REPORT NO: TB-0515

PROJECT NO: MCD05A

DATE: October 13, 2005

TYPE: **TECHNICAL REPORT**

TITLE:

SUBSTRUCTURE FLOODING POTENTIAL OF THE GREAT MIAMI RIVER AQUIFER CITY OF DAYTON MONTGOMERY COUNTY, OHIO

AUTHORS: Kelly C. Smith, CPG
Brent E. Huntsman, CPG
Terran Corporation

PREPARED FOR:
The Miami Conservancy District
Groundwater Preservation Program
38 E. Monument Avenue
Dayton, Ohio 45402-1265
Attn: Michael Ekberg

TABLE OF CONTENTS

TABLE OF CONTENTS (cont.)

LIST OF FIGURES

LIST OF TABLES

LIST OF TABLES (cont.)

APPENDICES

1.0 EXECUTIVE SUMMARY

The Miami Conservancy District (MCD) was originally formed to control and manage flood waters as a result of the March 1913 flood. Since then, the MCD mission objectives and goals include protecting lives, property, and economic vitality within the Great Miami River Watershed through an integrated and balanced system that provides unfailing flood protection, preserves water resources, and promotes enjoyment of the Great Miami River watershed.

Since the 1970s, groundwater in the Great Miami River aquifer has been rising, primarily due to declines in groundwater pumpage associated with industry over the years. As a result, the incidents of basement flooding has increased in areas along the Great Miami River water shed, causing building owners and managers to seek methods to prevent future flooding damage. In an effort to manage the risk of basement flooding, the MCD commissioned Terran Corporation to construct a computer groundwater model of the Great Miami River aquifer and identify areas of potential for basement flooding based on stream recurrence intervals for the Great Miami River in the City of Dayton, Ohio.

The U.S. Geological Survey modular, finite-difference computer model MODFLOW was used to construct the aquifer flow model. The stream-flow routing module was used to simulate the groundwater and stream flow interactions between the Great Miami River, its tributaries and the aquifer system. The model was calibrated to groundwater information of the Great Miami buried aquifer system, collected by the U.S. Geological Survey in 1993. Simulations were conducted for flood recurrence intervals of 10-years, 50-years and 100-years based on flood stream flow and flood elevations calculated by the Federal Emergency Management Agency (1987). The simulations were conducted as steady-state conditions with all known dewatering wells turned off in order to produce the most conservative water level estimates for substructure flooding. Each simulation's groundwater potentiometric surface was then transposed upon a base map of the Dayton area. To identify areas with potential for substructure and basement flooding, a depth of 10 feet below ground surface was used to define the minimum depth for groundwater seepage into a substructure or basement. Areas with a difference of 10 or less feet between the ground surface elevation and the simulated water table elevation were then identified as zones with potential for substructure flooding.

Results of this study indicate that areas with potential for substructure flooding are found most commonly along the outwash aquifer of the Great Miami River and its tributaries where land surface elevations range from 720 to 750 feet mean sea level. Structures that occur on the kames and ground moraines at an elevation of 750 feet mean sea level or higher in the downtown Dayton area appear to have some measure of natural protection against substructure flooding due to their elevation above the river flood plain. However, this is not an all encompassing measure of protection as site specific conditions may contribute to substructure flooding such as deep basements, drainage ditches, sanitary sewers, storm sewers and localized geologic/hydrogeologic conditions.

2.0 BACKGROUND

2.1 Purpose

The study area encompasses the major metropolitan area of the City of Dayton, Montgomery County, Ohio (Figure 2.1). Situated along the Great Miami River and the tributaries of the Mad River and Wolf Creek, the City of Dayton has tremendous groundwater resources available through the Great Miami River buried valley aquifer system. This aquifer system supplies drinking water to the City of Dayton and many of its surrounding suburban neighborhoods by way of the Mad River and Miami River well fields. Many industries throughout the years have used this resource to supply water for heating and air conditioning, and manufacturing purposes.

During the mid-1970s, groundwater levels in the Great Miami River aquifer rose in elevation, primarily due to declines in industrial groundwater pumpage (Figure 2.2). The rise in water table caused a resulting decrease in the available aquifer storage capacity, thus providing less room in the aquifer to accommodate surface water infiltrating into the aquifer from flood events along the Great Miami River. This in turn has led to more frequent and severe basement flooding in some areas of Dayton, especially for buildings with substructures designed and constructed before the mid-1970s. For instance, the Montgomery County Administrative building, located in downtown Dayton, has been experiencing substructure flooding in recent years during certain flood events along the Great Miami River. The Montgomery County Administrative building was designed and constructed during the late-1960s when the water table was at its lowest on record (Figure 2.2.)

Susceptibility to substructure or basement flooding is contingent upon several factors including building proximity to the Great Miami River, the land surface elevation, depth to the water table, the depth of the building basement, and the types and capacity of preventive equipment available (i.e. sump pumps, dewatering wells, floor drains, etc). During the summer months when the water table is seasonally low, basement flooding is not a common problem because of the available storage capacity of the aquifer to adsorb base flow from the river. However, during times of high water tables, such as during the winter months, or during exceptionally rainy seasons, much of the aquifer available storage capacity is already filled, causing the aquifer water levels to flood basements. Dewatering systems, such as foundation drains and sumps, help prevent elevated water levels from seeping into substructures when properly designed, constructed and operated. However, for many buildings designed and constructed during the late 1960s and early 1970s, the rise in groundwater water levels during the late 1970s is now causing substructure drainage systems to operate year round. This year round system operation costs building owners in terms of electrical consumption, equipment maintenance and labor wages to manage the situation. The problem is further compounded when flooding occurs along the Great Miami River. Floods along the river cause the water table near the river to rise rapidly and may overwhelm substructure dewatering systems, causing basements to flood and resulting in further expense to manage and repair the water damage.

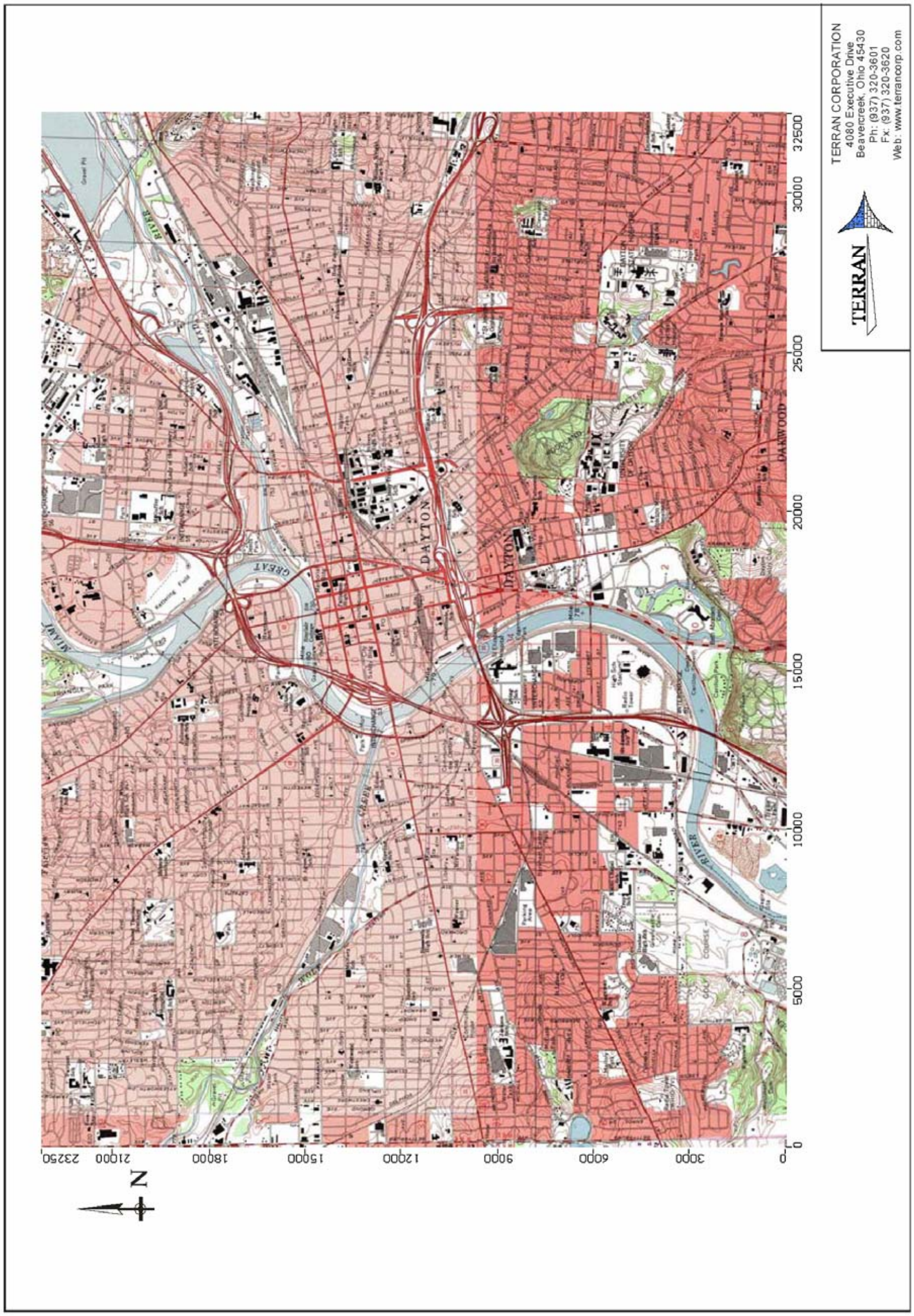

Figure 2.1, Study Area for Substructure Flooding Potential, Dayton, Montgomery County, Ohio.

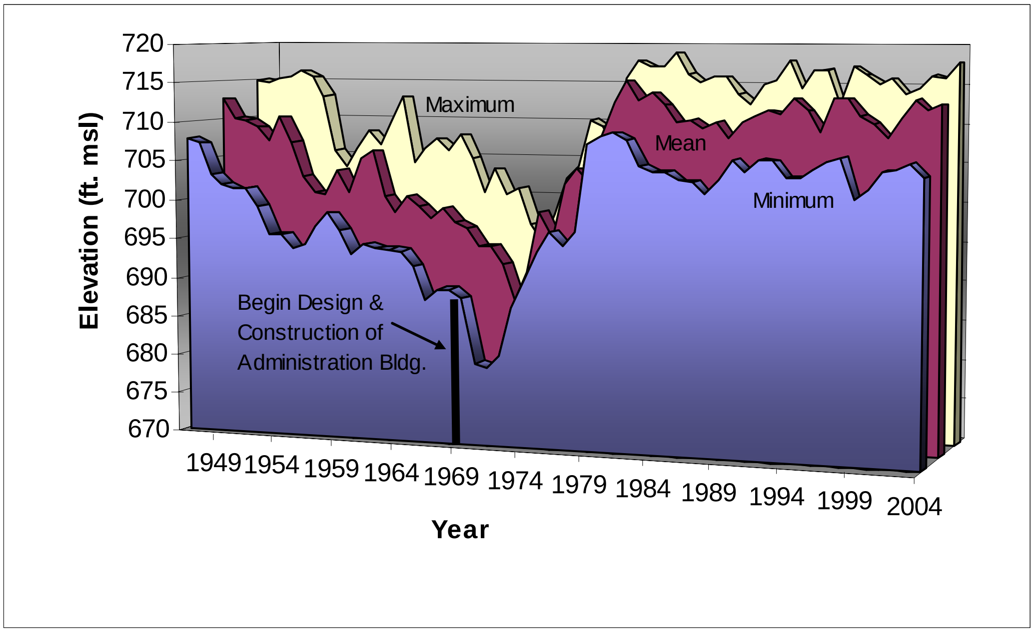

Figure 2.2 Groundwater Levels in the Great Miami River Aquifer since the 1940s, City of Dayton, Ohio

2.2 Project Scope of Work

The objective of this project was to determine the areas most vulnerable to basement flooding in the downtown Dayton area along the Great Miami River for the purpose of planning and crisis management. To accomplish the objective, a computerized model of the Great Miami River aquifer was needed to represent and simulate the surface water/subsurface (aquifer) system. This computer model must be capable of simulating both groundwater and stream flow interactions. The U.S. Geological Survey finite-difference computer model MODFLOW was selected for use in this study.

Four tasks were proposed for this project: Task 1, Data Collection and Review; Task 2, Computer Model Construction; Task 3, Computer Model Simulations; and Task 4, Results Documentation and Reporting. Task 1 entailed the collection and review of available geologic, hydrogeologic, and operational data that pertains to the study area. Available copies of Dayton area subsurface investigations, aquifer testing reports and supporting operation data were collected and reviewed, including various governmental, university and private sources such as the U.S. Geological Survey (USGS), The Ohio Dept. of Natural Resources, Divisions of Geological Survey and Water, consultant models/reports and others. These resources were reviewed for pertinent information to develop a conceptual understanding of the geologic and hydrogeologic properties of the subject area.

Task 2 involved the construction of the model input files to simulate the Great Miami River, its tributaries and the aquifer. The model was constructed in layers then calibrated to available surface water and groundwater potentiometric surface data for the area. A sensitivity analysis was completed to identify the parameters of greatest impact on the model results.

Task 3 entailed the simulation of flooding events based on recurrence intervals for the aquifer system. The simulations were used to predict groundwater levels in the aquifer system in response to flooding events. These predicted levels were then used to identify areas most vulnerable to basement flooding as a result of elevated water tables.

Task 4 was the preparation of a report summarizing the results of the study. The report presents the computer modeling results with a basic description of the model domain, boundary conditions, model assumptions, and aquifer yield calculations. The sensitivity analysis results were tabulated for ease of review and presented in the report (Appendix A).

In addition to a technical report summarizing methods, procedures and results of this study, Task 4 deliverables include a graphical representation of the substructure flood potential which could be integrated into MCD's geographic information system (GIS).

2.3 Bibliography and Information Resources

Because of the abundant groundwater resources in Montgomery County, the region encompasses many investigations, studies and related sources of geologic and hydrogeologic information. The types of available information used in this study include the following categories:

- Hydrogeologic/geologic text references
- Environmental investigation reports
- Well field investigations and aquifer tests
- Municipal well head protection plans
- State and Federal soil and geologic investigations
- State and Federal surface water studies/records
- State and Federal hydrogeologic studies/records
- Construction investigations/studies
- Resource development studies

A partial summary of the types of record categories and the references used in support of this study is provided in Table 2.1.

Table 2.1. Partial Summary of Information Resources, Montgomery County, Ohio

Category	Subject	Reference
Municipal well head protection plans	City of Oakwood	1) Lockwood, Jones and Beal (1993)
State and Federal soil and geologic investigations	Montgomery Co. Soil Survey Quaternary deposits Bedrock surface elevation maps Bedrock reconnaissance maps	1) Davis et. al. (1976) 2) Pavey et. al. (1999) 3) Brockman (1999) 4) Brockman et. al., (1999)
State and Federal surface water studies/records	Surface water/groundwater flow	1) Yost, W. P. (1995) 2) Cross and Mayo (1969) 3) U.S. Geological Survey (2005) 4) Federal Emergency Management Agency (1987)
State and federal hydrogeologic & hydrologic studies & records	Well logs, Production well records, Recharge rates, Montgomery Co. water resources, U.S. Geological Models Hydrologic atlas	1) Norris et. al., (1948) 2) Norris and Spieker (1966) 3) ODNR, Div. of Water, Well Log Section 4) ODNR (2005) 5) Dumouchelle & Schiefer (2002) 6) Dumouchelle (1997) 7) Dumouchelle (1998) 8) Pettyjohn and Henning (1979) 9) Fidler, R.E. (1975) 10) Schmidt (1986) 11) Harstine (1991)
Construction and Geotechnical studies	Dewatering Projects	1) Bowser Morner (1979) 2) Bowser Morner (1980) 3) Mueser et. al., (1982) 4) LJB (2005)
	Building Construction	1) ATC Associates, Inc., 2002
General hydrogeologic & geologic text references	Hydrogeology	1) Freeze and Cherry (1979)
Well field investigations and aquifer tests	Dayton Well Fields	1) Harding ESE (2001)
	City of Oakwood Well Field	1) Lockwood, Jones and Beal (1993)

2.4 Previous Studies

The Great Miami aquifer system has been the focus of many geologic and hydrogeologic studies throughout the years. Key studies of the area include Norris (1948), Norris and Spieker (1966), and Dumouchelle (1998) among others.

Computer model studies of the aquifer system date back to the early 1970s. The U.S. Geological Survey, in cooperation with the Miami Conservancy District, constructed a single layer finite-difference computer of the model of the Dayton, Ohio area (Fidler, 1975). This study focused on groundwater consumption in the Dayton area during the 1960s and early 1970s. The model incorporated the available geologic and hydrogeologic information of the time, and provided a simulated groundwater potentiometric surface of the aquifer showing the resultant impact of the groundwater consumption caused by industrial and municipal pumping. Of particular importance noted in this study is that the average groundwater consumption in the Dayton area was about 180 ft^3/s in 1960 and steadily increased to approximately 250 ft^3/s in 1972. Water level elevations in the aquifer beneath downtown Dayton based on Norris and Spieker (1966) during the early 1960s were approximately 710 feet mean sea level (msl). River elevations for the Great Miami River in this same area are approximately 720 to 725 feet msl. The early 1970s was the peak of groundwater consumption in the Dayton area. Thereafter, groundwater consumption began to decline as industrial demand for water waned.

A second groundwater computer model study was conducted of the Great Miami River aquifer system during the early 1990s. The U.S. Geological Survey conducted an extensive study of the aquifer system involving field measurements of river stages, stream bed permeability measurements, and basin wide water level readings (Yost, 1995). This information was used to prepare a large scale groundwater potentiometric surface map (Dumouchelle, 1993) and a computer model of the aquifer (Dumouchelle, 1998). The modular U.S. Geological Survey finite-difference computer model MODFLOW (McDonald and Harbaugh, 1984) was used to construct the model domain. The finite-difference grid model domain consisted of 230 rows and 370 columns to simulate the lateral extent of the model, and three layers simulating the unconsolidated deposits that fill the bedrock valley beneath the Great Miami River and its tributaries.

3.0 REGIONAL HYDROGEOLOGY

3.1 Review of Existing Information

Terran researched, assembled and reviewed available published and unpublished sources of geologic, soils and hydrogeologic data to develop a better understanding of the hydrogeologic setting of Montgomery County. Sources included ODNR well logs, published geologic and hydrogeologic reports/maps, the Montgomery County Soil Survey, and unpublished consultant reports. A listing of references used in support of this investigation is provided in Section 8 of this report.

3.2 Regional/Site Location Map

Montgomery County, Ohio is situated in the glaciated region of Ohio. Flat to rolling terrain, broad river valleys and occasional bedrock outcrops characterize the area. The bedrock of the area consists of thin to thick-bedded limestone of the Silurian System overlying thin-bedded, fossiliferous limestone and shale of the Ordovician system. The Silurian limestone is found outcropping along the bluffs of the Great Miami River and its tributaries along the northern half of the county. The Ordovician limestone and shale formation is the most common formation, comprising the principle bedrock underlying the County. It subcrops along the walls and bottom of the buried valley system, and outcrops in the highlands of the central and southern portions of the County (Bownocker, 1920).

The valleys and highlands of Montgomery County are covered with a mantle of unconsolidated glacial deposits (Figure 3.1). The highlands are covered with glacial till deposits that form ground moraine, a thin to thick layer of glacial till that was deposited beneath the Pleistocene glacier ice mass. Glacial till is a mixture of clay, silt, sand and gravel that, in Ohio, is typically massive and fine-grained in texture with over 50 percent of it comprised by silt and clay by weight. It is not considered a significant water-bearing zone from the standpoint of water resource development although intermittent sand and gravel seams or glacio-fluvial deposits occur within the glacial till that can be moderate to prolific water-bearing zones or aquifers. Glacial till layers are also found interbedded within the sand and gravel deposits of the buried valley aquifer. These till lenses act as local confining beds that separate the sand and gravel into upper and lower layers or aquifers in places. The till layers are not continuous across the entire valley, thus allowing hydraulic connection to occur between shallow and deep sand and gravel deposits.

Thin to thick glacial outwash “valley train” deposits occur along the river courses of the region. These deposits are comprised of variably bedded layers of sand, gravel, and cobbles that are typically sorted and stratified. These deposits were placed by the flow of glacial meltwater as it discharged from the glacial ice along the river valleys of the region. Layers of silt and clay, such as glacial layers or lacustrine clay, are occasionally found interbedded in the outwash deposits. These deposits appear to originate from either advances of the glacier ice, depositing a layer of glacial till, or from ice damming of the river valley, forming lacustrine clay deposits and/or silt layers.

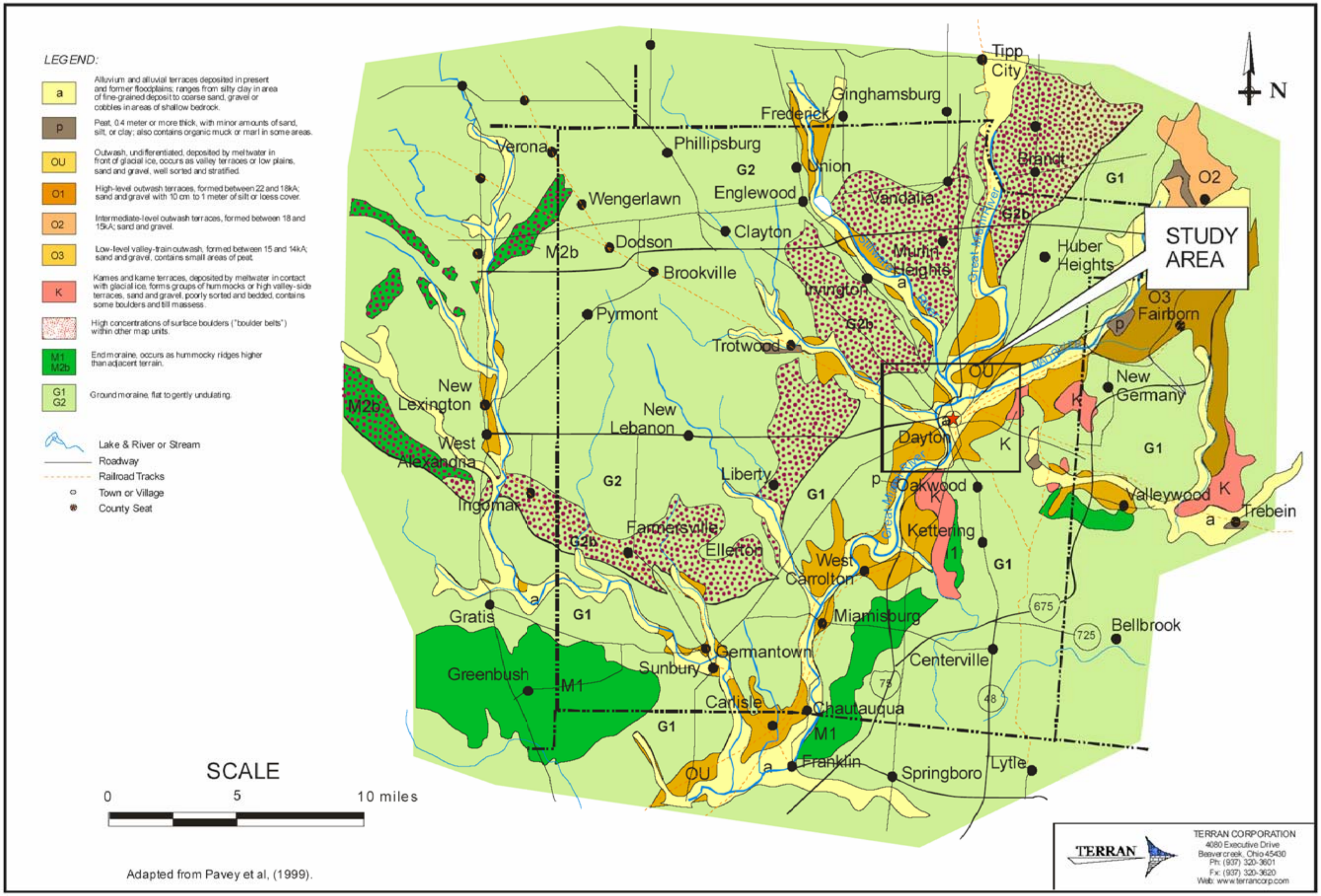

Figure 3.1 Quaternary Geology of Montgomery County, Ohio.

Other deposits of significance in Montgomery County include glacial kames, which are formed at ice contact margins or within stagnant and melting glacial ice. These deposits are usually characterized by highly variable grain size distributions that are mixtures of stratified, outwash deposits and glacial till deposits of variable thickness and sorting.

3.3 Regional Hydrogeologic Description

The regional hydrogeologic setting of Montgomery County consists of an upper buried valley aquifer (BVA) and a lower BVA. In addition to the aquifers of glacial origin, a carbonate bedrock aquifer is also found in certain locations along the river valley walls, primarily in the northern reaches of Montgomery County. However, this aquifer is not prevalent in the study area around downtown Dayton, Ohio. The BVA system is one of the most-prolific types of aquifers in Ohio. Though restricted to the valleys of Montgomery County, this aquifer can have thicknesses of over 200 feet in places (Norris et al, 1948). Pumping yields of 500 to >1,000 gallons per minute (gpm) can be developed from portions of the BVAs where the coarsest, cleanest gravel beds are found in hydraulic connection with the river that flows through the BVA system. Other areas of the BVA may produce 100 to 300 gpm in lesser regions of the BVA system (Schmidt, 1986). The upper and lower BVA system is the primary source of water to the major municipal well fields in the County.

The upper BVA consists of high-yielding sand and gravel outwash deposits found within the bedrock river valleys of the major river systems of Montgomery County. It occurs primarily along the Great Miami River at elevations of approximately 700 to 740 feet msl. The lower BVA is a deeper extension of the upper BVA. The lower BVA occurs at approximate elevations of 500+ to 700 feet msl in Montgomery County and is the principal aquifer from which the municipal well fields draw their water. The lower BVA is hydraulically connected with the upper BVA in areas were the glacial till confining bed is absent.

Other aquifers of minor importance in Montgomery County include sand and gravel aquifers associated with glacial kames and minor sand and gravel deposits interbedded in clayey glacial moraine deposits (Figure 3.1). These deposits tend to be more localized in their occurrence and lateral distribution, and are generally more fine-grained in their overall grain-size distributions, making them of limited value for development as a municipal well field. Yields of these deposits range from less than 10 gpm up to 100 gpm or more depending upon the hydraulic properties and sources of recharge to the aquifer in question. Kame deposits are found along the margins of the Great Miami River, especially in the southern reaches of the county.

Table 3.1. Summary of Hydraulic Conductivity Values, Montgomery County, Ohio

Location	Aquifer Media	Hydraulic Conductivity (feet/day)	Reference
AQUIFER MEDIA (K_h,)			
Miami River Well Field	Outwash	308	Norris and Spieker (1966)
Tait Station		267	Norris and Spieker (1966)
Oakwood		48 to 228*	Lockwood, Jones and Beal (1993)
CONFINING BEDS (K_v)			
Rohrers Island area	Silt & Clay	0.004 to 0.017	Norris and Spieker (1966)
RIVER BEDS (K_v) (Feet/Second)			
Webster Street Bridge	Mad River	0.1 to 51.8	Yost (1995)
St. Rt. 35 Bridge	Great Miami River	0.003 to 0.02	
Broadway St. Bridge	Great Miami River	0.8	

* Calculated from aquifer transmissivity values with estimated aquifer thicknesses

4.0 BVA MODEL HYDROGEOLOGY

4.1 Site Hydrogeological Formations

The regional hydrogeologic setting of the Great Miami River BVA is quite complex because of the varied and repeated nature of the glacial deposits in the area. To model the BVA, the various geologic and hydrogeologic study reports were reviewed to define patterns in the regional stratigraphy that can be computer modeled as groups or units. The hydrogeologic units of Montgomery County consists of two major outwash deposits, divided in part by clay layers, overlying shaley bedrock (Figure 4.1). For this evaluation, the hydrogeologic formations or units have been named as follows:

- **Hydrogeologic Outwash Unit 1**: A heterogeneous outwash mixture of brown to gray sand, gravel and cobbles (Figure 4.1). This formation is the uppermost outwash deposit and ranges from ground surface to approximately 750 feet msl in elevation in the upper reaches of both the Great Miami River and Mad River in the study area, to 710 feet msl in the lower reaches of the Great Miami River. This unit appears to be continuous throughout the Great Miami River basin and its tributaries of Mad River, Stillwater River and Wolf Creek. The formation varies in its stratigraphy but appears to be primarily a coarse-grained sand and gravel deposit with sand zones, cobble/boulder zones and clay lenses throughout it. At the base of Unit 1 occurs a layer of clayey glacial till that separates it from the next hydrogeologic unit (where present).

- **Hydrogeologic Outwash Unit 2**: A gray sand and gravel outwash deposit that occurs stratigraphically below Unit 1. This formation is the lowermost and thickest outwash deposit of the Great Miami River basin, ranging in elevation from roughly 690 to 500+ feet msl in the study area. This unit also appears to be fairly continuous throughout much of the Great Miami River and the Mad River; although it does have great variations in thickness and elevation (both thinning and thickening).

- **Ordovician Bedrock:** Bedrock of the Ordovician Richmond Group is primarily brown-buff to grayish green calcareous shale interbedded with thin-bedded limestone lenses. This thick bedrock unit is the most prevalent bedrock formation of Montgomery County, out-cropping and/or sub-cropping beneath the deep buried valleys of the Great Miami River and its tributaries. The bedrock is considered an aquiclude or confining bed because of its high shale content. Generally, well yields in this formation are less than 3 gallons per minute (Schmidt, 1986), deriving its water from secondary porosity such as joints, bedding planes and minor fractures.

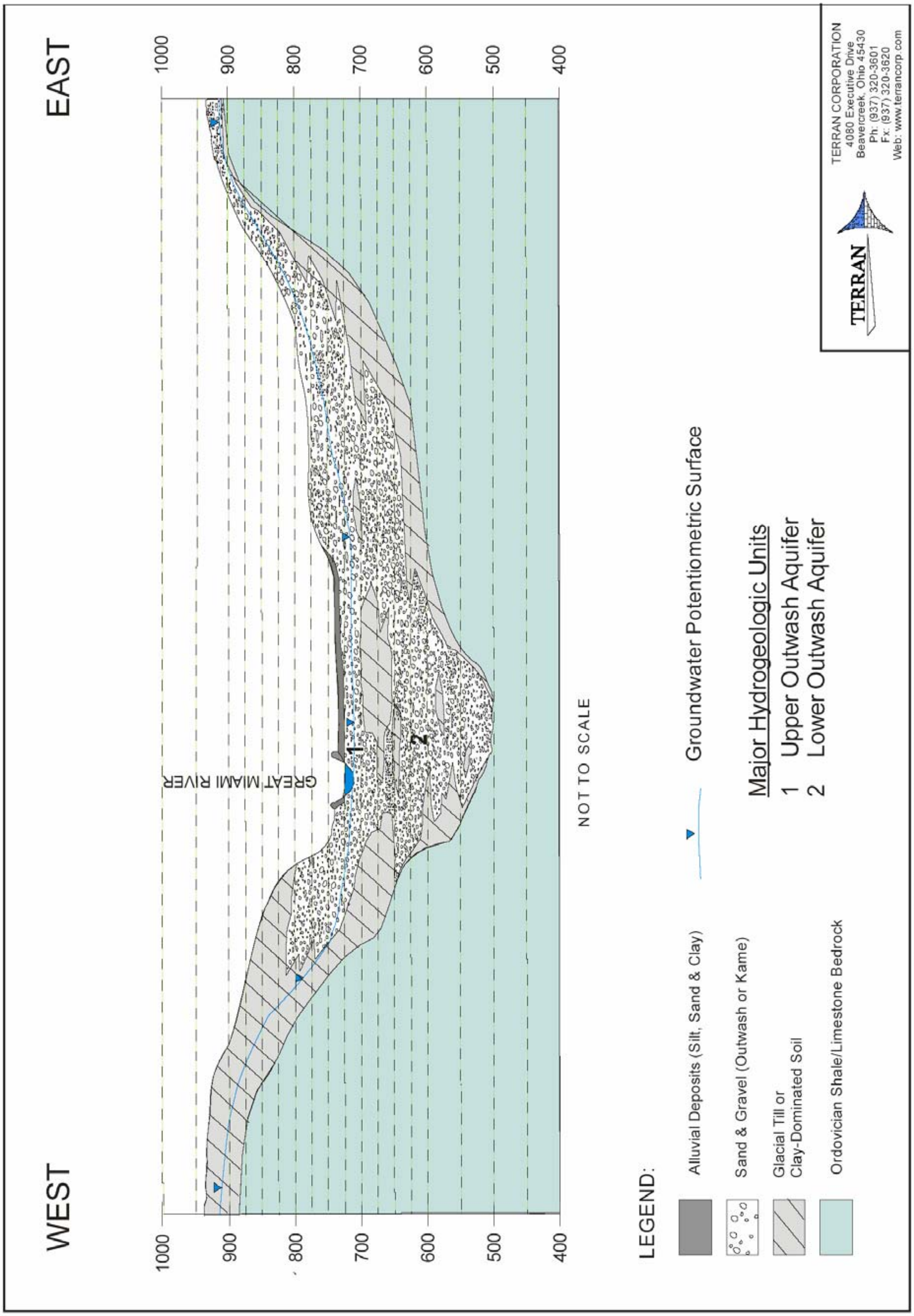

Figure 4.1 Conceptual Schematic Profile Across Great Miami River Valley, Dayton, Ohio.

4.2 Ground Water Flow

Groundwater potentiometric surfaces, gradients and flow directions were mapped through both large and small scale investigations across the entire regional domain, through the use of available monitoring wells and water wells in the area. Sources of groundwater potentiometric information included:

- U.S. Geological Survey reports/maps including Norris and Spieker (1966), Yost (1995) and Dumouchelle (1997).
- Consultant reports such as Harding ESE (2001) and others.

The primary groundwater potentiometric surface used to calibrate the model was the regional potentiometric surface information of Yost (1995). Other potentiometric surface maps were used to evaluate flow patterns in areas of concern not addressed by Yost (1995) as the information was available.

The groundwater potentiometric surface in the Dayton area, as measured during the September 1993 U.S. Geological Survey study of the Great Miami BVA, is illustrated in Figure 4.2. Groundwater elevations range from 850 to 900+ feet msl on the highlands flanking the buried valley aquifer to 710 to 730 feet msl within the study area. The potentiometric surface is steepest in the areas dominated by clayey soils and topographic highlands such as the glacial till ground moraine on the valley walls and is flattest where the flow system is dominated by gently sloping glacial outwash sand and gravel deposits of the BVA system. Groundwater flow is southwest along the BVA from the juncture of the Mad River and the Great Miami River, paralleling the slope and flow direction of the river.

An apparent cone of depression is found along the Mad River in the Dayton area, with an elevation of 700 feet msl (Figure 4.2). The cause of this cone of depression is unknown but may be the result of one or more production wells used for building dewatering efforts or heating and air conditioning.

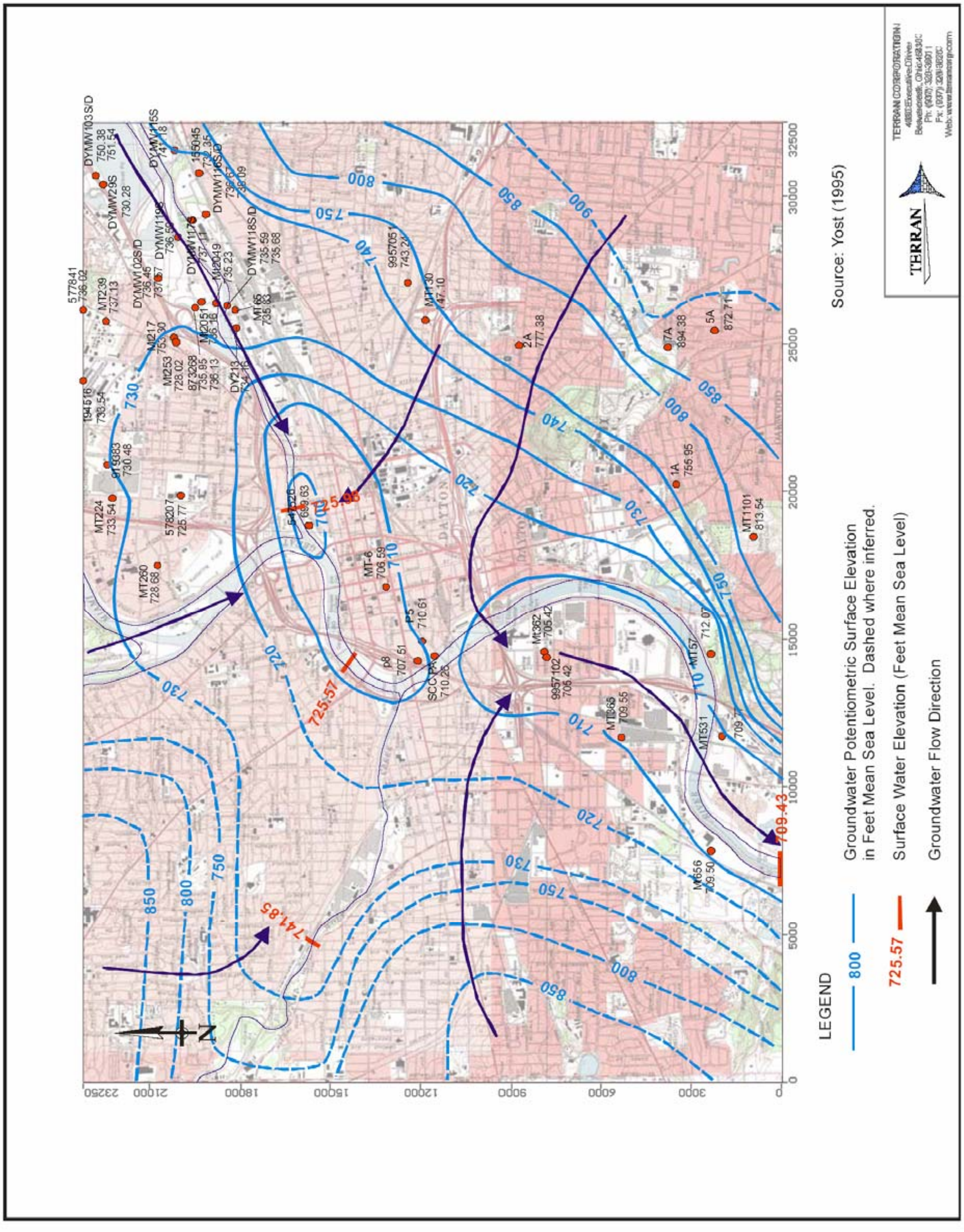

Figure 4.2 Groundwater Potentiometric Surface Elevations, U. S. Geological Survey Study, September 1993, Dayton, Ohio

5.0 COMPUTER GROUNDWATER MODEL

Computer groundwater modeling was conducted as a tool to assist in the evaluation of basement flooding along the Great Miami River. A description of the model constructed to simulate the study area is provided below.

5.1 Groundwater Model Descriptions

For this study, groundwater computer modeling was accomplished using one computer model and a preprocessor/post-processor software package. The computer model used included:

- MODFLOW, a finite-difference model capable of simulating complex, three-dimensional, porous, granular hydrogeologic settings such as the outwash aquifer underlying the site.

The U.S. Geological Survey advective flow modeling program MODFLOW (McDonald and Harbaugh, 1984) was selected to provide the basic advective flow model simulations. MODFLOW is a robust, industry-accepted flow model that has been used by both private industry and government entities to simulate aquifers of many types. For instance, the U.S. Geological Survey used MODFLOW to simulate the Great Miami River BVA as part of its research into the regional groundwater flow system of southwest Ohio (Dumouchelle, 1998).

MODFLOW is a 3-dimensional numerical model that simulates the advective flow of groundwater using a finite-difference block-centered grid and iterative calculations to solve the mathematical equations representing hydrogeologic flow. The model simulates the key elements for a hydrogeologic system including single or multiple, stacked layers, unconfined or confined (or combinations thereof) aquifers, recharge, streams, drains, wells and evapotranspiration. The model calculates potentiometric head elevation values for each active block or cell and calculates the mass transfer and balance of water as it migrates into and out of the model domain. MODFLOW was used to provide the primary advective flow model simulating the buried valley aquifer beneath the river.

A preprocessor/postprocessor software program was used to aid with the construction of the model and to produce and display the output information. The program, Visual MODFLOW© v. 3.0.1, provided by Waterloo Hydrogeologic, Inc. of Waterloo, Canada, was used in support of this project. Visual MODFLOW is a Microsoft Corp. Windows-based software package that helps to assign and edit the various input packages of the MODFLOW and MODPATH computer models, runs the models, then displays the model results, creating various maps, overlays, lists and graphs that are used to analyze and display the model output.

5.2 MODFLOW Advective Flow Model Description

Prior to constructing the advective flow model, Terran personnel gathered and reviewed available geologic and hydrogeologic information to determine the best size and position for the model domain and its boundaries. Available information included published reports and maps from the Ohio Dept. of Natural Resources (ODNR), U.S. Geological Survey, ant the U.S. Dept. of Agriculture. Unpublished resources included well logs and open file maps on file with ODNR, Internet and municipal data base information, field notes, and consultant reports. From this information, a summary of values and ranges used as input into the model is provided in Table 5.1.

5.2.1 Model Grid Boundaries

The model's boundaries were chosen based on the best fit between key geologic and hydrogeologic features and the location of the area of greatest concern for basement flooding. A model domain measuring 32,500 feet wide and 23,250 feet long was chosen, to encompass the primary area of interest, the BVA beneath the Great Miami River and its tributaries in around the City of Dayton (Figure 5.1). The model domain was subdivided into 133 rows and 105 columns of variable widths and lengths to create a model domain of 13,566 cells per layer. The largest grid cells measure 580 by 810 feet in area. The smallest cells measure 50 by 50 feet in area. The model cell sizes are differentiated in a transitional manner, approximately 1.5 times in size, to reduce error in the head and flow calculations, primarily around major pumping centers in the area.

In evaluating how best to model the complex distribution of geologic layers, the Fixed Grid Approach was chosen to simulate the vertical layers of the outwash aquifer system. In this approach, the finite difference grid consists of uniformly flat horizontal layers. The grid cell property values are assigned as needed to represent the approximate shape of the geologic units. Using this approach, the resultant computer model is a 30-layer domain of variable layer thicknesses (Figure 5.2). The varying layer thicknesses resulted from using best match approximations to simulate thin single layer thicknesses such as Hydrogeologic Units 1 and 2 and the glacial till layer that separate them. Thicker layers or combination of layers were used to simulate substantial geologic units such as the ground moraine valley walls of the highlands surrounding the Great Miami River.

The use of the Fixed Grid Approach fully respects the finite difference assumptions and results in a more stable solution. However this approach can be much more difficult to design and modify then a model using the Deformed Grid Approach which tends to be more realistic in terms of layer top and bottom elevations. The major drawback of the Deformed Grid Approach in this study is a lack of reliable top and bottom elevation information for geologic layers on a regional basis needed to build a defensible model. The major advantage of the fixed layer approach is it allows incorporation of new subsurface information as that information is developed without major modifications to the model domain. The incorporation of new subsurface information becomes a matter of modifying individual cell hydrogeologic properties to reflect the identified geologic profile.

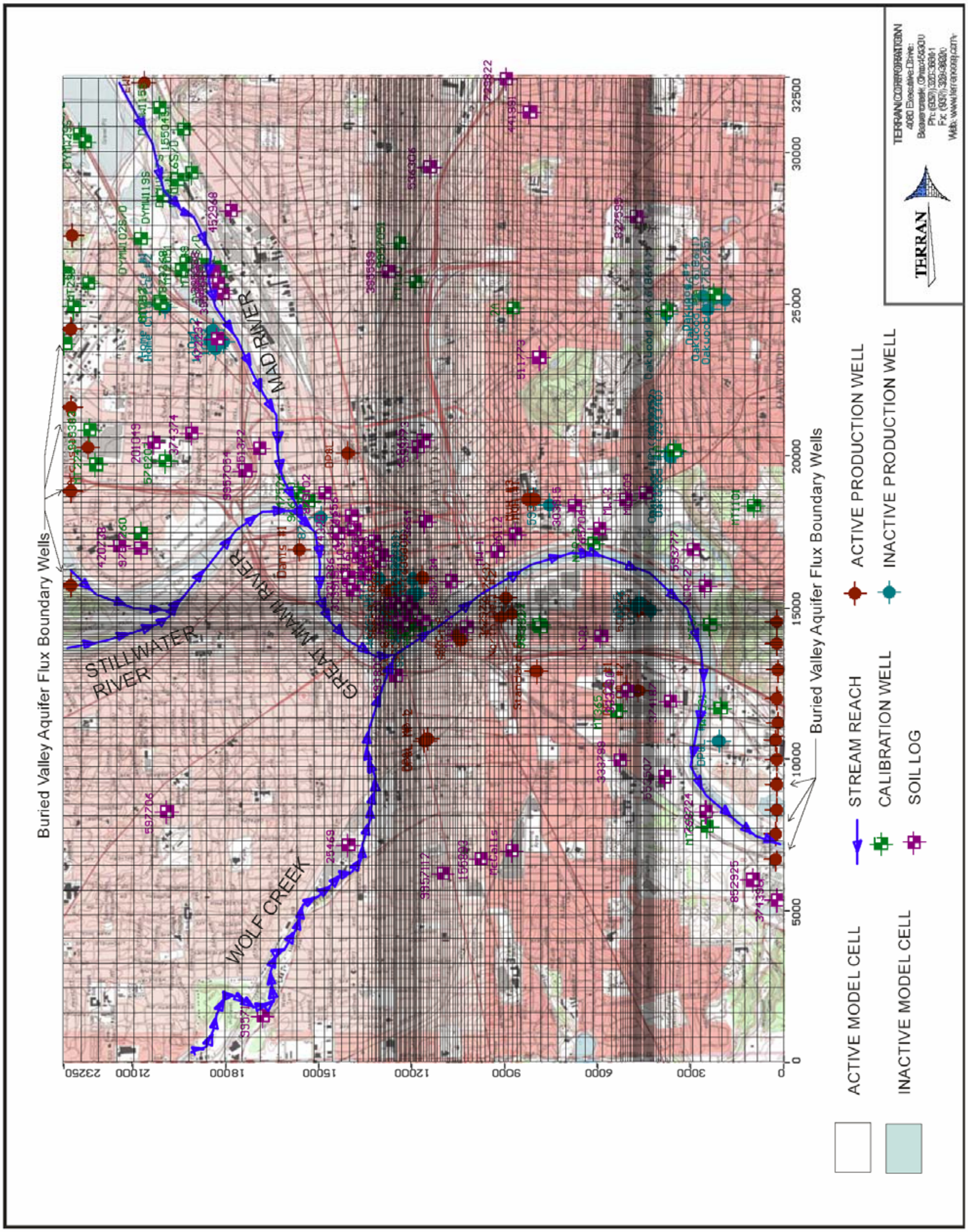

Figure 5.1 Groundwater Model Domain, Dayton, Ohio

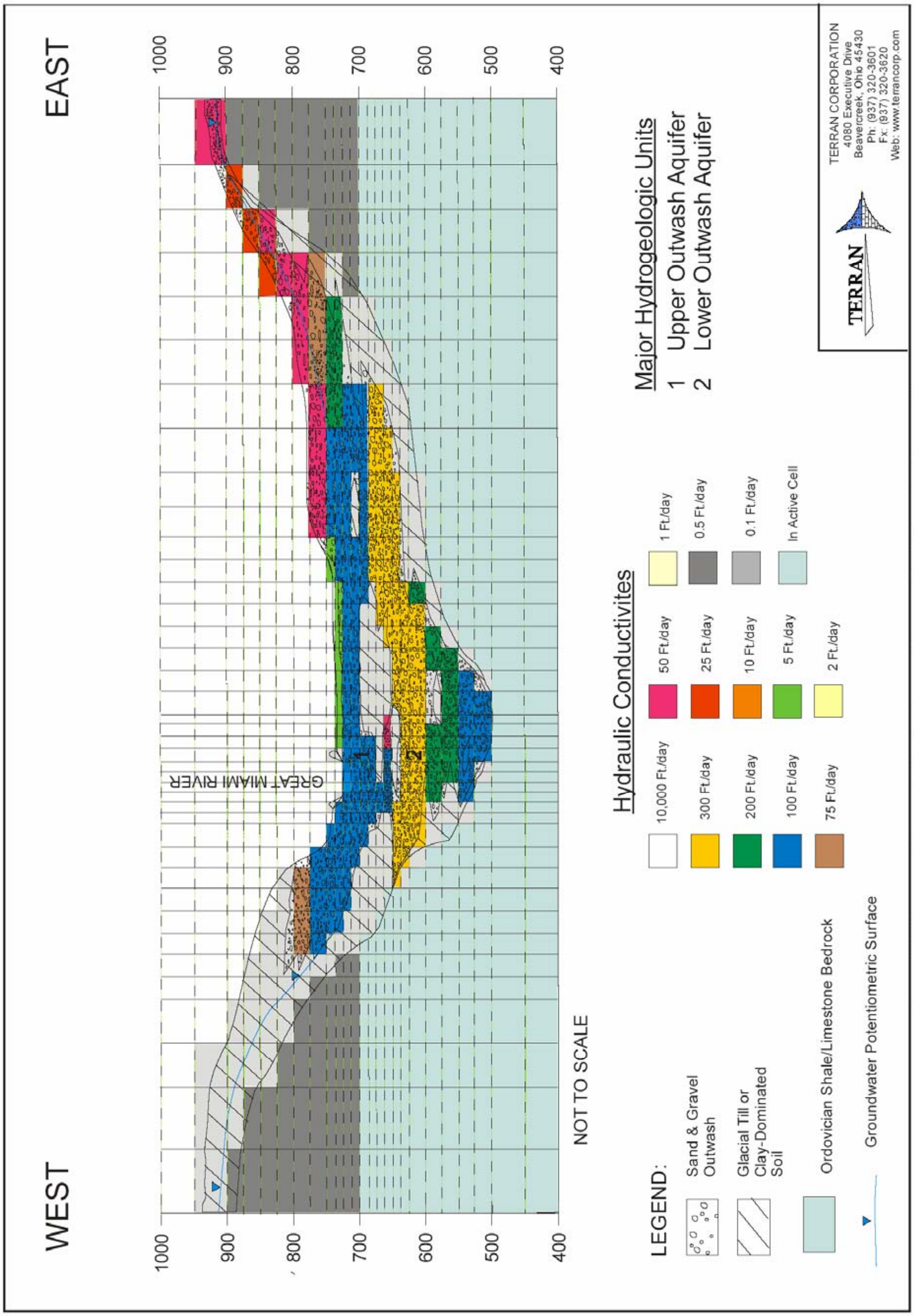

Figure 5.2 Conceptual Schematic Profile Across ComputerModel Domain, Dayton, Ohio.

Table 5.1. Model Parameters and Data Sources used in the Advective Flow Model

Parameter	Media	Model Values	References
Hydraulic Conductivity	Outwash Kame Glacial Till	5 to 500 ft./day 1 to 100 ft./day 0.1 to 0.5 ft/day	1) Norris and Speiker (1966) 2) Lockwood, Jones and Beal (1993) 3) Freeze and Cherry (1979)
Streams	Surface Water & Bed Elevations	709.5 to 750 Ft.	1) U.S. Geological Survey (1965, 1966) 2) Miami Conservancy District
	Flow Rates	86,400 to 134,160,000 ft^3/day	1) U.S. Geological Survey (1997) 2) FEMA (1987) 3) Yost (1995)
	Bed Conductance	0.003 to 1.0 ft./day	1) U.S. Geological Survey (1997)
Ground Water Levels	Outwash Kame Glacial Till	710 to 950 ft msl	1) Yost (1995) 2) Dumouchelle (1997)
Recharge	Soil permeability	4 to 10 inches per year	1) Garner et al (1978)
	Recharge rates		1) Dumouchelle and Schiefer (2002) 2) Pettyjohn and Henning (1979)

Basic MODFLOW can represent a layer using transmissivity only and can also simulate clay layers indirectly using VCONT, a numerical equation that incorporates layer thickness and vertical hydraulic conductivity. Visual MODFLOW requires a thickness and hydraulic conductivity to visually represent the layers in 3-dimensional space. Thus, in constructing the model, major clay deposits or confining beds within the outwash aquifer were assigned a layer status. The reports and well logs in the area were searched to find distinctive clay layers in the outwash that could be modeled by one or more distinct layers.

5.2.2 Hydraulic Conductivity Distribution

Hydraulic conductivity is a measure of the ability for geologic materials to transmit water through a unit surface area under a unit hydraulic pressure gradient, fluid viscosity and temperature. Hydraulic conductivity is largely controlled by the porous medium through which the water flows, with the properties of porosity and grain size sorting serving as important influences. Given the strong influences of the geologic properties on hydraulic conductivities, this property can be quantified using either field aquifer tests and/or laboratory tests on representative materials, and mapped as a function of geologic properties in the computer model.

Using this principle, certain key geologic deposits such as the glacial till, glacial kame deposits and outwash deposits can be assigned a range of hydraulic conductivity values that best represent their inherent geologic properties. For instance, the available literature indicates that measured hydraulic conductivity values for the outwash aquifer in the Dayton area ranges from 11 to 2,500 feet per day with most values occurring between 100 and 500 feet per day (Dumouchelle, 1998). Thus in assigning hydraulic conductivity values for cells representing the outwash aquifer, representative hydraulic conductivity values of 100 ft./day to 300 ft./day were assigned to represent the overall range values for this geologic unit.

A summary of the hydraulic conductivity value ranges for each key geologic media is presented in Table 5.1. Examples of the hydraulic conductivity distribution for four model layers (layer #6, #9, #15 and #28) is provided in Figure 5.3. An example of the hydraulic conductivity distribution in the vertical profile is provided in Figure 5.2.

Where glacial till or other silt/clay layers were mapped with certainty, the hydraulic conductivity for the corresponding model layer(s) was given values ranging from 0.1 to 0.5 ft./day. In places where it was thicker, two or more layers were used to simulate the clay deposit, as those layers approximate the top and bottom elevations of the clay layer (Figure 5.2).

Other areas were given values that reflected the apparent properties of the associated deposits, based on supplementary and/or ancillary information such as well logs, geologic reports, soil reports and similar information.

For regions of the model that are occupied by atmosphere, an extremely high hydraulic conductivity (K) value of 10,000 ft./day was assigned to the appropriate model cells. These high K values are found in Layers 1 to 10 where the topography slopes below the bottom elevation of appropriate layer. This was done to create a strong contrast between earthen K values and atmospheric K values as exists in nature. At the conclusion of the model’s steady-state calibration, most of these “high K cells” calculated as “dry” cells. This was the intended output for these cells since they are generally higher in elevation than the land surface and thus are not an active part of the model aquifer’s hydrologic system, other than through flooding and/or high water table simulations.

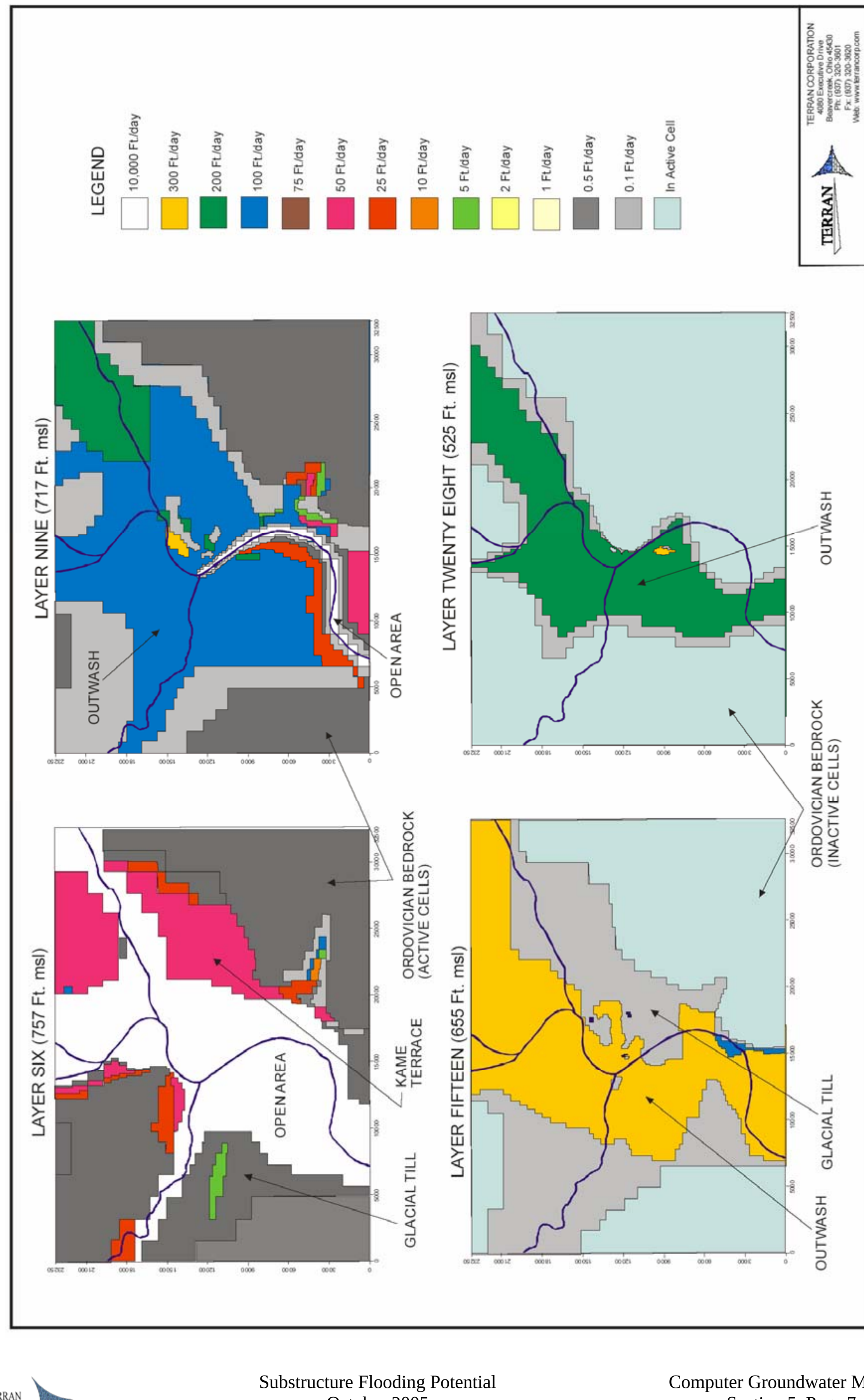

Figure 5.3 Hydraulic Conductivity Distributions, Layers 6, 9, 15 and 28, Dayton, Ohio

5.2.3 Stream Boundary Conditions

The rivers of the study area were modeled using the Streamflow-Routing Package STR1 (Prudic, 1989). This package simulates the interaction between surface streams and groundwater and accounts for the amount of flow in each stream. This allows for a more comprehensive evaluation of the stream-aquifer relationships than the standard MODFLOW river package. Streams are divided into segments and reaches. Each reach corresponds to individual model cells, while segments consist of groups of cells connected in a down stream order. Stream flow is accounted for by specifying a stream inflow for the first reach in each segment, and then calculating the stream flow to adjacent downstream reaches in each segment. This is equal to inflow in the upstream reach plus/minus leakage from or to the aquifer in the upstream reach. Information used in the Streamflow-Routing package includes stream inflow, stream stage, streambed top, streambed bottom, streambed conductance, and stream width. This information was gathered from various sources as listed in Table 2.1. A tabulated summary of the input information for the model stream reaches is presented in Table 5.2

Table 5.2 Streamflow-Routing Package Input Parameters, Dayton, Ohio

River Name and Module Segment #	Stream Surface Elevation (Ft. msl)	Streambed Elevation (Ft. msl)	Streambed Thickness (feet)	Streambed Hydraulic Conductivity (ft/day)	Stream Width (feet)	Stream In-Flow (Ft3/day)
Great Miami River #1	735.5 to 736.0	722 to 731	1.5	0.003 to 0.05	300 to 700	19,440,000
Great Miami River #2	725.8 to 730.0	718 to 722	1.5	0.01	700 to 500	36,936,000
Great Miami River #3	725.6 to 725.8	716 to 718	1.5	0.1	500 to 400	54,432,000
Great Miami River #4	716.0 to 720.5	711 to 716	1.5	0.5	400 to 500	55,512,000
Great Miami River #5	709.5 to 716.0	704 to 711	1.5	0.5	500	56,592,000
Wolf Creek #6	721.5 to 755.5	721 to 755	1.0 to 1.5	0.05	50 to 150	864,000
Stillwater River #7	735.5 to 736.0	725 to 734	1.5	0.05	200	7,776,000
Mad River #8	725.8 to 750.0	720 to 743	1.5	0.05 to 1.0	150 to 200	27,216,000

Stream flow rates were inputted using flow rates reported in Yost (1995) as a guide. Yost (1995) collected a comprehensive round of flow measurements of the Great Miami River and its tributaries on September 8 & 9, 1993. For the flood recurrence simulations, the flow rates were adjusted up to simulate the flood elevations predicted for that recurrence level by FEMA (1987). Stream surface elevations were obtained from the U.S.G.S. 7.5 minute topographic maps, Miami Conservancy District stream bed profiles, FEMA (1987) and stream bed conductivity values were obtained from Yost (1995).

5.2.4 Recharge (and Evapotranspiration) Boundary Conditions

The recharge for the computer model were simulated using the MODFLOW recharge package. This package simulates the amount of aerially distributed recharge to the groundwater system, most commonly as a result of precipitation that percolates into the groundwater system. Precipitation in Ohio ranges from 30 inches to 44 inches (Harstine, 1991), with an average annual precipitation of 38 inches (U.S.G.S. 1997). Average annual precipitation in Montgomery County ranges from 36 inches to 40 inches (Harstine, 1991). Of the average annual precipitation, approximately 4 to 10 inches manages to percolate into the subsurface and ultimately to discharge to the regional streams, thus serving as a measure of recharge to the regional aquifers. Studies such as Pettyjohn and Henning (1970), and Dumouchelle and Schiefer (2002) have calculated recharge rates to regional aquifers through the baseflow component of flowing rivers and streams. Results of their investigations have determined that recharge rates for till-dominated terrains range from 4 to 6 inches per year and up to 9 to 10 inches per year for outwash-dominated terrains.

Using these published recharge values, recharge rates were inputted into the model based on the predominate soil types present in the model cell (Figure 5.4). Areas dominated by steep topography, clayey soils developed over glacial till or intensive development were given lower recharge rates from 4 to 6 inches per year. Areas with flat topography and sandy soils developed over outwash were given higher rates of recharge ranging from 6 to 9 inches per year (Figure 5.4). Recharge rates were assigned to Layer 1 in constructing the model, but are applied to the highest active model cell during each simulation. This allows for the application of the recharge to the appropriate active layer, given that some layers have high K values simulating atmospheric conditions that solve as dry cells in the final model output.

The boundary condition of evapotranspiration (evaporation and transpiration through plants) was not included in the model. This boundary condition was considered negligible in terms of its impact on the water table because most flood events occur in the winter and early months when the ambient temperatures are low and plant life is mostly dormant.

5.2.5 Production Wells and Floor Drains

Production wells in the study area consist primarily of industrial and commercial wells used for either heating and cooling ("chiller wells") or for dewatering purposes. Presently, there is one municipality operating a drinking water well field in the study area, the City of Oakwood. The City of Dayton well fields are located north of the study area along the Mad and Great Miami Rivers, however, their pumping effects extend south into the study area.

During the mid-1900s, there were many large industrial consumers of groundwater, however, many of these industrial consumers are no longer in production in the Dayton area. To provide a comprehensive groundwater model, information on the location, screen interval, and pumping rates of production wells was researched and compiled for this study. Information on file with the Ohio Dept. of Natural Resources, Division of Water was used to identify large

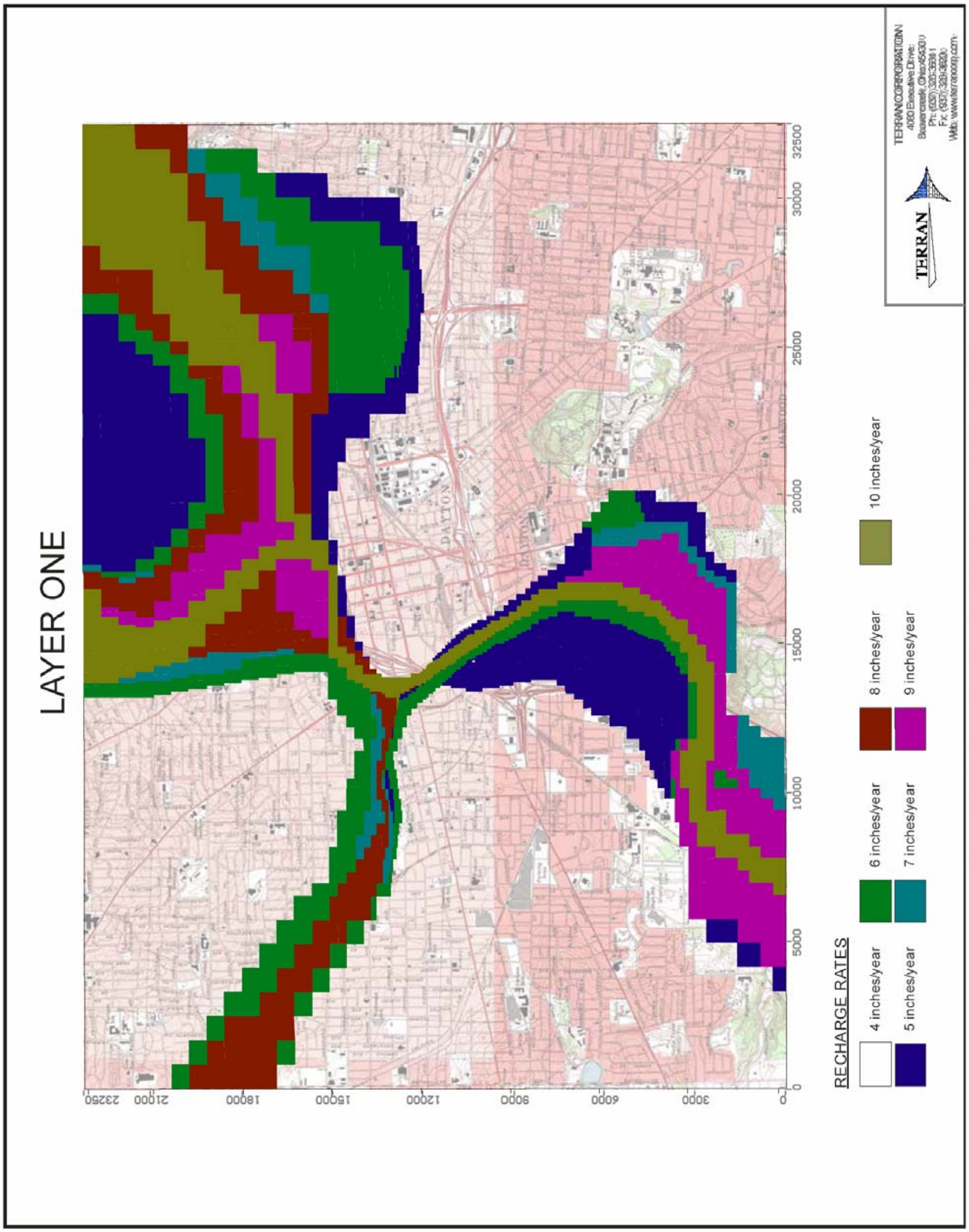

Figure 5.4 Recharge Boundary Condition Assignments, Dayton, Ohio.

consumers of groundwater in the study area. Also, available sources of information concerning the construction and operation of dewatering wells was gathered and used in the model.

In addition to facility production wells, a series of production wells were placed along the northern and southern boundaries of the model domain, across the buried valley aquifer (Figure 5.1). These wells were placed with screens across the entire saturated zone of the outwash aquifer for the purpose of simulating the flux of groundwater into and out of the model domain. The boundary well pumping rates were adjusted during the calibration process to simulate the aquifer water levels measured in the aquifer caused by the pumping stresses of the municipal well fields both north and south of the study area.

5.2.6 Observation Wells

To help construct the model and to evaluate the model calibration, 37 observation wells were inputted into model domain area with potentiometric surface levels for comparison purposes. The wells used for calibration purposes were from the 1993 study of the Great Miami River aquifer (Yost, 1995). These measured well points/water levels were inputted into the model, based on their latitude and longitude readings, and used to calibrate the model's steady-state potentiometric surface.

Wells that had good stratigraphic information were also selected for input into the model for use as a stratigraphic construction point. These wells were given another graphic identity to differentiate them from the calibration point wells (Figure 5.1). Wells used for observation wells and stratigraphic control points included Miami Conservancy District observation wells, ODNR well logs/residential wells, monitoring wells, and inactive production wells. Wells were selected based on their location and level of trustworthy information. Some well stratigraphic information was taken from geologic cross-sections presented in the various geologic reports in Table 2.1.

5.2.7 Model Cell Re-Wetting Setting

The MODFLOW model was constructed using the cell re-wetting option for simulating the water table. This option allows for the re-wetting of model cells after they have become dry (i.e. the calculated potentiometric surface falls below the bottom elevation of the cell). This option allows for better simulations of pumping scenarios by re-saturating the cells every specified iteration cycle. The drawback of the cell re-wetting option is that it can create instability in the solution of the finite difference equations due to repetitive drying and re-wetting of grid cells in sensitive regions of the model.

5.2.8 Model Equation Solver

The Link-Algebraic Multigrid Solver (LMG) was used to solve the finite-difference equations (Mehl and Hill, 2001). The LMG solver was chosen because of its ability to handle a large grid and highly variable hydraulic-conductivity fields, both of which are applicable for this model. The model budget closure criteria was adjusted to produce an overall model water budget closure of less than 1.0%.

5.3 Advective Flow Model Calibration

The model was calibrated to groundwater potentiometric surface elevations measured during a 1993 aquifer characterization study by the U.S. Geological Survey (Yost, 1995) and illustrated in Figure 4.2. To calibrate the model, the various model parameters were adjusted to obtain a best fit between the measured values and the calculated model heads. The model was adjusted to develop a steady-state groundwater potentiometric surface that appears to be the best, most representative surface of the entire model domain.

To evaluate the calibration effort, key observation well data points were included in the advective flow model to aid in measuring the "best fit" of the model's calculated head distribution versus the measured head distribution for the outwash aquifer. A graph showing the distribution of calculated heads versus measured heads (i.e. residuals) is provided in Figure 5.5. Of the 37 measuring points, the highest residual is 30 feet for ODNR well 547526 which is located next to the Mad River on the north side of Dayton. The minimal residual is well 5A which is -0.31 feet. The residual mean for all 37 observation wells is 5.65 feet difference.

The model calibration also involved the evaluation of the model's cumulative water budget. A balanced water budget between water flow into the model and water flow out of the model was required for acceptance. The calibrated model produced a balanced water balance of 0.00% (Table 5.3).

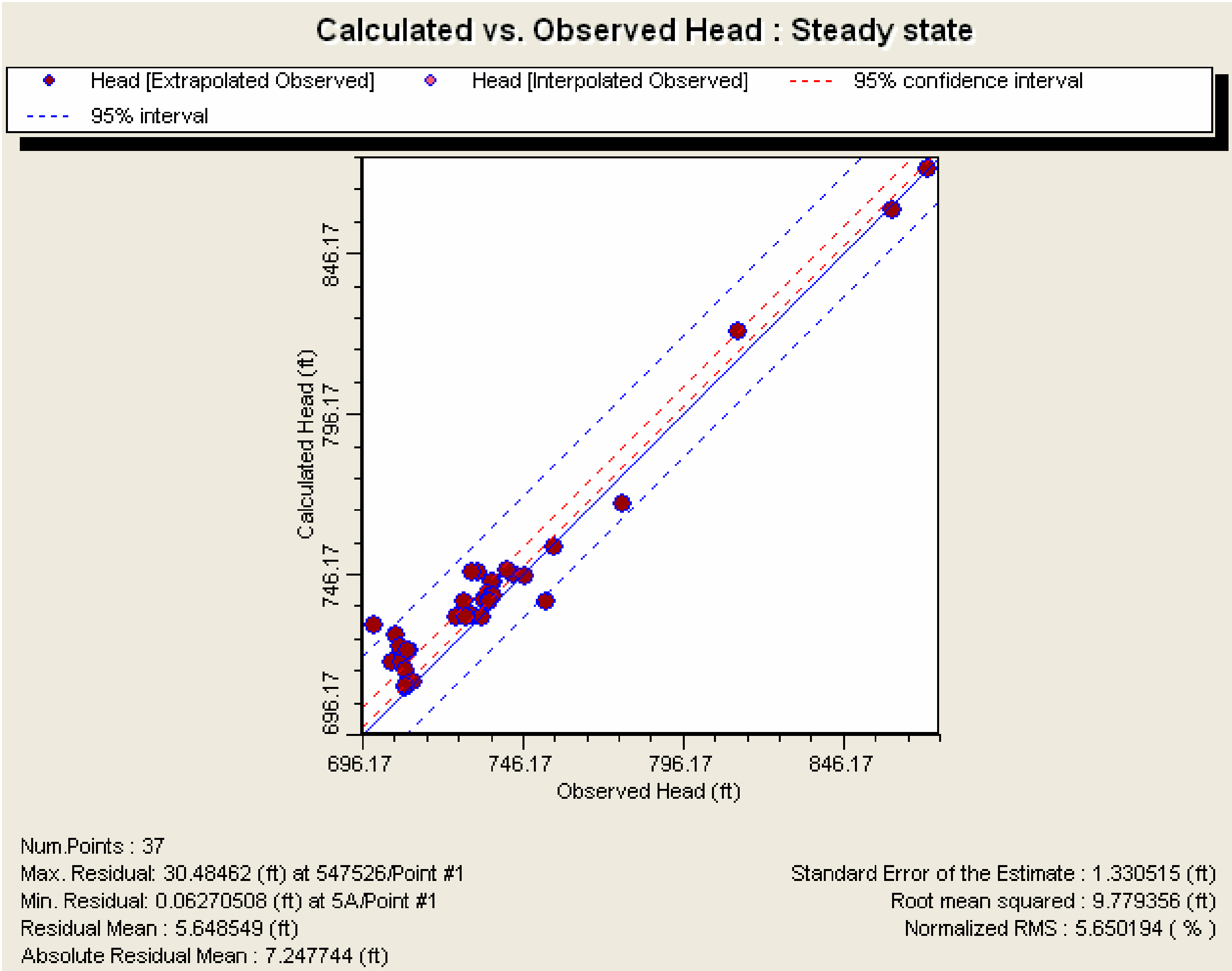

Figure 5.5. Graph of Calculated versus Observed heads for Observation Wells in Model Domain (no drains), Dayton, Ohio.

Developing a calibrated flow model posed a considerable challenge, especially in the downtown Dayton area. Many of the model cells in the vicinity of the downtown metropolitan area have high residuals when compared to the well measurements and potentiometric surface of the 1993 study. The 1993 groundwater potentiometric surface map indicates there is a cone of depression in the downtown area as demarked by the 710 and 700 feet msl contours (Figure 4.2). In reviewing the available literature, it has become evident that the probable source of this cone of depression is from the combined effects of substructure footer/floor drains, chiller wells and dewatering wells that are in operation for the many buildings in this area. To test this theory, a series of drain cells were activated in the downtown area with drain elevations of 710 ft. msl to evaluate the effect this would have on the calibration of the model. The result was the

Table 5.3. MODFLOW Basic Package Volumetric Budget Print File Listing

```
           VOLUMETRIC BUDGET FOR ENTIRE MODEL AT END OF TIME STEP  1 IN STRESS PERIOD  1
           ------------------------------------------------------------------------------
                CUMULATIVE VOLUMES      L**3       RATES FOR THIS TIME STEP      L**3/T
                ------------------                 ------------------------
                   IN:                                       IN:
                   ---                                       ---
        STORAGE =           0.0000             STORAGE =           0.0000
        CONSTANT HEAD =           0.0000       CONSTANT HEAD =           0.0000
        WELLS =           0.0000               WELLS =           0.0000
        ET =           0.0000                  ET =           0.0000
        RECHARGE =      912569.3750            RECHARGE =      912569.3750
        STREAM LEAKAGE =     1092608.3750      STREAM LEAKAGE =     1092608.3750

        TOTAL IN =     2005177.7500            TOTAL IN =     2005177.7500

                  OUT:                                      OUT:
                  ----                                      ----
        STORAGE =           0.0000             STORAGE =           0.0000
        CONSTANT HEAD =           0.0000       CONSTANT HEAD =           0.0000
        WELLS =     1289840.7500               WELLS =     1289840.7500
        ET =           0.0000                  ET =           0.0000
        RECHARGE =           0.0000            RECHARGE =           0.0000
        STREAM LEAKAGE =      715368.0000      STREAM LEAKAGE =      715368.0000

        TOTAL OUT =     2005208.7500           TOTAL OUT =     2005208.7500

        IN - OUT =         -31.0000            IN - OUT =         -31.0000

        PERCENT DISCREPANCY =           0.00   PERCENT DISCREPANCY =           0.00
```

production of a groundwater cone of depression in the downtown area and an improvement in the calibration residuals (Figure 5.6). This scenario is consistent with the observation that there are several outfall drain pipes along the Great Miami River that flow with water in the downtown area and discharge into the river (Yost, 1995). It appears these flowing outfalls are fed by various floor drains, dewatering wells and chiller wells that discharge into the storm sewers.

The difficulty in building a defensible model is quantifying the numbers, locations and drain elevations/pumping rates of the various substructure dewatering drains/wells present in the downtown area that are actively producing groundwater. Some information does exist for certain buildings, however, this information is not comprehensive for the downtown area. Further, additional pumping sources such as the Riverscape production wells have been added since the 1993 study. Given the level of uncertainty associated with the downtown area in terms of substructure dewatering efforts, it was decided to proceed without the inclusion of these hydraulic stresses in order to develop a more conservative estimate of substructure flooding potential without the impact of floor drains and dewatering wells in the downtown area.

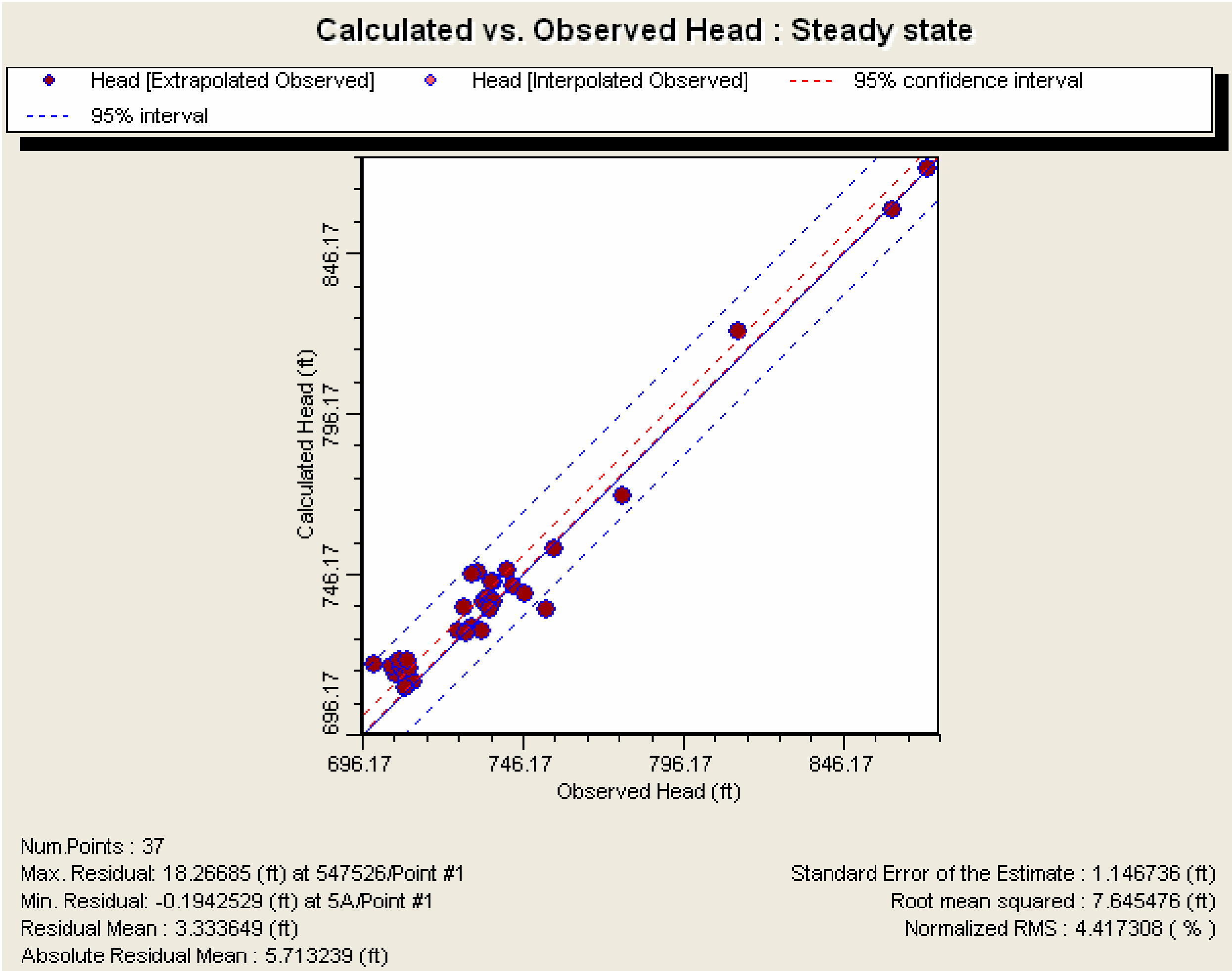

Figure 5.6 Graph of Calculated versus Observed heads for Observation Wells in Model Domain (with drains @ 710 ft. msl), Dayton, Ohio.

5.4 Model Sensitivity Analysis

To evaluate the key parameters that control the model's output, a sensitivity analysis was conducted. The sensitivity analysis consisted of changing model parameters such as hydraulic conductivity, recharge, and stream water elevations, and recording the resultant head changes to the model's output. Each parameter was increased and decreased to see what affect the change had on the head distribution. Key model locations, primarily observation well locations, were selected as points to measure and record the output changes. The resultant changes were then compared to the original calibrated model's heads and a percent change was calculated. Positive percent differences indicate rises in the calculated model heads. Negative percent differences indicate declines in the model's calculated heads. The higher the percent difference, either positive or negative, the greater the sensitivity of the model's output to that parameter.

The five parameters that were tested included aquifer hydraulic conductivity, recharge, stream bed hydraulic conductivity, surface water flow rates, and the boundary well pump rates. The five parameters were increased and decreased globally and the model ran to see how the change effected the calculated head values. The sensitivity analysis observation wells calculated heads and their percent differences are presented in Appendix A. A summary of the sensitivity analysis results is presented in Table 5.4.

Table 5.4. Summary of the Model Sensitivity Analysis Results

Sensitivity	Kx100 % Diff.	K÷100 % Diff.	Rx 1.5 % Diff.	R÷1.5 % Diff.	SBKx10 % Diff.	SBK÷10 % Diff.	SFx2 % Diff.	SF÷2 % Diff.	BWRx2 % Diff.	BWR÷2 % Diff.
Smallest Change	-0.05	-0.02	0.04	-0.04	0.02	0.08	0.00	0.00	-0.02	0.03
Average Change	-2.15	8.01	0.59	-0.99	0.11	-0.21	0.01	0.07	-0.23	0.13
Largest Change	-9.59	47.3	2.54	-4.45	0.55	-1.3	0.10	0.53	-1.78	0.52

Where K = aquifer hydraulic conductivity, R = recharge, SBK = stream bed hydraulic conductivity, SF = stream flow rates, and BWR = boundary well (pump) rate.

Results of the sensitivity analysis demonstrated that hydraulic conductivity had the highest sensitivity of the parameters tested. Percent changes ranged from –0.02% to +47.3% for this parameter (Table 5.4), with negative percent differences (i.e. decreasing calculated head values) occurring for the increase in hydraulic conductivity and positive percent differences for the reduction in conductivity values (i.e. rising calculated head values). The least sensitive parameter was the stream flow rates which produced less than 0.6 percent change overall in model heads.

6.0 MODEL SIMULATIONS

A series of simulations were conducted to evaluate the relationship of the aquifer system and its water levels to those of the rivers and streams of the Great Miami River. Of primary interest is to identify areas most prone to basement or substructure flooding as a result of flooding along the Great Miami River. To accomplish this, a set of flood recurrence intervals were simulated to evaluate the potential for basement flooding. A flood recurrence interval is the statistical probability of a flood of certain water height and flow rate occurring over time. For instance, a flood with a recurrence interval of 10 years has a probability of occurring once every ten years. It doesn't mean it will happen every 10 years, just that based on the historical record, a flood of equivalent size could happen.

Recurrence intervals of 10-years, 50-years and 100-years were simulated to estimate the height of the water table occurring in the aquifer around the Great Miami River. For each of the three flood recurrence intervals, the existing levee system along the Great Miami River is designed to contain the flood water within the banks of the Great Miami River and its tributaries, thus protecting downtown Dayton from surface flooding by the river. Thus, the main difference between the three flood recurrence intervals is the height of the water in the river and the water flow rate along the river course.

Each of the flood recurrence simulations were conducted as steady-state simulations, thus providing a conservative estimate of the water table relative to the river. Also, all building dewatering and pumping wells were turned off for each simulation to calculate the resultant water table free from manmade pumping stresses.

To identify areas of potential impact by the simulated flood, a scale depth of 10 feet for a standard basement depth was used. For each recurrence simulation, the difference from the ground elevation to the water table was calculated. Areas where the difference between the surface elevation and the water table was less than 10 feet were then identified as occurring in an area of possible basement flooding as a result of that recurrent flood event.

6.1 Simulation #1: Steady-state 1993 Surface Water-Ground Water Flow System

The first model simulation is of a steady-state simulation of the groundwater potentiometric surface based on the 1993 U.S. Geological Survey study (Yost, 1995). Surface water elevations of the Great Miami River and its tributaries for the simulation are shown in Figure 6.1. A summary of the stream flow information used for this simulation is provided in Table 6.1.

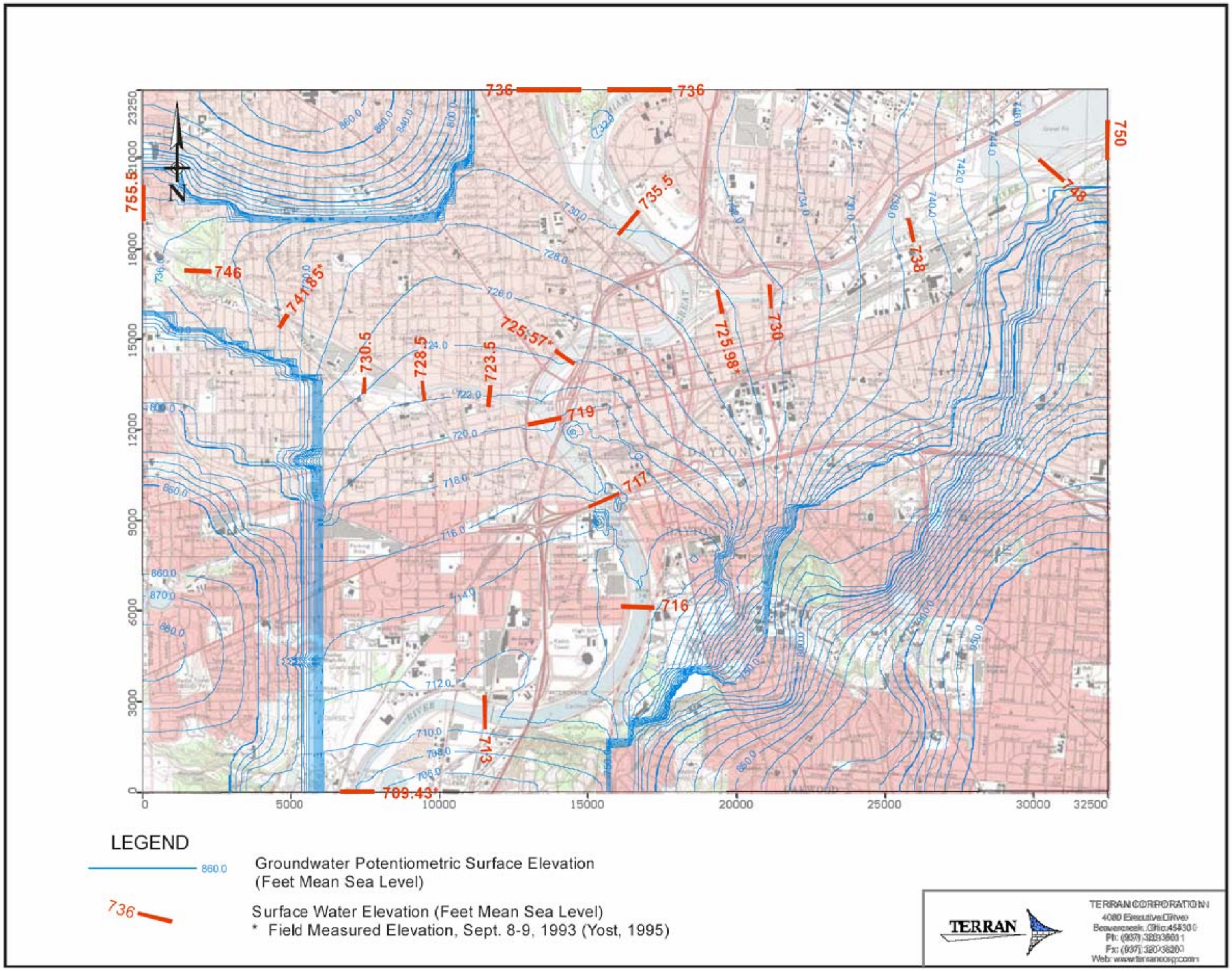

Figure 6.1 Simulation #1, Steady-State Simulation, Dayton, Ohio.

Table 6.1 1993 Steady-State Model Stream Input Values.

Simulated River	Stream Bottom Elevation (Feet MSL)	1993 Stream Flow Elevations (Feet MSL)	River Stage Height (Ft.)	River Flow Rate (Ft3/sec)
Great Miami River	731 to 704	736 to 709.5	5	225 to 655
Mad River	743 to 720	750 to 725.8	5 to 7	315
Stillwater River	734 to 725	735 to 732.5	1 to 7	90
Wolf Creek	755 to 721	755.5 to 721.5	0.5	20

The groundwater surface (Figure 6.1) shows a relatively flat groundwater gradient within the Great Miami River valley where the highly permeable outwash aquifer occurs. The water table slopes to the south along the Great Miami River across the study area with groundwater flow paralleling the stream flow of the rivers. On the northern end of the study area, there is an approximate 10-foot to 15-foot hydraulic break between the water table and the surface water of the Great Miami River. This hydraulic break appears to be a combination of the silty streambed underlying the rivers and the voluminous groundwater pumping that is occurring in the City of Dayton Miami and Mad River well fields north of the study area. The hydraulic difference between the Great Miami River and the aquifer decreases towards the south where river surface elevations and groundwater potentiometric surface elevations converge.

Along the margins of the BVA, the water table rises steeply where the BVA pinches out into less permeable glacial till ground moraine. The steady-state groundwater potentiometric surface of Figure 6.1 represents the average flow conditions of the BVA under normal conditions. This potentiometric surface was then used as starting heads for the 10-year, 50-year and 100-year recurrence interval floods through the Dayton area.

6.2 Simulation #2: 10-Year Flood Recurrence Interval

Simulation #2 is the revision of the input parameters in the stream-flow routing module to simulate a 10-year recurrence interval flood. Information prepared by the Federal Emergency Management (1987), and Cross and Mayo (1969) was used to simulate a 10-year recurrence interval flood. The model stream segments were revised to simulate the profile, width and flow rates of each stream segment. A summary of the stream flow information is provided in Table 6.2. The model parameter of recharge was not changed in order to provide a look at the aquifer response in terms of a rise in surface water elevations only. This scenario is also consistent with floods along the Great Miami River that originate from storm events in the northern reaches of the Great Miami River basin.

Table 6.2 Model 10-Year Flood Recurrence Stream Input Values.

Simulated River	Stream Bottom Elevation (Feet MSL)	1993 Stream Flow Elevations (Feet MSL)	10-YR Stream Flow Elevations (Feet MSL)	Flood Stage Height (Ft.)	River Flow Rate (Ft3/sec)
Great Miami River	731 to 704	736 to 709.5	745 to 726	14 to 22	24,500 to 56,000
Mad River	743 to 720	750 to 725.8	758 to 736	15 to 16	17,000
Stillwater River	734 to 725	735 to 732.5	745 to 742	11 to 17	9,600
Wolf Creek	755 to 721	755.5 to 721.5	767 to 734	12 to 13	6,670

Predicted groundwater elevations for the simulated 10-year recurrence interval flood are illustrated in Figure 6.2 along with the inputted river flood elevations and flood limits. In this simulation the Great Miami River stream elevations are approximately 9 to 17 feet above the 1993 stream levels and groundwater levels in the aquifer have risen approximately 14 to 30 feet in places.

6.3 Simulation #3: 50-Year Flood Recurrence Interval

Simulation #3 is the revision of the input parameters in the stream-flow routing module to simulate a 50-year recurrence interval flood. Information prepared by the Federal Emergency Management (1987), and Cross and Mayo (1969) was used to simulate a 50-year recurrence interval flood. The model stream segments were revised to simulate the profile, width and flow rates of each stream segment. A summary of the stream flow information is provided in Table 6.3. The model parameter of recharge was again not changed in order be consistent with the 10-year flood simulation.

Table 6.3 Model 50-Year Flood Recurrence Stream Input Values.

Simulated River	Stream Bottom Elevation (Feet MSL)	1993 Stream Flow Elevations (Feet MSL)	50-YR Stream Flow Elevations (Feet MSL)	Flood Stage Height (Ft.)	River Flow Rate (Ft3/sec)
Great Miami River	731 to 704	736 to 709.5	747.5 to 729	16.5 to 25	35,000 to 78,000
Mad River	743 to 720	750 to 725.8	760 to 739	15 to 16	24,000
Stillwater River	734 to 725	735 to 732.5	746.5 to 742	11 to 17	11,400
Wolf Creek	755 to 721	755.5 to 721.5	770.5 to 734	12 to 13	10,500

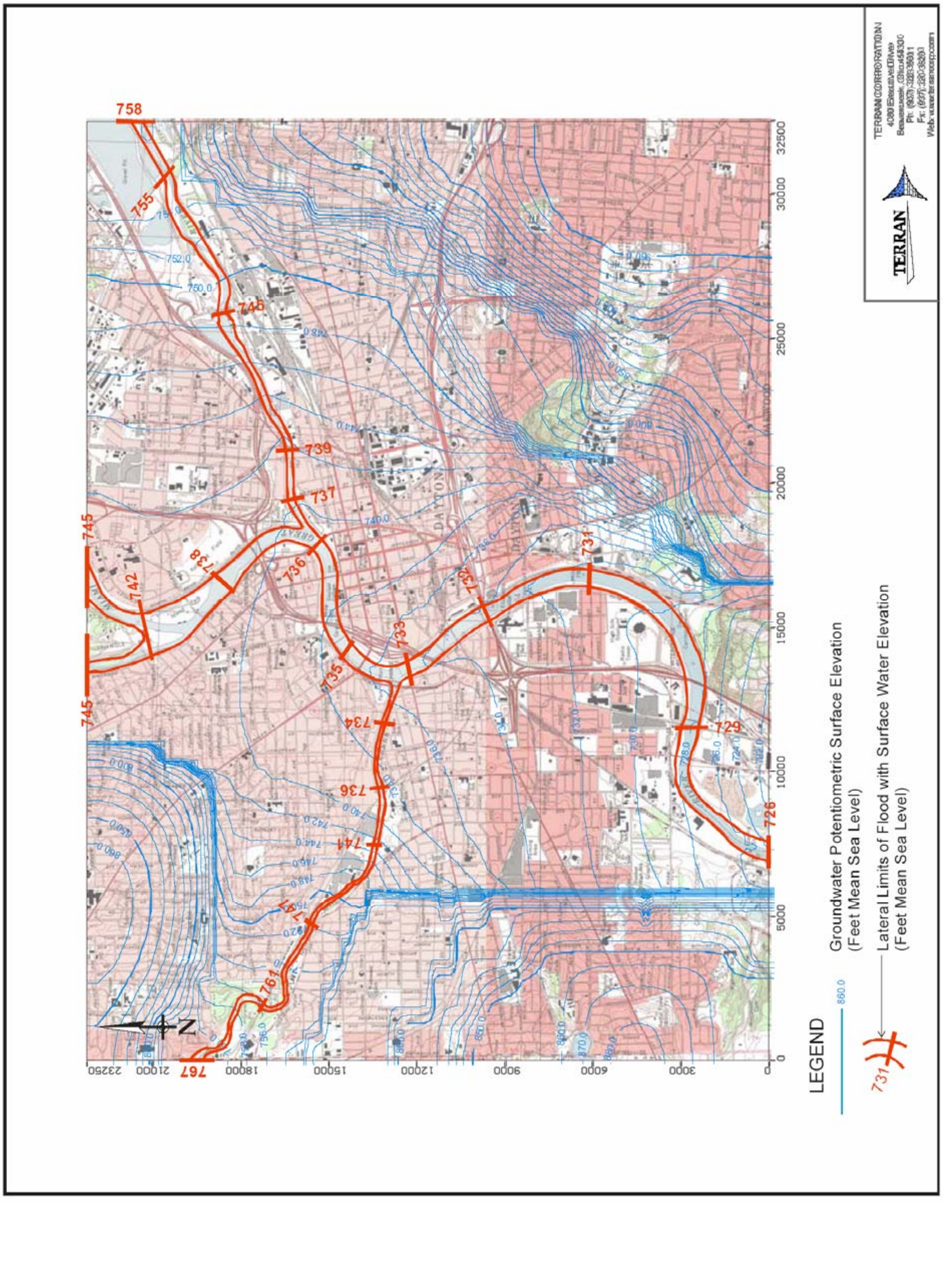

Figure 6.2 Simulation #2, Steady-State Simulation, 10 YR Flood Recurrence Interval, Dayton, Ohio.

Predicted groundwater elevations for the simulated 50-year recurrence interval flood are illustrated in Figure 6.3 along with the inputted river flood elevations and flood limits. In this simulation the Great Miami River stream elevations are approximately 10 to 20 feet above the 1993 stream levels and groundwater levels in the aquifer have risen approximately 16 to 34 feet in places.

6.4 Simulation #4: 100-Year Flood Recurrence Interval

Simulation #4 is the revision of the input parameters in the stream-flow routing module to simulate a 100-year recurrence interval flood. Information prepared by the Federal Emergency Management (1987), and Cross and Mayo (1969) was used to simulate a 100-year recurrence interval flood. The model stream segments were revised to simulate the profile, width and flow rates of each stream segment. A summary of the stream flow information is provided in Table 6.4. The model parameter of recharge was again not changed in order be consistent with the 10-year and 50-year flood simulations.

Table 6.4 Model 100-Year Flood Recurrence Stream Input Values.

Simulated River	Stream Bottom Elevation (Feet MSL)	1993 Stream Flow Elevations (Feet MSL)	100-YR Stream Flow Elevations (Feet MSL)	Flood Stage Height (Ft.)	River Flow Rate (Ft3/sec)
Great Miami River	731 to 704	736 to 709.5	748.5 to 730	26 to 32	40,000 to 86,000
Mad River	743 to 720	750 to 725.8	761 to 740.5	15 to 16	27,500
Stillwater River	734 to 725	735 to 732.5	748.5 to 745	11 to 17	12,000
Wolf Creek	755 to 721	755.5 to 721.5	772 to 734	12 to 13	12,400

Predicted groundwater elevations for the simulated 100-year recurrence interval flood are illustrated in Figure 6.4 along with the inputted river flood elevations and flood limits. In this simulation the Great Miami River stream elevations are approximately 13 to 21 feet above the 1993 stream levels and groundwater levels in the aquifer have risen approximately 18 to 40 feet in places.

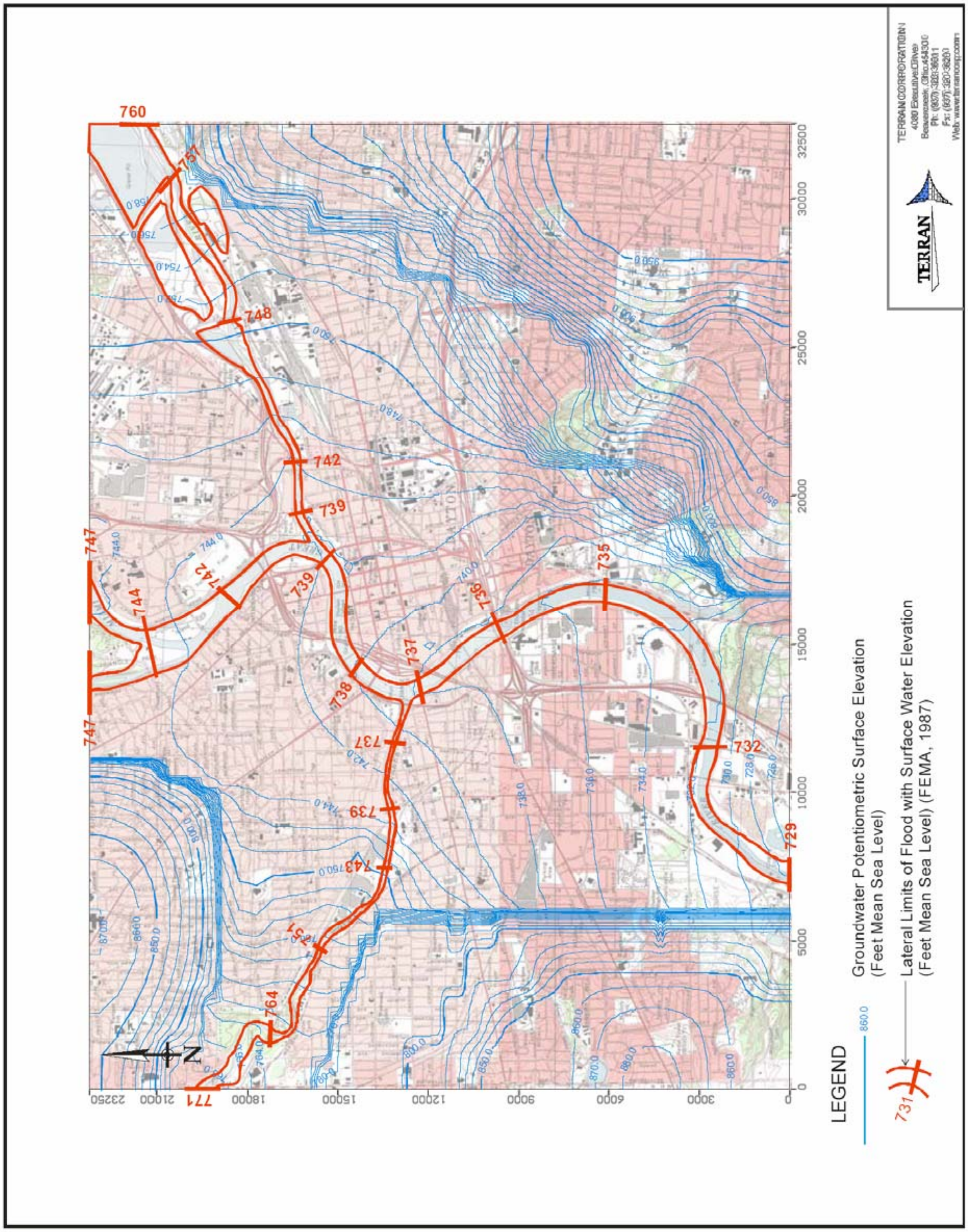

Figure 6.3 Simulation #3, Steady-State Simulation, 50 YR Flood Recurrence Interval, Dayton, Ohio.

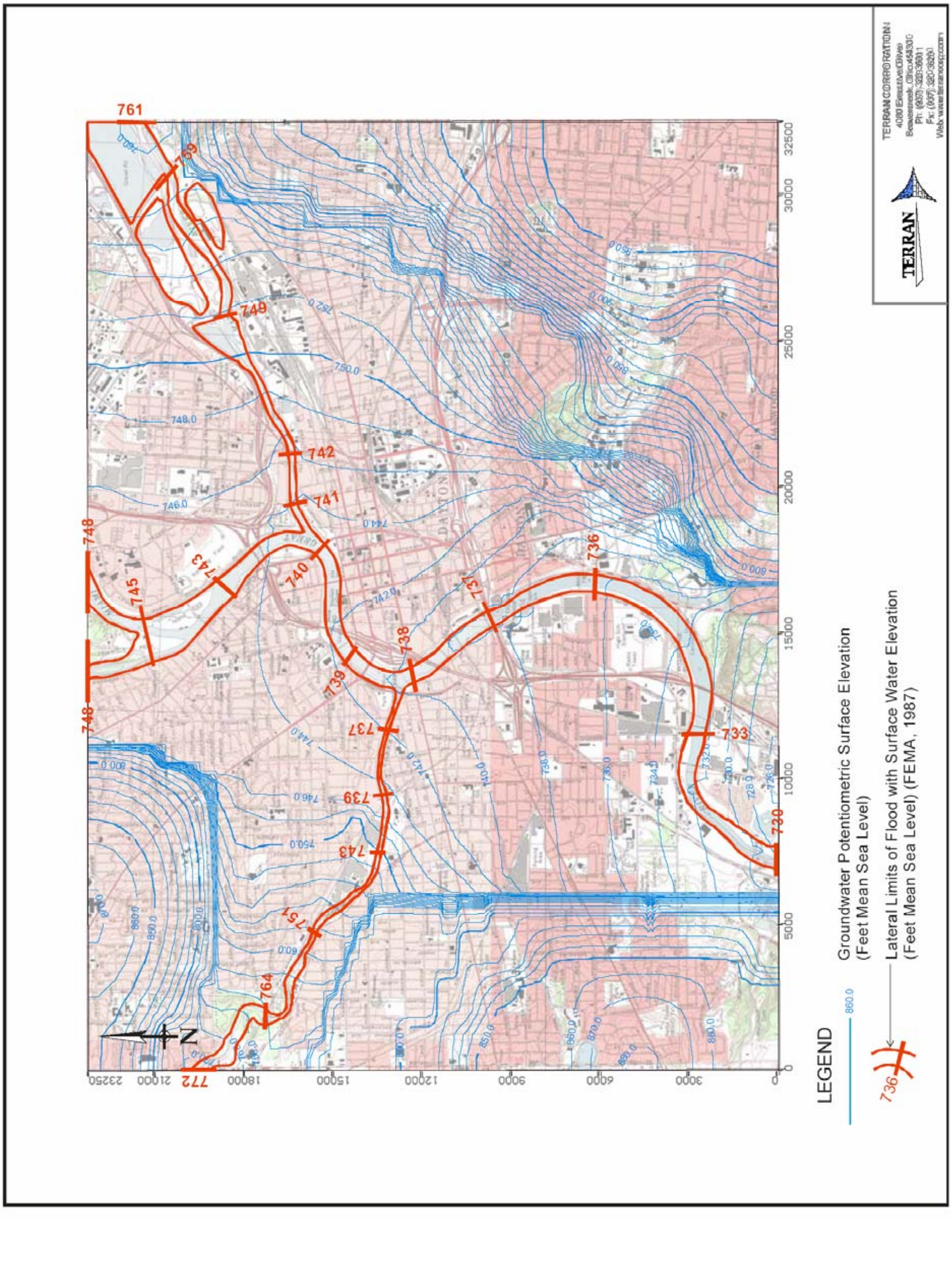

Figure 6.4 Simulation #4, Steady-State Simulation, 100 YR Flood Recurrence Interval, Dayton, Ohio

7.0 PROJECT SUMMARY AND CONCLUSIONS

7.1 Computer Model Results and Discussion

The U.S. Geological Survey computer model MODFLOW was used to construct and simulate the study area of the Great Miami River aquifer system in Dayton, Montgomery County, Ohio. This model was then used to simulate 10-year, 50-year and 100-year recurrence interval floods to predict the resulting water table in response to these flood events. The results are discussed in Section 6.0 entitled Model Simulations and illustrated in Figures 6.2 to 6.4.

To identify the potential for substructure and basement flooding, a depth of 10 feet below ground surface was used to define the minimum depth for groundwater seepage into a substructure or basement. Areas with difference of 10 or less feet between the ground surface elevation and the simulated water table elevation were identified as zones with potential for substructure flooding.

Zones with potential for substructure flooding based on the simulated flood recurrence intervals are presented in Figure 7.1 The zones indicate potential for substructure flooding, however, the potential for flooding is contingent upon a number of factors including depth to water table during a flood event, depth of the substructure or basement, ground surface elevation, site geology and presence of manmade influences such as pumping or dewatering wells, storm sewers and sanitary lines. These factors together combine to influence the amount of available storage capacity in the aquifer at any given time. Storage is a term that describes the amount of aquifer porosity available to hold groundwater in the subsurface, and to a lesser degree, the amount of water that can be stored due to compression in confined aquifers. Areas containing sand and gravel deposits generally have higher storage capacity than areas with more fine-grained deposits such as silt and clay.

The three computer simulations used to develop the zone of potential substructure flooding in Figure 7.1 were steady-state simulations. Steady-state simulations assume that all of the hydrologic and hydrogeologic factors are constant and unchanging over time, thus they are not time dependent. With the steady-state simulation, the aquifer experiences no net change in it's storage, thus providing a "snap shot" of the predicted groundwater levels for a specific set of hydrologic conditions such as precipitation recharge, stream levels, stream discharge and pumping rates. In reality, aquifer systems are dynamic and transient, that is, they change and fluctuate over time in response to constantly changing hydrologic and manmade stresses.

Also, the three flood simulations were conducted with all sources of artificial pumping stress in downtown Dayton turned off. This was done to provide a conservative prediction of the river and groundwater levels during each recurrent flood along the Great Miami River. Thus the predicted groundwater levels in the aquifer essentially return to "natural" flow conditions without the interference of sources of de-watering pumpage, much like a situation where there is a power outage to downtown Dayton

During times when the water table is low, the available aquifer storage is high, thus providing available capacity in the aquifer for adsorbing water seeping from the river without causing widespread basement flooding. This was a common condition during the 1960s and early 1970s, when industrial pumping lowered the water table in the Dayton area, thus providing increased storage capacity in the aquifer for adsorbing and storing water from flood events along the Great Miami River. However, when the water table is high, such as during the winter months, there is little available aquifer storage, which causes the water table to rise up into subsurface structures and basements in flood prone areas. Thus the potential for a 10-year recurrent flood to cause significant, widespread substructure flooding is greater during times of seasonally high water tables (i.e. winter months) than during times of seasonally low water tables (i.e. summer months). The occurrence of higher water tables is further compounded by the decreased industrial pumping that has occurred since the 1970s. Buildings and substructures designed based on 1960s-1970's water level information are now finding more frequent and severe episodes of substructure flooding due to the rise in water levels in the aquifer. To offset the problem of substructure flooding, many of these building owners are having to install and operate dewatering wells to lower the water table beneath their structures to maintain dry foundations.

7.2 Conclusions

Results of this study indicate that areas with greatest potential for substructure flooding are found primarily along the outwash aquifer of the Great Miami River and its tributaries (Figure 7.1). Structures that occur on the kames and ground moraines at an elevation of 750 feet mean sea level or higher appear to have some measure of natural protection against substructure flooding due to their elevation above the river flood plain. However, this is not an all encompassing measure of protection as site specific conditions may contribute to substructure flooding such as drainage ditches, sanitary sewers, storm sewers and localized geologic/hydrogeologic conditions.

7.3 Recommendations

The following recommendations are suggested, based on the preparation of this model and its results:

- Develop a comprehensive collection of information on the active groundwater pumping and substructure drains/dewatering efforts in the downtown Dayton area. Incorporate this information into the computer model domain.
- Organize an area-wide monitoring network for the collection of groundwater static water levels in key hydrogeologic units in relation to the surface water elevations of the Great Miami River, Mad River and Wolf Creek. Develop one or more county-wide potentiometric surface maps, including stream elevations across the area and cones of depression for the active substructure dewatering that is being conducted in downtown Dayton.
- Improve the characterization of the aquifer system. Areas in need of better stratigraphic definition and elevation control include the west side of Dayton, particularly along Wolf Creek, Third Street, Salem Avenue and Germantown Street. Vertical profiling with emphasis on the lower portions of the aquifer, and the glacial till deposits is needed in the central and southern reaches of the Dayton area.

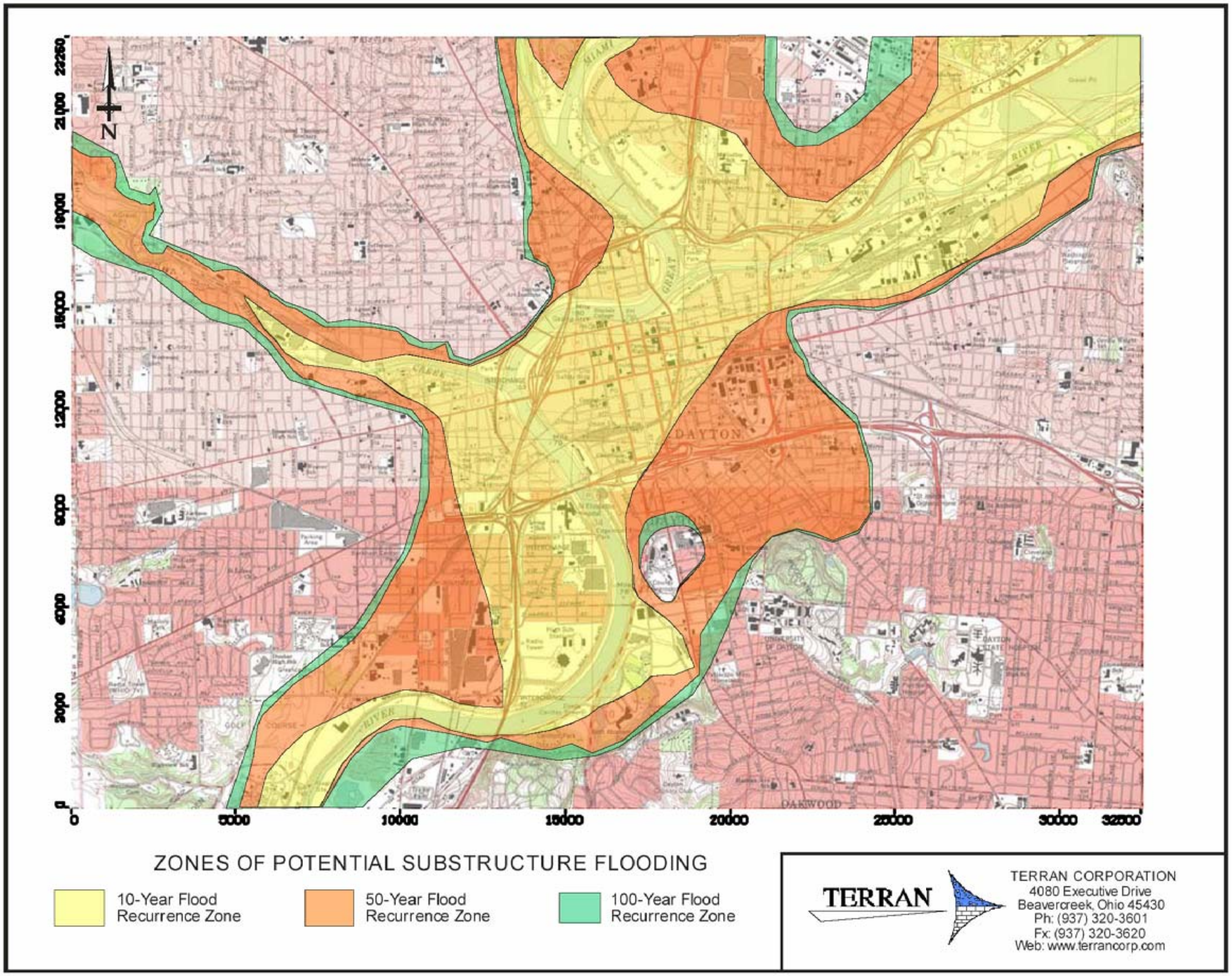

Figure 7.1. Zones of Potential Substructure Flooding along the Great Miami River, Dayton, Ohio.

Report Authenticity

In the creation of this report the authors have developed conclusions that are based upon objective data. Some of this data was collected and evaluated using methods that generally are recognized as the current state of the art at the time of the report preparation. The veracity of other data utilized in this investigation is unknown. The conclusions reached by the authors represent our opinions and professional judgement. Subsurface conditions are known to vary in space and time that may render some of the conclusions reached in this report imperfect.

Respectfully Submitted,

Signature Date

______________________________ _____________________

Brent E. Huntsman, CPG
Chief Hydrogeologist
Terran Corporation

Signature Date

______________________________ _____________________

Kelly C. Smith, CPG
Senior Hydrogeologist
Terran Corporation

8.0 REFERENCES

1. ATEC Associates, 2002, Geotechnical Engineering Investigation Proposed Juvenile Detention Building, Second Street and St. Mary's Street, Dayton, Ohio: Consultant Report prepared for City of Dayton, ATEC File # 13.32935.0002.
2. Bowser-Morner, Inc., May 30, 1979, Study of Groundwater Seepage into Basement Areas at Sinclair College: Consultant Report prepared for Sinclair Community College, report # 25116-579.
3. Bowser-Morner, Inc., May 12, 1980, Dewatering Project for Sinclair Community College, 444 West Third Street, Dayton, Ohio 45402: Consultant Report prepared for Sinclair Community College, report # 25489-580.
4. Bownocker, J.A., 1920, Geologic Map of Ohio: Ohio Dept. of Natural Resources, Division of Geological Survey, 1 map.
5. Brockman, S., 1999, Bedrock Topography of the Dayton North Quadrangle: Ohio Dept. of Natural Resources, Div. of Geological Survey, BT-B5G2, 1 map.
6. Brockman, C.S., Shrake, D.L. and J. Leow, 1999, Bedrock Topography of the Dayton South Quadrangle: Ohio Dept. of Natural Resources, Div. of Geological Survey, BT-B5F2, 1 map.
7. Cross W.P. and R.I. Mayo, 1969, Floods in Ohio, Magnitude and Frequency, A Supplement to Bulletin 32, Ohio Dept. of Natural Resources, Division of Water Bulletin 43, 230 p.
8. Davis, P.E., Lerch, N., Tornes, L., Steiger, J., Smeck, N., Andrus, H., Trimmer J., and G. Bottrell, 1976, Soil Survey of Montgomery County, Ohio; Ohio Dept. of Natural Resources, Div. of Lands and Soil, and Soil Conservation Service, United States Department of Agriculture, 107 p, maps.
9. Dumouchelle, D.H., 1997, Ground-water Levels and Flow Directions in the Buried Valley Aquifer around Dayton, Ohio, September 1993: U.S. Geological Survey Water-Resources Investigations Report 97-4255, 1 map.
10. Dumouchelle, D.H., 1998, Simulation of Ground-water Flow, Dayton Area, Southwestern Ohio: U.S. Geological Survey Water-Resources Investigations Report 98-4048, 57p.
11. Dumouchelle, D.H. and M.C. Schiefer, 2002, Use of Streamflow Records and Basin Characteristics to Estimate Ground-Water Recharge Rates in Ohio: Ohio Dept. of Natural Resources, Division of Water Bulletin 46, 45 pp.
12. Freeze, R.A. and J.A. Cherry, 1979, GROUNDWATER, Prentice-Hall, Inc., Englewood Cliffs, New Jersey, 604pp.
13. Federal Emergency Management Agency, 1987, Flood Insurance Study, County of Montgomery, Ohio: Community Number 3907755.
14. Fidler, R.E., September 1975, Digital Model Simulation of the Glacial-Outwash Aquifer at Dayton, Ohio: U.S. Geological Survey Water-Resources Investigations Report 18-75 Prepared in cooperation with the Miami Conservancy District, 25p.
15. Harding ESE, December 4, 2001, Results of the October 17, 2001 Groundwater Elevation Study in Dayton, Ohio: Letter report prepared by Harding ESE for City of Dayton, Ohio, December 4, 2001.

16. Harstine, L.J., 1991, Hydrologic Atlas for Ohio: Ohio Dept. of Natural Resources, Div. of Water, Water Inventory Report No. 28, 13 p., 4 maps.
17. Lockwood, Jones and Beal, Inc., 1993, City of Oakwood Wellhead Protection Program: Consultant Report prepared for City of Oakwood, Ohio.
18. LJB, Inc., 2005, Dewatering System Upgrade, Phase 1 – Study, Montgomery County Administration Building: Consultant Report prepared for Montgomery County, Ohio, May 26, 2005.
19. McDonald, M.G., and A.W. Harbaugh, 1984, "A Modular Three-Dimensional Finite-Difference Ground-Water Flow Model. U.S. Geological Survey Open-File Report 83-875.
20. Miami Conservancy District, 1959, Stream Profiles for Miami River, March 1913; June 1958; and January 1959:, Drawing No. 7248 A, Sheet No. 22.
21. Mehl, S.W. and Hill, M.C., 2001, MODFLOW-2000, the U.S. Geological Survey Modular Ground-Water Model- User Guide to the Link-MG (LMG) Package for Solving Matrix Equations Using an Algebraic Multigrid Solver: U.S. Geological Survey Open-File Report 01-177.
22. Mueser, Rutledge, Johnston & Desimone, 1982, Sinclair Community College Seepage Study, Dayton, Ohio: Consultant Report prepared for Sinclair Community College, Dayton, Ohio, August 5, 1982.
23. Norris, S.E.; Cross, W.P.; and Goldthwait, R.P., 1948, The Water Resources of Montgomery County, Ohio: Ohio Water Resources Board, Columbus, Ohio, Bulletin 12, 83p.
24. Norris, S.E.; and A.M. Spieker, 1966, Ground-Water Resources of the Dayton Area, Ohio: U.S. Geological Survey Water-Supply Paper 1808, 167p.
25. Ohio Dept. of Natural Resources, Unpublished Well Logs: ODNR, Division of Water, Well Log Section.
26. Ohio Dept. of Natural Resources, 2005, Water Withdrawal Report for Year Ending December 31, 2004: ODNR, Division of Water, Water Resources Section, electronic data base summary for Montgomery County, Ohio.
27. Pavey, R.R.; Goldthwait, R.P., Brockman C.S., Hull, D.N., Swinford, E.M., and R.G. Van Horn, 1999a, Quaternary Geology of Ohio; Ohio Department of Natural Resources, Division of Geological Survey, 1 map.
28. Pettyjohn, W.A. and R. Henning, 1979, Preliminary Estimate of Ground-Water Recharge Rates, Related Streamflow and Water Quality in Ohio: Water Resources Center, The Ohio State University, Columbus, Ohio, Report No. 552, 323 p.
29. Prudic, D.E., 1989, Documentation of a Computer Program to Simulate Stream-Aquifer Relations using a Modular, Finite-Difference, Ground-Water Flow Model, U.S. Geological Survey, 113pp.
30. Schmidt, J.J., 1986, Ground-water Resources of Montgomery County, Ohio; Ohio Department of Natural Resources, Division of Water, Ground-Water Resource Section, 1 map.
31. U.S. Geological Survey, 2005, *Real-Time Data for Ohio, Daily Streamflow Conditions*: U.S. Geological Survey Water-Resources Web Site.
32. U.S. Geological Survey, 1966 (revised 1981), 1:24,000 scale, 7.5 Minute Dayton South, Ohio Quadrangle, 1 map.

33. U.S. Geological Survey, 1965 (revised 1992), 1:24,000 scale, 7.5 Minute Dayton North, Ohio Quadrangle, 1 map.
34. Yost, W.P., 1995, Data on Ground-water Levels and Ground-water/Surface-Water Relations in the Great Miami River and Little Miami River Valleys, Southwestern Ohio: U.S. Geological Survey Open-File 95-357, 57p.

APPENDIX A

SENSATIVITY ANALYSIS RESULTS

Table A-1
Sensitivity Analysis Results
Groundwater Model
Dayton, Ohio

Measuring Point	1993 Measured	Initial Calculated	KX10	% Diff	K/10	% Diff	Streambed KX10	% Diff	Streambed K/10	% Diff
MT260	728.65	732.325	724.433	-1.08%	732.195	-0.02%	733.569	0.17%	726.731	-0.76%
MT2049	735.23	739.838	726.562	-1.79%	739.157	-0.09%	739.976	0.02%	730.228	-1.30%
p5	710.61	723.119	720.282	-0.39%	726.826	0.51%	722.868	-0.03%	722.071	-0.14%
1A	755.95	755.096	722.544	-4.31%	842.113	11.52%	759.238	0.55%	759.413	0.57%
2A	777.38	768.463	751.819	-2.17%	862.325	12.21%	768.5	0.00%	770.422	0.25%
MT362	708.28	718.551	717.441	-0.15%	721.867	0.46%	718.773	0.03%	717.808	-0.10%
MT656	709.50	711.404	712.907	0.21%	710.944	-0.06%	711.667	0.04%	709.253	-0.30%
7A	861.59	859.459	777.046	-9.59%	1265.85	47.28%	860.91	0.17%	860.172	0.08%
MT365	709.55	716.007	715.676	-0.05%	717.69	0.24%	716.415	0.06%	714.462	-0.22%

Measuring Point	1993 Measured	Initial Calculated	Stream Flow FX2	% Diff	Stream Flow F/2	% Diff	Recharge RX1.5	% Diff	Recharge R/2	% Diff
MT260	728.65	732.325	732.319	0.00%	732.319	0.00%	733.15	0.11%	729.111	-0.44%
MT2049	735.23	739.838	739.86	0.00%	739.86	0.00%	740.18	0.05%	729.034	-1.46%
p5	710.61	723.119	723.006	-0.02%	722.941	-0.02%	723.568	0.06%	721.792	-0.18%
1A	755.95	755.096	754.951	-0.02%	759.079	0.53%	767.368	1.63%	741.868	-1.75%
2A	777.38	768.463	768.617	0.02%	768.617	0.02%	773.362	0.64%	765.255	-0.42%
MT362	708.28	718.551	718.555	0.00%	718.574	0.00%	719.341	0.11%	718.015	-0.07%
MT656	709.50	711.404	711.366	-0.01%	711.366	-0.01%	711.678	0.04%	711.086	-0.04%
7A	861.59	859.459	860.335	0.10%	860.335	0.10%	881.286	2.54%	821.2	-4.45%
MT365	709.55	716.007	716.014	0.00%	716.235	0.03%	716.771	0.11%	715.367	-0.09%

Measuring Point	1993 Measured	Initial Calculated	Boundary Well PX2	% Diff	Boundary Well P/2	% Diff
MT260	728.65	732.325	728.278	-0.55%	732.917	0.08%
MT2049	735.23	739.838	726.671	-1.78%	740.105	0.04%
p5	710.61	723.119	722.338	-0.11%	723.493	0.05%
1A	755.95	755.096	758.617	0.47%	759.059	0.52%
2A	777.38	768.463	770.532	0.27%	770.28	0.24%
MT362	708.28	718.551	717.976	-0.08%	718.766	0.03%
MT656	709.50	711.404	710.282	-0.16%	711.933	0.07%
7A	861.59	859.459	859.263	-0.02%	860.138	0.08%
MT365	709.55	716.007	715.072	-0.13%	716.635	0.09%

APPENDIX B

COMPUER MODEL CD ROM