen, Dissolved Organic", "Nitrogen, Total", "Nitrogen, Total Kjeldahl", "Nitrogen, Total Kjeldahl", "Nitrogen, Total Nitrate", "Nitrogen, Total Nitrate", "Nitrogen, Total Nitrate", "Nitrogen, Total Nitrate and Nitrite", "Nitrogen, Total Nitrite", "Nitrogen, Total Organic", "Nitrogen, Unionized", "Oil and Grease", "Oxidation Reduction Potential", "pH", "Phosphorus, Dissolved", "Phosphorus, Dissolved Organic", "Phosphorus, Dissolved Ortho Phosphate", "Phosphorus, Ortho Phosphate", "Phosphorus, Total", "Phosphorus, Total", "Phosphorus, Total Suspended", "Potassium, Total", "Sodium, Total", "Solids, Total Dissolved", "Solids, Total Suspended", "Solids, Total Volatile", "Specific Conductance", "Sulfate, Total", "Sulfate, Total", "Turbidity", "Zinc, Dissolved", "Zinc, Total"}

'Table Info

Public WetlandChannel(,) As String = {{120.72, 112.71, 49105550, 49105550, 0, 0, 11.15976833, 0, 1.745294358}, {131.345, 139.393, 7855800, 7855800, 0, 0, 11.15976833, 0, 1.745294358}, {0.065333333, 0.166333333, 3045866.667, 2993200, 1.729119244, 0, 11.15976833, 0, 1.745294358}, {0.05, 0.05625, 7265100, 7265100, 0, 0, 11.15976833, 0, 1.745294358}, {0, "NA", 7855800, 7855800, 0, 0, 11.15976833, 0, 1.745294358}, {0.01, 0.01, 6674400, 6674400, 0, 0, 11.15976833, 0, 1.745294358}, {0, 4.5, 4923100, 4923100, 0, 0, 11.15976833, 0, 1.745294358}, {0.011071333, 0.17375, 6484433.333, 6484433.333, 0, 0, 11.15976833, 0, 1.745294358}, {19.937, 17.577725, 91536700, 91536700, 0, 0, 11.15976833, 0, 1.745294358}, {34.51, 194.325, 1415800, 1257800, 11.15976833, 0, 11.15976833, 0, 1.745294358}, {10, 9,
```

6674400, 6674400, 0, 0, 11.15976833, 0, 1.745294358}, {16.892, 88.016, 1415800, 1257800, 11.15976833, 0, 11.15976833, 0, 1.745294358}, {63.424, 43.873, 5094400, 5094400, 0, 0, 11.15976833, 0, 1.745294358}, {3.983, 17.77975, 46476250, 46397250, 0.16997929, 0, 11.15976833, 0, 1.745294358}, {0.013, 0.01125, 7265100, 7265100, 0, 0, 11.15976833, 0, 1.745294358}, {0.007952333, 3.340861, 6484433.333, 6484433.333, 0, 0, 11.15976833, 0, 1.745294358}, {0.0059325, 0.0060625, 7265100, 7265100, 0, 0, 11.15976833, 0, 1.745294358}, {0.005675667, 3.341427, 6484433.333, 6484433.333, 0, 0, 11.15976833, 0, 1.745294358}, {0, 540, 4923100, 4923100, 0, 0, 11.15976833, 0, 1.745294358}, {0.028594, 0.033393, 7265100, 7265100, 0, 0, 11.15976833, 0, 1.745294358}, {0.7120315, 0.3535715, 7265100, 7265100, 0, 0, 11.15976833, 0, 1.745294358}, {0.00862975, 0.011274, 4912075, 4855500, 1.151753587, 0, 11.15976833, 0, 1.745294358}, {0.021336, 0.856980167, 4220733.333, 4183016.667, 0.893604587, 0, 11.15976833, 0, 1.745294358}, {2.987, 6.474, 46476250, 46397250, 0.16997929, 0, 11.15976833, 0, 1.745294358}, {0.005, 0.005, 6674400, 6674400, 0, 0, 11.15976833, 0, 1.745294358}, {0.036969667, 153.3610833, 6484433.333, 6484433.333, 0, 0, 11.15976833, 0, 1.745294358}, {0.01, 0.01375, 7265100, 7265100, 0, 0, 11.15976833, 0, 1.745294358}, {0.006666667, 10.00666667, 6484433.333, 6484433.333, 0, 0, 11.15976833, 0, 1.745294358}, {0.013, 0.2225, 48229900, 48229900, 0, 0, 11.15976833, 0, 1.745294358}, {0.527, 2.964, 1415800, 1257800, 11.15976833, 0, 11.15976833, 0, 1.745294358}, {1.44072675, 2.5888, 19691040, 19645780, 0.229850734, 0, 11.15976833, 0, 1.745294358}, {0, 1.8, 4923100, 4923100, 0, 0, 11.15976833, 0, 1.745294358}, {1.6475, 1.2855, 4746375, 4729300, 0.359748229, 0, 11.15976833, 0, 1.745294358}, {0.1625, 0.036, 91536700, 91536700, 0, 0, 11.15976833, 0, 1.745294358}, {0, 1.9, 4923100, 4923100, 0, 0, 11.15976833, 0, 1.745294358}, {0.383333333, 0.619666667, 1957033.333, 1881600, 3.854473608, 0, 11.15976833, 0, 1.745294358}, {1.615, 1.244, 7265100, 7265100, 0, 0, 11.15976833, 0, 1.745294358}, {0.079, 0.096, 7855800, 7855800, 0, 0, 11.15976833, 0, 1.745294358}, {0.527, 3.454, 1415800, 1257800, 11.15976833, 0, 11.15976833, 0, 1.745294358}, {0.044, 0.055, 1047400, 1047400, 0, 0, 11.15976833, 0, 1.745294358}, {0.7, 0.89, 2985250, 2985250, 0, 0, 11.15976833, 0, 1.745294358}, {0.187, 0.112, 91536700, 91536700, 0, 0, 11.15976833, 0, 1.745294358}, {5.059333333, 7.607333333, 34771866.67, 34771866.67, 0, 0, 11.15976833, 0, 1.745294358}, {0.1146, 0.1162, 4080260, 4035000, 1.109243038, 0, 11.15976833, 0, 1.745294358}, {0.104333333, 0.102666667, 4324633.333, 4249200, 1.744271191, 0, 11.15976833, 0, 1.745294358}, {0, 0.08, 4923100, 4923100, 0, 0, 11.15976833, 0, 1.745294358}, {0.093, 0.09875, 7265100, 7265100, 0, 0, 11.15976833, 0, 1.745294358}, {0.1085, 0.165193867, 32502400, 32502400, 0, 0, 11.15976833, 0, 1.745294358}, {0.2614, 0.3455, 4080260, 4035000, 1.109243038, 0, 11.15976833, 0, 1.745294358}, {0.084, 0.734, 1415800, 1257800, 11.15976833, 0, 11.15976833, 0, 1.745294358}, {1.509, 8.827, 1415800, 1257800, 11.15976833, 0, 11.15976833, 0, 1.745294358}, {3.325, 17.771, 1415800, 1257800, 11.15976833, 0, 11.15976833, 0, 1.745294358}, {74.675, 652.9735, 3169450, 3090450, 2.492546025, 0, 11.15976833, 0, 1.745294358}, {68.598, 119.0669286, 15721814.29, 15689485.71, 0.205628758, 0, 11.15976833, 0, 1.745294358}, {16.8316, 12.5998, 20816440, 20771180, 0.217424305, 0, 11.15976833, 0, 1.745294358}, {246.753, 256.6875, 49696250, 49696250, 0, 0, 11.15976833, 0, 1.745294358}, {6.48, 4.88, 91536700, 91536700, 0, 0, 11.15976833, 0, 1.745294358}, {8.284, 31.449, 1415800, 1257800, 11.15976833, 0, 11.15976833, 0, 1.745294358}, {20, 10.5, 91536700, 91536700, 0, 0, 11.15976833, 0, 1.745294358}, {0.031799333, 0.038291, 5315333.333, 5262666.667, 0.990844099, 0, 11.15976833, 0, 1.745294358}, {0.04497925, 5.05930525, 5217275, 5177775, 0.75710021, 0, 11.15976833, 0, 1.745294358}}

```
Private Sub Form1_Load(ByVal sender As System.Object, ByVal e As System.EventArgs) Handles
MyBase.Load
```

```
        'Display welcome info: START
        lbl_welcome.Visible = True
        'Display welcome info: END

        'Start Button Hides: START
        tabctrl_main_process.Visible = False
        'Start Button Hides: END

        'Turn on scrollbars
        txtbox_results.ScrollBars = ScrollBars.Vertical

        'Disable storm events
        txtbox_event.Enabled = False

        'Set storm default values
        txtbox_event.Text = ""

        'Set tabpages disabled
        tabpg_results_event1.Enabled = False

    End Sub

    Private Sub btn_main_start_Click(ByVal sender As System.Object, ByVal e As System.EventArgs)
Handles btn_main_start.MouseHover
```

```
    ToolTip_main_start.SetToolTip(btn_main_start, "Select this button to begin the BMP assisted
selection process.")

  End Sub


  Private Sub btn_main_options_Click(ByVal sender As System.Object, ByVal e As System.EventArgs)
Handles btn_main_Databases.MouseHover

    ToolTip_main_options.SetToolTip(btn_main_Databases, "Select this button to view the databases
behind the results of this program.")

  End Sub


  Private Sub btn_main_help_Click(ByVal sender As System.Object, ByVal e As System.EventArgs) Handles
btn_main_help.MouseHover

    ToolTip_main_help.SetToolTip(btn_main_help, "Select this button to view help files including an
example runthrough, methods behind the program, and how to use the Update Database feature.")

  End Sub


  Private Sub btn_main_about_Click(ByVal sender As System.Object, ByVal e As System.EventArgs)
Handles btn_main_about.MouseHover

    ToolTip_main_help.SetToolTip(btn_main_about, "Select this button to view version, development,
funding, and contact information.")

  End Sub


  Private Sub btn_main_start_Click_1(ByVal sender As System.Object, ByVal e As System.EventArgs)
Handles btn_main_start.Click


    tabctrl_main_process.Visible = True

    tabctrl_main_process.SelectedTab = tabpg_welcome

    'Set tabs enabled

    tabpg_welcome.Enabled = True

    tabpg_data_inquiry.Enabled = False
```

```
tabpg_cont_select.Enabled = False

tabpg_conc_volume_data.Enabled = False


'turn

chkbox_start_concdata.CheckState = CheckState.Unchecked

chkbox_start_concdata_fail.CheckState = CheckState.Unchecked


'Disable storm events

txtbox_event.Enabled = False


'Set storm default values

txtbox_event.Text = ""


'Set tabpages disabled

tabpg_results_event1.Enabled = False



'Clear out selected contaminants

Dim i As Integer

For i = 0 To (chklistbox_cont.Items.Count - 1)

   chklistbox_cont.SetItemCheckState(i, False)

Next

lstbox_cont_selected.Items.Clear()


'Clear out results

txtbox_results.Clear()

txtbox_results.Text = "Results:"
```

```
End Sub

Private Sub chkbox_start_singlecont_CheckedChanged(ByVal sender As System.Object, ByVal e As System.EventArgs) Handles chkbox_start_concdata.CheckedChanged
    If chkbox_start_concdata.CheckState = CheckState.Checked Then
        chkbox_start_concdata_fail.CheckState = CheckState.Unchecked
    End If
End Sub

Private Sub chkbox_start_multcont_CheckedChanged(ByVal sender As System.Object, ByVal e As System.EventArgs) Handles chkbox_start_concdata_fail.CheckedChanged
    If chkbox_start_concdata_fail.CheckState = CheckState.Checked Then
        chkbox_start_concdata.CheckState = CheckState.Unchecked
    End If
End Sub

Private Sub btn_cont_welcome_Click(ByVal sender As System.Object, ByVal e As System.EventArgs) Handles btn_cont_welcome.Click
    tabctrl_main_process.SelectedTab = tabpg_data_inquiry
    tabpg_data_inquiry.Enabled = True
    tabpg_welcome.Enabled = False


End Sub

Private Sub btn_back_welcome_Click(ByVal sender As System.Object, ByVal e As System.EventArgs) Handles btn_back_welcome.Click
```

```
        tabctrl_main_process.Visible = False


    End Sub


    Private Sub btn_continue_selection_Click(ByVal sender As System.Object, ByVal e As System.EventArgs)
Handles btn_cont_inquiry.Click


        If chkbox_start_concdata.Checked = False And chkbox_start_concdata_fail.Checked = False Then

            MessageBox.Show("Please select one of the options above before continuing.")

        End If

        If chkbox_start_concdata.Checked = True Then

            tabctrl_main_process.SelectedTab = tabpg_cont_select

            tabpg_cont_select.Enabled = True

            tabpg_data_inquiry.Enabled = False

        ElseIf chkbox_start_concdata_fail.Checked = True Then

            tabctrl_main_process.SelectedTab = tabpg_cont_select

            tabpg_cont_select.Enabled = True

            tabpg_data_inquiry.Enabled = False

        End If


    End Sub


    Private Sub btn_back_selection_Click(ByVal sender As System.Object, ByVal e As System.EventArgs)
Handles btn_back_inquiry.Click


        tabctrl_main_process.SelectedTab = tabpg_welcome

        tabpg_data_inquiry.Enabled = False

        tabpg_welcome.Enabled = True
```

```
        chkbox_start_concdata.Checked = False

        chkbox_start_concdata_fail.Checked = False


    End Sub


    Private Sub Button1_Click(ByVal sender As System.Object, ByVal e As System.EventArgs) Handles
btn_deselect_all.Click

        Dim i As Integer

        For i = 0 To (chklistbox_cont.Items.Count - 1)

            chklistbox_cont.SetItemCheckState(i, False)

        Next

        lstbox_cont_selected.Items.Clear()


    End Sub


    Private Sub chklistbox_cont_SelectedIndexChanged(ByVal sender As System.Object, ByVal e As
System.EventArgs) Handles chklistbox_cont.SelectedIndexChanged

        Dim i1 As Integer

        Dim checked As String

        checked = String.Empty

        lstbox_cont_selected.Items.Clear()


        For i1 = 0 To (chklistbox_cont.Items.Count - 1)

            If chklistbox_cont.GetItemChecked(i1) = True Then

                checked = chklistbox_cont.Items(i1).ToString

                lstbox_cont_selected.Items.Add(checked)

            End If

        Next
```

```
End Sub

Private Sub Button2_Click(ByVal sender As System.Object, ByVal e As System.EventArgs) Handles
btn_cont_selection.Click
    Dim i As Integer
    For i = 1 To 30
        tabpg_conc_volume_data.Controls.Item("Contaminant" & i).Enabled = False
        tabpg_conc_volume_data.Controls.Item("Contaminant" & i).Text = "Contaminant"
        tabpg_conc_volume_data.Controls.Item("Concentration" & i).Enabled = False
        tabpg_conc_volume_data.Controls.Item("Unit" & i).Text = ("No Unit")
        tabpg_conc_volume_data.Controls.Item("Unit" & i).Enabled = False
    Next
    If chkbox_start_concdata.Checked = True Then
        If chklistbox_cont.CheckedItems.Count.ToString > 30 Then
            MessageBox.Show("Please select thirty or less contaminants.")
        Else : For i = 1 To chklistbox_cont.CheckedItems.Count.ToString
                tabpg_conc_volume_data.Controls.Item("Contaminant" & (i)).Enabled = True
                tabpg_conc_volume_data.Controls.Item("Contaminant" & i).Text =
chklistbox_cont.CheckedItems(i - 1).ToString
                tabpg_conc_volume_data.Controls.Item("Concentration" & (i)).Enabled = True
                tabpg_conc_volume_data.Controls.Item("Unit" & (i)).Enabled = True
                tabpg_conc_volume_data.Controls.Item("Unit" & (i)).Text = "mg/L"
            Next
            btn_cont_data.Enabled = True
            tabpg_conc_volume_data.Enabled = True
            tabctrl_main_process.SelectedTab = tabpg_conc_volume_data
            txtbox_event.Enabled = True
```

```
        End If
      ElseIf chkbox_start_concdata_fail.Checked = True Then
        If chklistbox_cont.CheckedItems.Count.ToString > 30 Then
          MessageBox.Show("Please select thirty or less contaminants.")
        Else : For i = 1 To chklistbox_cont.CheckedItems.Count.ToString
            tabpg_conc_volume_data.Controls.Item("Contaminant" & (i)).Enabled = True
            tabpg_conc_volume_data.Controls.Item("Contaminant" & i).Text =
chklistbox_cont.CheckedItems(i - 1).ToString
            tabpg_conc_volume_data.Controls.Item("Concentration" & (i)).Enabled = False
            tabpg_conc_volume_data.Controls.Item("Unit" & (i)).Enabled = True
            tabpg_conc_volume_data.Controls.Item("Unit" & (i)).Text = "mg/L"
          Next
          btn_cont_data.Enabled = True
          tabpg_conc_volume_data.Enabled = True
          tabctrl_main_process.SelectedTab = tabpg_conc_volume_data
          txtbox_event.Enabled = True
        End If
      End If
    End Sub

    Private Sub btn_back_selection_Click_1(ByVal sender As System.Object, ByVal e As System.EventArgs)
Handles btn_back_selection.Click
      tabctrl_main_process.SelectedTab = tabpg_data_inquiry
      tabpg_data_inquiry.Enabled = True
      tabpg_cont_select.Enabled = False
      Dim i As Integer
      For i = 0 To (chklistbox_cont.Items.Count - 1)
        chklistbox_cont.SetItemCheckState(i, False)
```

```
        Next
        lstbox_cont_selected.Items.Clear()

    End Sub

    Private Sub btn_back_data_Click(ByVal sender As System.Object, ByVal e As System.EventArgs) Handles
btn_back_data.Click
        Dim i As Integer
        For i = 1 To 30
            tabpg_conc_volume_data.Controls.Item("Contaminant" & i).Enabled = False
            tabpg_conc_volume_data.Controls.Item("Contaminant" & i).Text = "Contaminant"
            tabpg_conc_volume_data.Controls.Item("Concentration" & i).Enabled = False
            tabpg_conc_volume_data.Controls.Item("Concentration" & i).Text = ""
            tabpg_conc_volume_data.Controls.Item("Unit" & i).Text = ("No Unit")
            tabpg_conc_volume_data.Controls.Item("Unit" & i).Enabled = False
        Next
        If chkbox_start_concdata.Checked = False Then
            tabctrl_main_process.SelectedTab = tabpg_cont_select
            tabpg_cont_select.Enabled = True
            tabpg_conc_volume_data.Enabled = False
        ElseIf chkbox_start_concdata.Checked = True Then
            tabctrl_main_process.SelectedTab = tabpg_cont_select
            tabpg_cont_select.Enabled = True
            tabpg_conc_volume_data.Enabled = False
        End If

        'Remove all event information
```

```
        txtbox_event.Text = ""


    End Sub


    Private Sub Event1Results(ByVal sender As System.Object, ByVal e As System.EventArgs) Handles
btn_cont_data.Click

        'Clear out all of the previous data

        txtbox_results.Clear()

        'Counting the number of active fields

        txtbox_results.AppendText("Results provided by the RRCLIDF program." & Environment.NewLine & ""
& Environment.NewLine & "Results:")

        If chkbox_start_concdata.Checked = True Then

            txtbox_results.AppendText(Environment.NewLine & "(Calculated from User Input Data)" &
Environment.NewLine)

        ElseIf chkbox_start_concdata_fail.Checked = True Then

            txtbox_results.AppendText(Environment.NewLine & "(Calculated from Default Data)" &
Environment.NewLine)

        End If

        If chkbox_start_concdata.Checked = True Then

            Dim i As Integer

            Dim count As Integer = 0

            For i = 1 To 30

                If tabpg_conc_volume_data.Controls.Item("Concentration" & i).Enabled = True Then

                    count = count + 1

                End If

            Next

            'Calculating the number of unfilled fields

            Dim errors As Integer

            errors = 0
```

```
        For i = 1 To count
            If tabpg_conc_volume_data.Controls.Item("Concentration" & i).Text = "" Then
                errors = errors + 1
            End If
        Next
        If txtbox_event.Text = "" Then
            MessageBox.Show("Please give event volume data.")
        Else
            If errors > 0 Then
                MessageBox.Show("Please fill in the concentration data for the " & errors & " contaminants
missing data.")
            Else
                Dim selected(2, count - 1) As String
                'column 0 = contaminant
                'column 1 = concentraton
                'column 2 = units

                For i = 0 To count - 1
                    selected(0, i) = tabpg_conc_volume_data.Controls.Item(("Contaminant" & i +
1)).Text.ToString
                    selected(1, i) = tabpg_conc_volume_data.Controls.Item(("Concentration" & i +
1)).Text.ToString
                    selected(2, i) = tabpg_conc_volume_data.Controls.Item(("Unit" & i + 1)).Text.ToString
                Next
                'MessageBox.Show("Data Collected")
                'btn3.Enabled = True
                'Process all information.
```

```
Dim bmp(,) = {{"Biofilter"}, {"DetentionBasin"}, {"HydrodynamicDevice"}, {"InfiltrationBasin"},
{"MediaFilter"}, {"PercolationTrenchWell"}, {"PorousPavement"}, {"RetentionPond"}, {"WetlandBasin"},
{"WetlandChannel"}}

Dim numofbmps As Integer = bmp.GetLength(0)

Dim state(,) As String = {{"null", "null"}, {"null", "null"}, {"null", "null"}, {"null", "null"}, {"null",
"null"}, {"null", "null"}, {"null", "null"}, {"null", "null"}, {"null", "null"}, {"null", "null"}}

Dim current As String

For i = 0 To count - 1

  current = selected(0, i) '<-- selects a contaminant then cycles it

  Dim location As String = Array.IndexOf(rowBiofilter, current)

  Dim Biofilter_location As String = "null"

  Dim DetentionBasin_location As String = "null"

  Dim HydrodynamicDevice_location As String = "null"

  Dim InfiltrationBasin_location As String = "null"

  Dim MediaFilter_location As String = "null"

  Dim PercolationTrenchWell_location As String = "null"

  Dim PorousPavement_location As String = "null"

  Dim RetentionPond_location As String = "null"

  Dim WetlandBasin_location As String = "null"

  Dim WetlandChannel_location As String = "null"

  state(0, 1) = "Biofilter"

  If location > -1 Then

    state(0, 0) = "available"

    Biofilter_location = location

  Else : state(0, 0) = "unavailable"

  End If

  location = Array.IndexOf(rowDetentionBasin, current)

  state(1, 1) = "DetentionBasin"
```

```
If location > -1 Then
   state(1, 0) = "available"
   DetentionBasin_location = location
Else : state(1, 0) = "unavailable"
End If
location = Array.IndexOf(rowHydrodynamicDevice, current)
state(2, 1) = "HydrodynamicDevice"
If location > -1 Then
   state(2, 0) = "available"
   HydrodynamicDevice_location = location
Else : state(2, 0) = "unavailable"
End If
location = Array.IndexOf(rowInfiltrationBasin, current)
state(3, 1) = "InfiltrationBasin"
If location > -1 Then
   state(3, 0) = "available"
   InfiltrationBasin_location = location
Else : state(3, 0) = "unavailable"
End If
location = Array.IndexOf(rowMediaFilter, current)
state(4, 1) = "MediaFilter"
If location > -1 Then
   state(4, 0) = "available"
   MediaFilter_location = location
Else : state(4, 0) = "unavailable"
End If
location = Array.IndexOf(rowPercolationTrenchWell, current)
```

```
state(5, 1) = "PercolationTrenchWell"
If location > -1 Then
   state(5, 0) = "available"
   PercolationTrenchWell_location = location
Else : state(5, 0) = "unavailable"
End If
location = Array.IndexOf(rowPorousPavement, current)
state(6, 1) = "PorousPavement"
If location > -1 Then
   state(6, 0) = "available"
   PorousPavement_location = location
Else : state(6, 0) = "unavailable"
End If
location = Array.IndexOf(rowRetentionPond, current)
state(7, 1) = "RetentionPond"
If location > -1 Then
   state(7, 0) = "available"
   RetentionPond_location = location
Else : state(7, 0) = "unavailable"
End If
location = Array.IndexOf(rowWetlandBasin, current)
state(8, 1) = "WetlandBasin"
If location > -1 Then
   state(8, 0) = "available"
   WetlandBasin_location = location
Else : state(8, 0) = "unavailable"
End If
```

```
location = Array.IndexOf(rowWetlandChannel, current)
state(9, 1) = "WetlandChannel"
If location > -1 Then
   state(9, 0) = "available"
   WetlandChannel_location = location
Else : state(9, 0) = "unavailable"
End If

'Now complete math.
Dim i2 As Integer
For i2 = 0 To 9
   'MessageBox.Show(state(i2, 0))
   If state(i2, 0) = "available" Then
      'computing
      Dim NA As String = "Not Available"
      Dim row_val As Integer
      Dim default_conc_in As String = "null"
      Dim default_conc_out As String = "null"
      Dim default_vol_in As String = "null"
      Dim default_vol_out As String = "null"
      Dim default_min_vol_red As String = "null"
      Dim default_max_vol_red As String = "null"
      Dim default_med_vol_red As String = "null"
      Dim default_ave_vol_red As String = "null"

      If state(i2, 1) = "Biofilter" Then
         row_val = Biofilter_location
```

```
    default_conc_in = Biofilter(row_val, 0).ToString
    default_conc_out = Biofilter(row_val, 1).ToString
    default_vol_in = Biofilter(row_val, 2).ToString
    default_vol_out = Biofilter(row_val, 3).ToString
    default_min_vol_red = (Biofilter(row_val, 5).ToString + 0).ToString("N2")
    default_max_vol_red = (Biofilter(row_val, 6).ToString + 0).ToString("N2")
    default_med_vol_red = (Biofilter(row_val, 7).ToString + 0).ToString("N2")
    default_ave_vol_red = (Biofilter(row_val, 8).ToString + 0).ToString("N2")

ElseIf state(i2, 1) = "DetentionBasin" Then
    row_val = DetentionBasin_location
    default_conc_in = DetentionBasin(row_val, 0).ToString
    default_conc_out = DetentionBasin(row_val, 1).ToString
    default_vol_in = DetentionBasin(row_val, 2).ToString
    default_vol_out = DetentionBasin(row_val, 3).ToString
    default_min_vol_red = (DetentionBasin(row_val, 5).ToString + 0).ToString("N2")
    default_max_vol_red = (DetentionBasin(row_val, 6).ToString + 0).ToString("N2")
    default_med_vol_red = (DetentionBasin(row_val, 7).ToString + 0).ToString("N2")
    default_ave_vol_red = (DetentionBasin(row_val, 8).ToString + 0).ToString("N2")

ElseIf state(i2, 1) = "HydrodynamicDevice" Then
    row_val = HydrodynamicDevice_location
    default_conc_in = HydrodynamicDevice(row_val, 0).ToString
    default_conc_out = HydrodynamicDevice(row_val, 1).ToString
    default_vol_in = HydrodynamicDevice(row_val, 2).ToString
    default_vol_out = HydrodynamicDevice(row_val, 3).ToString
    default_min_vol_red = (HydrodynamicDevice(row_val, 5).ToString + 0).ToString("N2")
```

```
                    default_max_vol_red = (HydrodynamicDevice(row_val, 6).ToString + 0).ToString("N2")
                    default_med_vol_red = (HydrodynamicDevice(row_val, 7).ToString +
0).ToString("N2")
                    default_ave_vol_red = (HydrodynamicDevice(row_val, 8).ToString + 0).ToString("N2")

                ElseIf state(i2, 1) = "InfiltrationBasin" Then
                    row_val = InfiltrationBasin_location
                    default_conc_in = InfiltrationBasin(row_val, 0).ToString
                    default_conc_out = InfiltrationBasin(row_val, 1).ToString
                    default_vol_in = InfiltrationBasin(row_val, 2).ToString
                    default_vol_out = InfiltrationBasin(row_val, 3).ToString
                    default_min_vol_red = (InfiltrationBasin(row_val, 5).ToString + 0).ToString("N2")
                    default_max_vol_red = (InfiltrationBasin(row_val, 6).ToString + 0).ToString("N2")
                    default_med_vol_red = (InfiltrationBasin(row_val, 7).ToString + 0).ToString("N2")
                    default_ave_vol_red = (InfiltrationBasin(row_val, 8).ToString + 0).ToString("N2")

                ElseIf state(i2, 1) = "MediaFilter" Then
                    row_val = MediaFilter_location
                    default_conc_in = MediaFilter(row_val, 0).ToString
                    default_conc_out = MediaFilter(row_val, 1).ToString
                    default_vol_in = MediaFilter(row_val, 2).ToString
                    default_vol_out = MediaFilter(row_val, 3).ToString
                    default_min_vol_red = (MediaFilter(row_val, 5).ToString + 0).ToString("N2")
                    default_max_vol_red = (MediaFilter(row_val, 6).ToString + 0).ToString("N2")
                    default_med_vol_red = (MediaFilter(row_val, 7).ToString + 0).ToString("N2")
                    default_ave_vol_red = (MediaFilter(row_val, 8).ToString + 0).ToString("N2")
```

```
ElseIf state(i2, 1) = "PercolationTrenchWell" Then
    row_val = PercolationTrenchWell_location
    default_conc_in = PercolationTrenchWell(row_val, 0).ToString
    default_conc_out = PercolationTrenchWell(row_val, 1).ToString
    default_vol_in = PercolationTrenchWell(row_val, 2).ToString
    default_vol_out = PercolationTrenchWell(row_val, 3).ToString
    default_min_vol_red = (PercolationTrenchWell(row_val, 5).ToString +
0).ToString("N2")
    default_max_vol_red = (PercolationTrenchWell(row_val, 6).ToString +
0).ToString("N2")
    default_med_vol_red = (PercolationTrenchWell(row_val, 7).ToString +
0).ToString("N2")
    default_ave_vol_red = (PercolationTrenchWell(row_val, 8).ToString +
0).ToString("N2")

ElseIf state(i2, 1) = "PorousPavement" Then
    row_val = PorousPavement_location
    default_conc_in = PorousPavement(row_val, 0).ToString
    default_conc_out = PorousPavement(row_val, 1).ToString
    default_vol_in = PorousPavement(row_val, 2).ToString
    default_vol_out = PorousPavement(row_val, 3).ToString
    default_min_vol_red = (PorousPavement(row_val, 5).ToString + 0).ToString("N2")
    default_max_vol_red = (PorousPavement(row_val, 6).ToString + 0).ToString("N2")
    default_med_vol_red = (PorousPavement(row_val, 7).ToString + 0).ToString("N2")
    default_ave_vol_red = (PorousPavement(row_val, 8).ToString + 0).ToString("N2")

ElseIf state(i2, 1) = "RetentionPond" Then
    row_val = RetentionPond_location
    default_conc_in = RetentionPond(row_val, 0).ToString
```

```
    default_conc_out = RetentionPond(row_val, 1).ToString
    default_vol_in = RetentionPond(row_val, 2).ToString
    default_vol_out = RetentionPond(row_val, 3).ToString
    default_min_vol_red = (RetentionPond(row_val, 5).ToString + 0).ToString("N2")
    default_max_vol_red = (RetentionPond(row_val, 6).ToString + 0).ToString("N2")
    default_med_vol_red = (RetentionPond(row_val, 7).ToString + 0).ToString("N2")
    default_ave_vol_red = (RetentionPond(row_val, 8).ToString + 0).ToString("N2")

ElseIf state(i2, 1) = "WetlandBasin" Then
    row_val = WetlandBasin_location
    default_conc_in = WetlandBasin(row_val, 0).ToString
    default_conc_out = WetlandBasin(row_val, 1).ToString
    default_vol_in = WetlandBasin(row_val, 2).ToString
    default_vol_out = WetlandBasin(row_val, 3).ToString
    default_min_vol_red = (WetlandBasin(row_val, 5).ToString + 0).ToString("N2")
    default_max_vol_red = (WetlandBasin(row_val, 6).ToString + 0).ToString("N2")
    default_med_vol_red = (WetlandBasin(row_val, 7).ToString + 0).ToString("N2")
    default_ave_vol_red = (WetlandBasin(row_val, 8).ToString + 0).ToString("N2")

ElseIf state(i2, 1) = "WetlandChannel" Then
    row_val = WetlandChannel_location
    default_conc_in = WetlandChannel(row_val, 0).ToString
    default_conc_out = WetlandChannel(row_val, 1).ToString
    default_vol_in = WetlandChannel(row_val, 2).ToString
    default_vol_out = WetlandChannel(row_val, 3).ToString
    default_min_vol_red = (WetlandChannel(row_val, 5).ToString + 0).ToString("N2")
    default_max_vol_red = (WetlandChannel(row_val, 6).ToString + 0).ToString("N2")
```

```
    default_med_vol_red = (WetlandChannel(row_val, 7).ToString + 0).ToString("N2")

    default_ave_vol_red = (WetlandChannel(row_val, 8).ToString + 0).ToString("N2")

End If


Dim event_volume_in As String = "null"

Dim event_volume_out As String = "null"

Dim event_volume_change As String = "null"

Dim cont_conc_in As String = "null"

Dim cont_conc_out As String = "null"

Dim cont_conc_change As String = "null"

Dim total_cont_load_in As String = "null"

Dim total_cont_load_out As String = "null"

Dim total_cont_load_reduction_from_flow As String = "null"

Dim total_cont_load_change As String = "null"

Dim default_conc_change As String = "null"

Dim default_vol_change As String = "null"

Dim cont_conc_in_rough As String = "null"


If default_conc_in = "NA" Then

    cont_conc_out = NA

    cont_conc_change = NA

    default_conc_change = NA

    total_cont_load_out = NA

    total_cont_load_reduction_from_flow = NA

    total_cont_load_change = NA

End If
```

```
                If default_conc_out = "NA" Then
                    cont_conc_out = NA
                    cont_conc_change = NA
                    default_conc_change = NA
                    total_cont_load_out = NA
                    total_cont_load_reduction_from_flow = NA
                    total_cont_load_change = NA
                End If

                If default_conc_change <> NA Then
                    default_conc_change = ((default_conc_in - default_conc_out) /
default_conc_in).ToString
                End If

                If default_vol_in = "NA" Then
                    default_vol_change = NA
                    event_volume_out = NA
                    event_volume_change = NA
                    total_cont_load_out = NA
                    total_cont_load_reduction_from_flow = NA
                    total_cont_load_change = NA
                End If

                If default_vol_out = "NA" Then
                    default_vol_change = NA
                    event_volume_out = NA
                    event_volume_change = NA
```

```
                    total_cont_load_out = NA

                    total_cont_load_reduction_from_flow = NA

                    total_cont_load_change = NA

                End If


                If default_vol_change <> NA Then

                    default_vol_change = ((default_vol_in - default_vol_out) / default_vol_in).ToString

                End If


                event_volume_in = txtbox_event.Text.ToString


                If event_volume_out <> NA Then

                    event_volume_out = (event_volume_in - (event_volume_in *
default_vol_change)).ToString("N0")

                End If


                If event_volume_change <> NA Then

                    event_volume_change = (event_volume_in - event_volume_out).ToString("N0")

                End If


                cont_conc_in_rough = tabpg_conc_volume_data.Controls.Item(("Concentration" & i +
1)).Text.ToString

                cont_conc_in = (cont_conc_in_rough - 0).ToString("N4")


                If cont_conc_out <> NA Then

                    cont_conc_out = (cont_conc_in - (cont_conc_in *
default_conc_change)).ToString("N4")

                End If
```

```
                If cont_conc_change <> NA Then
                    cont_conc_change = (cont_conc_in - cont_conc_out).ToString("N4")
                End If

                If total_cont_load_in <> NA Then
                    total_cont_load_in = (event_volume_in * cont_conc_in).ToString("N0")
                End If

                If total_cont_load_out <> NA Then
                    total_cont_load_out = (event_volume_out * cont_conc_out).ToString("N0")
                End If

                If total_cont_load_reduction_from_flow <> NA Then
                    total_cont_load_reduction_from_flow = (event_volume_in * cont_conc_in -
event_volume_out * cont_conc_in).ToString("N0")
                End If

                If total_cont_load_change <> NA Then
                    total_cont_load_change = (total_cont_load_in - total_cont_load_out).ToString("N0")
                End If

                txtbox_results.AppendText(Environment.NewLine & "Contaminant: " & current)
                txtbox_results.AppendText(Environment.NewLine & "Best Management Practice: " &
bmp(i2, 0))
                txtbox_results.AppendText(Environment.NewLine & "Event Volume Inflow: " &
txtbox_event.Text.ToString & " L")
                txtbox_results.AppendText(Environment.NewLine & "Average Event Volume Outflow: "
& event_volume_out & " L")
```

```
txtbox_results.AppendText(Environment.NewLine & "Event Volume Reduction: " & event_volume_change & " L")

txtbox_results.AppendText(Environment.NewLine & "Maximum Reported Volume Reduction: " & default_max_vol_red & "%")

txtbox_results.AppendText(Environment.NewLine & "Minimum Reported Volume Reduction: " & default_min_vol_red & "%")

txtbox_results.AppendText(Environment.NewLine & "Median Reported Volume Reduction: " & default_med_vol_red & "%")

txtbox_results.AppendText(Environment.NewLine & "Average Reported Volume Reduction: " & default_ave_vol_red & "%")

txtbox_results.AppendText(Environment.NewLine & "Contaminant Influent Concentration: " & default_conc_in & " " & tabpg_conc_volume_data.Controls.Item(("Unit" & i + 1)).Text.ToString)

txtbox_results.AppendText(Environment.NewLine & "Contaminant Effluent Concentration: " & cont_conc_out & " " & tabpg_conc_volume_data.Controls.Item(("Unit" & i + 1)).Text.ToString)

txtbox_results.AppendText(Environment.NewLine & "Contaminant Concentration Reduction: " & cont_conc_change & " " & tabpg_conc_volume_data.Controls.Item(("Unit" & i + 1)).Text.ToString)

If tabpg_conc_volume_data.Controls.Item(("Unit" & i + 1)).Text = "mg/L" Then

  txtbox_results.AppendText(Environment.NewLine & "Contaminant Load In: " & total_cont_load_in & " mg")

  txtbox_results.AppendText(Environment.NewLine & "Contaminant Load Out: " & total_cont_load_out & " mg")

  txtbox_results.AppendText(Environment.NewLine & "Contaminant Load Reduction: " & total_cont_load_change & " mg")

  txtbox_results.AppendText(Environment.NewLine & "Contaminant Load Reduction Due to Flow Volume Reduction: " & total_cont_load_reduction_from_flow & " mg")

Else : txtbox_results.AppendText(Environment.NewLine & "Contaminant Load In: " & total_cont_load_in & tabpg_conc_volume_data.Controls.Item(("Unit" & i + 1)).Text.ToString & "*L")

  txtbox_results.AppendText(Environment.NewLine & "Contaminant Load In: " & total_cont_load_in & tabpg_conc_volume_data.Controls.Item(("Unit" & i + 1)).Text.ToString & "*L")

  txtbox_results.AppendText(Environment.NewLine & "Contaminant Load Out: " & total_cont_load_out & tabpg_conc_volume_data.Controls.Item(("Unit" & i + 1)).Text.ToString & "*L")
```

```
                    txtbox_results.AppendText(Environment.NewLine & "Contaminant Load Reduction: "
& total_cont_load_change & tabpg_conc_volume_data.Controls.Item(("Unit" & i + 1)).Text.ToString &
"*L")

                    txtbox_results.AppendText(Environment.NewLine & "Contaminant Load Reduction
Due to Flow Volume Reduction: " & total_cont_load_reduction_from_flow &
tabpg_conc_volume_data.Controls.Item(("Unit" & i + 1)).Text.ToString & "*L")

                  End If

                  txtbox_results.AppendText(Environment.NewLine)

                End If

              Next

            Next

            MessageBox.Show("Analysis Complete")

            tabpg_results_event1.Enabled = True

            tabctrl_main_process.SelectedTab = tabpg_results_event1

            tabpg_conc_volume_data.Enabled = False

          End If

        End If

      ElseIf chkbox_start_concdata_fail.Checked = True Then

        Dim i As Integer

        Dim count As Integer = 0

        For i = 1 To 30

          If tabpg_conc_volume_data.Controls.Item("Contaminant" & i).Enabled = True Then

            count = count + 1

          End If

        Next

        'Calculating the number of unfilled fields

        If txtbox_event.Text = "" Then

          MessageBox.Show("Please give event volume data.")

        Else
```

```
        Dim selected(2, count - 1) As String

        'column 0 = contaminant

        'column 1 = concentraton

        'column 2 = units


        For i = 0 To count - 1

            selected(0, i) = tabpg_conc_volume_data.Controls.Item(("Contaminant" & i + 1)).Text.ToString

            selected(1, i) = tabpg_conc_volume_data.Controls.Item(("Concentration" & i +
1)).Text.ToString

            selected(2, i) = tabpg_conc_volume_data.Controls.Item(("Unit" & i + 1)).Text.ToString

        Next

        'MessageBox.Show("Data Collected")

        'btn3.Enabled = True

        'Process all information.

        Dim bmp(,) = {{"Biofilter"}, {"DetentionBasin"}, {"HydrodynamicDevice"}, {"InfiltrationBasin"},
{"MediaFilter"}, {"PercolationTrenchWell"}, {"PorousPavement"}, {"RetentionPond"}, {"WetlandBasin"},
{"WetlandChannel"}}

        Dim numofbmps As Integer = bmp.GetLength(0)

        Dim state(,) As String = {{"null", "null"}, {"null", "null"}, {"null", "null"}, {"null", "null"}, {"null",
"null"}, {"null", "null"}, {"null", "null"}, {"null", "null"}, {"null", "null"}, {"null", "null"}}

        Dim current As String

        For i = 0 To count - 1

            current = selected(0, i) '<-- selects a contaminant then cycles it

            Dim location As String = Array.IndexOf(rowBiofilter, current)

            Dim Biofilter_location As String = "null"

            Dim DetentionBasin_location As String = "null"

            Dim HydrodynamicDevice_location As String = "null"

            Dim InfiltrationBasin_location As String = "null"

            Dim MediaFilter_location As String = "null"
```

```
Dim PercolationTrenchWell_location As String = "null"

Dim PorousPavement_location As String = "null"

Dim RetentionPond_location As String = "null"

Dim WetlandBasin_location As String = "null"

Dim WetlandChannel_location As String = "null"

Dim NA As String = "Not Available"

state(0, 1) = "Biofilter"

If location > -1 Then

   state(0, 0) = "available"

   Biofilter_location = location

Else : state(0, 0) = "unavailable"

End If

location = Array.IndexOf(rowDetentionBasin, current)

state(1, 1) = "DetentionBasin"

If location > -1 Then

   state(1, 0) = "available"

   DetentionBasin_location = location

Else : state(1, 0) = "unavailable"

End If

location = Array.IndexOf(rowHydrodynamicDevice, current)

state(2, 1) = "HydrodynamicDevice"

If location > -1 Then

   state(2, 0) = "available"

   HydrodynamicDevice_location = location

Else : state(2, 0) = "unavailable"

End If

location = Array.IndexOf(rowInfiltrationBasin, current)
```

```
state(3, 1) = "InfiltrationBasin"
If location > -1 Then
   state(3, 0) = "available"
   InfiltrationBasin_location = location
Else : state(3, 0) = "unavailable"
End If
location = Array.IndexOf(rowMediaFilter, current)
state(4, 1) = "MediaFilter"
If location > -1 Then
   state(4, 0) = "available"
   MediaFilter_location = location
Else : state(4, 0) = "unavailable"
End If
location = Array.IndexOf(rowPercolationTrenchWell, current)
state(5, 1) = "PercolationTrenchWell"
If location > -1 Then
   state(5, 0) = "available"
   PercolationTrenchWell_location = location
Else : state(5, 0) = "unavailable"
End If
location = Array.IndexOf(rowPorousPavement, current)
state(6, 1) = "PorousPavement"
If location > -1 Then
   state(6, 0) = "available"
   PorousPavement_location = location
Else : state(6, 0) = "unavailable"
End If
```

```
location = Array.IndexOf(rowRetentionPond, current)
state(7, 1) = "RetentionPond"
If location > -1 Then
    state(7, 0) = "available"
    RetentionPond_location = location
Else : state(7, 0) = "unavailable"
End If
location = Array.IndexOf(rowWetlandBasin, current)
state(8, 1) = "WetlandBasin"
If location > -1 Then
    state(8, 0) = "available"
    WetlandBasin_location = location
Else : state(8, 0) = "unavailable"
End If
location = Array.IndexOf(rowWetlandChannel, current)
state(9, 1) = "WetlandChannel"
If location > -1 Then
    state(9, 0) = "available"
    WetlandChannel_location = location
Else : state(9, 0) = "unavailable"
End If

'Now complete math.
Dim i2 As Integer
For i2 = 0 To 9
    'MessageBox.Show(state(i2, 0))
    If state(i2, 0) = "available" Then
```

```
'computing
Dim row_val As Integer
Dim default_conc_in As String = "null"
Dim default_conc_out As String = "null"
Dim default_vol_in As String = "null"
Dim default_vol_out As String = "null"
Dim default_min_vol_red As String = "null"
Dim default_max_vol_red As String = "null"
Dim default_med_vol_red As String = "null"
Dim default_ave_vol_red As String = "null"

If state(i2, 1) = "Biofilter" Then
   row_val = Biofilter_location
   default_conc_in = Biofilter(row_val, 0).ToString
   default_conc_out = Biofilter(row_val, 1).ToString
   default_vol_in = Biofilter(row_val, 2).ToString
   default_vol_out = Biofilter(row_val, 3).ToString
   default_min_vol_red = (Biofilter(row_val, 5).ToString + 0).ToString("N2")
   default_max_vol_red = (Biofilter(row_val, 6).ToString + 0).ToString("N2")
   default_med_vol_red = (Biofilter(row_val, 7).ToString + 0).ToString("N2")
   default_ave_vol_red = (Biofilter(row_val, 8).ToString + 0).ToString("N2")

ElseIf state(i2, 1) = "DetentionBasin" Then
   row_val = DetentionBasin_location
   default_conc_in = DetentionBasin(row_val, 0).ToString
   default_conc_out = DetentionBasin(row_val, 1).ToString
   default_vol_in = DetentionBasin(row_val, 2).ToString
```

```
    default_vol_out = DetentionBasin(row_val, 3).ToString
    default_min_vol_red = (DetentionBasin(row_val, 5).ToString + 0).ToString("N2")
    default_max_vol_red = (DetentionBasin(row_val, 6).ToString + 0).ToString("N2")
    default_med_vol_red = (DetentionBasin(row_val, 7).ToString + 0).ToString("N2")
    default_ave_vol_red = (DetentionBasin(row_val, 8).ToString + 0).ToString("N2")

ElseIf state(i2, 1) = "HydrodynamicDevice" Then
    row_val = HydrodynamicDevice_location
    default_conc_in = HydrodynamicDevice(row_val, 0).ToString
    default_conc_out = HydrodynamicDevice(row_val, 1).ToString
    default_vol_in = HydrodynamicDevice(row_val, 2).ToString
    default_vol_out = HydrodynamicDevice(row_val, 3).ToString
    default_min_vol_red = (HydrodynamicDevice(row_val, 5).ToString + 0).ToString("N2")
    default_max_vol_red = (HydrodynamicDevice(row_val, 6).ToString + 0).ToString("N2")
    default_med_vol_red = (HydrodynamicDevice(row_val, 7).ToString + 0).ToString("N2")
    default_ave_vol_red = (HydrodynamicDevice(row_val, 8).ToString + 0).ToString("N2")

ElseIf state(i2, 1) = "InfiltrationBasin" Then
    row_val = InfiltrationBasin_location
    default_conc_in = InfiltrationBasin(row_val, 0).ToString
    default_conc_out = InfiltrationBasin(row_val, 1).ToString
    default_vol_in = InfiltrationBasin(row_val, 2).ToString
    default_vol_out = InfiltrationBasin(row_val, 3).ToString
    default_min_vol_red = (InfiltrationBasin(row_val, 5).ToString + 0).ToString("N2")
    default_max_vol_red = (InfiltrationBasin(row_val, 6).ToString + 0).ToString("N2")
    default_med_vol_red = (InfiltrationBasin(row_val, 7).ToString + 0).ToString("N2")
    default_ave_vol_red = (InfiltrationBasin(row_val, 8).ToString + 0).ToString("N2")
```

```
ElseIf state(i2, 1) = "MediaFilter" Then
    row_val = MediaFilter_location
    default_conc_in = MediaFilter(row_val, 0).ToString
    default_conc_out = MediaFilter(row_val, 1).ToString
    default_vol_in = MediaFilter(row_val, 2).ToString
    default_vol_out = MediaFilter(row_val, 3).ToString
    default_min_vol_red = (MediaFilter(row_val, 5).ToString + 0).ToString("N2")
    default_max_vol_red = (MediaFilter(row_val, 6).ToString + 0).ToString("N2")
    default_med_vol_red = (MediaFilter(row_val, 7).ToString + 0).ToString("N2")
    default_ave_vol_red = (MediaFilter(row_val, 8).ToString + 0).ToString("N2")

ElseIf state(i2, 1) = "PercolationTrenchWell" Then
    row_val = PercolationTrenchWell_location
    default_conc_in = PercolationTrenchWell(row_val, 0).ToString
    default_conc_out = PercolationTrenchWell(row_val, 1).ToString
    default_vol_in = PercolationTrenchWell(row_val, 2).ToString
    default_vol_out = PercolationTrenchWell(row_val, 3).ToString
    default_min_vol_red = (PercolationTrenchWell(row_val, 5).ToString + 0).ToString("N2")
    default_max_vol_red = (PercolationTrenchWell(row_val, 6).ToString + 0).ToString("N2")
    default_med_vol_red = (PercolationTrenchWell(row_val, 7).ToString + 0).ToString("N2")
    default_ave_vol_red = (PercolationTrenchWell(row_val, 8).ToString + 0).ToString("N2")

ElseIf state(i2, 1) = "PorousPavement" Then
    row_val = PorousPavement_location
    default_conc_in = PorousPavement(row_val, 0).ToString
    default_conc_out = PorousPavement(row_val, 1).ToString
```

```
    default_vol_in = PorousPavement(row_val, 2).ToString
    default_vol_out = PorousPavement(row_val, 3).ToString
    default_min_vol_red = (PorousPavement(row_val, 5).ToString + 0).ToString("N2")
    default_max_vol_red = (PorousPavement(row_val, 6).ToString + 0).ToString("N2")
    default_med_vol_red = (PorousPavement(row_val, 7).ToString + 0).ToString("N2")
    default_ave_vol_red = (PorousPavement(row_val, 8).ToString + 0).ToString("N2")

ElseIf state(i2, 1) = "RetentionPond" Then
    row_val = RetentionPond_location
    default_conc_in = RetentionPond(row_val, 0).ToString
    default_conc_out = RetentionPond(row_val, 1).ToString
    default_vol_in = RetentionPond(row_val, 2).ToString
    default_vol_out = RetentionPond(row_val, 3).ToString
    default_min_vol_red = (RetentionPond(row_val, 5).ToString + 0).ToString("N2")
    default_max_vol_red = (RetentionPond(row_val, 6).ToString + 0).ToString("N2")
    default_med_vol_red = (RetentionPond(row_val, 7).ToString + 0).ToString("N2")
    default_ave_vol_red = (RetentionPond(row_val, 8).ToString + 0).ToString("N2")

ElseIf state(i2, 1) = "WetlandBasin" Then
    row_val = WetlandBasin_location
    default_conc_in = WetlandBasin(row_val, 0).ToString
    default_conc_out = WetlandBasin(row_val, 1).ToString
    default_vol_in = WetlandBasin(row_val, 2).ToString
    default_vol_out = WetlandBasin(row_val, 3).ToString
    default_min_vol_red = (WetlandBasin(row_val, 5).ToString + 0).ToString("N2")
    default_max_vol_red = (WetlandBasin(row_val, 6).ToString + 0).ToString("N2")
    default_med_vol_red = (WetlandBasin(row_val, 7).ToString + 0).ToString("N2")
```

```
    default_ave_vol_red = (WetlandBasin(row_val, 8).ToString + 0).ToString("N2")

ElseIf state(i2, 1) = "WetlandChannel" Then
    row_val = WetlandChannel_location
    default_conc_in = WetlandChannel(row_val, 0).ToString
    default_conc_out = WetlandChannel(row_val, 1).ToString
    default_vol_in = WetlandChannel(row_val, 2).ToString
    default_vol_out = WetlandChannel(row_val, 3).ToString
    default_min_vol_red = (WetlandChannel(row_val, 5).ToString + 0).ToString("N2")
    default_max_vol_red = (WetlandChannel(row_val, 6).ToString + 0).ToString("N2")
    default_med_vol_red = (WetlandChannel(row_val, 7).ToString + 0).ToString("N2")
    default_ave_vol_red = (WetlandChannel(row_val, 8).ToString + 0).ToString("N2")

End If

Dim event_volume_in As String = "null"
Dim event_volume_out As String = "null"
Dim event_volume_change As String = "null"
Dim cont_conc_in As String = "null"
Dim cont_conc_out As String = "null"
Dim cont_conc_change As String = "null"
Dim total_cont_load_in As String = "null"
Dim total_cont_load_out As String = "null"
Dim total_cont_load_reduction_from_flow As String = "null"
Dim total_cont_load_change As String = "null"
Dim default_conc_change As String = "null"
Dim default_vol_change As String = "null"
```

```
If default_conc_in = "NA" Then
    cont_conc_out = NA
    cont_conc_change = NA
    default_conc_change = NA
    total_cont_load_in = NA
    total_cont_load_out = NA
    total_cont_load_reduction_from_flow = NA
    total_cont_load_change = NA
End If

If default_conc_out = "NA" Then
    cont_conc_out = NA
    cont_conc_change = NA
    default_conc_change = NA
    total_cont_load_out = NA
    total_cont_load_reduction_from_flow = NA
    total_cont_load_change = NA
End If

If default_conc_change <> NA Then
    default_conc_change = ((default_conc_in - default_conc_out) /
default_conc_in).ToString
End If

If default_vol_in = "NA" Then
    default_vol_change = NA
```

```
            event_volume_out = NA
            event_volume_change = NA
            total_cont_load_in = NA
            total_cont_load_out = NA
            total_cont_load_reduction_from_flow = NA
            total_cont_load_change = NA
        End If

        If default_vol_out = "NA" Then
            default_vol_change = NA
            event_volume_out = NA
            event_volume_change = NA
            total_cont_load_out = NA
            total_cont_load_reduction_from_flow = NA
            total_cont_load_change = NA
        End If

        If default_vol_change <> NA Then
            default_vol_change = ((default_vol_in - default_vol_out) / default_vol_in).ToString
        End If

        event_volume_in = (txtbox_event.Text.ToString - 0).ToString("N0")

        If event_volume_out <> NA Then
            event_volume_out = (event_volume_in - (event_volume_in * (default_ave_vol_red /
100))).ToString("N0")
        End If
```

```
If event_volume_change <> NA Then
   event_volume_change = (event_volume_in - event_volume_out).ToString("N0")
End If

If default_conc_in <> NA Then
   cont_conc_in = default_conc_in.ToString
Else : cont_conc_in = default_conc_in
End If

If cont_conc_out <> NA Then
   cont_conc_out = (default_conc_out).ToString
End If

If cont_conc_change <> NA Then
   cont_conc_change = (default_conc_in - default_conc_out).ToString("N4")
End If

If total_cont_load_in <> NA Then
   total_cont_load_in = (default_vol_in * default_conc_in)
End If

If total_cont_load_out <> NA Then
   total_cont_load_out = (event_volume_out * cont_conc_out).ToString("N0")
End If

If total_cont_load_reduction_from_flow <> NA Then
```

```
                    total_cont_load_reduction_from_flow = (default_vol_in * default_conc_in -
event_volume_out * default_conc_in).ToString("N0")

                End If


                If total_cont_load_change <> NA Then

                    total_cont_load_change = (total_cont_load_in - total_cont_load_out).ToString("N0")

                End If


                txtbox_results.AppendText(Environment.NewLine & "Contaminant: " & current)

                txtbox_results.AppendText(Environment.NewLine & "Best Management Practice: " &
bmp(i2, 0))

                txtbox_results.AppendText(Environment.NewLine & "Event Volume Inflow: " &
txtbox_event.Text.ToString & " L")

                txtbox_results.AppendText(Environment.NewLine & "Average Event Volume Outflow: " &
event_volume_out & " L")

                txtbox_results.AppendText(Environment.NewLine & "Event Volume Reduction: " &
event_volume_change & " L")

                txtbox_results.AppendText(Environment.NewLine & "Maximum Reported Volume
Reduction: " & default_max_vol_red & "%")

                txtbox_results.AppendText(Environment.NewLine & "Minimum Reported Volume
Reduction: " & default_min_vol_red & "%")

                txtbox_results.AppendText(Environment.NewLine & "Median Reported Volume
Reduction: " & default_med_vol_red & "%")

                txtbox_results.AppendText(Environment.NewLine & "Average Reported Volume
Reduction: " & default_ave_vol_red & "%")

                txtbox_results.AppendText(Environment.NewLine & "Contaminant Influent
Concentration: " & default_conc_in & " " & tabpg_conc_volume_data.Controls.Item(("Unit" & i +
1)).Text.ToString)

                txtbox_results.AppendText(Environment.NewLine & "Contaminant Effluent
Concentration: " & cont_conc_out & " " & tabpg_conc_volume_data.Controls.Item(("Unit" & i +
1)).Text.ToString)
```

```
                    txtbox_results.AppendText(Environment.NewLine & "Contaminant Concentration
Reduction: " & cont_conc_change & " " & tabpg_conc_volume_data.Controls.Item(("Unit" & i +
1)).Text.ToString)

                    If tabpg_conc_volume_data.Controls.Item(("Unit" & i + 1)).Text = "mg/L" Then

                      txtbox_results.AppendText(Environment.NewLine & "Contaminant Load In: " &
total_cont_load_in & " mg")

                      txtbox_results.AppendText(Environment.NewLine & "Contaminant Load Out: " &
total_cont_load_out & " mg")

                      txtbox_results.AppendText(Environment.NewLine & "Contaminant Load Reduction: " &
total_cont_load_change & " mg")

                      txtbox_results.AppendText(Environment.NewLine & "Contaminant Load Reduction Due
to Flow Volume Reduction: " & total_cont_load_reduction_from_flow & " mg")

                    Else : txtbox_results.AppendText(Environment.NewLine & "Contaminant Load In: " &
total_cont_load_in & tabpg_conc_volume_data.Controls.Item(("Unit" & i + 1)).Text.ToString & "*L")

                      txtbox_results.AppendText(Environment.NewLine & "Contaminant Load In: " &
total_cont_load_in & tabpg_conc_volume_data.Controls.Item(("Unit" & i + 1)).Text.ToString & "*L")

                      txtbox_results.AppendText(Environment.NewLine & "Contaminant Load Out: " &
total_cont_load_out & tabpg_conc_volume_data.Controls.Item(("Unit" & i + 1)).Text.ToString & "*L")

                      txtbox_results.AppendText(Environment.NewLine & "Contaminant Load Reduction: " &
total_cont_load_change & tabpg_conc_volume_data.Controls.Item(("Unit" & i + 1)).Text.ToString & "*L")

                      txtbox_results.AppendText(Environment.NewLine & "Contaminant Load Reduction Due
to Flow Volume Reduction: " & total_cont_load_reduction_from_flow &
tabpg_conc_volume_data.Controls.Item(("Unit" & i + 1)).Text.ToString & "*L")

                    End If

                    txtbox_results.AppendText(Environment.NewLine)

                  End If

                Next

              Next

              MessageBox.Show("Analysis Complete")

              tabpg_results_event1.Enabled = True

              tabctrl_main_process.SelectedTab = tabpg_results_event1

              tabpg_conc_volume_data.Enabled = False
```

```
        End If
    End If
End Sub


Private Sub Button3_Click(ByVal sender As System.Object, ByVal e As System.EventArgs) Handles
Button3.Click
    tabpg_conc_volume_data.Enabled = True
    tabctrl_main_process.SelectedTab = tabpg_conc_volume_data
    tabpg_results_event1.Enabled = False
    txtbox_results.Clear()
    txtbox_results.Text = "Results:"

End Sub

Private Sub btn_results1_new_Click(ByVal sender As System.Object, ByVal e As System.EventArgs)
Handles btn_results1_new.Click

    tabctrl_main_process.Visible = True
    tabctrl_main_process.SelectedTab = tabpg_data_inquiry
    'Set tabs enabled
    tabpg_welcome.Enabled = False
    tabpg_data_inquiry.Enabled = True
    tabpg_cont_select.Enabled = False
    tabpg_conc_volume_data.Enabled = False

    'turn
```

```
chkbox_start_concdata.CheckState = CheckState.Unchecked

chkbox_start_concdata_fail.CheckState = CheckState.Unchecked


'Repeat startup process

'Hide contaminant info


'Disable storm events

txtbox_event.Enabled = False


'Set storm default values

txtbox_event.Text = ""


'Set tabpages disabled

tabpg_results_event1.Enabled = False


'Clear out selected contaminants

Dim i As Integer

For i = 0 To (chklistbox_cont.Items.Count - 1)

   chklistbox_cont.SetItemCheckState(i, False)

Next

lstbox_cont_selected.Items.Clear()


'Clear out results

txtbox_results.Clear()

txtbox_results.Text = "Results:"

Dim i2 As Integer

For i2 = 1 To 30
```

```
        tabpg_conc_volume_data.Controls.Item("Contaminant" & i2).Enabled = False

        tabpg_conc_volume_data.Controls.Item("Contaminant" & i2).Text = "Contaminant"

        tabpg_conc_volume_data.Controls.Item("Concentration" & i2).Enabled = False

        tabpg_conc_volume_data.Controls.Item("Concentration" & i2).Text = ""

        tabpg_conc_volume_data.Controls.Item("Unit" & i2).Text = ("No Unit")

        tabpg_conc_volume_data.Controls.Item("Unit" & i2).Enabled = False

    Next


End Sub


Private Sub btn_print_results1_Click(ByVal sender As System.Object, ByVal e As System.EventArgs)
Handles btn_print_results1.Click

    StringToPrint = txtbox_results.Text

    prnDoc.Print()

End Sub


Private Sub prnDoc_PrintPage(ByVal sender As Object, ByVal e As
System.Drawing.Printing.PrintPageEventArgs) Handles prnDoc.PrintPage

    Dim numChars As Integer

    Dim numLines As Integer

    Dim stringForPage As String

    Dim strFormat As New StringFormat()

    Dim PrintFont As Font

    PrintFont = txtbox_results.Font

    Dim rectDraw As New RectangleF(e.MarginBounds.Left, e.MarginBounds.Top, e.MarginBounds.Width,
e.MarginBounds.Height)

    Dim sizeMeasure As New SizeF(e.MarginBounds.Width, e.MarginBounds.Height -
PrintFont.GetHeight(e.Graphics))

    strFormat.Trimming = StringTrimming.Word
```

```
        e.Graphics.MeasureString(StringToPrint, PrintFont, sizeMeasure, strFormat, numChars, numLines)

        stringForPage = StringToPrint.Substring(0, numChars)

        e.Graphics.DrawString(stringForPage, PrintFont, Brushes.Black, rectDraw, strFormat)

        If numChars < StringToPrint.Length Then

            StringToPrint = StringToPrint.Substring(numChars)

            e.HasMorePages = True

        Else

            e.HasMorePages = False

        End If


    End Sub


    Private Sub btn_main_Databases_Click(ByVal sender As System.Object, ByVal e As System.EventArgs)
Handles btn_main_Databases.Click

        Form2.Show()

    End Sub


    Private Sub btn_main_about_Click_1(ByVal sender As System.Object, ByVal e As System.EventArgs)
Handles btn_main_about.Click

        Form3.Show()

    End Sub


    Private Sub btn_main_help_Click_1(ByVal sender As System.Object, ByVal e As System.EventArgs)
Handles btn_main_help.Click

        Form4.Show()

    End Sub


    Private Sub PrintDocument1_PrintPage(ByVal sender As System.Object, ByVal e As
System.Drawing.Printing.PrintPageEventArgs) Handles prnDoc.PrintPage
```

```
    End Sub

    Private Sub tabpg_conc_volume_data_Click(ByVal sender As System.Object, ByVal e As
System.EventArgs) Handles tabpg_conc_volume_data.Click

    End Sub

    Private Sub btn_save_Click(ByVal sender As System.Object, ByVal e As System.EventArgs) Handles
btn_save.Click
        Dim saveFileDialog1 As New SaveFileDialog()

        saveFileDialog1.Filter = "txt files (*.txt)|*.txt |CSV (*.csv)|*.csv| All (*.*)|*.*"
        saveFileDialog1.Title = "Save the results:"
        saveFileDialog1.FilterIndex = 2
        saveFileDialog1.RestoreDirectory = True
        If saveFileDialog1.ShowDialog() = DialogResult.OK Then
            System.IO.File.WriteAllText(saveFileDialog1.FileName, txtbox_results.Text)
        End If
    End Sub
End Class
```

Form 2

```
Public Class Form2

    Private Sub Button1_Click(ByVal sender As System.Object, ByVal e As System.EventArgs) Handles
Button1.Click
```

```
    If My.Computer.FileSystem.FileExists("P:\BMP_Toolbox_V_2\BMP_Toolbox_V_2_Solution\BMP
Toolbox\Resources\ExcelFiles\Concentration and Volume Data.xls") Then

        Process.Start("P:\BMP_Toolbox_V_2\BMP_Toolbox_V_2_Solution\BMP
Toolbox\Resources\ExcelFiles\Concentration and Volume Data.xls")

    ElseIf My.Computer.FileSystem.FileExists("C:\Program
Files\EML\RRCLIDF\Resources\ExcelFiles\Concentration and Volume Data.xls") Then

        Process.Start("C:\Program Files\EML\RRCLIDF\Resources\ExcelFiles\Concentration and Volume
Data.xls")

    Else

        MessageBox.Show("The file you requested is missing.")

    End If


  End Sub


  Private Sub Button2_Click(ByVal sender As System.Object, ByVal e As System.EventArgs) Handles
Button2.Click

    If My.Computer.FileSystem.FileExists("P:\BMP_Toolbox_V_2\BMP_Toolbox_V_2_Solution\BMP
Toolbox\Resources\ExcelFiles\Flow Tables.xls") Then

        Process.Start("P:\BMP_Toolbox_V_2\BMP_Toolbox_V_2_Solution\BMP
Toolbox\Resources\ExcelFiles\Flow Tables.xls")

    ElseIf My.Computer.FileSystem.FileExists("C:\Program Files\EML\RRCLIDF\Resources\ExcelFiles\Flow
Tables.xls") Then

        Process.Start("C:\Program Files\EML\RRCLIDF\Resources\ExcelFiles\Flow Tables.xls")

    Else

        MessageBox.Show("The file you requested is missing.")

    End If


  End Sub


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

```
    If My.Computer.FileSystem.FileExists("P:\BMP_Toolbox_V_2\BMP_Toolbox_V_2_Solution\BMP
Toolbox\Resources\ExcelFiles\Rough Data.xls") Then

        Process.Start("P:\BMP_Toolbox_V_2\BMP_Toolbox_V_2_Solution\BMP
Toolbox\Resources\ExcelFiles\Rough Data.xls")

    ElseIf My.Computer.FileSystem.FileExists("C:\Program
Files\EML\RRCLIDF\Resources\ExcelFiles\Rough Data.xls") Then

        Process.Start("C:\Program Files\EML\RRCLIDF\Resources\ExcelFiles\Rough Data.xls")

    Else

        MessageBox.Show("The file you requested is missing.")

    End If

  End Sub

End Class
```

Form 3

```
Public Class Form3


  Private Sub LinkLabel1_LinkClicked(ByVal sender As System.Object, ByVal e As
System.Windows.Forms.LinkLabelLinkClickedEventArgs) Handles LinkLabel1.LinkClicked

    Process.Start("http://www.usgs.gov")

  End Sub


  Private Sub LinkLabel2_LinkClicked(ByVal sender As System.Object, ByVal e As
System.Windows.Forms.LinkLabelLinkClickedEventArgs) Handles LinkLabel2.LinkClicked

    Process.Start("mailto:" & "pouyan@msu.edu")

  End Sub


  Private Sub LinkLabel3_LinkClicked(ByVal sender As System.Object, ByVal e As
System.Windows.Forms.LinkLabelLinkClickedEventArgs) Handles LinkLabel3.LinkClicked

    Process.Start("mailto:" & "prohask2@msu.edu")
```

```
    End Sub

End Class
```

Form 4

```
Public Class Form4


    Private Sub Form4_Load(ByVal sender As System.Object, ByVal e As System.EventArgs) Handles
MyBase.Load


    End Sub


End Class
```

Blueprint for integration of models into a Watershed Management Spatial Decision Support System

Basic Information

Title:	Blueprint for integration of models into a Watershed Management Spatial Decision Support System
Project Number:	2010MI166B
Start Date:	3/1/2010
End Date:	2/28/2011
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Congressional District:	8
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Descriptors:	watershed, integrated decision support system, water quality, and water quantity
Principal Investigators:	Yi Shi, Phanikumar S Mantha

Publications

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Descriptors: watershed, integrated decision support system, water quality, and water quantity
Primary PI: Yi Shi, Ph.D, Specialist-Research, Institute of Water Research, Michigan State University, East Lansing, MI 48823, shiyi1@msu.edu
Other PI: Phanikumar S. Mantha, Department of Civil and Environmental Engineering, Michigan State University
Project Class: Research

Introduction

Numerous environmental models characterizing watershed processes have been developed. However, these models have not been linked with either their required databases or together to provide support in watershed management decision making process in an operational manner. Connecting land use decision making and its environmental impacts on local watersheds via watershed models allows decision makers to identify the sources and factors that affect the delivery of pollutants to our water bodies. In this project, we compared several watershed models in terms of their strengths and weaknesses. We also evaluated approaches for integration of components from different models into a holistic spatial decision support system. Finally a blueprint is developed for a decision support system that incorporates model components with appropriate data at proper scales to provide useful information for local decision makers.

Blueprint for Integration of Models into a Watershed Management Spatial Decision Support System

Review of Hydrologic Models

Many hydrologic models have been historically developed to study different hydrologic systems. Models are often developed with specific scientific objectives in mind. Thus each model has its own strengths in some areas and may be inadequate in some other areas. For example, SWAT is designed as a long term water balance and non-point source pollution simulator *[Arnold and Allen,* 1996; *Arnold and Fohrer,* 2005]. Thus simulating short term point source pollution with SWAT may not be advantageous.

Broadly, there are two categories of models: conceptual and physically-based (or mechanistic). Generally, in conceptual hydrologic models (CHM), the modeler forms hypotheses, either from experience or his own perceptions, about the hydrologic processes and proposes mathematical formulations to represent these processes with sometimes strong simplifying assumptions. CHM are often based on empirical relations and conceptual state variables that cannot be always measured. Physically-based hydrologic models (PBHM), on the other hand, are derived deductively from established physical principles with appropriate assumptions and physically meaningful/measurable parameters *[Beven,* 2002]. Historically there have been heated discussions about the relative advantages and disadvantages of the two approaches. In 1966, the paper *[Freeze and Harlan,* 1969] laid out a blueprint for physically based hydrologic modeling, writing out the equations for different flow processes and the linkages via common boundary conditions. The development of such a physically based model in the years followed, however, has been limited by the computational power, data availability, understanding of the complex hydrologic system and, to a lesser extent, the accumulation of mathematical technique. *[Beven,*2002] has challenged that blueprint and provided an alternative blueprint to hydrologic modeling that is based on lumped conceptual models. These models do not use the process theory to build a model structure *a priori,* but rely on observed data to define an appropriate model structure (described by Beven as 'hypothesis testing').
He also stressed on the importance of quantifying the uncertainty of the models. With the advancement of computer power, Geographic Information System (GIS) and readily available databases, recently published models lean more and more toward the physically-based approach *[Karvonen et al,* 1999]. However, to date there does not seem to be a conclusion to that debate and the two schools of models continue to be created and advanced.

In fact, both types of models have their own advantages and disadvantages. Some of the notable conceptual models include TOPMODEL *[Beven and Kirkby,* 1979], DLBRM *[Croley and He,* 2005], Sacramento Soil Moisture Accounting Model (SAC-SMA) *[Burnash,* 1995], HEC-HMS *[HEC,* 2000], VIC-3L *[Liang and Xie,*2001; *Reed et al,* 2004], etc (also see *[Borah and Bera,* 2003; *Reed et al,* 2004]). Usually, conceptual models require less physical input as its components are idealized. The models tend to be structurally simple, computationally inexpensive and more easily operational. However, they need long term monitoring data to calibrate. The parameters generally cannot be applied for ungauged watersheds. Moreover, the conceptualization process blurs the underlying dynamics and extension of conceptual models

beyond the range of calibration is questionable *[Beven,* 1985]. It is not rare that a CHM that describes completely different physics from the study region and still get fair results after optimization, but the physics can be far from reality. In fact, a large number of papers have been published to quantify the uncertainties associated with the conceptual models (e.g. see *[Beven,* 2006; *Beven and Binley,* 1992; *van Griensven and Bauwens,* 2003; *Vrngt et al,* 2005; *Yang et al,* 2008], etc). The large uncertainties undermine the reliability of the model, especially since estimated parameters cannot be interpreted.

A review of current physically-based models, on the other hand, reveals that there is still much room for improvement, especially in achieving the right balance between process descriptions and computational demands. PBHM generally tend to be data intensive and computationally expensive and thus their applicability tends to be limited. The reported results from PBHMs are often simulations for small areas during short periods of time. The published comparisons with observations indicate that these models, as commented by *[Ivanov et al,* 2004a], are yet to emerge as the preferred tool for prediction and analysis. Some well-documented physically based hydrologic models include the MIKESHE model *[DHI,* 2001], Soil & Water Assessment Tool (SWAT) *[Arnold and Fohrer,* 2005], Water and Energy Transfer Process (WEP) model *[Jia et al,* 2001; *Jia et al,* 2006], CASC2D/GSSHA *[Downer and Ogden,* 2004b] and tRIBS *[Ivanov et al,* 2004b], etc. We must mention here that some regard SWAT as a semi-physically based model since considerable amount of empiricism is included in the model, as highlighted in section 3.2. Although almost all PBHMs still carry some level of empiricism, the models can be constrained much better by real data since most parameters are physically based.

Here we review six watershed-scale and one macro-scale (VIC) PBHM. In its completeness, watershed hydrologic models should incorporate several flow domains that cover various flow paths possible after rain drops to the ground: overland flow, unsaturated subsurface flow (the vadose zone model), saturated subsurface flow (groundwater flow) and channel flow. Water also exists in canopy interception, snowpack, biomass and depression storage. Besides the flow domain, one of the processes of utmost importance is the evapotranspiration, which on average is estimated to take out 70% of the rainfall in North America *[Jensen et al,* 1990]. In order to account for the seasonal dynamics of a watershed, a reasonable vegetation growth module should also be included. A sufficient PBHM should contain all of the relevant processes.

The InHM *[VanderKwaak and Loague,* 2001] is a processe-based model that integrates overland flow with the mixed form three-dimensional Richards equation for the subsurface. InHM simulations in showed that both the Horton and Dunne overland flow mechanisms can be important streamflow generation processes. The InHM simulations also suggested that accurate accounting of soil water storage can be as important as exhaustive characterization of spatial variations in near-surface permeability. However, the InHM is very computationally demanding such that it can only be applied at the plot-scale.

The GSSHA model, developed for the Army Corps of Engineers, evolved from CASC2D *[Downer and Ogden,* 2004b]. CASC2D uses Green and Ampt infiltration method *[Green and Ampt,* 1911] with redistribution (GAR) for moisture accounting. However, it has been found that the processes modeled in the CASC2D model cannot adequately describe watersheds where saturation excess is important *[Downer et al,*2002]. This research highlights the importance of

incorporating the correct processes in physically-based models and applying hydrologic models in the settings where they are applicable. In GSSHA, the subsurface flow component is improved by coupling the Richards equation with the groundwater flow equation. The height of the water table is provided as the lower boundary condition to the Richards equation. A constantly changing discretization is used to cope with the rise and fall of the groundwater table. This coupling approach will cause soil moisture profile to be inconsistent with the location of the groundwater table. Moreover, it is difficult to evaluate the potential of GSSHA or CASC2D as a large-scale long term analysis tool as most of the published results are for small catchment areas in a short time frame (<200 days). The comparison is also limited to streamflow measurements.

The WEP was originally developed by *[Jia et ah*, 2001] and applied in Japan to a small size urban watershed. Later, it was expanded into a large scale version WEP-Land applied to a very large basin — the Yellow River Basin in China *[Jia et ah*, 2006]. The WEP model uses the mosaic approach which allows sub-grid heterogeneity to be parameterized. Three layers of soils are defined in the model and water is allowed to move only vertically in the soil. The soil layers are connected to the unconfmed aquifer which is modeled using the Boussinesq equation. The proposed model shares some similarities in the structure with the WEP model. The results reported for both the Japanese watershed and the Yellow River basin are promising. Unfortunately, this model is not available so direct comparison is not possible. It is felt that applications to some medium-sized watersheds with different hydrologic settings and geologic configurations may help further illustrate the general applicability of the WEP model.

[Panday andHuyakorn, 2004] details the processes included in the MODHMS model, which is a commercial package. Overland flow exchange with channel is modeled as flow over a rectangular weir. A similar approach is used by the proposed model. The subsurface is modeled with a variably saturated 3D flow model. 3D modeling is generally considered to be computationally too expensive for watershed-scale modeling. Since in this paper no application to real watershed is presented, we cannot assess the applicability of this approach.

tRIBs uses a unique Triangular Irregular Network (TIN)-based discretization and thusis thought to be capable of more properly capturing the spatial heterogeneity in topography, land use or soils. However, the mapping of data into the triangular element ('Voronoi Regions' in the original paper) requires special mesh generation and processing procedures, which can be non-trivial for other modelers. The tRIBs model has been applied to several medium-sized watersheds *[Ivanov et al*, 2004a] and obtained reasonable results. More recently, a sophisticated weather generator *[Ivanov et al*, 2004b] and a vegetation growth module have been added to the model. The impact of topographic controls has been studied in detail, prompting new directions of catchment hydrology *[Ivanov et al*, 2008a; b].

The MIKE-SHE model is a commercial hydrologic model that contains comprehensive modules. The model was developed in Europe. It has an ID Richards equation for the unsaturated zone linked to the groundwater aquifers. 3D groundwater flow is simulated. Procedurally, 3D saturated flow modeling is not very much different from 2D modeling. The difficulty is mainly with the unsaturated vadose zone. To be able to simulate transport process in a 8.7 km^2 watershed, *[Thompson et al*,2004] created a MIKESHE model with a 30x30m grid.

We believe the applicability of Physically-based hydrologic models can be improved by finding the right balance between processes, data and computation. With proper components integrated in a new modeling framework in a spatial decision support system, physically-based hydrologic model can provide valuable information for local environmental decision makers.

Blueprint for Integrated Watershed Management Spatial Decision Support System

Extensive resources are available for implementing best management practices (BMPs) and other improvements in the landscape of a watershed. Presently no system is available to effectively guide the location and application of these practices in such a way as to be complementary of practices with one another, and to maximize the economic development and ecosystem health benefits. A detailed physically-based hydrologic model can provide decision makers much needed information about the potential impact of BMPs and other environmental measures. But to make it usable to local decision makers, a user friendly watershed management spatial decision support system based on GIS needs to be developed. Such a system will integrate the physically-based hydrologic model into the GIS system seamless so end users can directly prepare all spatial and other related data within the GIS system and run the model for different management scenarios to evaluate pros and cons. The detailed steps for implementing this system are described below:

1. Development of a new improved physically-based hydrologic model.
2. Development of a GIS interface for the new model.
3. Development of a coupled management scenario simulator.
4. System integration and overall user interface development.
5. Application of the system to selected study watersheds.

Next Steps

The initial development of the new improved physically-based hydrologic model called Process-based Adaptive Watershed Simulator (PAWS) has been done. This model simulates evapotranspiration, overland flow, channel flow, unsaturated soil moisture, groundwater flow, depression storage, vegetation growth and snowpack. PAWS focuses on the dynamic surface-subsurface interactions and integrated responses by efficiently coupling runoff and groundwater flow to the vadose zone processes governed by the Richards equation. The model is applied to a medium-sized watershed in Michigan achieving high performance metrics in terms of streamflow prediction at two gages during the calibration period and the verification period. The baseflow flow periods are described particularly well. Starting from a rough initial estimate of the groundwater heads, the model describes the observed groundwater heads well (R^2 =0.98). The annual hydrologic fluxes are close to those estimated by a calibrated SWAT model. The model is considerably less expensive than previous physically-based models of similar complexity. To make this model more accessible to decision makers, a user friendly GIS interface needs to be developed first so a local resource manager without hydrology background can prepare the data and run model for different management scenarios. The project team is currently in the planning phase of this future task.

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USGS Award No. G10AC0034 Continued Technical Support of MI Water Withdrawal Assessment Process & Development of an Internet-Based Water-Use Database

Basic Information

Title:	USGS Award No. G10AC0034 Continued Technical Support of MI Water Withdrawal Assessment Process & Development of an Internet-Based Water-Use Database
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Descriptors: Conjunctive Use
Primary PI: Jon Bartholic, Director, Institute of Water Research, Michigan State University, East Lansing, MI 48823, bartholi@msu.edu
Other PI: Jeremiah Asher, GIS Specialist, Institute of Water Research, Michigan State University
Project Class: Research

Introduction

On July 9, 2008, Michigan Public Act 185 of 2008 became law. A water withdrawal assessment process and screening tool was developed in 2006-09 by the Michigan Ground Water Conservation Advisory Council in consultation with the Departments of Environmental Quality, Natural Resources (MDNR) and Agriculture, and a Technical Advisory Committee appointed by the Council. Scientists from U.S. Geological Survey (USGS) and the Institute of Water Research at Michigan State University (IWR) played important roles in the Technical Advisory Committee and continue to work with similar committees formed under the auspices of the new Michigan Water Resources Conservation Advisory Council (WRCAC).

Since the early 1900's, the USGS has published over 50 regional or county-scale studies of groundwater resources in Michigan, including those in bedrock and glacial aquifers. Furthermore, USGS has considerable expertise and experience in Michigan and nationally in the area of quantifying ground-water/surface-water interactions, a scientific issue central to development of the water-withdrawal assessment tool. The USGS Cooperative Streamgaging Network provides the basis for computation of streamflow statistics that are a key component of the prototype tool developed in 2006-07. USGS and IWR scientists were members of the Technical Advisory Subcommittee of the Ground Water Conservation Advisory Council that developed the water-withdrawal assessment process and screening tool. The USGS also recently completed, in a cooperative effort with MDEQ and Michigan State University (MSU), a statewide groundwater inventory and map in response to Public Act 148 of 2003. This inventory and map has key linkages to the water-withdrawal assessment tool.

Problem and Research Objectives

Provide technical scientific guidance to the Departments of Environmental Quality and Natural Resources in the support of technical committees of the WRCAC implementing, testing, and improving the water-withdrawal assessment process and screening tool. This support will include (1) research to improve the hydrologic framework used to underpin the assessment process and screening tool, and (2) research to determine the extent to which lakes and wetlands can be included in the assessment process. IWR will lead work with MDEQ to develop a water-

use database that is accessible through the internet and will work in conjunction with Water Withdrawal Assessment Tool (WWAT) and Water Withdrawal Accounting Ledger (WWAL).

Methodology

A description of the approach to completing the project objective, including a workplan, milestones, review schedule, and interim products will be mutually agreed upon among USGS, MDEQ, and the Institute for Water Research at Michigan State University (IWR). All of the work on this project will require substantial collaboration and communication among these parties. All major decisions regarding the product and approach will be agreed upon by these parties. Major tasks, products, and budgets for USGS and IWR follow.

USGS

Currently, the parties have agreed upon the following tasks. The major USGS roles will be related to tasks 1, 2 and 3. Note that MDEQ is the lead for task 4 and both IWR and USGS providing support for this task.

1. Develop and test methods to improve estimates of index flow using a regression method that is constrained to the flow network and observed flows at stream gages.
2. Provide technical support to the DEQ in the development of future enhancements of the Water Withdrawal Assessment Tool.
3. Provide technical support to the Lakes and WWAT Evaluation Subcommittees of the WRCAC.
4. Continue to support on-line screening tool testing and to provide suggestions for its improvement.
5. Assist in development of the water use database to ensure it can be used by the USGS in the National Water Use Compilation project and Great Lakes efforts to manage the water resources of the Great Lakes Basin.

IWR

Currently, the parties have agreed upon the following tasks. The major IWR roles will be related to task 1. Note that MDEQ is the lead for task 3 and both IWR and USGS providing support for this task.

1. Develop a water-use database and associated internet-based interface to work with the WWAT and WWAL.
2. Provide technical support to the DEQ in the development of future enhancements of the WWAT and WWAL.
3. Continue to support on-line screening tool testing and to provide suggestions for its improvement.

Products

USGS will participate in technical subcommittees of the WRCAC and will provide information to these committees in a timely manner. USGS, IWR, MDNR, and MDEQ will agree upon a schedule of presentations and meetings regarding the improvement of index flow estimates and support of the on-line screening tool. These presentations and meetings will be regarded as interim products that show progress toward completion of the project and which constitute a basis for billing and ongoing funding.

The USGS may publish peer-reviewed USGS reports or journal articles that document parts of the assessment tool or processes in consultation with MDEQ.

Principal Findings and Significance

The water-withdrawal assessment process and screening tool will provide critical planning and regulatory information needed by multiple parties in the State of Michigan and the Great Lakes Watershed to make sound decisions regarding water withdrawals. Improving the hydrologic framework underlying both the process and the screening tool will provide better information and increase confidence in the methods used to evaluate the environmental impact of water withdrawals. This tool should have broad transferability to other parts of the nation with similar hydrologic characteristics or database information availability. A major improvement to the process will be the addition of an on-line water-use database. This database will assist MDEQ and MDNR in managing the water resources of the State and contribute to regional efforts in the management of the waters of the Great Lakes.

Products

The final product will be an on-line water-use database. Upon project completion, no later than January 31, 2011, the product will be delivered to MDEQ. The product will be designed to be hosted by the State of Michigan, Department of Information Technology after the delivery date.

USGS, IWR, MDNR, and MDEQ will agree upon a schedule of progress reviews, presentations, and demonstrations throughout the course of development of the final product and upon the agencies or organizations to be present at these reviews and presentations. Reviews and presentations will be regarded as interim products that show progress toward completion of the project and which constitute a basis for billing and ongoing funding.

The IWR may publish peer-reviewed reports or journal articles in consultation with MDEQ.

Publications

Reeves, H.W., D.A. Hamilton, P.W. Seelbach, and A.J. Asher. 2009. Ground-Water-Withdrawal Component of the Michigan Water-Withdrawal Screening Tool: U.S. Geological Survey Scientific Investigations Report 2009-5003 (36 pages).

USGS Award No. G10AP00153 The Great Lakes Tributary Modeling Program 516(e): Purdue University and Michigan State University

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Descriptors: Spatial Decision Support System
Primary PI: Jon Bartholic, Director, Institute of Water Research, Michigan State University, East Lansing, MI 48823, bartholi@msu.edu
Project Class: Research

Introduction

Over the past decade, the Institute of Water Research (IWR) and the U.S. Army Corps of Engineers (USACE) have developed a strong working relationship through the Great Lakes Tributary Modeling Program. This relationship has yielded research on sediment loadings at multiple scales, GIS models for erosion and sediment loading risk, new and advanced modeling algorithms, multi-scaled prioritization maps, and on-line decision support systems to help users maintain and restore water quality in their watersheds. These achievements have been published in scientific journals, presented at numerous conferences, and disseminated through hands-on workshops. As a new decade begins, IWR seeks to strengthen its partnership with USACE by building off of these earlier achievements to create new and more advanced decision support systems, faster and more efficient models, for broader geographic areas and larger, more diverse user-groups. The end result will be better tools in the hands of more decision makers, which will help keep more sediment on the land and out of the Great Lakes.

Problem and Research Objectives

Project Description

IWR, in coordination with Purdue University, will develop four on-line water-quality management (sediment reduction) decision support systems for four priority watersheds identified by the U.S. Environmental Protection Agency as part of the Great Lakes Restoration Initiative:

- Saginaw River (Lake Huron - MI)
- Genessee River (Lake Ontario - NY)
- Maumee River (Lake Erie - OH)
- Fox River (Lake Michigan - WI)

The 2010-2011 project will involve three main components: modeling, system design/development, and outreach/tech transfer.

IWR will generate High Impact Targeting (HIT) models for each of the watersheds, utilizing the best available local data it can acquire. The HIT models will quantify erosion and sediment loading in each of the watersheds, and produce GIS layers identifying areas within fields where erosion and sediment loading is likely taking place.

USACE supported IWR and Purdue in the development of similar systems, Burns-Ditch/Trail Creek in 2007 and Swan Creek in 2009. The Swan Creek Watershed Management System (SCWMS) helps users identify and utilize tools to address agricultural and urban water quality issues in and around Toledo, OH. The proposed new systems for the Saginaw, Genesee, and Maumee watersheds will utilize the SCWMS as a template. For the Fox River watershed, IWR will develop a new interface that better integrates the tools of the SCWMS into a single mapping application. Through its success, the Fox River system could serve as a new decision support system template, readily expandable and scalable throughout the Great Lakes Basin.

IWR will engage local partners in each of the watersheds to solicit user needs and feedback, and to facilitate technology transfer. In the Fox River, IWR will conduct in-person hands-on training for users of the new system. In the other watersheds, IWR will conduct webinars illustrating the new systems' utilities.

Methodology

Modeling

As part of previous work IWR completed for USACE, HIT models already exist for all four of this project's study watersheds. These models were created in the development of a Great Lakes Basin-wide HIT model. However, these models are relatively coarse and generalized. In order to generate such a small-scale model IWR had to utilize 30-meter Digital Elevation Models (DEMs) to characterize surface-water flow, make assumptions about farming practices across entire states, utilize state-wide soil surveys (STATSGO – 1:100,000 scale), and incorporate medium-resolution stream location data (National Hydrography Dataset – 1:100,000 scale). For this project, IWR will generate new and finer models, utilizing (where available) 10-meter DEMs, county-level crop and tillage acreages, county-level soil-surveys (SSURGO – 1:24,000 scale), and high-resolution stream locations (NHD – 1:24,000 scale).

System Design/Development

As mentioned earlier, the decision-support systems for the Saginaw, Genesee, and Maumee River watersheds will be based upon the template of the SCWMS. The systems will include a question-oriented front-end helping users define their problem and select an appropriate tool to address that problem. For example, if a user is interested in prioritizing sub-watersheds by sediment BMP cost/benefits then she will be guided to HIT and provided appropriate instruction. If a user wants to estimate specific nutrient loadings from an urban location he will be guided into Purdue's L-THIA (Long Term Hydrologic Impact Assessment). If a user wants to identify and analyze impaired waters in a particular location, she will be guided into Digital Watershed. In coordination with IWR, Purdue will improve its existing back-end mapping applications that allow users to digitize and evaluate land-cover change scenarios.

IWR and Purdue will develop a more advanced and integrated on-line system for the Fox River Watershed. Whereas in the SCWMS users are routed into the various tools' individual interfaces, the Fox River system will link all of the analysis tools into a single mapping interface. For example, tables of HIT watershed prioritizations will be accessible from the Fox River map, as opposed to being generated separately in the HIT mapping interface, which users must do in the SCWMS. L-THIA analyses will delineate local watersheds and display results on the Fox River Map, as opposed to being spread over several browser windows. Most data layers of Digital Watershed will also be accessible through the single Fox River map interface. The end result is a single, simple window through which users can analyze a broad spectrum of data related to sediment management and water quality protection.

As IWR receives feedback on the Fox River system it will refine the system so that it will be expandable to other project watersheds, as well as other parts of the Great Lakes region.

Principal Findings and Significance

Outreach / Tech Transfer

In the development of the SCWMS IWR partnered with the Toledo Metropolitan Area Council of Governments (TMACOG) and the Lucas County Soil and Water Conservation District to get user feedback on the system and coordinate tech transfer. Both groups were well-connected to the types of users best served by the features of the SCWMS, such as watershed groups, planners, and researchers, among others. These connections provided IWR with opportunities to demonstrate the system during its development stage and receive critical inputs on design and utility. TMACOG also coordinated a hands-on workshop at the end of the project, allowing users from diverse sectors of the labor force to interact with and provide additional feedback on the system.

For this project, IWR will seek out similar partnerships with local groups and agencies in the selected watersheds. IWR will dialogue with these partners as their respective systems are in development, and attempt to tailor the systems to each partner's identified needs and inputs. Upon completion of the Genesee, Maumee, and Saginaw systems IWR will hold a webinar for each watershed where attendees can learn about their respective system and follow instructor-led tutorials on their own computers. For the Fox River Watershed, a hands-on workshop similar to the one held for the SCWMS will be held with local users in the watershed.

This project is in the beginning phase and was presented at the ACOE All Hands meeting May 17-18, 2011 at the Kensington Court Hotel, Ann Arbor, MI called by Jan A. Miller.

Information Transfer Program Introduction

Information is readily accessible in today s society at the click of a button. However, that information can come from any source without any oversight, peer-review, or science to back up its claims. Thus, it is important that science-based information is also readily available and easily accessible to the general public and specific user groups. With a reputation for dependable and accurate information, one important role of Universities is to provide current, reliable, nonbiased and readily transferable information to a wide audience in formats that are easily understood via the web but also in alternate formats. Thus, an effective information dissemination program will provide research-based information to a wide and often diverse audience, and offer alternative solutions to problems being addressed.

The Institute of Water Research's (IWR) Technology Transfer and Information Dissemination program addresses key water issues facing the citizens of Michigan. Through this program, the IWR staff: 1) develop and present educational programs designed to increase the public's awareness, knowledge and appreciation of the water quality and quantity problems in Michigan; 2) stress the environmental and economic trade-offs required to solve real world water related problems; 3) address high priority and emerging issues; 4) evaluate the projects disseminated and incorporate lessons learned into new programs; 5) develop programs in a variety of formats that suit the needs of individuals and user groups, including conferences, seminars, training workshops, computer models, web-based programs, and printed material; and 6) coordinate and develop multidisciplinary projects with extension educators within Michigan State University Extension, other agencies, and faculty on campus to make water-related information readily available to a vast clientele across the state.

Information Dissemination and Technology Transfer Training Programs

Basic Information

Title:	Information Dissemination and Technology Transfer Training Programs
Project Number:	2010MI164B
Start Date:	3/1/2010
End Date:	2/28/2011
Funding Source:	104B
Congressional District:	8
Research Category:	Water Quality
Focus Category:	Education, Surface Water, Groundwater
Descriptors:	Water Quality, Water Quantity, Watershed Management, Macroinvertebrates
Principal Investigators:	Lois G Wolfson

Publications

1. Krizek, Allen, Wolfson, Lois G., Herbert, Jane. 2010. "What Can You Do to be Phosphorus Smart?" MSU Bulletin E-3135. Michigan State University Extension, East Lansing, MI.
2. Reeves, H.W. and J.A. Asher. 2010. Internet-based interface for STRMDEPLO8: US Geological Survey Open-File Report 2010-1247, 17 pp.
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6. Wolfson, Lois. 2010. Harmful Algal Blooms on the Rise. 2010. Lake Effect: Vol. 2. February 2010. Michigan Chapter, North American Lake Management Society. Pages: 6,9.
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INFORMATION TRANSFER PROGRAM

The following programs were coordinated, developed and delivered for fiscal year 2010-2011.

Conferences

The Institute has developed a number of conferences that focus on key priority issues for the IWR and the State. For its 20th year running, the annual Great Lakes conference highlighted some of the most critical issues facing the Great Lakes ecosystem. Titled, The Great Lakes: Learning from the Past, Looking Toward the Future, the conference included presentations on climate change impacts on water levels and food webs, the potential introduction and problems relating to Asian Carp, the near-shore shunt and muck problems, and wind energy issues. The IWR took the lead in cosponsoring the conference along with its partners, the Michigan Sea Grant Extension Program, MSU Department of Fisheries and Wildlife, and The Office of the Great Lakes, Michigan Department of Environmental Quality. A standing room only audience of over 200 people attended the conference including state and local agency personnel, researchers and educators, environmental organizations, and interested citizens. Over 95% of people submitting evaluation forms rated the conference as excellent or very good.

The State of Michigan Source Water Protection Conference is an annual joint effort between the Michigan Department of Environmental Quality and IWR, focusing on surface water-groundwater interactions, pollution prevention, wellhead protection, and health issues. It is largely targeted at local public health departments and district agency personnel. Approximately 100 attend this annual meeting.

IWR teamed up with the Michigan Chapter of the North American Lake Management Society to co-sponsor a conference focusing on inland waters. The conference, "Taking Charge: Lake and Shoreline Management at the Local Level, addressed the benefits of native shorelines, effects of woody debris on fish populations, low impact development and ordinances for lake shorelines, and steps to become a lake leader. The conference attracted nearly 100 individuals and evaluations indicated that participants will use the information presented in their lake-related activities.

Internet-Based Programs

The IWR staff continues to build upon their widespread web-based decision support systems that enable citizens to make science based informed decisions through the aid of computer models, extensive data, and visual programs. Staff employees are continually upgrading the software, incorporating new models, and writing code to enable seamless entry to other web programs such as Bing Maps, Google Earth, and social networks. With funding from several sources, the IWR has been able to address a variety of water-related issues, and offer models, visualization, and seamless GIS capabilities for users. Examples of these systems include: the Water Withdrawal Assessment Tool, a legislatively designated program for large capacity wells owners to register their wells, High Impact Targeting for prioritizing areas of high erosion risks, Networked Neighborhoods for Eco-conservation Online, a program that is utilizing social networks and web-based mapping to assist users in implementing low impact practices and determining the amount of water managed or captured within the watershed; and Social Indicator Data Management and Analysis (SIDMA), a program that helps communities, particularly 319 projects, evaluate behavior changes that have occurred as a result of their watershed management activities. The nation-wide capabilities of Digital Watershed and its links to hydrologic and land use models continues to be

reassessed and upgraded annually. The IWR also continues to produce a periodic on-line newsletter, *The Watershed Post*. This electronic newsletter provides the most current information on Institute activities as well as general articles of interest. Contributions are made by faculty, staff, and students.

Aquatic Ecology Training

The IWR provided support to a variety of educational programs, by helping in their development, serving as a resource, giving lectures and implementing hands-on experiential learning. For FY 2010, workshops included the Conservation Stewards Program, Inland Lakes Program, Oakland County Waterfront program, and Volunteer Monitoring program. All of these sessions were directed to a variety of participants, such as local decision makers, agency personnel, watershed organizations, and interested citizens. Evaluations were very positive for all programs. Participation averaged 20-25 people per session.

Lake and Stream Leaders Institute Alumni Program

The Lake and Stream Leader's Institute provides an educational experience that seeks to improve participant's understanding of local water resource management planning and program implementation. Participants in the alumni program are those from previous year's classes and include University professors from other fields, drain commissioners, organization representatives and state and local government personnel, Extension personnel, and interested citizens and riparians. Although a program was offered for this year, there were not a sufficient number of respondents to justify the expense and time of running the program and bringing in speakers. Thus, the session was cancelled. Another session will be offered in 2011 to continue the program.

Exhibitions and Demonstrations

MSU's Ag Expo, an agricultural oriented exposition is held annually during summer to highlight the work of MSU in the area of agriculture. Each year the IWR features an educational exhibit that relates water quality to agricultural practices. This year's exhibit focused on phosphorus impacts on water quality and low impact development practices. Approximately 20,000 people attended the 3-day event with about 1000 visiting the tent where the IWR exhibit was held. The IWR will also participated in a variety of University-sponsored or on campus one day events that showcased the University's role in science based education. These includes Grandparents' University, AutumnFest , FFA days, the Michigan Science Olympics State finals, and the Children's Water Festival.

Lectures and Seminars

A variety of presentations in the form of guest lectures and seminars were provided by IWR staff members on issues such as stormwater and LID practices, exotic species, stream monitoring, water withdrawals and the water withdrawal assessment tool, wellhead protection, and indicator species for water quality testing. Staff members also give class lectures in the Departments of Fisheries and Wildlife, Community and Agriculture, Recreation and Resource Systems. Audience or class participation ranges from approximately 25 to over 100 for each presentation.

In-house Contributors

The IWR's technology transfer program is under the direction of Principal Investigator Dr. Lois Wolfson, with several IWR personnel contributing to the project, including Dr. Jon Bartholic, Ruth Kline-Robach, Jeremiah Asher, Glen O'Neil, Stephanie Smith, and Yi Shi.

USGS Summer Intern Program

None.

Student Support					
Category	**Section 104 Base Grant**	**Section 104 NCGP Award**	**NIWR-USGS Internship**	**Supplemental Awards**	**Total**
Undergraduate	0	0	0	0	0
Masters	2	0	0	0	2
Ph.D.	1	0	0	0	1
Post-Doc.	0	0	0	0	0
Total	3	0	0	0	3

Notable Awards and Achievements

Michigan's Innovative Tool for Water Withdrawal Process Wins Two Awards

The Michigan Water Withdrawal Assessment Tool (WWAT), an innovative tool that gives an initial, screening-level assessment of the impact of a potential water withdrawal on local stream and river ecosystems, recently was honored with two national awards.

The application won the Outstanding Achievement Award for 2010 from the Renewable Natural Resources Foundation, and was one of four innovations to receive the State Program Innovation Award from the Environmental Council of States.

"It is a great achievement that the Water Withdrawal Assessment Tool has been recognized nationally for its innovation and many uses for applying science in the management of our state's water resources," said Department of Natural Resources and Environment Director Rebecca Humphries. "This tool has helped the state better manage our resources and has safely accelerated the water withdrawal request approval process without an onerous burden on the users."

The WWAT is an innovative program designed to prevent large surface or groundwater withdrawals that would have an adverse affect on the natural resources, habitat and ecosystems of Michigan s streams and rivers. It was developed to protect water resources without imposing a burdensome permit process. It is part of a Great Lakes-wide effort to protect overall water resources and prevent large diversions of water from the Great Lakes basin.

Since its introduction in 2009, the WWAT has been used extensively to assess more than 200 large capacity water withdrawals (more than 100,000 gallons a day). Nearly 80 percent of the assessments were automatically registered and authorized to begin their withdrawals. The remaining 21 percent were held back for site-specific reviews by the DNRE staff.

The WWAT determines what management zone a proposed water withdrawal falls in, and provides instructions on what to do. The results page also presents options to the user on how to revise their proposal to avoid a problem. The revision options include reduce the pumping frequency, reduce the pump capacity, increase the well depth, and relocate the well farther from nearby streams. These measures all tend to reduce a well s impact on a stream, and may allow a revised proposal to receive the authorization to proceed.

The DNRE is committed to the conservation, protection, management and accessible use of the state's environment, natural resources and related economic interests for current and future generations. For more information, go to www.michigan.gov/dnre.

Funding Agency: USGS Michigan Water Science Center, MDEQ