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I, Brendan P. Merk,
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Ground Water Flow Modeling and Transient Particle Tracking, Applications for the Transport of *Cryptosporidium parvum* in an Unconfined Buried Bedrock Valley Aquifer, Springfield, Ohio

This work and its defense approved by:

Chair: Dr. David Nash
Dr. Barry Maynard
Dr. Thomas Lowell

Ground Water Flow Modeling and Transient Particle Tracking, Applications for the Transport of *Cryptosporidium parvum* in an Unconfined Buried Bedrock Valley Aquifer, Springfield, Ohio

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By

Brendan P. Merk

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Committee Chair: Dr. David Nash

Abstract

This study addresses concerns of surface water contamination entering a valley-train aquifer used by the Springfield Water Treatment Plant in Clark County, Ohio. Ground water is derived partly from infiltration of surface water through the riverbed of the adjacent Mad River. Of particular concern is biological pathogen *Cryptosporidium parvum* that is resistant to conventional treatment.

Transient, finite-difference ground water flow modeling and particle tracking are conducted, based on a geologically similar model near Dayton, Ohio. Site-specific parameters used for modeling are derived from previous investigations, pump tests, and gain-loss studies conducted at the SWTP.

Modeling is conducted for a flooding event when the aquifer is most sensitive to surface infiltration. Minimum travel times from Mad River to the production wells were estimated at around a day, but do not account for river bank filtration. The results provide a basis for additional study on the sensitivity of infiltration of surface contaminants.

Acknowledgements

Special thanks go to my loving and incredibly patient wife, Leslie and my daughter Caroline.

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1.0 INTRODUCTION

A new public water treatment system was developed for the City of Springfield, Clark County, Ohio in 1958. The Springfield Water Treatment Plant (SWTP) provides an average of twelve million gallons of potable water per day through a series of twelve production wells in a highly productive aquifer northwest of the city immediately adjacent to the Mad River. The aquifer is a thick deposit of highly permeable sand and gravel, which receives recharge through infiltration from Mad River and provides a steady and plentiful water supply. A water source under the direct influence of surface water, however, may allow contaminants to enter the water supply. A ground water flow model has been developed for the SWTP employing transient, finite-differences particle tracking to determine the susceptibility of the aquifer to surface water contamination, especially biological contaminants such as *Cryptosporidium parvum*.

1.1 Statement of Purpose

A wellhead protection area (WHPA) for the facility was established at the SWTP as a state demonstration project by the Ohio Environmental Protection Agency (OEPA) in 1990. The WHPA defines one- and five-year time of travel zones for the production wells. The possibility remains, however, that the production wells may produce ground water under the direct influence (GWUDI) of surface water. This problem is of concern to the City of Springfield, the OEPA and the Miami Conservancy District (MCD), due to close proximity of the production wells to Mad River.

Previous investigations have indicated that ground water in the area has a large base flow component, indicating a natural flow of ground water that discharges at Mad River (Schneider

1957, Kaser 1962, Cross and Feulner 1964, Norris and Eagon 1971, Koltun 1995). The effect of pumping at the SWTP has been noted to lower the water table and reverse this flow pattern (Kaser 1962). The placement of the current well system was based on the availability of water infiltration through the streambed of Mad River (Norris et al. 1952, Norris and Eagon 1971). This method of river bank filtration has been widely used for developing productive sources of potable water (Hiscock and Grischek 2002). Contaminants are theoretically filtered out through the streambed and aquifer materials; however the effectiveness of river bank filtration is unknown.

Of particular concern is the biological contaminant *Cryptosporidium parvum*. A protozoal pathogen, *C. parvum* in drinking water has been responsible for several large outbreaks and is considered a significant risk, as it is resistant to traditional water treatment technologies. The parasite is formed as an oocyst approximately 5 micro-meters (μm) in diameter and has aquifer transport mechanisms similar to other colloids and may travel over significant distances (Smith and Thomson 2001).

A ground water flow model previously developed by Dumouchelle et al. (1993) for the nearby Wright-Patterson Air Force Base (WPAFB) was examined and used as a basis for the development of a similar model for the SWTP. The goal of this study was to develop a transient ground water flow model to provide a more accurate interpretation of ground water movement and to provide an estimate of the potential transport of colloidal particles from Mad River to the production wells, including the best time to sample for contamination, the time of year the risk from contamination is highest, and to determine how serious a risk exists.

1.2 Previous Investigations

1.2.1 Geology and Hydrogeology

Harker and Bernhagen (1943) prepared an early report on the geology and groundwater resources of Clark County, based in part on a water supply concern of the City of Springfield. The recommended exploration of buried valleys in the county as potential public water sources was suggested. Norris, Cross, Goldthwait and Sanderson (1952) presented a comprehensive report on the available water resources of Clark County and recommended the buried valley near Eagle City as a water supply based on the productivity of the aquifer and the potential to recharge the aquifer by infiltration from Mad River.

Kaser (1962) provided a detailed description of the aquifer properties in response to complaints of lowered ground water levels in the vicinity of the new water plant when operation began in 1958. The drop in water levels was attributed to a combination of pumping and low precipitation. It was determined that the water supply from the aquifer would be adequate during normal conditions. Norris and Eagon (1971) provided a detailed description of the Eagle City aquifer, including a conceptual model of seasonal fluctuations, an estimated water budget and an estimate of the amount of infiltration from Mad River. The OEPA (1990) developed a wellhead protection plan for the Springfield Water Treatment Plant and developed the first ground water flow model for the area. The model established one- and five-year time of travel capture zones for the area surrounding the well field. Doumechelle et al. (1993) constructed a detailed ground water flow model for the nearby Wright-Patterson Air Force Base (WPAFB). The basic structure of their steady state model was the basis for the current investigation based on the similar geologic areas. Additional important references are summarized in Table 1.

Table 1 Select references and descriptions	
Harker (1944)	Utilized an electrical resitivity survey, indicating the approximate locations of the buried valleys in the county.
Brown (1948)	Provided a countywide description of glacial deposits in an unpublished thesis.
Norris (1951)	Discussed the progress in mapping the bedrock surface of Clark and surrounding counties.
Norris (1957)	Published a paper on the characteristics of the bedrock aquifers of western Ohio.
Schneider (1957)	Related geology to stream flow and noted that dry weather discharge of Little Miami River is exceeded only by Mad River.
Walker (1960)	Discussed the geology and the ground water quality and quantity in the upper Mad River Basin.
Feulner (1961)	Noted a correlation between the ground water and Mad River water levels. Established values for the transmissivity, porosity and permeability of the aquifer in Clark County.
Cross and Feulner (1964)	Discussed the hydrogeology of Mad River and provided an inferred direction of ground water flow, indicating both underflow and base flow components.
Hassemer, Watkins and Bailey (1965)	Provided seismic refraction data on the bedrock surface around the SWTP well field.
Schmidt (1982)	Published a map of the Ground Water Resources of Clark County.
Struble (1987)	Detailed the sand and gravel resources of the County.
Larkin and Sharp (1992)	Published a study of underflow patterns including an analysis for a similar aquifer at Great Miami River.
Arnett (1994)	Developed a ground water flow model for a similar aquifer in Dayton, Ohio.
Sheets and Yost (1994)	Examined the ground water potential of the underlying bedrock aquifers in Mad River valley, including a gain-loss study.
Koltun (1995)	Discussed the high base flow for the Mad River area, indicating that an increase in base flow is either negligible or remained constant during the study.
Vormelker, Angle and Jones (1995)	Provided a report on the pollution potential of Clark County and designated Mad River area as the most sensitive in the county.
Schalk (1996)	Conducted a similar groundwater model for Columbus, Ohio in a similar geologic area.
Dumouchelle (1998)	Conducted a regional ground water model for Dayton, Ohio in a similar geologic area.
Bendula and Moore (1999)	Conducted studies on shallow ground water contamination in Clark County.
Markley (2001)	Reported on the depositional environment of glacial deposits in the county in an unpublished thesis.

1.2.2 River bank filtration and Cryptosporidium parvum

Hiscock and Grischek (2002) published an article in the Journal of Hydrology, in an issue of the periodical dedicated to the study of river bank filtration. An article in the same journal by Sheets, Darner and Whitteberry (2002) discussed river bank filtration and contamination by biological pathogen *Cryptosporidium parvum* in a similar geologic setting near Cincinnati, Ohio. Pillai (1998) was editor for a book discussing the presence and transport of pathogens in aquifers. Smith and Thomson (2001) were editors for a text providing detailed information on *Crytosporidium parvum*. Szewzyk et al. (2000) published a report on microbial hazards in drinking water.

2.0 DESCRIPTION OF INVESTIGATION

2.1 Study Area

2.1.1 Study Location

Clark County is located in the west-central portion of Ohio and the City of Springfield is located near the center of the county. The SWTP (figures 1 and 2) is located at 201 Eagle City Road in the area northwest of Springfield. The production wells for the facility are located where Eagle City Road crosses the Mad River and are visible from Highway 68, a divided highway approximately 400 meters (m) or 0.25 miles (mi) east of the well field, with moderate traffic volume. Areas surrounding the SWTP were primarily agricultural, but are becoming more residential and commercial. A map of the area is included on the Springfield, Ohio 7.5 minute USGS topographic quadrangle (Figure 3).

Figure 1 -Aerial Photograph of the Springfield Water Treatment Plant Model Area

Figure 2 - The Water Treatment Plant (from http://www.ci.springfield.oh.us/depts/service/wtp)

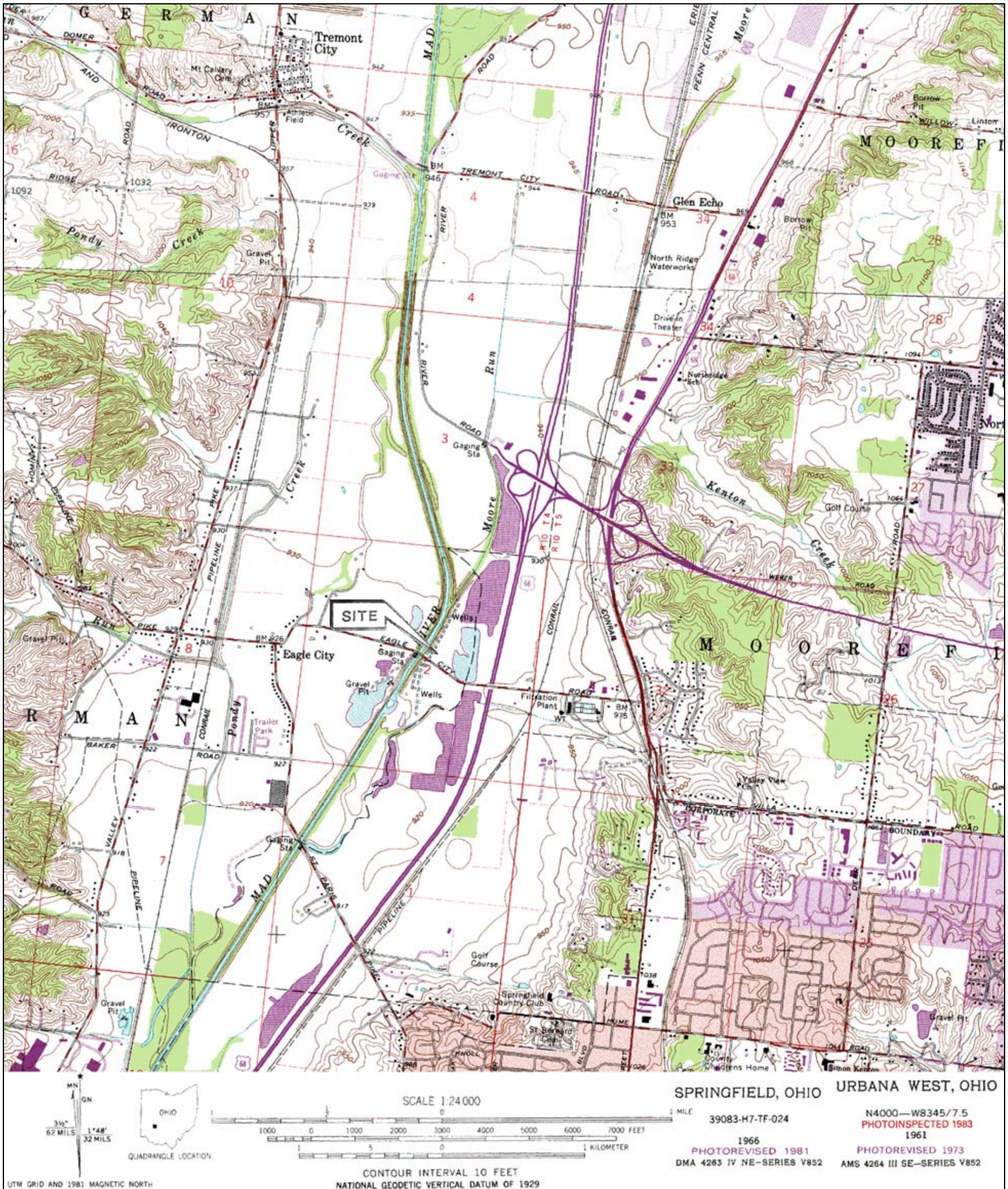

Figure 3 - Composite of the Springfield and Urbana West USGS 7.5 Minute Topographic Quadrangles

2.1.2 Topography

Clark County is located within the interior plains of Ohio, in the Central Lowland physiographic province and Till Plains section of the state (Figure 4). The western half of the county is located within the Southern Ohio Loamy Till Plain and the eastern half within the Mad River Interlobate Plain, with some of the Darby Plain in the southeast area of the county. The Southern Ohio and Darby Plain areas are moraine and kame deposits from two glacial lobes that converged in the Springfield area, creating the Mad River Plain outwash deposits (Brockman 1998).

The topography of the valley walls is rolling to steep and borders nearly level to gently rolling outwash deposits of the valleys which are in turn incised by the nearly level alluvial terraces and flood plains (Miller 1999). The flood plain rises from a southern elevation of approximately 920 feet (ft) or 280 meters (m) to 935 ft (285 m) to the north. Previous meanders of the Mad River are visible on the valley floor (Kaser 1962).

2.1.3 Climate

The climate of Clark County is temperate with fairly high temperatures in summer, moderate temperatures in winter and an average annual temperature of 52 °F. Summers are humid, averaging 21.7 degrees Celsius (°C) or 71 degrees Fahrenheit (°F), with an average daily maximum temperature of 27.8 °C (82.1 °F) and a record high of 37.8 °C (100 °F) between 1961 and 1990. Winters average -2.3 °C (27.8 °F), with an average daily minimum of -7.2 °C (19 °F) and a record low of -32.2 °C (-26 °F) between 1961 and 1990 (Miller 1999).

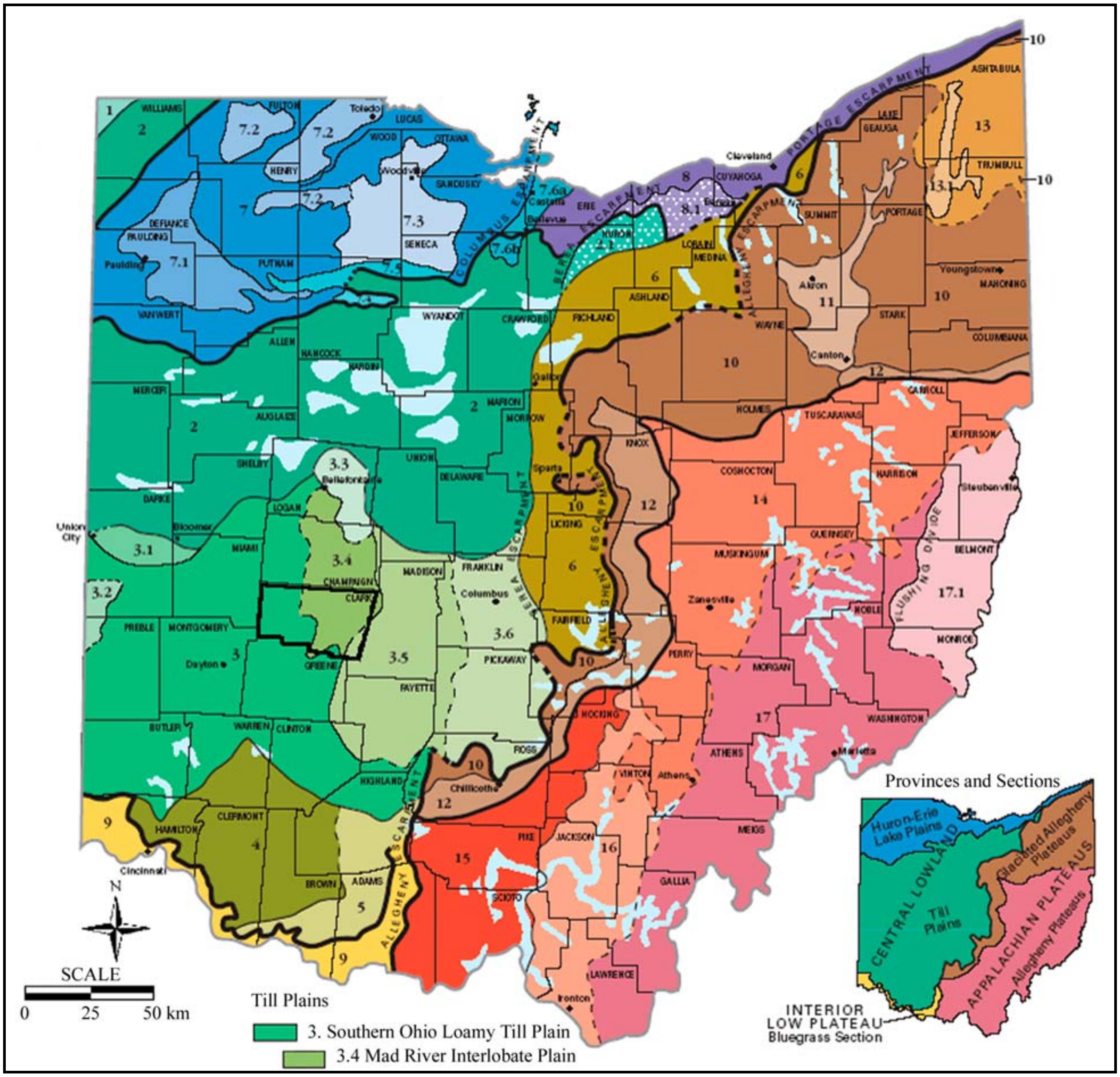

Figure 4 - The Physiographic Regions of Ohio (Adapted from Brockman 1998)

Annual precipitation averages 96 centimeters (cm) (37.8 inches). Precipitation is generally lowest in February with 4.67 cm (0.84 in) and highest in May and June with approximately 10.8 cm (4.25 in). Over half of the average annual precipitation occurs in the five months between April and August (Miller 1999). Average annual evaporation was estimated at 86.4 centimeters (34 inches) per year (Norris et al. 1952).

Daily temperature and precipitation records were collected from a weather station at the SWTP and were obtained through the website for the National Climatic Data Center (NCDC). Records are available from July 1, 1960 through the present. Monthly precipitation totals from 1960 through 1999 are included in Appendix A. Climatic data for Clark County were obtained from the Hydrologic Atlas of Ohio (Harstein 1991). Average temperature, precipitation and water loss are illustrated in figures 5, 6 and 7, respectively.

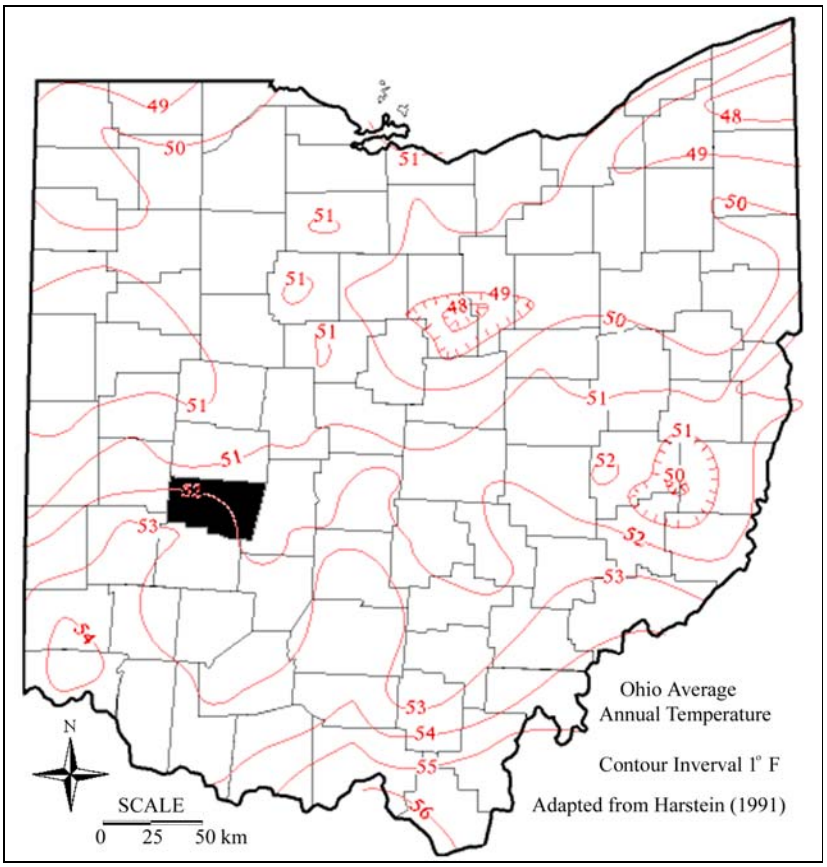

Figure 5 - Average Annual Temperature in Degrees Fahrenheit from 1931 to 1980

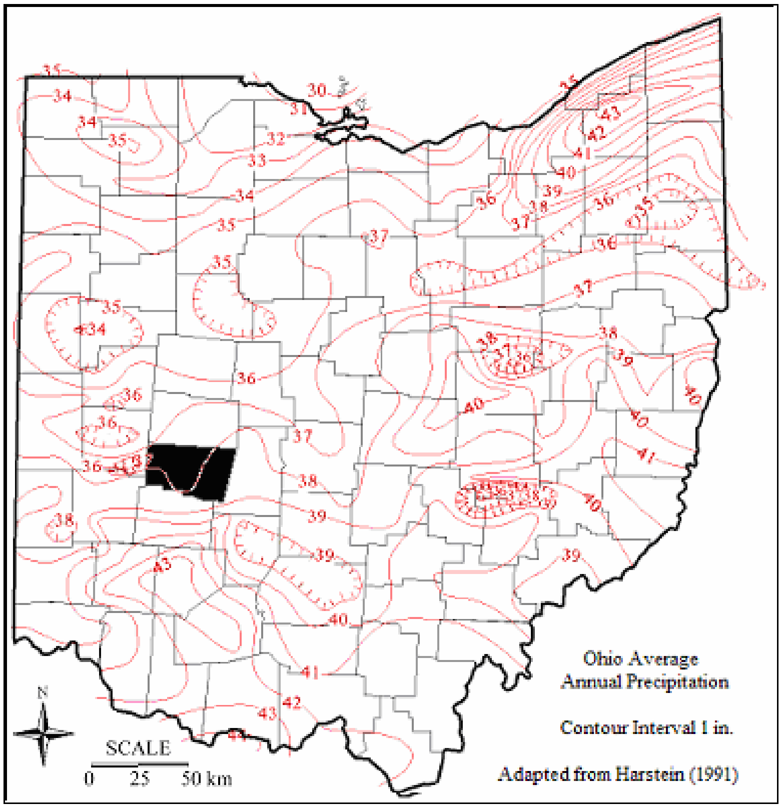

Figure 6 - Average Annual Precipitation in Inches from 1931 to 1980

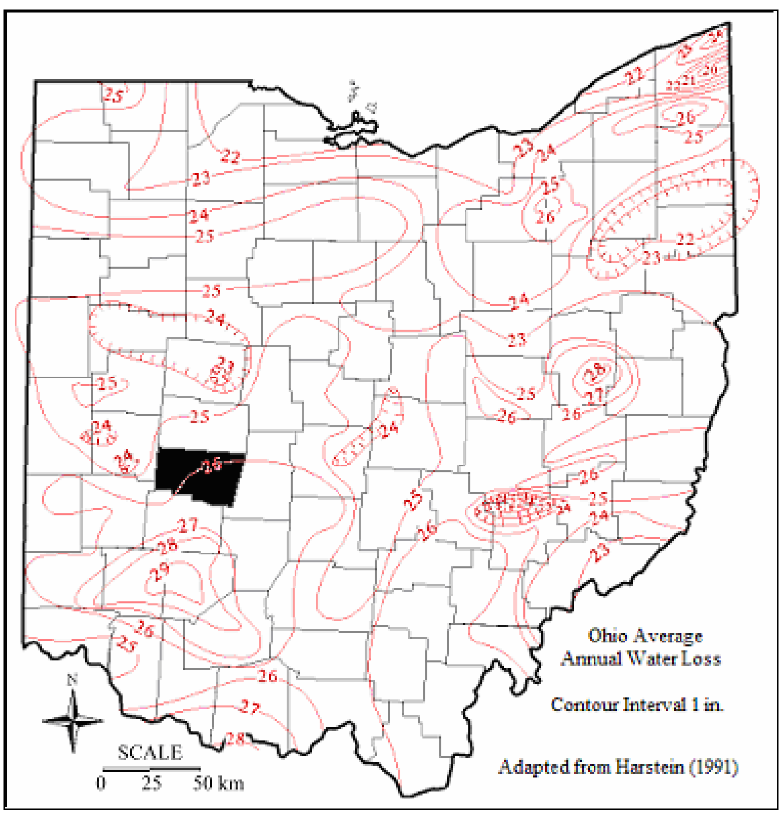

Figure 7 - Average Annual Water Loss in Inches from 1931 to 1980

2.1.4 Population

The population of both Springfield and Clark County grew steadily from 1820 through World War II. The population peaked for Springfield in 1960 and for Clark County in 1970. Population census data currently indicate a slow decline subsequent to these peaks (Figure 8). The historical census data for Clark County and Springfield are in Table 2.

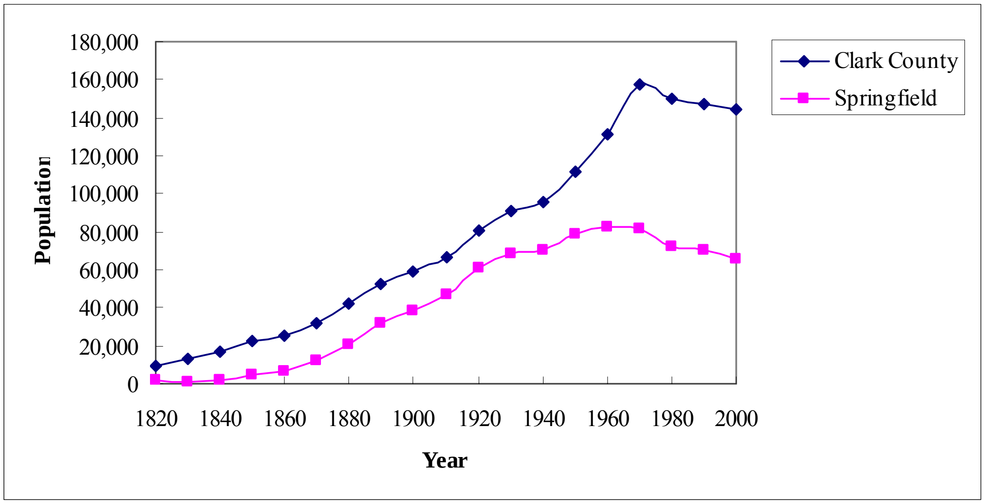

Figure 8 - Population Changes in Springfield and Clark County

Table 2
Historical census data for Clark County and Springfield, Ohio

Year	1820	1830	1840	1850	1860	1870	1880	1890	1900
Clark County	9,533	13,114	16,882	22,178	25,300	32,070	41,948	52,277	58,939
Springfield	1,868	1,080	2,062	5,108	7,002	12,652	20,730	31,895	38,253

1910	1920	1930	1940	1950	1960	1970	1980	1990	2000
66,435	80,728	90,936	95,647	111,661	131,440	157,115	150,236	147,548	144,742
46,921	60,840	68,743	70,662	78,508	82,723	81,941	72,563	70,487	65,358

2.1.5 Water Usage

2.1.5 (a) History of the Springfield Water Treatment Plant

The SWTP was originally established along Buck Creek in 1882 for fire protection purposes and began operations as a municipal water supply in 1896. Prior to 1958 the primary water supply consisted of surface water diverted from Buck Creek into infiltration galleries and allowed to percolate through a thin natural gravel filter. According to Norris et al. (1952) the average usage for potable water in Springfield was 13,500,000 gallons per day in 1947. The majority of this came from Buck Creek and only 2,000,000 gallons were derived from ground water sources. Water shortages were common as the low flow rate in Buck Creek was not sufficient to keep up with demand. The water quality suffered from sanitary issues due to the nature of the collection system. The majority of the water supply was therefore under the direct influence of surface water. It was apparent that the City of Springfield was faced with an inadequate water supply to meet the demands of the expected population growth for Springfield (Harker and Bernhagen 1943).

Springfield began searching for an alternate water supply as early as 1918, and in 1935 was ordered to make improvements by the Ohio Department of Health. It was recommended that the buried valleys of Clark County, including those northwest of Springfield, be investigated as a potential source of potable water (Harker and Bernhagen 1943). Norris et al. (1952) agreed, noting that "care should be taken to choose areas where infiltration from the Mad River will be induced under pumping conditions." Rather than using infiltration galleries, the new plant would utilize wells along the Mad River to pump ground water from the aquifer. The removal of water would be offset by the infiltration of surface water from the Mad River that would then be filtered naturally by the thick gravel aquifer. Advantages to this type of system include temperature equilibration and the reduction of adsorbed compounds, dissolved suspended solids, particles and biological compounds including bacteria, viruses and parasites (Hiscock and Grischek 2002). The water plant was moved to the current Eagle City Road location in 1958.

Shortly after the new facility began operations, local residents complained to the Ohio Water Commission that numerous private water wells had gone dry. It was asserted that the water pumped at the plant was being removed from storage and that more wells might become dry as pumping continued. A hydrologic investigation determined the extent to which the water table had been lowered due to pumping and its effect on local water supplies. A key question addressed by the study was whether the water produced by the SWTP was obtained from storage or from induced infiltration from the Mad River. The report by Kaser (1962) noted that the combined effects of pumping and low precipitation totals were responsible for the lowered ground water levels and that abundant water was available from induced infiltration of Mad River. Kaser estimated that sixty percent of the water pumped during a prolonged low-flow period was from infiltration from the Mad River.

2.1.5 (b) Description of the Current Water Treatment System

The SWTP produces an average of 45,425 cubic meters (m^3) or 12 million gallons (mgal) of ground water per day, with an estimated maximum capacity of 136,275 m^3 (36 mgal) per day, extracting ground water though a series of pumping wells located along the Mad River. Two of the production wells (PW-11 and PW-12) were installed in 1995. The extracted ground water is treated with lime softening and rapid sand filtration prior to distribution through over 494 kilometers (km) or 307 miles (mi) of water main. Monthly water quality sampling includes total coliform and nitrates. Copper and lead are sampled every three years. Hardness, alkalinity, pH, chlorine and turbidity and sampled every two hours. To date, no water quality violations have occurred at the water plant, and testing of the SWTP has detected no instances of *Cryptosporidium parvum*.

2.1.5 (b) (1) Production Wells

The SWTP extracts ground water from twelve pumping wells located where the Mad River intersects Eagle City Road northwest of Springfield. The well field is divided by Eagle City Road, with six wells on either side of the road. The wells are located an average of 91.4 m (300 ft) apart and are between 15 and 76 m (50 and 250 ft) from the river (Figure 3). Well depths range from 26.5 to 32.6 m (87 and 107 ft) (Norris and Eagon 1971). Each well has a 76.2 cm (30 in) casing and screened intervals ranging from 16.8 to 35 m (55 to 115 ft) below land surface. The screen length for each well is 13.7 m (45 ft). A photograph of the south well field is included as Figure 9. Copies of the well logs are included in Appendix B.

Figure 9 - Production Wells South of Eagle City Road

2.1.5 (b) (2) Sandpoints

Water levels from July 1960 through November 2000 were obtained from a set of thirteen (13) two-inch (2 in) diameter driven wells or "sandpoints" in the area surrounding the SWTP (Figure 10). No lithological data are available for these wells. Wells cl-7 and cl20 were installed by the USGS.

Elevations for the sandpoints were estimated from a comparison of GPS data provided by the SWTP and elevations cited in Kaser's 1962 investigation. The source and degree of uncertainty with the GPS elevations are unknown and discrepancies were noted with the Kaser elevation data. Uncertainties in well head elevation should be resolved for future investigations.

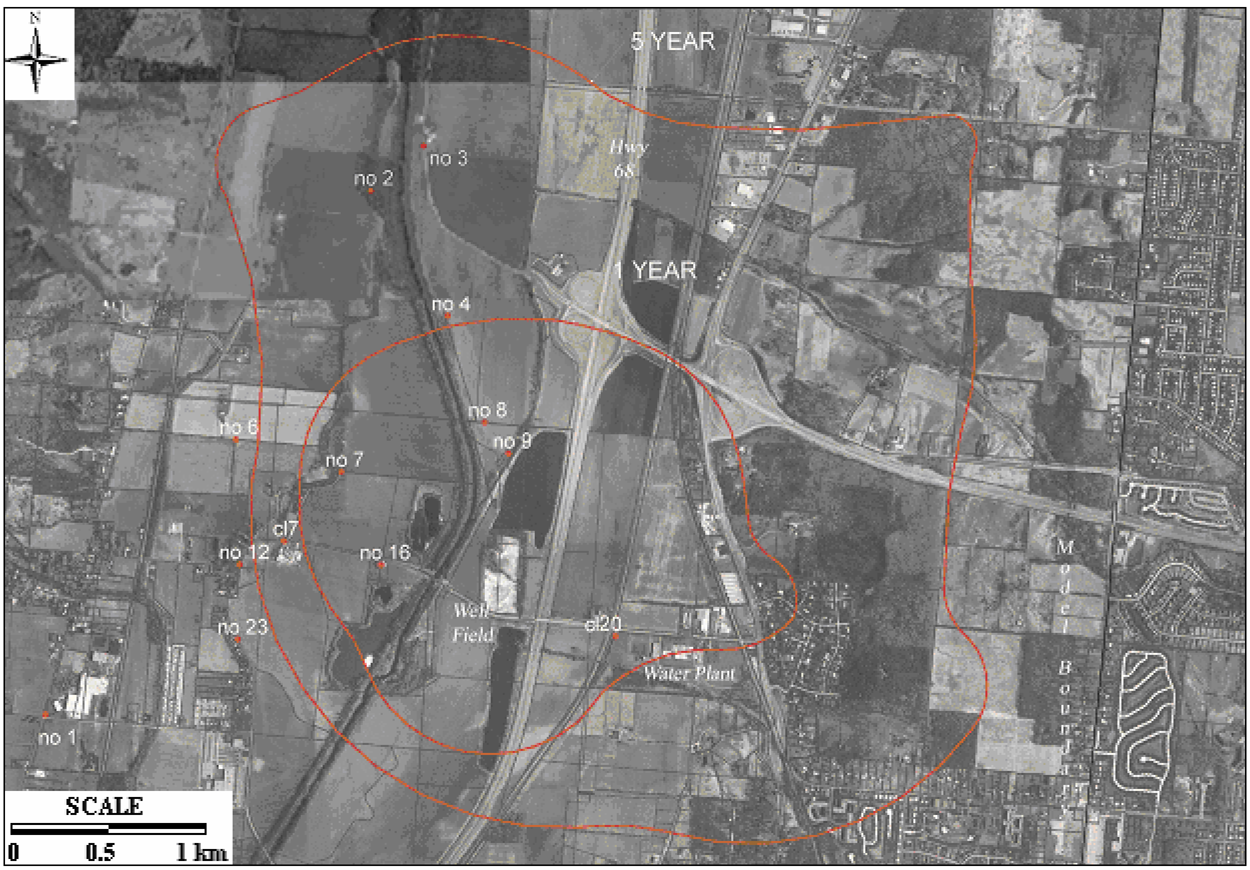

Figure 10 - Sandpoint Locations and SWTP Time of Travel Zones (based on OEPA 1990)

Water levels are collected on a monthly basis, although monitoring was more frequent in the months after they were first installed. Sandpoint cl20 was not measured prior to the end of 1988. Starting in August 1988 the water level measurements have been made on the first non-holiday week day of each month (exact date of each event was not recorded). Depth has been historically measured by steel tape to an accuracy of 0.01 ft (0.025 cm). A summary of the monthly water levels is included as Appendix C. Water levels have increased in all sandpoints since 1961 from a low of 45.7 cm (1.5 feet) at SP-16 to a high of 4.47 m (14.66 feet) at SP-3. The average water changes over time are shown in Table 3.

Table 3 Average historic sandpoint water levels

Year	SP-1	SP-2	SP-3	SP-4	SP-6	SP-7	SP-8	SP-9	SP-12	SP-16	SP-23	CL-7
1961-1965	277.31	282.66	280.15	278.46	277.48	276.89	277.36	276.69	276.29	277.72	276.72	276.76
1966-1970	277.39	282.54	279.93	278.27	277.07	276.95	277.22	276.44	276.37	277.68	277.22	276.89
1971-1975	278.10	283.60	280.81	279.43	278.29	278.22	278.58	278.06	277.51	279.19	278.14	278.08
1976-1980	277.93	283.37	280.44	279.23	278.01	278.08	278.43	277.91	277.12	279.00	278.04	278.16
1981-1985	278.33	283.15	281.19	279.25	278.67	278.56	278.61	278.32	--	278.98	278.28	278.70
1986-1990	277.89	282.49	280.67	279.19	278.23	278.13	278.32	277.92	277.92	278.39	276.91	278.61
1991-1995	278.14	283.31	282.82	279.67	278.90	278.70	279.00	278.66	278.38	279.05	278.20	278.98
1996-2000	278.29	283.33	284.62	279.79	279.00	278.91	279.11	278.85	278.57	278.19	278.45	278.66
Change (m)	0.98	0.67	4.47	1.33	1.52	2.02	1.75	2.15	2.28	0.47	1.73	1.90

Daily water levels have been continuously recorded by the USGS at cl-7 since October 1960. The measured data from the SWTP and automatic gage data from the USGS were compared for accuracy. The data for both wells were close from 1961 through 1980 with an average difference of approximately 0.25 cm (0.1 in). The difference increased to 2.1 cm (0.83 in) by

1985, to 42.7 cm (1.4 ft) by 1995 and over 152 cm (5 ft) by 2000. For the purposes of this investigation the automatically gaged data from cl-7 is considered inaccurate, while the monthly data is considered accurate based on the method of manual collection.

The automatic gage data does illustrate, however, the general rise in ground water levels during March and May before vegetation growth increases water consumption as noted by Norris and Eagon (1971). Comparisons of data from 1996 to 2000 are illustrated in Figure 11.

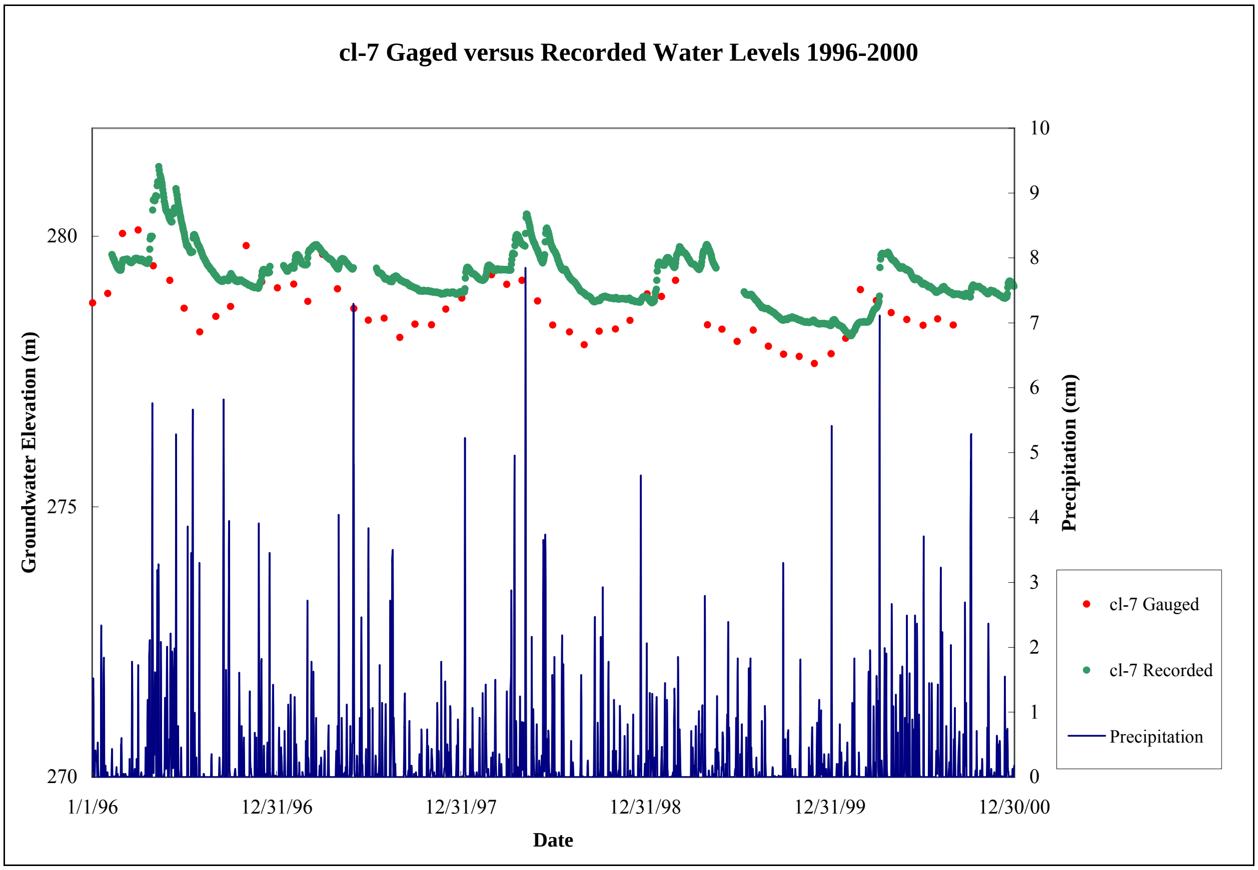

Figure 11 - Comparison of Measured and Gaged Water Levels in cl-7

2.1.5 (b) (3) Aquifer Monitoring

Seven new monitoring wells were installed by the Miami Conservancy District (MCD) in the area surrounding the SWTP in May and June 2003. The MCD is a political subdivision of the

State of Ohio, which exists to manage the watershed for flood prevention and preservation. The MCD has installed monitoring wells and performed testing throughout the Mad River watershed. Also, the SWTP has installed staff gages in the lakes surrounding the well field for additional monitoring of the piezometric surface. To date the wells and staff gages are lacking elevation data and are not included in the monthly water level measurement collection. These points are therefore not included in the current investigation, but should be utilized in future studies.

2.1.5 (c) Well-Head Protection

Wellhead protection areas were developed for the SWTP by the Ohio EPA (1990) wellhead demonstration project. The purpose of the protection areas is to determine the area that water supplying the production wells travels within a specified time frame. Once defined, these areas can be studied to determine the potential for contaminants to enter the water supply.

The OEPA study was largely based on site-specific data from Norris et al. (1952) and background water levels inferred from Kaser (1962). Ground water flow in the aquifer was modeled in a “semi-analytical” model utilizing the DOS programs CAPZONE and GWPATH. The model utilized background water levels from Kaser and calculated drawdown based on the stress from pumping and specified aquifer conditions. The drawdown in the model was calculated at the intersection of lines in a grid centered over the well field. The grid had a spacing of 400 feet with a grid size of 24 rows and 40 columns as illustrated in Figure 12.

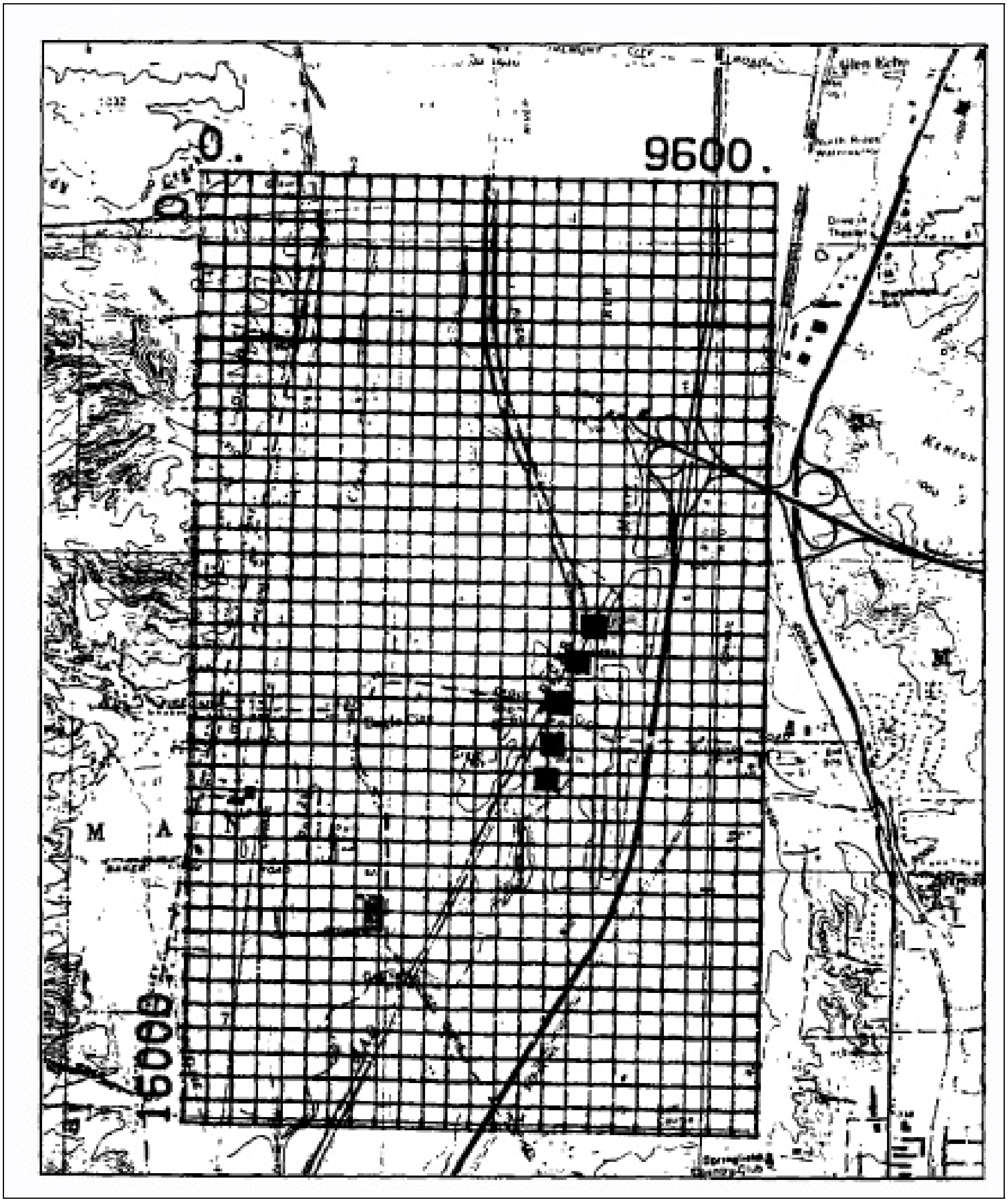

Figure 12 - OEPA Model Grid and Boundary (from OEPA 1990)

Aquifer transmissivity was set at 1,135.6 m^2 (300,000 gallons per ft) per day, hydraulic conductivity at 122 m (400 ft) per day and porosity at 20 percent. The depth of the aquifer was averaged at 30.5 m (100 ft) and the east and west valley walls were set as no-flow boundaries. Infiltration of water from the Mad River was estimated indirectly through boundary conditions. A time period of 270 days was modeled with no recharge.

Resulting water levels from the model were used for particle tracking to provide a one- and five-year time of travel area. The calculated travel time zones are illustrated in Figure 10. It was noted that these zones extend beyond the east boundary, indicating that ground water flow may occur there. Due to the lack of subsurface stratigraphic detail the protection area boundaries to the east were based on topographic highs within a mile of the SWTP.

2.2 Geology

2.2.1 Consolidated Deposits

Consolidated bedrock deposits consist of Silurian age shales and carbonates underlain by Ordovician age shales, limestones and dolomites. A geologic column of the consolidated bedrock formations is included in Table 4. Bedrock immediately in the area of the SWTP consists of the Brassfield Limestone and the Richmond Shale. The contact between the two formations is around 800 ft (243.84 m) contour. The average dip of the consolidated rocks is approximately 15 feet per mile to the northeast (Norris et al. 1952). The surface of the bedrock is flat to rolling except for incisions created by pre-glacial uplift and erosion (Sheets and Yost 1994).

Buried valleys exist to the east, west and north of Springfield (Harker 1944). The bedrock valley at the SWTP trends from the northeast to the southwest and roughly coincides with the present course of the Mad River. It connects with a larger bedrock valley to the northeast, which trends from the southeast to the northwest, cutting across Clark County to the north of Springfield (Kaser 1962).

Table 4
Geologic column of consolidated bedrock formations (adapted from Norris et al. 1952)

System	Group	Formation	Average Thickness (m)	Description
Silurian	Niagara	Cedarville LS	46	Massive, porous dolomite
		Springfield LS	4.3	Thin, dense dolomite
		Euphemia Dolomite	2.4	Massive, porous dolomite
		Massie Clay-Shale	1.2	Calcareous, dense
		Laurel Dolomite	1.5	Thin, dense
		Osgood Shale	6.1	Calcareous with limestone
		Dayton LS	1.8	Thin, dense
	Clinton	Brassfield LS	9	Fossiliferous, massive to irregularly bedded.
Ordovician	Upper Ordovician	Richmond, Maysville and Eden	328	Soft, fossiliferous, calcareous shale interbedded with thin, hard limestone

The dominant geologic structure of the region is the so-called “Cincinnati Arch” complex; a north-plunging anticline dipping at a low angle to the east (Norris 1951; Norris 1957). Bedrock was uplifted and tilted with the formation of the Cincinnati Arch during the Tertiary Period, around 10 to 15 mya. As a result of the uplift, streams began to erode the bedrock, forming large valley drainage systems, which passed through the Springfield area, flowing in a general northwest direction across Ohio (Sheets and Yost 1994).

The entrenched valley system is commonly known as the “Teays” river system (Harker and Bernhagen 1943; Brown 1948; Norris et al. 1952; Norris 1957). The elevation of the base of the

Teays valley system in Clark County is approximately 161.5 m (530 ft) above sea level (Harker and Bernhagen 1943; Norris 1951).

The Teays River drainage system was altered in the early Pleistocene, possibly by early Kansan stage glaciation. The advancing glaciers blocked the Teays and its tributaries north of Clark County, filling the bedrock valleys with sediment and forming large lakes. Eventually the lakes overflowed low divides and eroded deeper into the bedrock valleys, creating what is commonly called the “deep stage” drainage system. The deepest part of the valley was eroded below the Teays stage in most areas, to an estimated elevation of 198 to 213 m (650 to 700 ft) or approximately 76 m (250 ft) below the present flood plain (Norris 1957; Kaser 1962). This system was covered by later glaciers that advanced during the Illinoian stage, approximately 300,000 to 130,000 years ago. This was followed by the Wisconsinan stage, approximately 24,000 to 14,000 years ago, which deposited the present glacial deposits at the surface in Clark County. A contour map of the bedrock surface was generated by Norris (1951). Hassemer et al. (1965) conducted a seismic refraction survey of the area to determine the thickness and extent of the bedrock valley. The bedrock valley is approximately 3.2 km (2 mi) wide at the SWTP (OEPA 1990) (Figure 13).

2.2.2 Unconsolidated Deposits

The Wisconsin glacier advance was split by highlands in the area north of Clark County, near Bellfontaine (Norris et al. 1952). One of the glacial lobes advanced east to the Scioto Valley, while the other moved west to the Miami Valley, depositing till and forming moraines throughout both areas (Harker and Bernhagen 1943). Several north-south trending moraines have been noted throughout Clark County marking the oscillations of the boundary between the two lobes (Brown 1948). The interlobate area received glacial outwash deposits and the deep bedrock valleys were filled with glacial outwash (valley train) deposits over 76 m (250 ft) thick (Harker and Bernhagen 1943). The stratigraphy of the glacial deposits is not well known, but is thought to be highly variable, with high-permeability sands and gravels interbedded with low-permeability clays and tills (Kaser 1962).

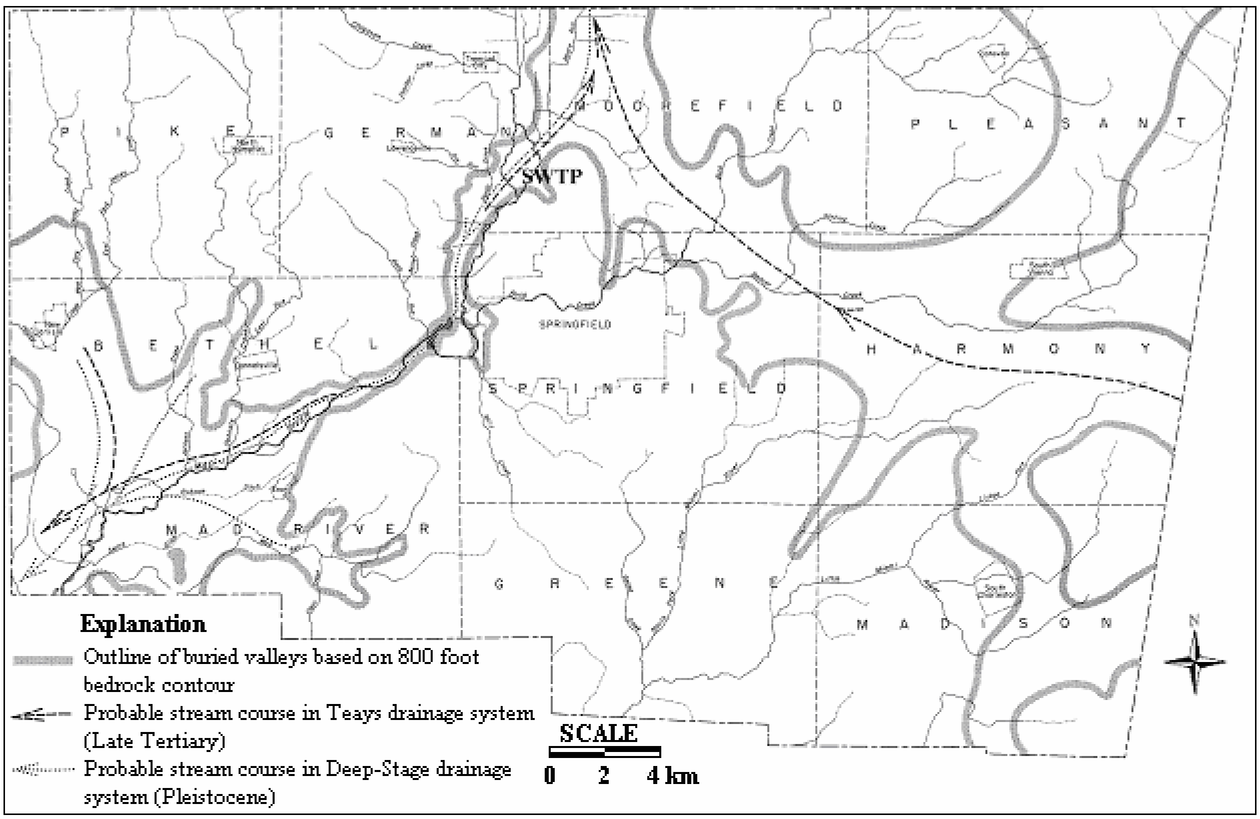

Figure 13 - Locations of Buried Valleys (Adapted from Norris et al. 1952)

2.2.2 (a) Valley Train Deposits

The deep-stage sediments were likely deposited by high velocity melt waters from the interlobate area, resulting in coarse, highly permeable gravel deposits in the bedrock valley (Norris et al. 1952). A cemented layer within the aquifer was noted at a depth of about 20 ft (6.1 m) by Kaser (1962), who attributed it to past fluctuations in ground water levels, with alternating wetting and aeration of the zone depositing cementing materials. The permeability of the cemented gravel was noted to be poor, but was not estimated nor was its extent determined. The thickness of the aquifer is at least 35 m (115 ft) based on the deepest wells; but is no doubt thicker at the deepest points in the valley. The thickness is highly variable, becoming shallower to the east and west near the edges of the buried valley. The topographic relief of the outwash deposits is low, generally less than 1.5 m (5 ft), and is marked by abrupt changes at the valley walls (Brown 1948).

The unconsolidated material of the main Teays bedrock valley, as found near Buck Creek to the east, is primarily fine sand with an extremely low permeability, making it unsuitable for the development of ground water. Conversely the deep stage buried valley system is relatively shallow, consisting of well-sorted gravel and sand, a high permeability and faster recharge than the Teays (Harker and Bernhagen 1943). Markley (2001) developed a conceptual depositional model for glacial deposits in southwest Clark County, stating that major landforms are generally laterally continuous with only minor lenses of other sediments. A notable exception included till deposits of moraine type structure that existed within the valley-train deposits. Tills are known to exist in the valley-train deposits of the study area, but their extents have not been defined.

2.2.2 (b) Till Deposits

Highlands to the east and west constitute the walls of the valley. Frontal moraines to the east are known as the Springfield Moraine, and till plains to the west are known as the North Hampton Till Plain, as noted by Brown (1948).

The North Hampton Till Plain is the most extensive in the county, covering approximately 233 km^2 (90 mi^2) and consisting primarily of ground moraines, typically less than 15.2 m (50 ft) thick. These deposits extend to depths of up over 30 m (100 ft) along the western bank of the Mad River in the areas to the north. Relief is gentle, often less than 1.5 m (5 ft), less rolling, as well as notably freer of boulders than the moraines. The till thickens to the north and has a higher percentage of gravel lenses to the east. The eastern edge, where it joins the outwash valley, is much more dissected than other edges, likely due to oscillations of the Miami lobe. The plain is cut deeply by Chapman's Creek in the northwest part of the study area where several glacial advances and retreats were noted (Brown 1948). The tills lie directly over bedrock and mark the western boundary of the buried aquifer near the SWTP (Norris and Eagon 1971) (Figure 14).

Figure 14 - View of Till Plains West of the SWTP

The Springfield Moraine to the east contains many enclosed depressions and relief is often greater than 6 m (20 ft) with a sharply rolling topography. The frontal moraines are marked by rolling topography with undrained depressions and surface relief of several meters. The surficial till averages more than 9 m (30 ft) thick and is underlain by gravel deposits 9 to 15.2 m (30 and 50 ft) thick. Deposits of glacial materials are discontinuous due to oscillations of the Scioto lobe of the late-Wisconsin age glacier (Brown 1948).

2.2.2 (c) Soils

A generalized soil map by Miller (1999) indicated the following soil type associations:

- Alluvium – Tremont-Ross-Sloan Association

The Tremont-Ross-Sloan soils are associated with flood plains and are nearly level. They are very deep and, except for the Sloan soil types, are at least moderately well drained.

- Valley train – Eldean-Lippincott Association

The Eldean-Lippincott soils are associated with outwash plains and valley train deposits and are nearly level to gently sloping. They are very deep and are well drained in the Eldean soils, and very poorly drained in the Lippincott soils.

- Till plains – Miamian-Kokomo-Celina Association

The Miamian-Kokomo-Celina soils associated with till plains and are nearly level to steep. They are described as very deep and, except for the Kokomo soils, are at least moderately well drained.

- Moraines – Miamian-Eldean-Kokomo Association

The Miamian-Eldean-Kokomo soils are associated with kame terraces and till plains and are nearly level to steep. They are very deep and, except for the Kokomo soils, are well drained.

2.2.2 (d) Quarry Operations

Several quarries have operated within both the current SWTP well field and in the surrounding areas for decades, as noted by the presence of the lakes there (Figure 3). Harker (1944) noted the existence of the "Estey" gravel pits within the flood plain at Eagle City, near the present well field. Brown (1948) described the supply of gravel from the outwash deposits as inexhaustible, with the best deposits being located in the Mad River valley train. Two quarry operations at the SWTP were noted by Kaser (1962) and included gravel plants near both well fields, stating that "One plant operates two pits east of the river and north of Eagle City Road; the other operates two pits south of Eagle City Road, one of either side of the river." The quarries are reportedly up to 27.4 m (90 ft) deep.

Currently an active quarry, operated by Baisden Excavating Sand and Gravel, is located to the southwest of the SWTP at 1812 Baker Road in Springfield. Conventional pumping for dewatering such a quarry would be impossible considering the highly permeable materials and shallow depth to water; therefore quarrying is done by drag line (Figure 15). Generally coarse gravels are removed, and boulders the size of the drag line bucket have been removed from the excavation.

Exploration studies were conducted prior to the start of plant operations and owner Brett Baisden made boring logs available. Data obtained from the quarry provided information on lithologies of the aquifer, including granulometry and depth to bedrock. A map of the quarry and pertinent information is included in Appendix D.

Figure 15 - Drag line operation at Baisden Excavating

2.3 Hydrogeology

2.3.1 Surface Water Features

The Mad River and its tributaries drain the entire study area. The Mad River was dredged and straightened in 1929. Moore Run has also been dredged and straightened from its original course (Kaser 1962). The current wells of the SWTP are sited between the current and previous courses of the Mad River.

2.3.1 (a) Mad River

The Mad River is the controlling feature of the hydrology of the area with a 906.5 km^2 (305 mi^2) drainage area. The extent of the Upper Mad River basin is illustrated in Figure 16. The daily flow of the river averages 586,740 m^3 (155 mgal) of water per day and exceeds 246,000 m^3 (65 mgal) of water per day 95 percent of the time (Norris and Eagon 1971).

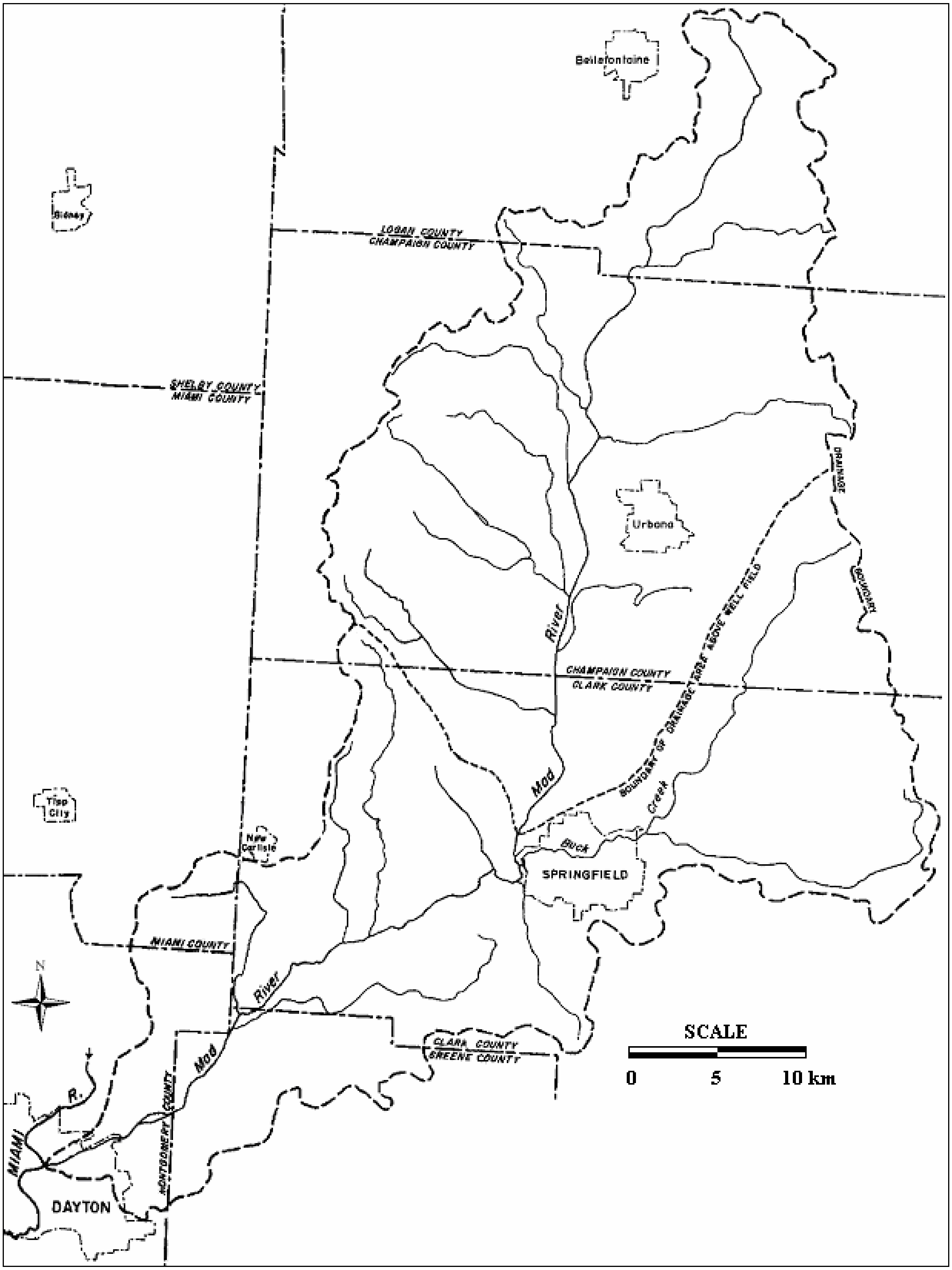

Figure 16 - The Extent of the Upper Mad River Basin (Adapted from Kaser 1962)

2.3.1 (b) Tributaries

The largest tributary is Moore Run, which joins the Mad River about 366 meters (1,200 feet) upstream of Eagle City Road. Located on the east side of the flood plain, Moore Run runs roughly parallel to the Mad River. Moore Run is approximately 13 km (8.1 mi) in length and drains 47.24 km^2 (18.24 mi^2) with an average gradient of 0.00125 (Kaser 1962).

The area to the west is drained by tributaries associated with Pondy Creek, which joins the Mad River approximately 1,463 m (4,800 ft) downstream of Eagle City Road. This stream flows to the south and is generally parallel to the Mad River. Pondy Creek is approximately 5.8 km (3.6 mi) in length, drains 17.6 km^2 (6.8 mi^2) and is often dry (Kaser 1962).

2.3.1 (c) Hydrographs

The Mad River valley is underlain by thick, permeable glacial outwash deposits resulting in high levels of sustained flow between rain events. Cross and Feulner (1964), Sheets and Yost (1994) and Koltun (1995) note that the Mad River has the highest level of dry weather flow in Ohio. Mad River is less responsive to flood events that other areas in Ohio, as precipitation is added to storage in ground water reserves. Cross and Feulner (1964) reported that the Mad River is a gaining stream with a hydraulic gradient toward the river. Under normal conditions ground water is effluent and is expected to contribute to the Mad River, primarily through base flow. Base flow accounts for approximately 68 percent of the annual stream flow with a typical average discharge of over 8.5 m^3 (300 ft^3) per second (Dumouchelle 1998). The flow is reversed at the SWTP due to pumping, where ground water does not contribute to the Mad River (Kaser 1962; Norris and Eagon 1971).

A comparison of stream flow to precipitation through a hydrograph can provide information on the storage capacity of the aquifer and allow comparisons of one drainage system to another. A flow duration curve plots stream flow against the percentage of time that flow is exceeded. A flatter curve indicates a stream with low flood peaks and a higher low-flow discharge.

The low flow index for the Mad River has been estimated to be twice that of the nearby Little Miami River (Schneider 1957). A hydrograph comparing the Mad River, Little Miami River and Ohio Brush Creek (which drains a less permeable area) is adapted from Schneider (1957) in Figure 17. Additional hydrographs of Mad River and highly detailed descriptions of the associated aquifer are in Norris et al. (1952).

2.3.1 (d) Gaging Stations

Previous investigations have attempted to directly measure the amount of infiltration of water from the Mad River into the gravel aquifer. Gages were placed upstream and downstream of the well field to determine the amount of water loss to the SWTP. As noted by Norris and Eagon (1971), results from these studies have not been successful. Many of the gages were located poorly and were subject to influence from the well field or confluence with tributaries

2.3.2 Hydrologic Properties of the Aquifer

2.3.2 (a) Consolidated Deposits

Ground water in consolidated formation typically occurs within joints, fractures and bedding planes. Water may also be stored in areas enlarged by solution of limestone (Norris et al. 1952), especially where weathered, prior to burial by glacial deposits, in a layer up to 15.2 m (50 ft) thick (Norris 1957). Wells drilled in the weathered layer produce less water with depth unless a bedding plane or change in lithology is encountered. High permeability zones are found in the Silurian age Brassfield and Cedarville formations, which can provide sufficient yield for farms and domestic wells (Harker and Bernhagen 1943).

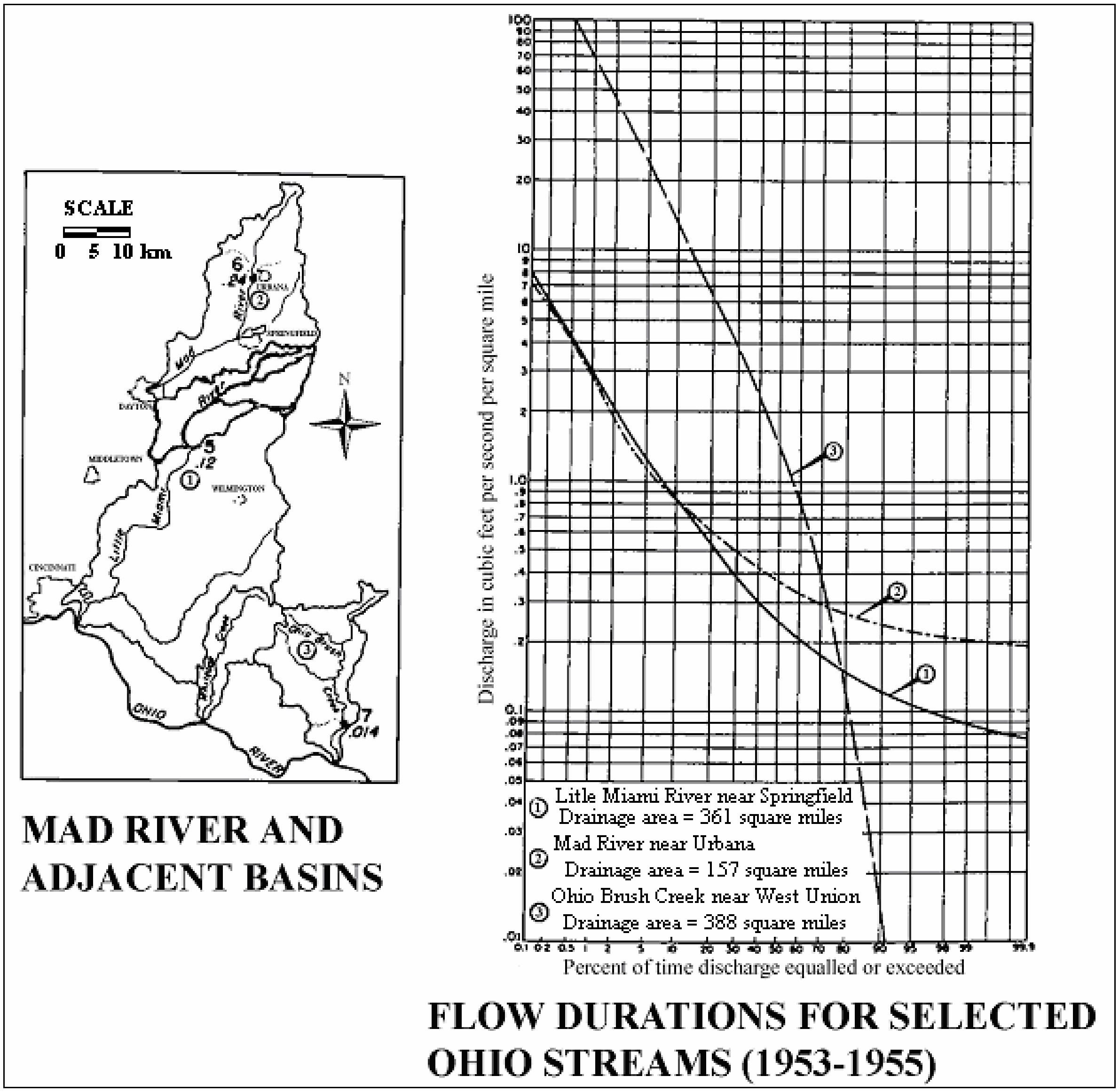

Figure 17 - Hydrograph for Select Streams in Ohio (Adapted from Schneider 1957)

The Ordovician shale and interbedded limestone is denser and less permeable, with a lower water yield (Kaser 1962; Harker and Bernhagen 1943). Ground water flow from the Silurian bedrock is often from springs at the base of the Brassfield Formation at the Silurian-Ordovician boundary. The springs are important as local discharge points and according to Sheets and Yost (1994) infiltrate considerable amounts of ground water into the unconsolidated deposits. Norris (1957) estimated that flow at larger springs produced approximately 0.76 m^3 (200 gal) per minute. On the whole, however, the limestone and shale formations are "relatively impermeable" (Cross and Feulner 1964). Norris (1957) noted that the properties of the bedrock aquifers couldn't be estimated easily due to the fact that bedrock wells are not discretely screened for particular formations or even completely within bedrock, giving unrealistically high values for transmissivity. Bedrock flow, then, is generally not considered a significant contributor to ground water flow within the aquifer (Norris and Eagon 1971; Larkin and Sharp 1992; Dumouchelle et al. 1993).

2.3.2 (b) Unconsolidated Deposits

The glacial deposits that fill the bedrock valley are highly conductive, consisting predominantly of permeable deposits of coarse gravel and sand, with lesser amounts of silt and clay. These thick, extensive deposits result in a reliable supply of ground water (Cross and Feulner 1964). The unconfined and unconsolidated valley train deposits have a high capacity to hold and transmit ground water and control the modern drainage systems. Within the Springfield study area, the present course of the Mad River roughly follows the previous course of the Teays drainage system.

Due to the fairly coarse gravels and sands with scattered silt and clay in the buried valley, the aquifer acts similar to a surface reservoir, in that water removed from storage is replaced during periods of higher flow. The highly permeable deposits result in the lowest annual variations in flow in all Ohio surface waters (Kaser 1962).

Kaser (1962) indicates that it is "beyond doubt" that Moore Run stream flow is derived from ground water throughout most of its length. Within approximately 1,219 m (4,000 ft) of its confluence with the Mad River, however, the flow direction changes and the stream begins to contribute to ground water due to the pumping influence of the SWTP. Ground water is not contributed to the Mad River in the vicinity of the well field area (Norris and Eagon 1971).

Underflow and direct percolation also contribute water to area streams. Norris and Eagon (1971) estimated underflow at 9,463.5 m^3 (2.5 mgal) per day. Ultimately all ground water pumped from the aquifer originated from induced infiltration. The rate of infiltration is proportional to the head difference between ground water and surface waters (Kaser 1962). Norris and Eagon (1971) estimated the radius of influence of the pumping wells at approximately 7.15 km^2 (2.75 mi^2) and suggests that the estimated radius of 11.65 km^2 (4.5 mi^2) of stream bed infiltration to the production wells reported by Kaser was too large. Vormelker et al. (1995) indicated that this area is the most prone to contamination in Clark County. The hydrologic system is fairly simple and the properties of the aquifer have been accurately determined. A summary of aquifer values is included in Table 5.

Table 5
Summary of aquifer properties from previous investigations

Parameter	Value	Units	Location	Source
Storage coefficient	0.20	--	SWTP	Feulner 1961 Kaser 1962 Norris and Eagon 1971
Storativity	0.005	--	Dayton	Arnett 1994
Transmissivity	2,732.3	m^2/day	SWTP	Feulner 1961
	6,793.4		SWTP	Kaser 1962
	3,725.8		SWTP	OEPA 1990
	2,237.8		Dayton	Arnett 1994
Permeability	101.9 – 162.3	m/day	Average for Mad River Valley	Cross and Feulner 1964
	224.1		SWTP	Norris and Eagon 1971
	162.3		SWTP	Feulner 1961
Underflow	< 2,21.2	m^3/day	Springfield	Cross and Feulner 1964
	9,463.5		SWTP	Norris and Eagon 1971
Hydraulic Conductivity	122	m/day	SWTP	OEPA, 1990
	0.018 – 5.2		WPAFB – Uplands	Dumouchelle et al. 1993
	0.06 – 64		WPAFB – Valley Train	Dumouchelle et al. 1993
	59		Dayton	Arnett, 1994
	9 – 114		Columbus	Schalk 1996
Vertical Hydraulic Conductivity	0.1524	m/day	Dayton	Arnett 1994
Hydraulic Gradient	0.001	N/A	Dayton	Arnett 1994
	0.00142		SWTP	Norris and Eagon 1971
Porosity	23.7	%	SWTP	Feulner 1961
	20		SWTP	OEPA 1990
Till recharge	0.00012	m/day	Clark County	Norris et al. 1952
Aquifer recharge	0.47	m/day	SWTP	Norris and Eagon 1971
Stream infiltration	0.393	m/day	SW TP	Norris and Eagon 1971
	0.1524		Dayton	Arnett 1994
	0.3742		SWTP	Kaser 1962

2.3.3 Surface / Ground water Interaction

Kaser (1962) indicates that the normal water level for the study area was approximately 2.5 to 3 m (8 to 10 ft) below land surface. Feulner (1961) notes that water level changes corresponded to changes in the stage of Mad River. The water level is lower in the vicinity of the well field, and no ground water is added to the Mad River in that area (Norris and Eagon 1971).

The Mad River runs from the north to the southwest through the study area, and intersects the buried valley near the SWTP. According to Kaser (1962), Mad River is hydraulically connected with the aquifer and the piezometric surface elevation correlated with river stated. He further observed that infiltration increases rapidly with stream discharge. Norris and Eagon (1971) state that the majority of the recharge to the aquifer is through induced infiltration from the Mad River. Kaser (1962) estimates about sixty percent of the total water pumped by the SWTP is supplied by the Mad River during periods of low flow.

The degree of connectivity between the river level and the surfaces of the nearby gravel pit lakes and ground water surface is not well established, however Norris and Eagon (1971) state that the ground water gradient will be similar to the surface water gradient. As noted by Kaser (1962), Mad River is in communication with the gravel pit to the east and the water table, under non-pumping conditions, should be the same elevation as the stream stage. Preliminary elevation data collected in April 2002, however, indicate that the water level in production well PW-1 was about 0.3 m (1 ft) below the river level and that the water level in the gravel pits was approximately 1.1 m (3.5 ft) above the water level in the production wells. Communication between the river and lakes may be diminished by the accumulation of silt (Dumouchelle 1998).

2.3.4 Aquifer Geochemistry

Historical geochemical data is available for bedrock wells in Harker and Bernhagen (1943) and for surface and well data in Norris et al. (1952), who note that mineral constituents were within the expected range for natural waters. Norris (1957) indicates that the ground water from the carbonate bedrock aquifers is excessively hard and that the iron content is "troublesome". Calcium sulfate is noted to make water unfit for consumption in some areas. Levels of hydrogen sulfide tended to increase with depth when drilling into limestone or shale (Walker 1960). Results of ground water samples indicate high levels of total dissolved solids in both consolidated and unconsolidated deposits.

According to Dumouchelle et al. (1993), ground water from unconsolidated material in geologically similar areas near Dayton is very hard, slightly alkaline, commonly anoxic and of the calcium-magnesium-bicarbonate type. Ground water from consolidated deposits is of variable composition, but primarily is sodium-chloride or sodium-calcium-chloride type. Shallow wells influenced by surface waters have increased levels of nitrate, sulfate, sodium and chloride. Ground water from the moderately permeable Brassfield formation however, is also of the calcium-magnesium-bicarbonate type and virtually indistinguishable from ground water in the unconsolidated formations. Determination of the Silurian bedrock contribution to ground water supply within the unconsolidated aquifer by geochemical analysis is difficult because of the similarity in composition. The brackish waters of the Ordovician shale and limestone are chemically distinctive, but add little saline water to the unconsolidated ground water due to their low permeability. Stable isotope analyses are also inconclusive in differentiating between the consolidated and unconsolidated waters (Dumouchelle et al. 1993). A piper diagram of the results presented in this study is included in Appendix E. Results from Harker and Bernhagen (1943), Norris et al. (1952) and the present study are also presented for comparison in Appendix E. Generally both the stream and ground water data are geochemically similar to the results noted by Dumouchelle et al. (1993). Bendula and Moore (1999) note that the bedrock aquifers generated calcium-magnesium-bicarbonate ground water that is very hard with objectionable levels of iron and manganese. Upland areas have turbidity problems following heavy rains, which result in problems with nitrates and coliform bacteria. Turbidity problems are a signature of ground water under the direct influence of surface water.

2.4 River Bank Filtration

Public aquifers are often closely connected to surface water sources resulting in very high potential yields. If ground water is under the direct influence (GWUDI) of surface water, however, quality problems may result, putting the aquifer at risk for contamination by infiltrating surface water contaminants and pathogens (Hiscock and Grischek 2002). The potential for contaminants from stream infiltration may be reduced by proper grouting methods and ensuring that well casings are extended below the water table. One qualitative indication of direct surface infiltration is the turbidity of the water following a precipitation event, which is often noted in shallow wells. Microscopic particulate analysis (MPA) is an accepted quantitative method commonly utilized to define a GWUDI aquifer (Bendula and Moore 1999).

Larkin and Sharp (1992) note that the hydrologic connection between surface streams and permeable aquifers is commonly used for the development of reliable water sources through induced infiltration. The induced movement through the aquifer materials results in the pretreatment of the water through the matrix of the aquifer sediments, with metals removed through cation exchange or adsorption and biological activity reducing nitrates and organics.

River bank filtration is recognized as an acceptable means to naturally reduce contaminant levels, if properly designed and managed. Design controls rely on quantitative studies of an aquifer and its characteristics, such as catchment and infiltration zones, the proportion of surface and ground water mixing and flow paths and velocities. The principle one, however, is the hydraulic conductivity of the river bed. As noted previously, however, this value will change as a function of flow velocities. The reduced filtering efficiency of the river bed during high flow events is compensated by a lowered hydraulic gradient and a rise in water levels. Reliable modeling is the first step to determine the input values required for the proper management of river bank filtration (Hiscock and Grischek 2002).

2.5 Cryptosporidium parvum

The biological pathogen *Cryptosporidium parvum* is of public concern to water supplies utilizing potential GWUDI aquifers. A known cause of waterbourne disease, *C. parvum* is described by Smith and Thomson (2001) as a protozoal parasite that is resistant to chlorination, filtration and other conventional water treatment technologies and must be assumed to be present by water treatment operators. First recognized as an animal pathogen in 1955 and a human pathogen in 1976 (Szewzyk et al. 2000), outbreaks of cryptosporidiosis affected 13,000 people in Georgia in 1987 and over 400,000 in Milwaukee in 1993 resulting in at least 50 deaths, indicating the ability of this contaminant to cause epidemic illness. Symptoms are similar to that of cholera and can result in chronic illness or fatality, especially in individuals with compromised immune systems.

There is no known treatment for this illness (Pillai 1998). It is suspected that sporadic cases of infection are misdiagnosed or not reported due to the tested presence of the cysts in fully treated water. It was determined that cases of cryptosporidiosis were present in Milwaukee over a year prior to the 1993 outbreak (Szewzyk et al. 2000).

The parasite is transmitted from an infected host as an oocyst, approximately 5 micro-meters (μm) in diameter, and can travel easily in water due to its small size. The oocyst is described as nearly inert, resistant to external environmental factors such as temperature, salinity and desiccation as well as chlorination. Upon entering the intestinal tract of a host, however, the oocyts are activated and can cause illness (Smith and Thomson 2001). Studies have demonstrated that doses as low as 10 cycts can be infectious, but are excreted from hosts in very high numbers (tens of millions) and can survive outside the host for several weeks or months. Contaminant sources include sewage and agriculture, and can be naturally occurring. Increased concentrations are encountered after rainfall events. Treatment for the parasite requires very effective filtration due to the small size of the oocyst. Such filtration has been documented to reduce concentrations of oocysts by three orders of magnitude (Szewzyk et al. 2000).

The transport of an oocyst through an aquifer is dependent on many physical, chemical and biological factors, which must be understood to assess the risk posed to a water source. The physical transport is dependent on the hydrologic properties of the aquifer such as porosity and ground water velocity, but also on other complex processes such as advection, dispersion, diffusion, adsorption and filtration (Pillai 1998). *C. parvum* can reproduce only within a host, so growth within the aquifer is not a concern as it is with other biological contaminants, and effects from chemical factors are reduced by the inert nature of the oocysts (Szewzyk et al. 2000). Risk assessment is essential to determine the occurrence and possible pathogen exposure. Effective monitoring is essential to ensure water quality and to assess public health issues. Modeling may be utilized to determine the potential exposure to the contaminants.

Modeling is typically based on transport associated with advection (simple transport by ground water in the direction of flow), dispersion (movement outside the direction of flow due to interference from properties of the aquifer), and adsorption (the chemical binding of a comtaminant to particles in the subsurface). Effective modeling can assist in predicting the potential for exposure and the subsequent risk to public health (Pillai 1998).

3.0 FIELD INVESTIGATIONS

3.1 Pump Test

Two pumping tests were conducted at the SWTP on April 16, 2002 to determine appropriate values for hydraulic conductivity and transmissivity for subsequent use in the development of a ground water flow model. Both tests utilized pumping well PW-3 as the production well and pumping well PW-2 as the observation well. These wells were chosen to ensure that the observation well was closer to the pumping well than the Mad River.

Prior to testing, all production wells were shut down on the order of three hours to allow the piezometric surface to return to its static level. Due to the limited storage capacity, however, the treatment plant was unable to stop pumping long enough to allow the water table to completely recover to static levels. Initial water levels were measured by chalked steel tape in both wells. A pressure transducer, set to record water levels every second, was placed in PW-2. During the test the pump discharge rate was monitored and later confirmed with data from the treatment plant to assure the withdrawal rate remained a constant 9.08 m^3 (2,400 gal) per minute. Data from the pump test is summarized in a plot of water level versus time in Figure 18.

An initial pump test was conducted for seven minutes and a second test was conducted for eight minutes. Care was taken to ensure that the start of the test was coordinated with the precise moment when the pump was engaged.

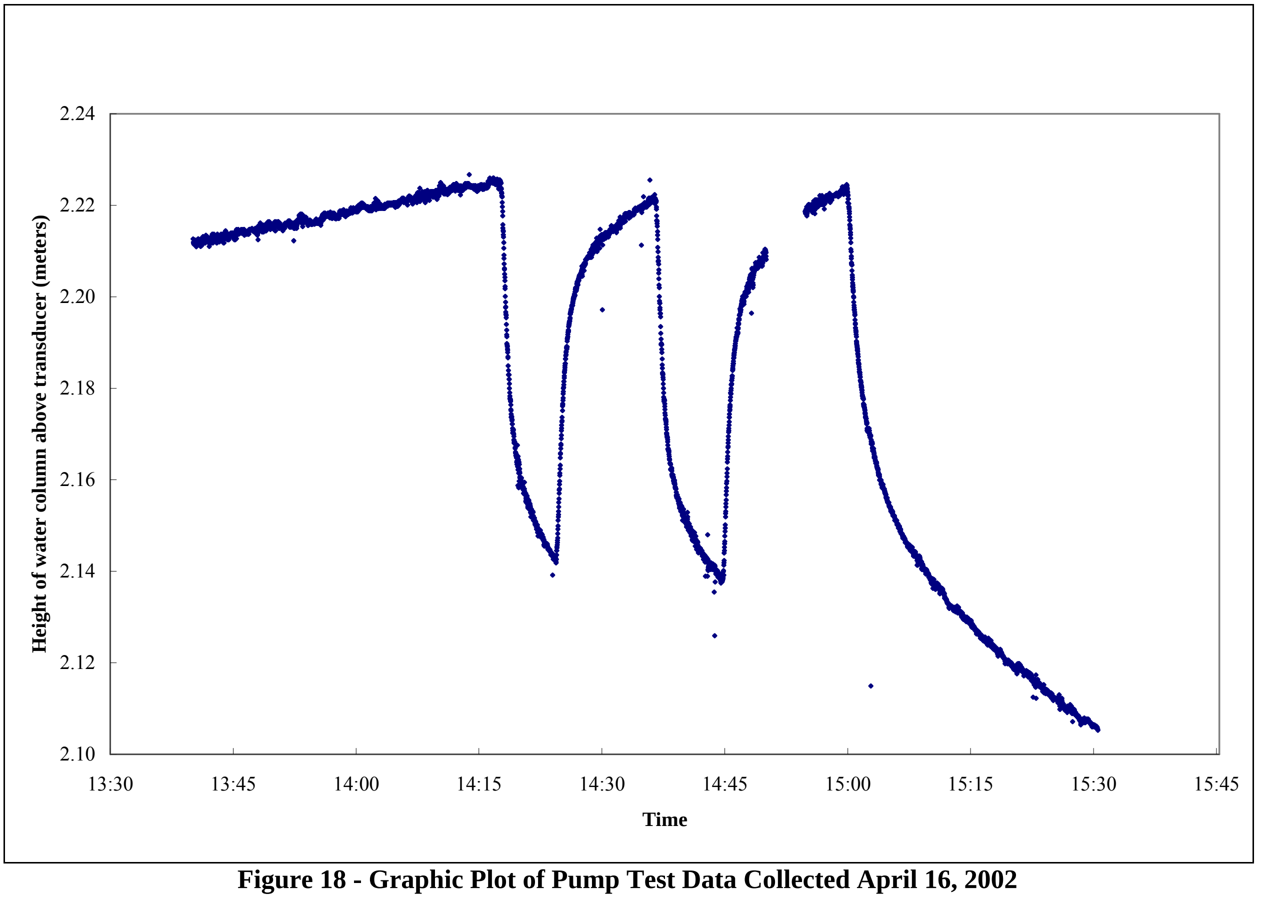

Figure 18 - Graphic Plot of Pump Test Data Collected April 16, 2002

The time prior to the initiation of the tests indicates that static water levels had not been reached and initial drawdown values may have been delayed because of the rising level of the water table. The data from each pump test was entered into the AQTESOLV program (AQTESOLV 2004) to determine values for hydraulic conductivity and storativity. Water level values were entered for every three-second interval during the first minute of pumping, followed by every six seconds through 1.5 minutes. A longer time frame was not used due to a break in the curve after approximately two minutes. Additional parameters for the pump test analysis included a saturated aquifer thickness of 35 m (115 ft) and partially penetrating pumping and observation wells in an unconfined aquifer. Results of the pump test are presented in Appendix F.

3.2 Surveying

Well head elevations were shot in with a rod and transit, from local survey bench mark RM19 on the top of the parapet wall of the Eagle City Road Bridge across Highway 68, with an elevation of 950.32 ft (289.658 m). The elevations for the sandpoints were estimated from GPS data provided by the SWTP and from the investigation by Kaser (1962). A summary of the locations and elevations for each measuring point is included in Table 6. Surveyed water level data are presented in Table 7.

3.3 Geochemical Analysis

Geochemical data were collected from production wells 1 and 12 and sandpoint 19 during the pump test on April 16, 2002. Additional samples were collected on May 14, 2002 from sandpoint cl-20, production wells PW-1, PW-5 and PW-12, the Mad River and two of the lakes near the well field. A summary of the data is included Table 8.

Table 6
Production well and sandpoint coordinates and elevations

Production Well	UTM E	UTM N	Elevation (meters)	Sandpoint	UTM E	UTM N	Elevation (meters)
PW-1	17258977	4428306	285.814	SP-1	17257088	4428103	280.556
PW-2	17258988	4428387	285.881	SP-2	17258734	4430582	285.656
PW-3	17258998	4428479	285.881	SP-3	17259013	4430760	285.214
PW-4	17259008	4428570	285.866	SP-4	17259069	4429993	284.516
PW-5	17259033	4428641	285.872	SP-6	17258068	4429419	282.809
PW-6	17259064	4428738	Not measured	SP-7	17258546	4429226	283.519
PW-7	17259109	4428829		SP-8	17259257	4429459	283.909
PW-8	17259155	4428911		SP-9	17259348	4429322	282.863
PW-9	17259196	4428992		SP-12	17258048	4428784	282.275
PW-10	17259257	4429114		SP-16	17258723	4428773	282.946
PW-11	17259120	4429088		SP-23	17258017	4428438	281.690
PW-12	17258901	4428438		cl-7	17258271	4428900	283.147
River gradient: 0.61 feet over 721 feet = 0.000845				cl-20	17259836	4428443	286.930

Table 7
Springfield water levels on April 16 and May 15, 2002

Description	Water Elevation (meters) 4/16/2002	Water Elevation (meters) 5/15/2002	Relation to PW-1 (meters) 4/16/2002
PW-1	279.413		0.00
PW-3	279.563		+0.150
PW-4	279.569		+0.156
PW-5	279.547		+0.134
SP-16	279.560		+0.147
Mad River 1		280.434	
Mad River 2	279.925	280.011	+0.512
Mad River 3		279.587	
Lake 1	280.675		+1.262
Lake 2	280.212		+0.799
Lake 3	280.364		+0.951
Lake 4	279.922		+0.509
Lake 5	279.922		+0.509
Lake 6	279.919		+0.506

Table 8 Laboratory analytical results for Springfield ground water sampling										
Well	Date	Ca	Mg	K	Na	HCO3	Cl	SO4	NO3	PO4
PW-1	4/16/2002	105.2	36.8	1.70	12.0	353	17.0	98.9	5.02	0.2
PW-5	4/16/2002	92.6	33.7	1.43	12.6	354	22.0	66.6	3.33	<.01
PW-12	4/16/2002	80.9	37.4	1.65	8.9	320	16.0	69.3	2.79	<.01
SP-16	4/16/2002	97.8	35.0	1.75	8.9	357	14.6	61.7	8.38	<.01
Mad River	4/16/2002	89.7	32.6	1.59	7.8	305	15.0	56.7	4.32	<.01
Lake	4/16/2002	59.0	29.4	1.27	25.7	230	28.6	38.7	0.50	<.01
PW-1	5/14/2002	100.9	36.2	2.22	14.4	296	26.0	99.0	3.98	
PW-5	5/14/2002	95.9	33.5	2.22	16.9	325	28.9	62.7	2.29	
PW-12	5/14/2002	71.3	31.4	2.22	11.2	256	16.7	56.7	2.66	
Mad River	5/14/2002	78.1	28.6	2.22	8.1	244	9.0	44.8	4.47	
Lake 1	5/14/2002	58.8	25.8	2.22	20.4	214	27.9	28.8	0.58	
Lake 2	5/14/2002	62.2	33.6	3.47	17.0	203	20.3	82.6	0.26	

All results in ppm (mg/l)
PW = Production well
SP = Sandpoint
Lake 1 is east of the well field and south of Eagle City road
Lake 2 is east of the well field and north of Eagle City road
SP-16 was incompletely purged

Results from the analysis were plotted within a Piper diagram and the results are illustrated with historical data from Springfield and surrounding areas in Appendix E. The waters at the SWTP do not vary significantly from those measured by previous investigations and confirm the water as of the calcium-magnesium-bicarbonate type. Mad River results generally matched previous measurements, however higher level of sodium, potassium and chloride were noted in samples collected from the surface lakes. The chemistry of samples from the production well results also matches results previously measured from wells within the valley train deposits. All samples collected were similar in geochemistry and are not readily distinguishable.

3.4 Cross-Section and Bedrock Topography Mapping

Well logs for private water wells in the vicinity of the SWTP were obtained from the Ohio Department of Natural Resources (ODNR) in Columbus, Ohio. These were collected from both the valley and surrounding highlands to ensure each well was properly identified and located and to construct cross-sections.

Data utilized in the development of the conceptual model, the construction of cross-sections and the development of the map of bedrock topography were obtained from several sources. Primary sources included ODNR well logs, bedrock topography maps from Swinford and Shrake (1993), Shrake (1994) and Brockman and Swinford (2001), as well as older studies by Norris et al. (1952) and Kaser (1962).

Cross-section A – A′ runs from west to east along Eagle City Road, cutting through the SWTP well field. Cross-section B - B′ extends from the north to the south along the Mad River and passes through the SWTP well field (figures 19, 20 and 21).

3.5 Gain-Loss Study

A gain-loss study was conducted on October 18, 2003 with purpose to determine the infiltration loss from Mad River as it passes the SWTP pumping wells. Channel data was collected upstream of the SWTP well field across both Moore Run and the Mad River, and immediately downstream of the well field across the Mad River.

Previous studies by Norris, Kaser and others were conducted during low flow or 75 percent of the flow-duration curve. Kaser (1962) estimated a flow loss average of 1,325 m^3 (0.35 mgal) per day or approximately 60 percent of the total pumpage supplied by the Mad River during low flow.

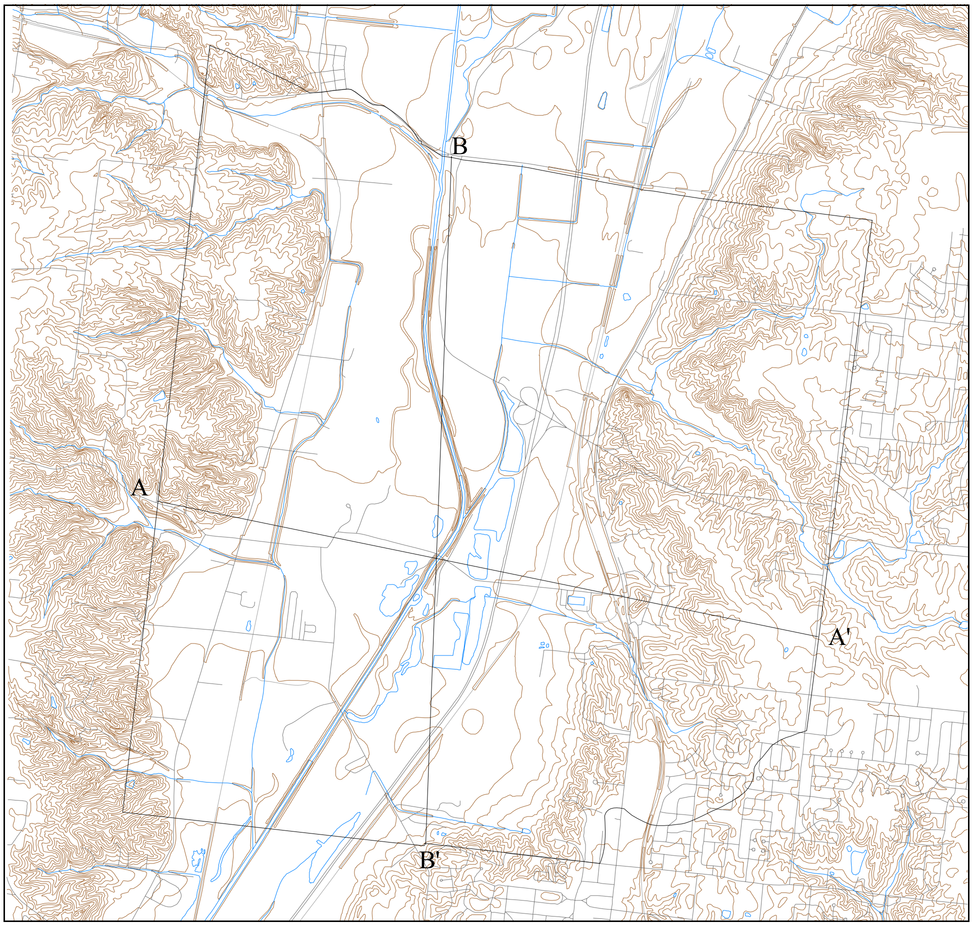

Figure 19 - Cross-section A - A' and B - B' Locations

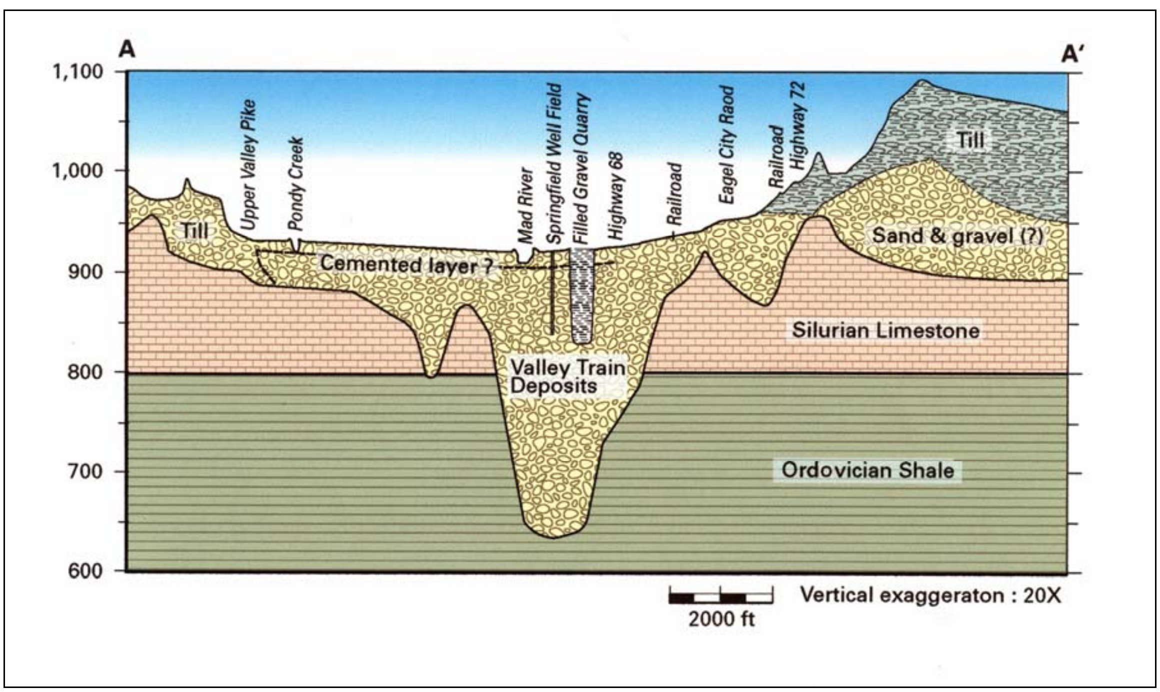

Figure 20 - Cross-section A-A'

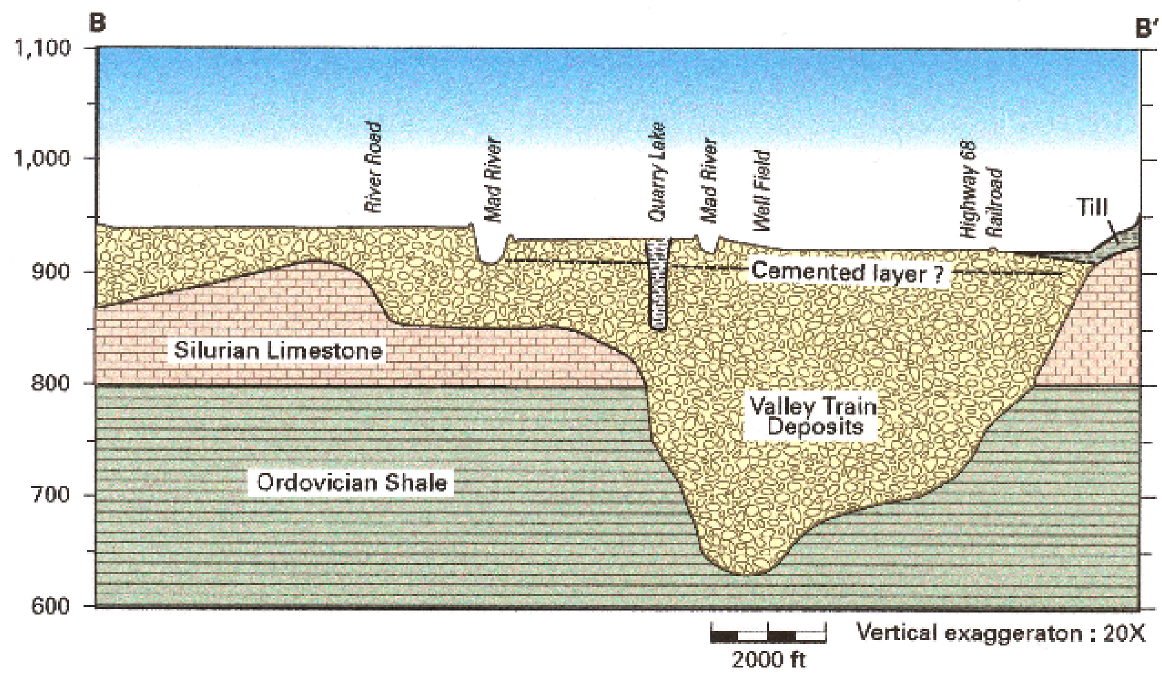

Figure 21 - Cross-section B-B'

Field measurements included the width and depth of the river as well as velocity readings at 4 ft (1.22 m) intervals, perpendicular to stream flow. The depth of the river was calculated at each point, and velocity was collected at sixty percent of the depth, which generally represents the average velocity. Based on the results, the precise discharge at each area was calculated from the cross-sectional area of the river times the velocity. The collected data are included as Table 9.

The channel loss measured was 68,140 m^3 (18 mgal) per day or 1,670 cubic feet per second, much greater than what is typically pumped from the SWTP well field. The results, however, may also be affected as the study was not conducted during low flow events as done with previous studies. This indicates that some of the water loss may have been due to recharge to storage. This rate is dependent on gage height and channel permeability and must therefore be considered transient.

Table 9
Data from gain-loss study on October 13, 2003

Upstream discharge calculations

Location	Station	Depth (ft.)	Velocity (fps)	Average velocity (fps)
Moore Run (approximately 100 meters upstream from Eagle City Bridge)	0	0	0	
	4	0.92	0.6	0.552
	6	1.14	1.08	1.7304
	8	1.17	1.24	2.6796
	10	1.19	1.48	3.2096
	12	1.23	1.41	3.4969
	14	1.33	1.35	3.5328
	16	1.33	0.84	2.9127
	18	0	0	0.5586
			Total:	18.67

Location	Station	Depth (ft.)	Velocity (fps)	Average velocity (fps)
Mad River (approximately adjacent to the first section on Moore Run)	0	0	0	
	4	1.34	0.88	1.1792
	8	2.03	1.31	7.3803
	12	2.22	1.78	13.1325
	16	2.195	1.86	16.0706
	20	2.07	2.12	16.9747
	24	2	2.34	18.1522
	28	2.95	2.38	23.364
	32	1.9	2.48	23.571
	36	1.93	2.45	18.8819
	40	1.87	2.48	18.734
	44	1.96	2.37	18.5755
	48	1.95	2.46	18.8853
	52	1.92	2.71	20.0079
	56	1.95	2.72	21.0141
	60	1.995	2.88	22.092
	64	1.995	2.91	23.1021
	68	1.95	2.83	22.6443
	72	1.94	2.76	21.7451
	76	1.96	2.64	21.06
	80	1.71	1.87	16.5517
	84	1.14	0.23	5.985
	84	0	0	0
			Total:	369.10
			Upstream Total:	387.78

Downstream discharge calculations

Location	Station	Depth (ft.)	Velocity (fps)	Average velocity (fps)
Mad River (approximately adjacent to the southernmost well)	0	0	0	
	4	1.8	1.04	1.872
	8	1.98	1.87	10.9998
	12	1.83	1.94	14.5161
	16	1.9	1.98	14.6216
	20	1.82	2.17	15.438
	24	1.83	2.49	17.009
	28	1.85	2.57	18.6208
	32	2.03	2.48	19.594
	36	2.09	2.89	22.1244
	40	2.09	2.76	23.617
	44	2.1	3.06	24.3858
	48	2.14	3	25.6944
	52	2.11	3.05	25.7125
	56	2.05	3.15	25.792
	60	2.04	2.71	23.9674
	64	1.97	2.55	21.0926
	68	1.72	2.51	18.6714
	72	1.7	2.59	17.442
	76	1.65	1.97	15.276
	80	0	0	3.2505
			Total:	359.70
			Difference in ft.2s-1:	28.08
			Difference in mgd:	18.15

Precipitation for September 2003 was above normal, with nearly 6 inches (15.24 cm) of rainfall. The last rainfall event occurred on September 27 and 28, with 1.67 inches (4.24 cm). This was followed by a period of no precipitation for over two weeks. The next rainfall event occurred on October 15 with 1.48 inches (3.76 cm) of rain. Another 0.1 inches (0.25 cm) fell immediately prior to the study on October 17th and 18th. Stream data for the Mad River at the St. Paris Pike gaging station indicate that water levels were above normal stage during the gain-loss study. A graph from USGS is included as Figure 22. Due to low levels of transpiration at this time of year, a large percentage of the calculated loss may have been to storage rather than pumping.

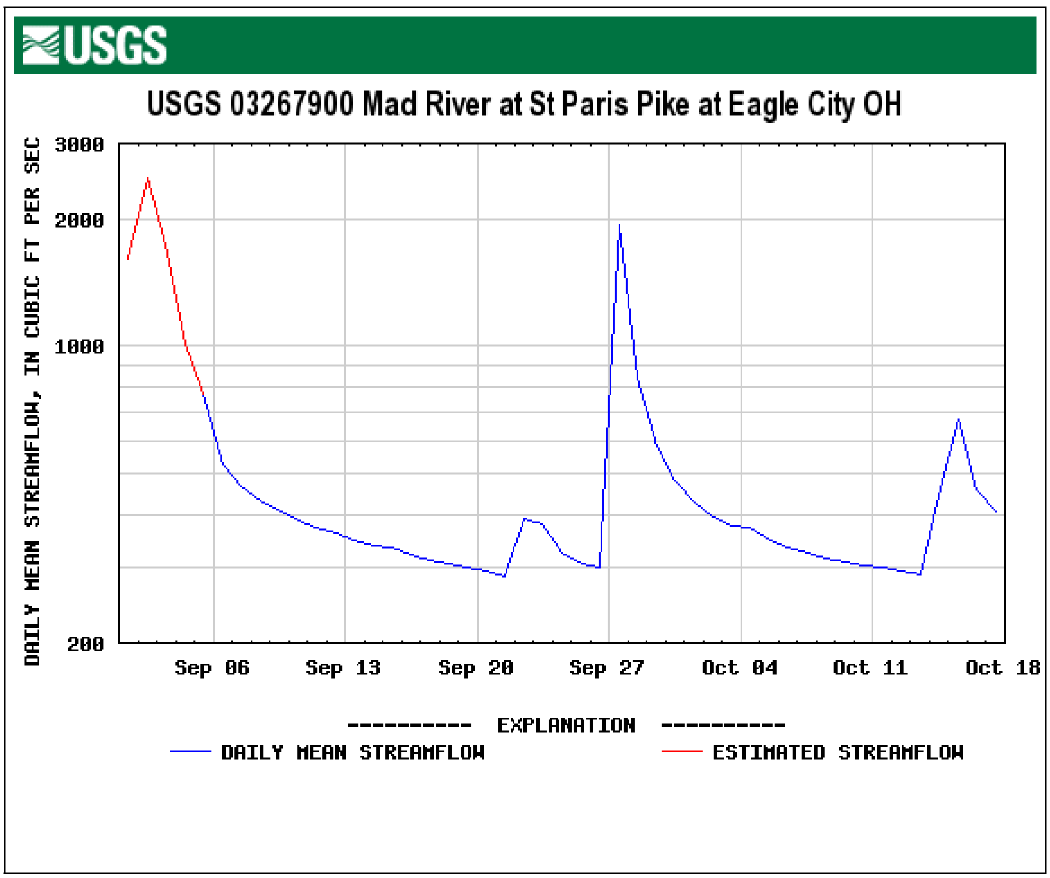

Figure 22 - USGS Stream Flow Data for the Mad River at St. Paris Pike

4.0 GROUND WATER MODELING

4.1 Analysis of the Wright-Patterson Air Force Base Model

A careful examination was made of the ground water flow model constructed for the Dayton, Ohio Wright-Patterson Air Force Base (WPAFB) by Dumouchelle et al. (1993) because of its similarities to the SWTP area. The WPAFB model and the SWTP aquifers are both located within buried bedrock valleys filled with highly permeable valley train deposits. Norris et al. (1952) noted that the permeability and ground water conditions are generally the same for geologically similar areas in Clark and Montgomery Counties (p. 50). The WPAFB and SWTP study areas are within 11.3 km (7 mi) of each other (Figure 23).

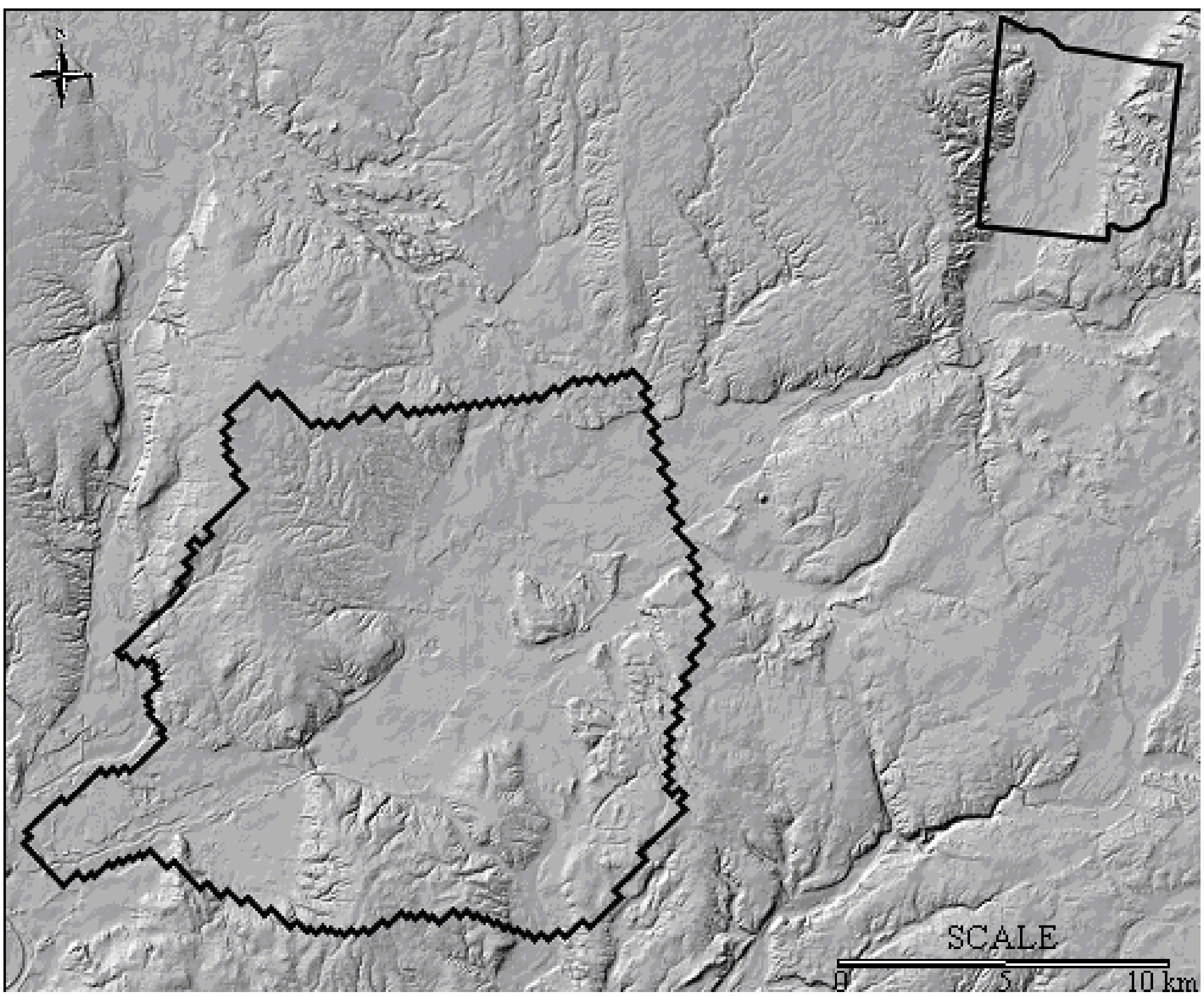

Figure 23 - Comparison of the WPAFB and SWTP Model Area Locations

4.1.1 Summary of Report

The WPAFB includes an approximate area of 259 km^2 (100 mi^2) (Figure 23). Model boundaries were based primarily on natural ground water flow boundaries such as streamlines or ground water divides. Artificial boundaries were set at a sufficient distance from the study area to minimize their effects near the center of the model. The vertical boundary for ground water flow was based the bedrock surface, which was essentially no-flow in comparison with the highly transmissive glacial deposits. These criteria were later used for the model of the SWTP area.

The aquifer, consisting of highly permeable sand and gravel within a bedrock valley, was modeled in three layers. Active areas of layer 1 consisted of the upland areas and valley-train deposits up to 200 ft (61 m) deep. Layer 2 encompassed the screened intervals of the production wells to depths up to 90 ft (27.4 m). Layer 3 extended from layer 2 to the shale bedrock and was up to 200 feet (61 m) thick. The report notes that the third layer was not necessary and could have been omitted from the model.

Parameters utilized in the development of the WPAFB model were derived from both field investigations and previous studies conducted at the site. Values for hydraulic conductivity, vertical hydraulic conductivity between model layers, transmissivity for confined layers, recharge, pumping wells and riverbed conductace were established. These values are later used in the development of the SWTP model.

Hydraulic conductivity values ranged from 1 ft (0.3m) to 1,000 ft (305 m) per day in the valley train deposits and 0.06 ft (0.02 m) to 17 ft (5.2 m) per day in the uplands. Transmissivity modeled in confined conditions for layers 2 and 3 ranged from 4 ft^2 (0.37 m^2) to 76,600 ft^2 (7,116 m^2) per day. Recharge values varied between the upland tills and valley train deposits. A value of 2 in (5 cm) per year was assigned to the uplands areas where precipitation is more likely to be lost to runoff. Recharge to the valley train deposits ranged from 3 in (7.6 cm) to 12 in (30.5 cm) per year. Pumping rates were collected from a survey of users of major ground water users in the WPAFB area. Underflow to and from the model boundaries was simulated by injection and extraction of water by lines of appropriately placed wells. Values for streambed conductance were assigned based on the size of the stream and the contributions to ground water. Riverbed conductance values ranged from 10.8 ft (3.3 m) to 18.7 ft (5.7 m) per day. Lower values were assigned to smaller streams and surface waters in the upland areas.

4.1.2 WPAFB Water Budget

A ground water flow budget was developed from the output of the calibrated model and was utlilized in establishing a conceptual model for the SWTP. Ground-water is added to the model through recharge, river leakage and underflow at the boundaries. Ground water is removed from the model through specified flux, production wells, river leakage and drains. Ground water contribution from bedrock was considered negligible, but was estimated to contribute between two and four percent of the total ground water flow.

4.1.3 Process of Duplication

The original WPAFB MODFLOW model was obtained in the form of FORTRAN input data files through a request to the author. Data was also received from the ArcGIS format in the form of "coverages" which included boundary outlines for the model and each layer, bedrock contacts, the grid area, cross-sections, topographic elevations, the simulated water-level surface and surface water features. The Arcview coverages were exported to Argus for analysis and for comparison in the replication of the WPAFB model. Details and illustrations of the coverages are included in Appendix G.

The uppermost layer (layer 1) of the WPAFB model was simulated as an unconfined, water table aquifer. The intermediate and bottom layers (layers 2 and 3, respectively) were modeled as confined layers. This was necessary to allow the transmissivity values to be assigned to these layers. Values for layer elevations, hydraulic conductivity, transmissivity, vertical hydraulic conductivity, wells, drains, streams and recharge were then imported (Appendix H) and used to generate output data from the original simulation (Appendix I). A map illustrating the finalized ground water flow contours is included as Figure 24.

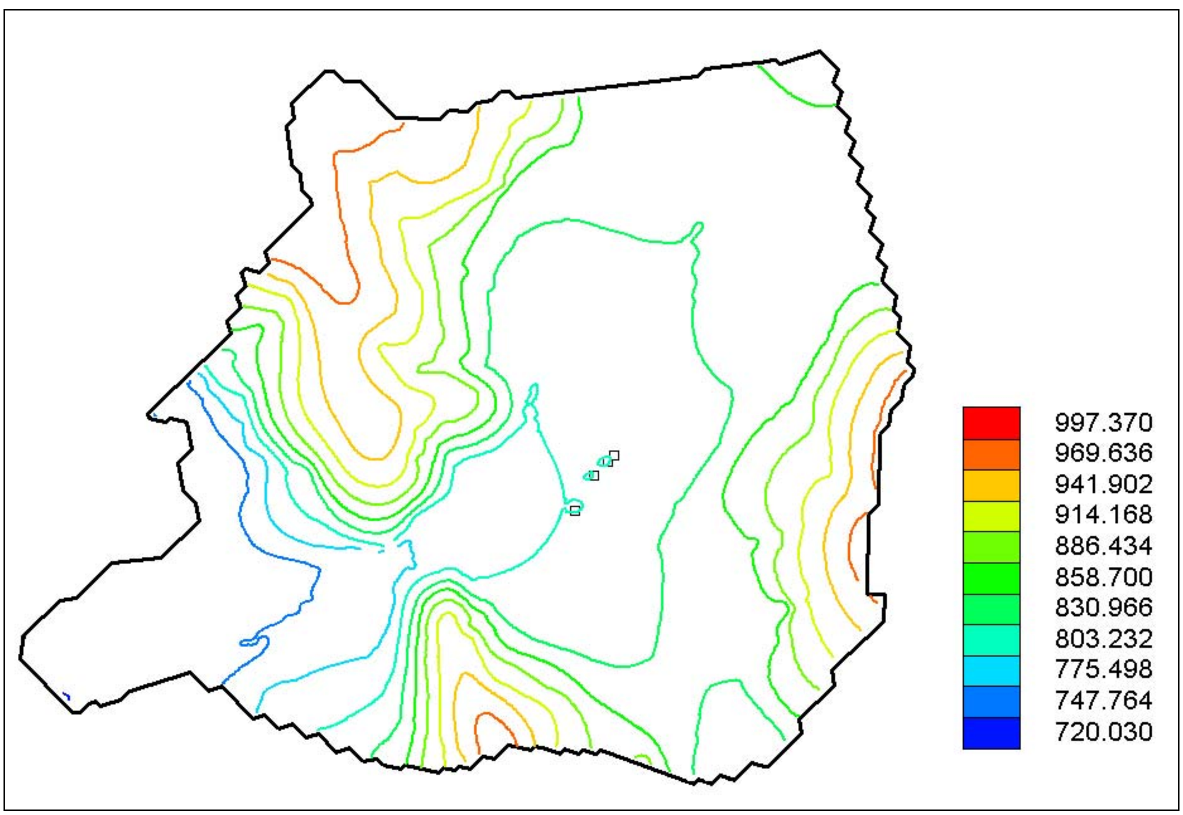

Figure 24 - Ground Water Contour Map from the WPAFB Model

4.2 Development of the Springfield Water Treatment Plant Model

A three-dimensional, finite difference, steady state approach is used to model the regional ground water flow in the vicinity of the SWTP. Modeling is performed utilizing the modular finite-difference ground water flow program (MODFLOW) developed by the USGS (McDonald and Harbaugh 1988). Solutions in MODFLOW are derived through mathematical iterations based on Darcy's Law within a mass balance equation:

$$\frac{d}{dx}(-K_{xx}\frac{dh}{dx}) + \frac{d}{dy}(-K_{yy}\frac{dh}{dy}) + \frac{d}{dz}(-K_{zz}\frac{dh}{dz}) - W = S_s\frac{dh}{dt}$$

where x, y and z represent movement in three dimensions, K represents the hydraulic conductivity in each direction, h is the hydraulic head, W is a volumetric flux per unit volume representing a source or sink of water, and S_s is the specific storage of the aquifer. According to McDonald and Harbaugh (1988) this equation "described ground-water flow under nonequilibrium conditions in a heterogeneous and anisotropic medium, provided the principal axes of hydraulic conductivity are aligned with the coordinate system." The equation, along with specified conditions of the aquifer, represents "a mathematical representation of a ground-water flow system." The program is run until solutions between iterations meet a previously determined level of tolerance, based on the calculation of head differences within adjacent cells (finite-differences).

The modeled area is divided into cells of a size appropriate to the scale of the study area to provide the minimum level of detail required by the investigation. Hydrologic properties are assigned to the center of each cell, which then apply to the entire area within that cell. The input parameters are adjusted, or “calibrated” to provide a solution that reasonably reflected the hydrologic conditions of the study area.

The model is generated using Argus Open Numerical Environments (ArgusONE or Argus), a general purpose program for numerical processing in combination with geographical information systems (GIS) (Argus 1997). According to the user manual, “Arugs ONE is also an application development environmenet for developing and deploying graphical user interfaces for numerical models”. The program is adaptable to different disciplines and can utilize plug-in extensions (PIEs) for project specific purposes. The USGS has created and continually updates a PIE for MODFLOW. Data from GIS or other sources can be entered, run and visualized all within Argus.

4.2.1 Description of the SWTP Conceptual Model

The development of a model for a natural system involves a simplification of its features and properties. Prior to creating a numerical model, a conceptual model should be developed. The purpose of a conceptual model is to emphasize that the boundaries and data entered must reflect the natural system to the degree possible for a quality model to be produced. Data for the Springfield model was collected during the pump test, gain loss study and historical water levels and then compared with information from previous investigations to ensure that the estimated values were reasonable.

Several simplifying assumptions are made in the development of the SWTP model. First, as in the WPAFB model, the ground water flow to and from bedrock is considered negligible (Norris and Eagon 1971; Larkin and Sharp 1992; Dumouchelle et al. 1993, Dumouchelle 1998). Therefore bedrock is modeled as a no-flow boundary at the base of the model. Second, as in the WPAFB model, discontinuous layers of till are known to exist in the valley train deposits, as discussed by Markley (2001), but the vertical and horizontal variations in the lithology of these deposits are unknown. Due to the lack of spatial data the aquifer must be assumed to be isotropic, heterogeneous and unconfined (Dumouchelle 1998), but this must be recognized as a potential source of error in the model. Third, based on similar assumptions by Dumouchelle et al. (1993), tributaries to the Mad River are assumed to have a constant width of five meters and the bed thickness of all hydrologic features are one meter. A more refined model can be developed in future investigations as additional data becomes available.

The SWTP aquifer was treated as a single layer Modular. Other models in the area, including Dumouchelle et al. (1993), Schalk (1996), Dumouchelle (1998) and Arnett (1994) all utilized multiple layer models (Table 10), however Dumouchelle et al. (1993) noted that the third layer of the WPAFB model was unnecessary. Generally the use of multiple layers was to increase the vertical resolution of ground water flow within the model and was not used in the SWTP model.

Table 10
Layer information from previous ground water modeling investigations

Layer	Dumouchelle et al. 1993	Arnett 1994	Schalk 1996	Dumouchelle 1998
Layer 1	Uplands and valley train deposits. Up to 200 feet thick	Water table to estimated till depth of 20 meters.	Glacial materials from water table to 15 feet.	Top of aquifer to clay confining layer. Up to 149 feet thick.
Layer 2	Production well screened interval. Up to 90 feet thick.	Semi-confined layer.	Saturated glacial drift. up to 95 feet thick.	Production well screened interval. Up to 145 feet thick.
Layer 3	Base of production wells to bedrock. Up to 200 feet thick.	N/A	Bedrock up to 375 feet thick.	Base of production wells to bedrock. Up to 190 feet thick.

The SWTP was initially set up with a fine grid interval of 50 meters, generating a model with 130 columns, 115 rows and 14,950 blocks. The grid interval was later reduced to 25 meters for better resolution, generating a model with 261 columns, 230 rows and 60,030 blocks. Further grid refinements were made within the 25-meter grid spacing for increased resolution for particle tracking in wells immediately adjacent to the Mad River. Care was taken to ensure that the model was not "non-diagonally dominant," a problem caused when the change in grid spacing is a multiple greater than 1.5 between individual cells. The final particle tracking model has 341 rows, 266 rows and 90,706 cells. The model covers an active area of 32.8 km^2 (12.7 mi^2). The orientation of the model is 83.5° north of east, based on the western boundary, which is located on a township line and roughly parallels the flow of the Mad River.

4.2.2 SWTP Water Budget

The natural water balance of the area consists of ground water entering and ground water exiting the hydrologic system. Under steady state conditions the amount of water entering the system equals the amount exiting the system, with no water added to or removed from storage. Over a discreet segment of time, more ground water may enter than exit the system, resulting in a water surplus. Likewise ground water may exit the system faster than it can enter, resulting in a deficit.

Water entering the modeled system at the SWTP consists of river infiltration, underflow, precipitation infiltration (recharge) and water removed from storage. Ground water discharge consists of underflow, pumping, infiltration to the river and water added to storage. Values for underflow are estimated from known information from the previously installed gaging stations. The information is used to generate an estimated water budget, as illustrated in Figure 25.

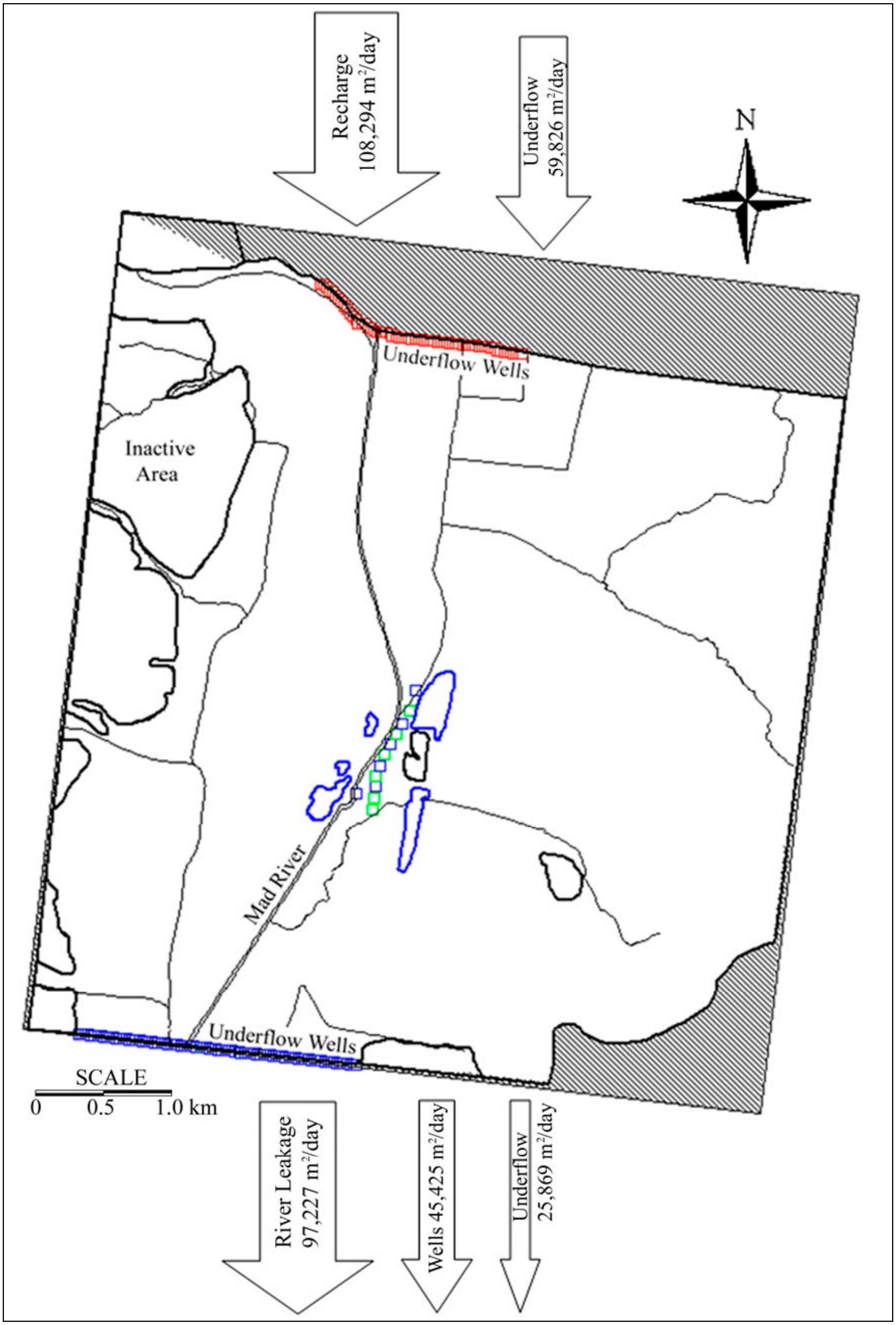

Figure 25 - Estimated SWTP Water Budget from Conceptual Model of Aquifer

Calculations for these values are presented in Appendix J. A comparison of the SWTP budget with budgets from previous investigations is included in Table 11. As noted within the table, changes in underflow values may be offset by changes in river leakage, indicating that both base flow and underflow components are active within the aquifer.

Table 11
Comparison of estimated and calculated water budget with previous investigations

	SWTP		Norris and Eagon (1971)	Dumouchelle et al. (1993)	Schalk (1996)	Dumouchelle (1998)
	Estimated	Calculated (Average 1968 Transient)				
Input (cubic meters per day)						
Storage	--	485	--	--	12,870	--
Underflow	59,826	48,709	9,464	--	68,516	177,935
Recharge	108,694	25,286	15,142	119,896	33,690	393,094
River Leakage	--	34,139	45,425	321,198	54,131	366,958
Other	--	--		177,796	16,277	1,552
Total	168,521	108,619	70,030	618,890	185,485	939,539
Output (cubic meters per day)						
Storage	--	484	9,464	--	12,492	--
Wells	45,425	52,500	52,996	214,698	70,030	509,618
River Leakage	97,227	15,408	--	123,275	18,927	344,673
Underflow	25,869	40,377	--	--	--	81,329
Other	--	--	--	275,557	84,036	5,762
Total	168,521	108,769	62,459	613,530	101,449	941,382

4.2.3 SWTP Model Boundary Conditions

Boundary conditions established for the SWTP model are based on the reasoning of the WPAFB model (Dumouchelle et al. 1993). Previous drawdown extents estimated by Kaser (1962), are used in determining the geographic extent of the model. Natural ground water divides are adapted from Norris et al. (1952), but few are available near the SWTP. As such, natural divides are limited to the southeast and northwest corners of the model. Artificial horizontal boundaries are set beyond the known radius of influence of the SWTP well field to minimize influence near the center of the model, as previously done for the WPAFB model, and to incorporate the previously established one- and five-year time of travel zones. The model boundary is illustrated over the map of glacial deposits by Norris et al. (1952) in Figure 26.

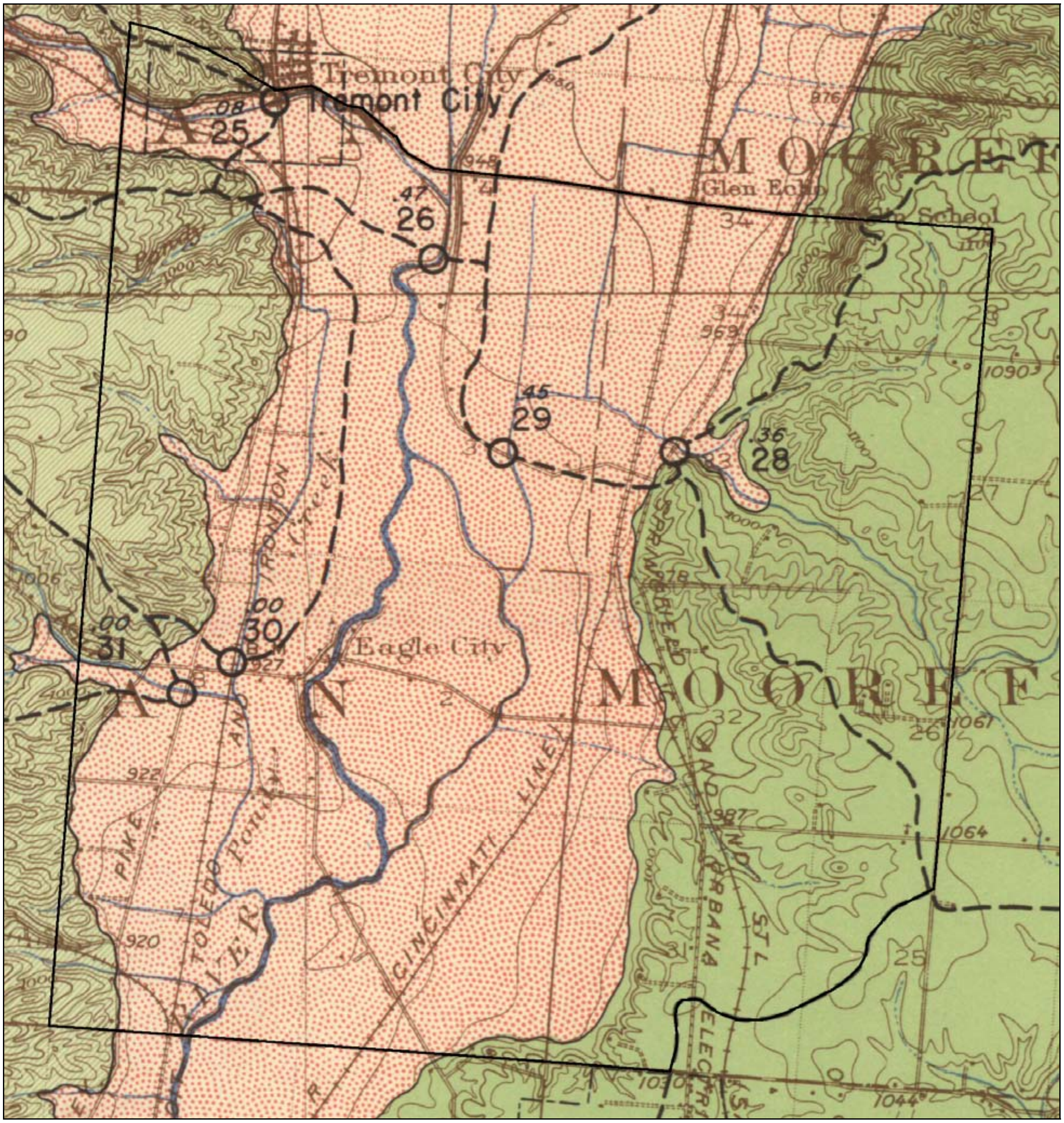

Figure 26 - Study Area Outline over Glacial Deposits Map (Adapted from Norris et al. 1952)

Bedrock forms the no-flow boundary at the base of the model. No-flow boundaries are also established along the east and west boundaries. Norris and Eagon (1971) stated that underflow from the uplands could be disregarded. The east and west boundaries were previously modeled as no-flow by the OEPA (1990) model. Additional inactive areas are placed in a former quarry filled with lime generated from SWTP operations, as well an area of shallow bedrock in the southwest corner of the model.

The western edge of the model is a no-flow boundary due to the presence of till directly over bedrock, as determined by well logs records and the map of glacial deposits by Struble (1987). The lithology is indicated on the west-east cross-section illustration in Figure 20.

The uplands to the east are more discontinuous layers of till, sand and gravel. The lithology is complex and discontinuous. The eastern border is modeled in a very general manner due to the lack of data, potential errors in the interpretation of well logs and rapid lateral changes that have not been mapped.

4.2.4 Bedrock Topography

Existing contour maps of the bedrock topography by Swinford and Shrake (1993) and Brockman and Swinford (2001) have been substantially revised to incorporate new data. A site-specific map of bedrock contours has been developed based on existing water well records, Baisden Excavating boring logs and references from Norris (1951), Hassemer et al. (1965), Schmidt (1982), Struble (1987), Swinford and Shrake (1993) and Brockman and Swinford (2001). Each bedrock point has been digitized for inclusion in the Argus model. Maps indicating the bedrock control points are included in Appendix K.

The final contour locations are based on the shape and general orientation of previous bedrock topography maps by Norris et al. (1952), Swinford and Shrake (1993) and Brockman and Swinford (2001). Bedrock topography is most poorly defined on the east side of the model where the buried valley is deepest and there are few control points. The final bedrock topography map with a 50 ft (15.24 m) contour interval is illustrated in Figure 27.

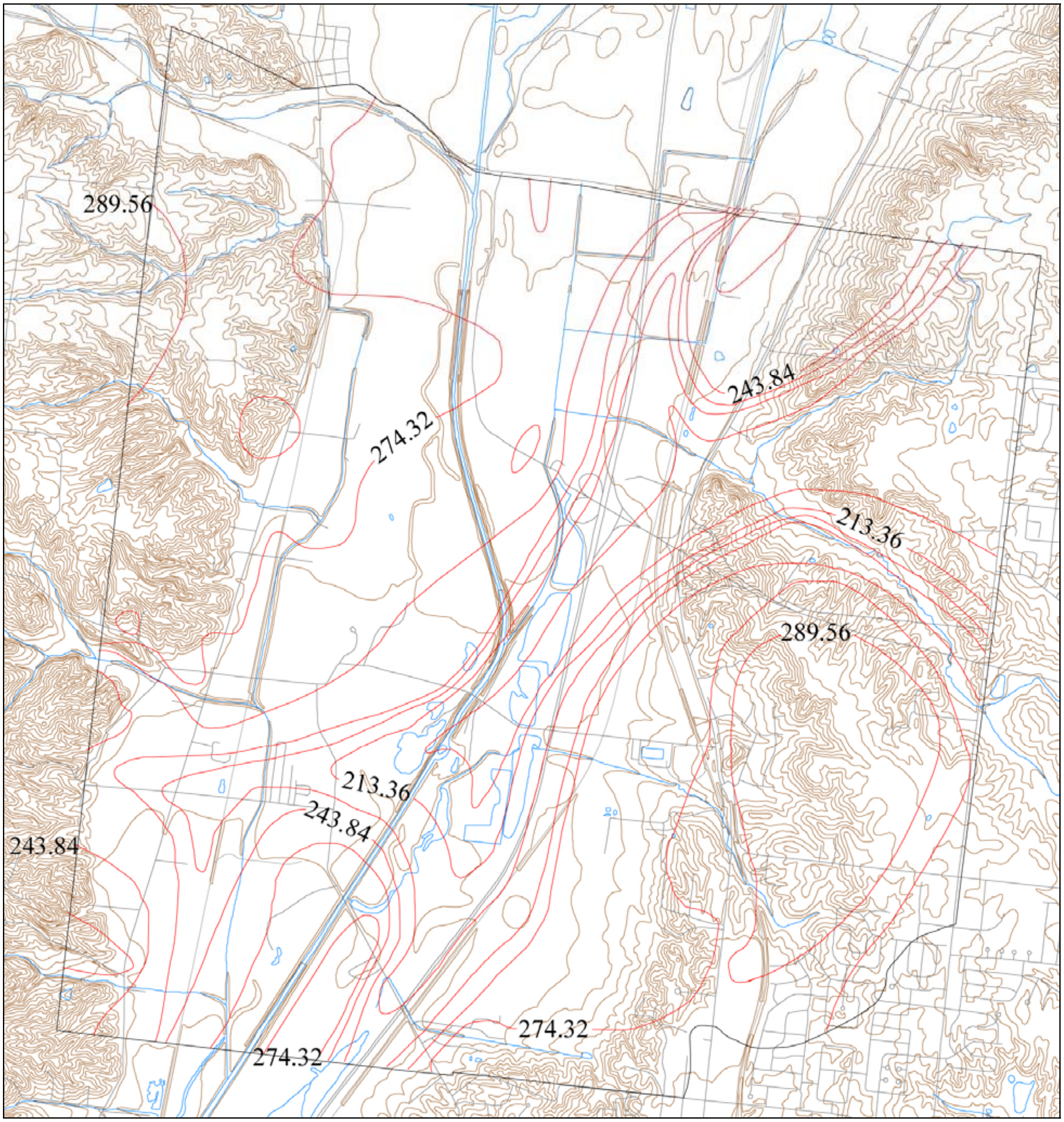

Figure 27 - SWTP Bedrock Topography - Contour Interval 15.24 meters (50 feet)

Areas with no thickness were set to inactive in the model. Shallow bedrock was noted to exist near the southern section of the modeled area near the Mad River. Elevations were adjusted along the borders and inactive areas were added. The thicknesses calculated by Argus ranged between 109.73 m (360 ft) and 1.74 m (5.7 ft). The thickness below the well field averaged 76.2 m (250 ft), greater than that reported by previous studies (Norris and Eagon 1971), who reported a maximum thickness of 38.1 m (125 ft).

4.2.5 Surface elevations

Well logs obtained from ODNR were reviewed in detail to determine the piezometric elevation in local water wells. It was noted that sand and gravel are found at discontinuous intervals in the uplands, and that discontinuous tills existed within the valley-train deposits. The eastern moraines in particular were noted to be highly discontinuous with rapid lateral changes and did not match the description by Brown (1948) who stated that the entire area was underlain by thick gravels.

Areas where till was located directly over bedrock are considered inactive areas within the model. The final surface elevation map with a ten-foot contour interval is included as Figure 28. The minimum elevation for the top of the layer is 274.32 m (900 ft). The maximum elevation is 289.56 m (950 ft). The thickness of the aquifer as calculated by Argus is included as Figure 29.

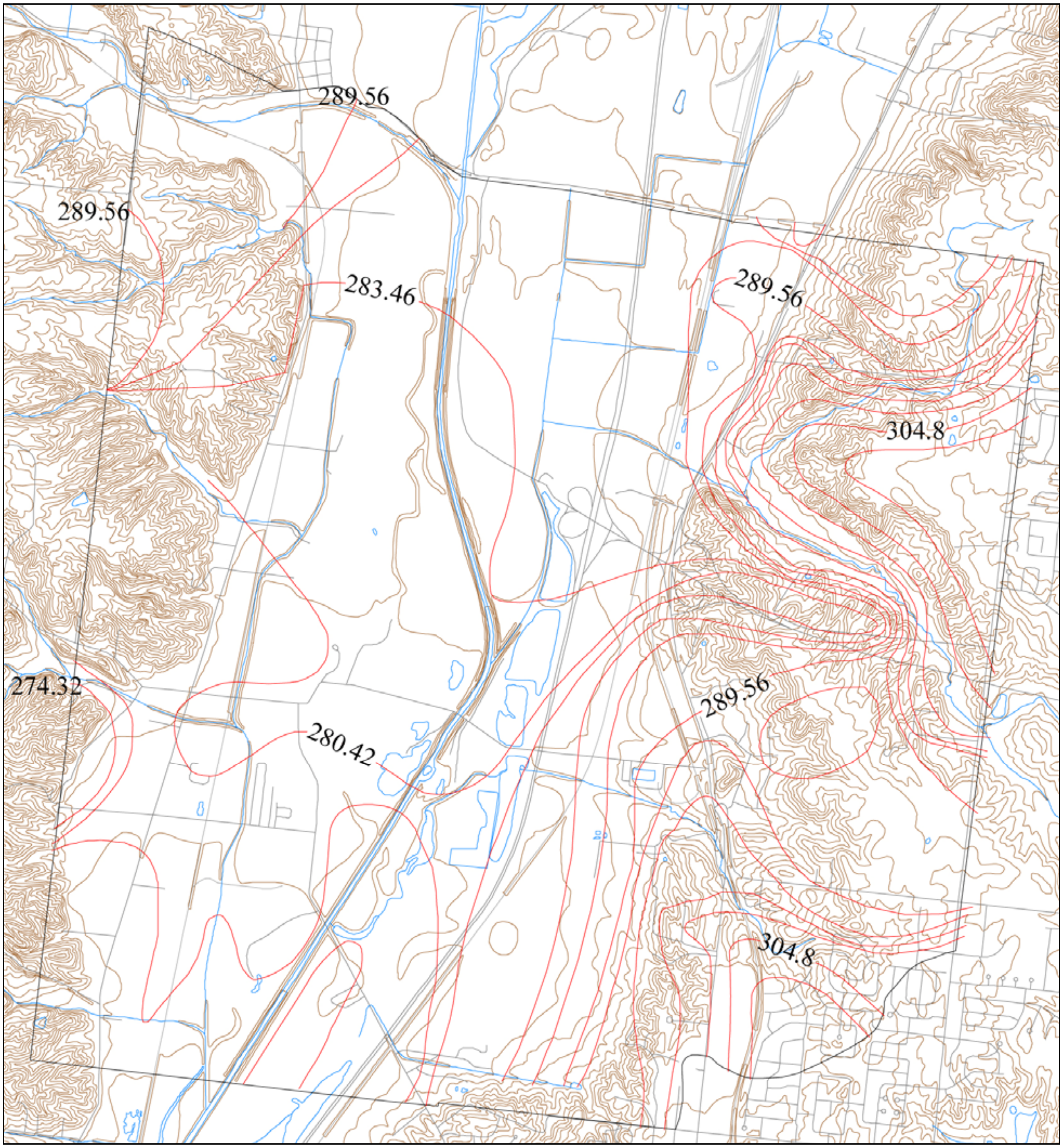

Figure 28 - Top Elevation Contours - Contour Interval 3.048 meters (10 feet)

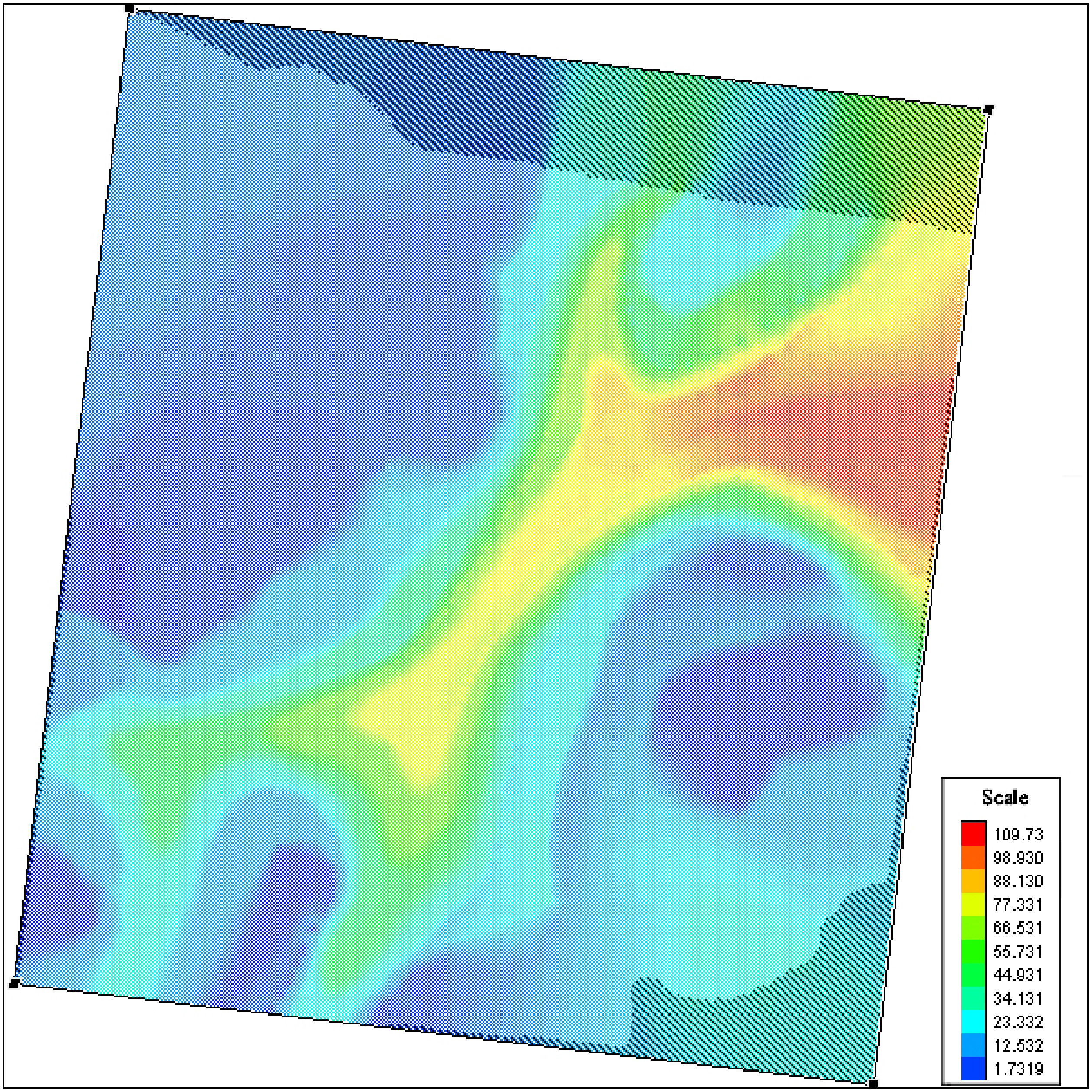

Figure 29 - Thickness in Meters of the SWTP Model, as Calculated by Argus

4.2.6 Recharge

Increased precipitation and decreased transpiration allow greater infiltration of precipitation to ground water from October through May. Conceptually, all water added to the hydrologic system is added from the water surplus during an "accretion period" between March and May (Kaser 1962; Norris and Eagon 1971). Snowfall is not considered a significant source of recharge due to the generally low annual snowfall amounts (Norris et al. 1952). Evaporation is estimated at 66 cm (26 in) per year (Harstein 1991).

Recharge values for the WPAFB study (Dumouchelle et al. 1993, p. 72) were compared with the "Map of Alluvial and Glacial Deposits of Clark County, Ohio" from Norris et al. (1952), upon which they were based. The valley train deposits found in both study areas had been assigned a recharge value of 30.5 cm (12 in) per year, approximately 32 percent of the annual recharge for this area. The preliminary recharge for the steady state model is set at 0.00084 m/d (12 in/year) for the valley train deposits and 0.000279 m/d (4 in/year) for the till uplands. Valley train recharge is estimated at 32 percent and till recharge at 11 percent of annual precipitation was utilized as the initial values for the model. A map of the recharge area is included as Figure 30.

4.2.7 Underflow

The extent of underflow at the northern and southern boundaries of the model is based on the extent of the valley train deposits on the map of "Sand and Gravel Resources of Clark County, Ohio" (Struble 1987) (Figure 31). In early runs of the model, underflow boundaries were also placed along the east and west borders, but resulted in an unstable model and were eliminated. This is presumably because of the shallow depth to bedrock in those areas.

The underflow was originally modeled as line wells adjacent to the domain outline. Values for underflow were estimated with data from the previously installed gaging stations. The values for underflow were later treated as a general head boundary, which proved to be more realistic for flow entering and exiting the model. Modeling underflow either with line wells or general head boundaries presented the problem that the boundary had a constant elevation and could not vary laterally.

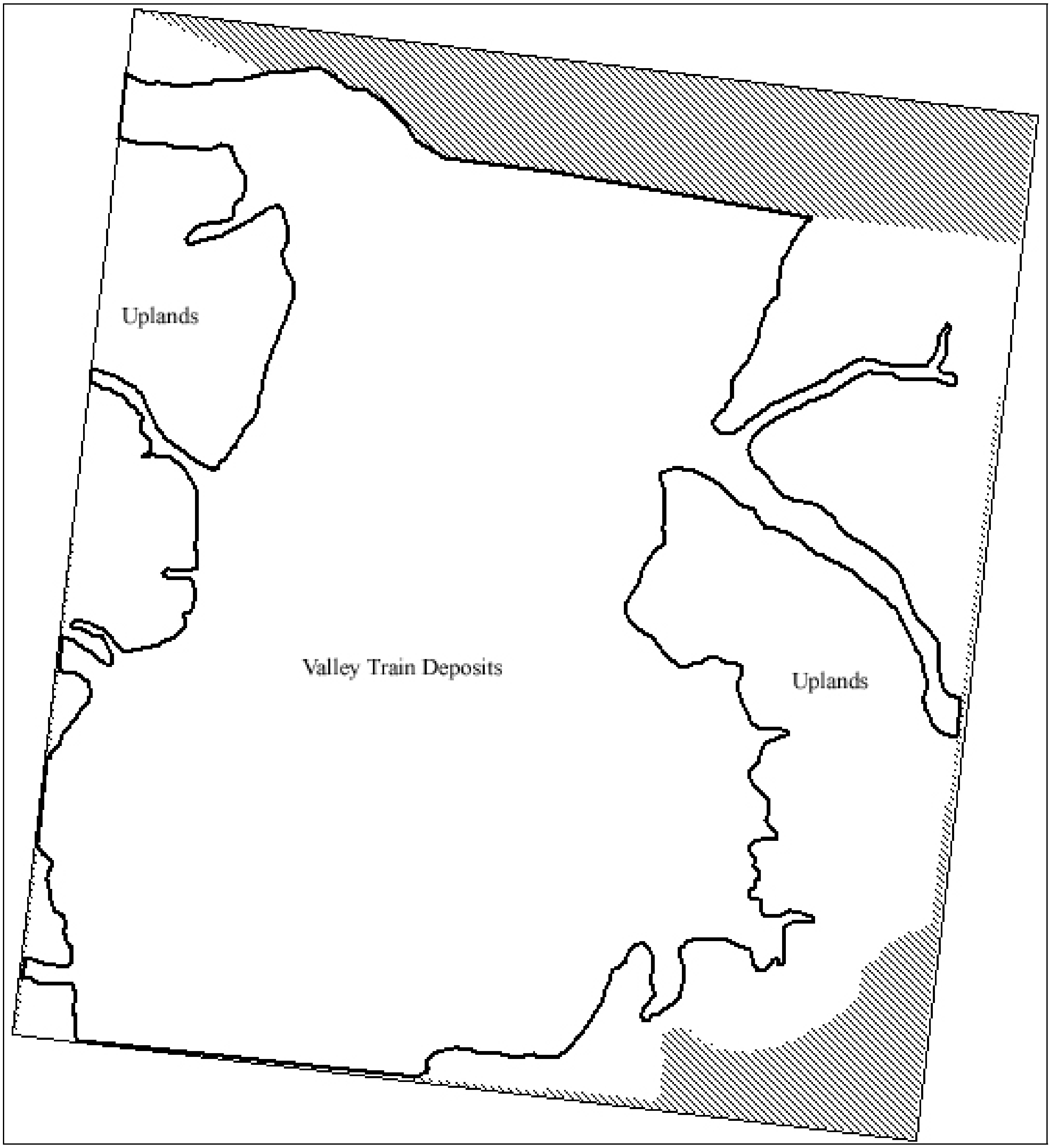

Figure 30 - SWTP Recharge and Hydraulic Conductivity Areas

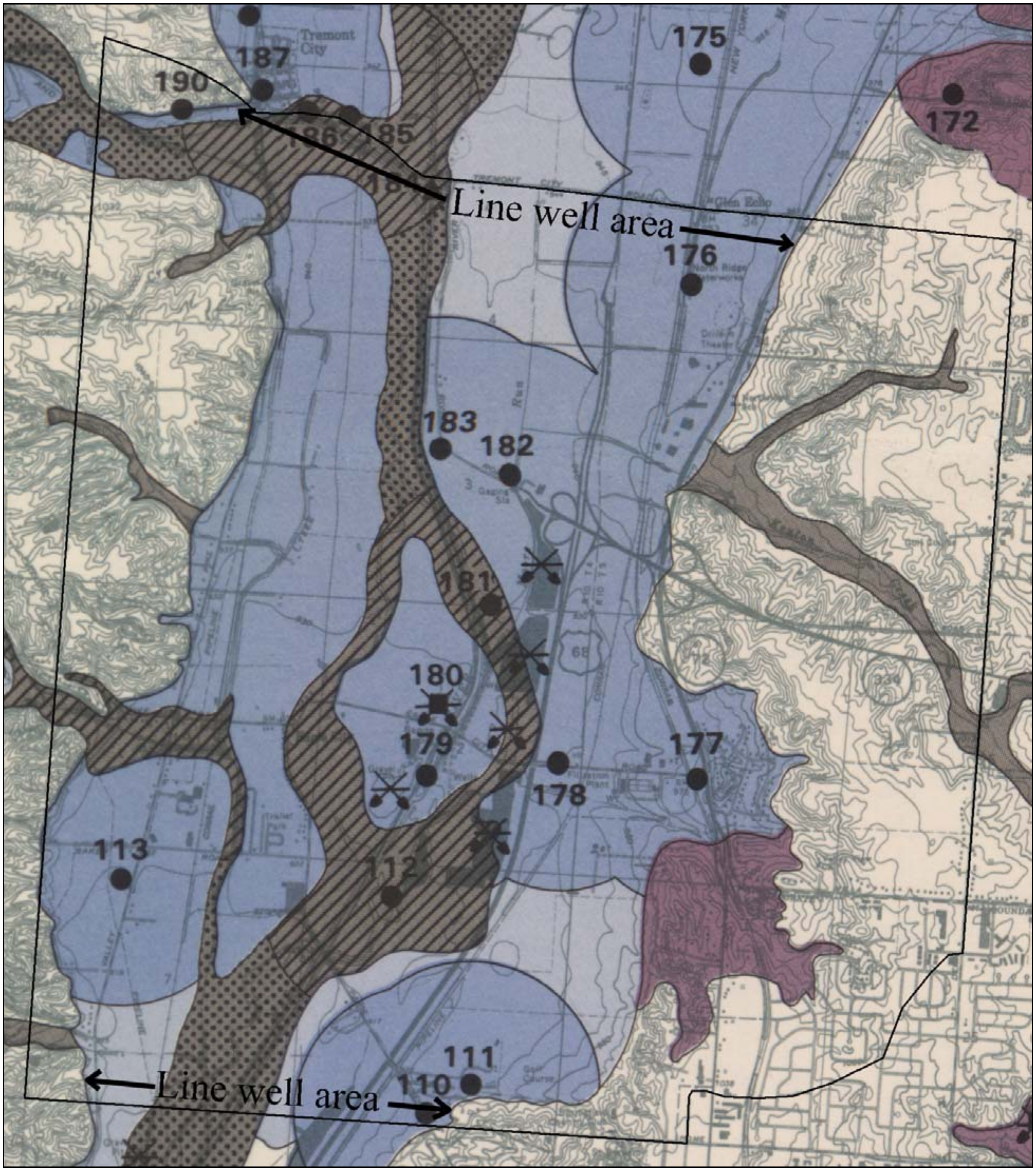

Figure 31 - Line Well Locations (Adapted from Struble 1987)

Previous investigations were reviewed for possible solutions, but Dumouchelle et al. (1993) did not provide a rationale for using point wells for modeling underflow, Arnett (1994) did not model underflow or provide a water budget and Schalk (1996) treated underflow as storage. For the SWTP the line boundaries were ultimately replaced with point wells in cell along the boundaries so that elevation and thickness could vary laterally.

Darcy's Law is utilized to calculate the "discharge" (Q), the amount of underflow entering and exiting the model. The calibrated value for hydraulic conductivity (K) is multiplied by the area (A), the width of each cell times the calculated thickness of the aquifer, and the hydraulic gradient (k), estimated at 0.00142 based on previous investigations by Norris and Eagon (1971).

$$Q = -KA\frac{dh}{dl} = -KAk$$

Values at the north edge of the model are positive values indicating water entering the model. Values at the south edge are negative indicating water exiting the model.

4.2.8 Rivers Layer

4.2.8 (a) Mad River

The location and elevation of the Mad River are based on shapefiles made from the Digital Line Graph (DLG) datasets of USGS 1:24,000 topographic maps of the area. Previous investigations' strategies for modeling rivers in Modular were reviewed. Arnett's (1994) general value for riverbed infiltration of 0.5 ft/day (0.1524 m/day) was initially used in the SWTP model. The riverbed thickness is set at a one-meter, based on the reasoning from the WPAFB model (Dumouchelle et al. 1993).

Initially, the area of the Mad River was multiplied by the conductance rate and divided by an assumed riverbed thickness of one meter. Conductance for the river was therefore given an initial value of:

$$\text{Conductance} = \frac{Area * rate}{Thickness} = \frac{134{,}380m^2 * 0.1524m/d}{0.3048m} = 67{,}190 \text{ m}^2\text{/d}$$

This method proved unworkable necessitating the use of a line river stress. An estimated width of 15 meters (a modeled width of 7.5 meters for each of the double lines from the topographic quadrangle) was utilized to calculate the conductance of the riverbed. Conductance for the line river was calculated as:

$$\text{Conductance} = \frac{Width * rate}{Thickness} * \text{ length (m)} = \frac{7.5m * 0.1524m/d}{0.3048m} * \text{ length (m)} = 3.75 \text{ m}^2\text{/d}$$

In the development of the steady state model the line conductance was reduced to 1.83 m/d due to an excess of water in the model. Results from the line river layer were also unsatisfactory; therefore the area and line river layers were ultimately replaced with a point river layer. To do this, the Mad River was divided into four reaches based on the elevation lines indicated on the topographic quadrangle. By utilizing the gradient along each reach it was possible to define appropriate stage stresses for each cell in contact with Mad River. The area was calculated in each cell along the Mad River on the 25 meter grid spacing. The area was manually estimated for each cell and was then multiplied by the river conductance to determine the appropriate conductance for each individual cell. The rate of conductance was adapted from the riverbed conductance (K_{riv}) from Dumouchelle et al. (1993) value of 13 feet per day for the Mad River, as calculated by:

$$K_{riv} = \frac{3.96m/day(13\,ft/day)}{1.0m(3.28\,ft)} \text{ * Area of cell } (m^2) = 13 \text{ } m^2/\text{day}.$$

A major problem with this value was that the rivers dominated the hydrology and changes in other parameters had little effect on the model. This rate from the WPAFB model was dramatically reduced based on model calibration for a value of 0.38 m^2 per day. This reduction of approximately one order of magnitude increased the sensitivity of the model to other parameters, including recharge and hydraulic conductivity, thereby creating a more realistic representation of the aquifer. A map of the riverbed conductance is included as Figure 32.

4.2.8 (b) Tributaries

Initially values for riverbed conductance were set to the Mad River only and tributaries were not modeled. Tributaries in the uplands especially were above the top elevation of the aquifer and created problems. The tributaries were limited to an elevation of 292.61 m (960 ft), eliminating river recharge in the till uplands.

The riverbed hydraulic conductivity for the tributaries is set to 0.03 m/day. As with the Mad River, the tributaries are modeled within the point river layer. A constant width of five meters is used to calculate tributary conductance and is then multiplied by the measured length of the tributary in each cell. The riverbed conductance is then automatically calculated for each cell as indicated by the formula:

$$K_{riv} = \frac{0.03m/day}{1.0m} \text{ * Width (5m) * Length (m)} = 0.15 \text{ } m^2/\text{day}$$

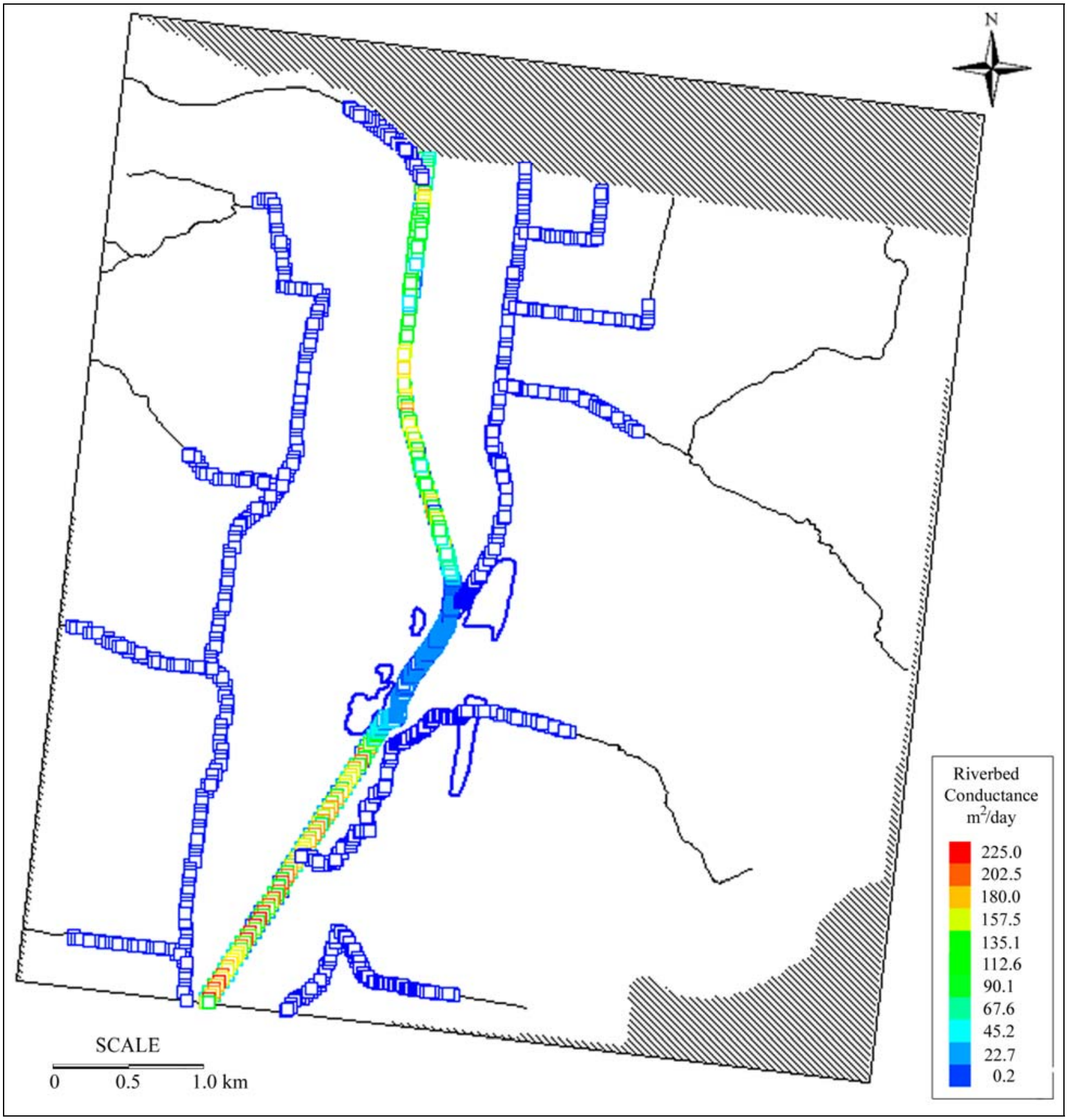

Figure 32 - Point River Layer Conductance

4.2.8 (c) Lakes

Lakes surrounding the well field area (Figure 32) were initially entered in the 'area river' layer, but did not produce satisfactory results and were later moved to the 'general head boundary' layer. This change was made to allow water to enter and exit the lakes freely, dependent only on relative head stress. Conductance was originally set relatively high at 3.75 m^2/day, which was the same value for the initial riverbed conductance of the Mad River. Once the model was working correctly this value was reduced based on Dumouchelle (1998) who also used a low conductance value for lakes based on the lack of scouring by flowing water and the settling of sediments. The elevations for the lakes are derived from the elevations of the nearest adjacent point river cell. The conductance for the lakes is set at 0.001 m^2/day, except for the lake adjacent to Moore Run. This lake is connected to Moore Run by a culvert and has a higher value of 0.0025 m^2/day.

4.2.9 Hydraulic Conductivity

Based on the WPAFB study, an initial hydraulic conductivity value of 64 m (193 ft) per day was assigned to the valley-train deposits. A later review of the literature revealed that this applied to the upper end of the values for the till and upland areas.

An increased value of 1,283.8 m/day is utilized based on the results of the 2002 pump test, which indicates a range for hydraulic conductivity of 564 to 1,584 m/day. A lower value of 5.18 m/day is applied to the upland till deposits and is not changed from its initial value. The area of the hydraulic conductivity layer is the same as that of the recharge layer. The outline of the active area is the same as the recharge indicated in Figure 30.

4.2.10 Specific Yield, Specific Storage and Porosity

A transient model is developed based on the calibrated results of the steady state model. Values for storage are not necessary for a steady state model, as the amount of water entering and exiting the model must balance. In a transient model, water can be added and removed from storage within the aquifer to provide a more realistic simulation and allow more diverse applications, such as appropriate times for sampling as is desired in this model.

A value of 0.002 was derived for the specific yield as an average of the pump test results, but values this low are traditionally not utilized in ground water modeling. The specific yield is therefore set to the default value of 0.1. This value is utilized to determine the specific storage.

The specific storage of the aquifer is the thickness of the aquifer multiplied by the specific yield. This formula is entered into Argus to compute this value automatically. The resultant values range from 0.0000182 to 0.0012. Most calculated cells tended toward the lower values except near areas with shallow bedrock, where values are higher and more variable. Aquifer porosity is set at twenty percent based on previous investigations.

4.2.11 Production Wells

An average well stress of 45,425 m^3 (12 mgal) per day is divided between six wells with a stress of 8,750 m^3 (approximately 2.3 mgal) per day. Stress is applied to production wells located closest to the Mad River, which are suspected to be most susceptible to influence to surface water contaminants.

Well elevations within the model are set to the top and bottom of the screened intervals. Each well has a 13.72 m (45 ft) screened interval. The elevation of the screened intervals and the modeled stress value for each production well is included in Table 12. The well logs for the production wells are included in Appendix B. The locations of the production wells are shown in Figure 33.

Table 12 **Production well screen elevations and modeled stress**			
Production Well	Top Elevation (m)	Bottom Elevation (m)	Modeled Stress (m^3/day)
1	268.99 (882.50 feet)	255.27 (837.50 feet)	0
2	266.95 (875.83 feet)	253.24 (830.83 feet)	0
3	266.85 (875.50 feet)	253.14 (830.50 feet)	-8,750
4	266.70 (875.00 feet)	252.98 (830.00 feet)	0
5	267.23 (876.75 feet)	253.52 (831.75 feet)	-8,750
6	265.73 (871.83 feet)	252.02 (826.83 feet)	0
7	264.80 (868.75 feet)	251.08 (823.75 feet)	-8,750
8	268.07 (879.50 feet)	254.36 (834.50 feet)	0
9	264.41 (867.50 feet)	250.70 (822.50 feet)	-8,750
10	267.16 (876.50 feet)	253.44 (831.50 feet)	0
11	266.85 (875.50 feet)	253.14 (830.50 feet)	-8,750
12	267.16 (876.50 feet)	253.44 (831.50 feet)	-8,750

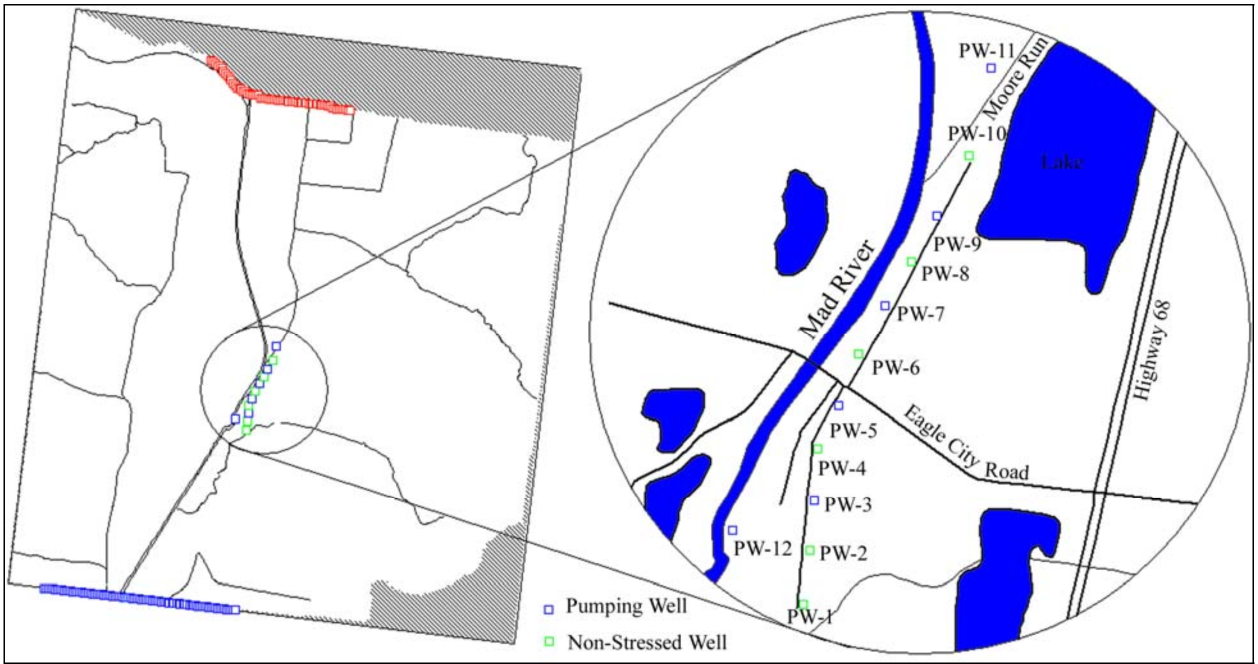

Figure 33 - Modeled Production Wells

4.2.12 Sandpoints

Sandpoint observation elevations are taken from the January 1968 gaging event and are used to calibrate the steady state model. The estimated top of casing and initial elevation values are indicated in Table 13. The locations of the sandpoints are illustrated in Figure 10.

Table 13
Sandpoint top of casing and water elevations

Sandpoint	Top of Casing Elevation	Initial Elevation (m)
1	280.56 (920.46 feet)	276.92 (908.52 feet)
2	285.66 (937.19 feet)	281.33 (922.99 feet)
3	285.21 (935.74 feet)	279.09 (915.66 feet)
4	284.52 (933.45 feet)	277.21 (909.48 feet)
6	282.81 (927.85 feet)	276.20 (906.16 feet)
7	283.52 (930.18 feet)	276.02 (905.59 feet)
8	283.91 (931.46 feet)	276.24 (906.29 feet)
9	282.86 (928.03 feet)	275.47 (903.76 feet)
12	282.28 (926.10 feet)	275.66 (904.38 feet)
16	282.95 (928.30 feet)	276.84 (908.27 feet)
23	281.69 (924.18 feet)	276.42 (906.89 feet)
cl-7	283.15 (928.96 feet)	276.20 (906.18 feet)

4.3 SWTP Steady State Model

The SWTP model was compared with input parameters from the WPAFB (Dumouchelle et al. 1993) to ensure that the modeled values were reasonable. Values from the model were systematically increased and decreased during model development in a trial and error approach to find the best fit between the initial head and the final head in the sandpoint observation wells. These calibrated values from the steady state model were used as the starting input for the development of the transient model. The results of the steady state model are illustrated in a ground water contour map (Figure 34).

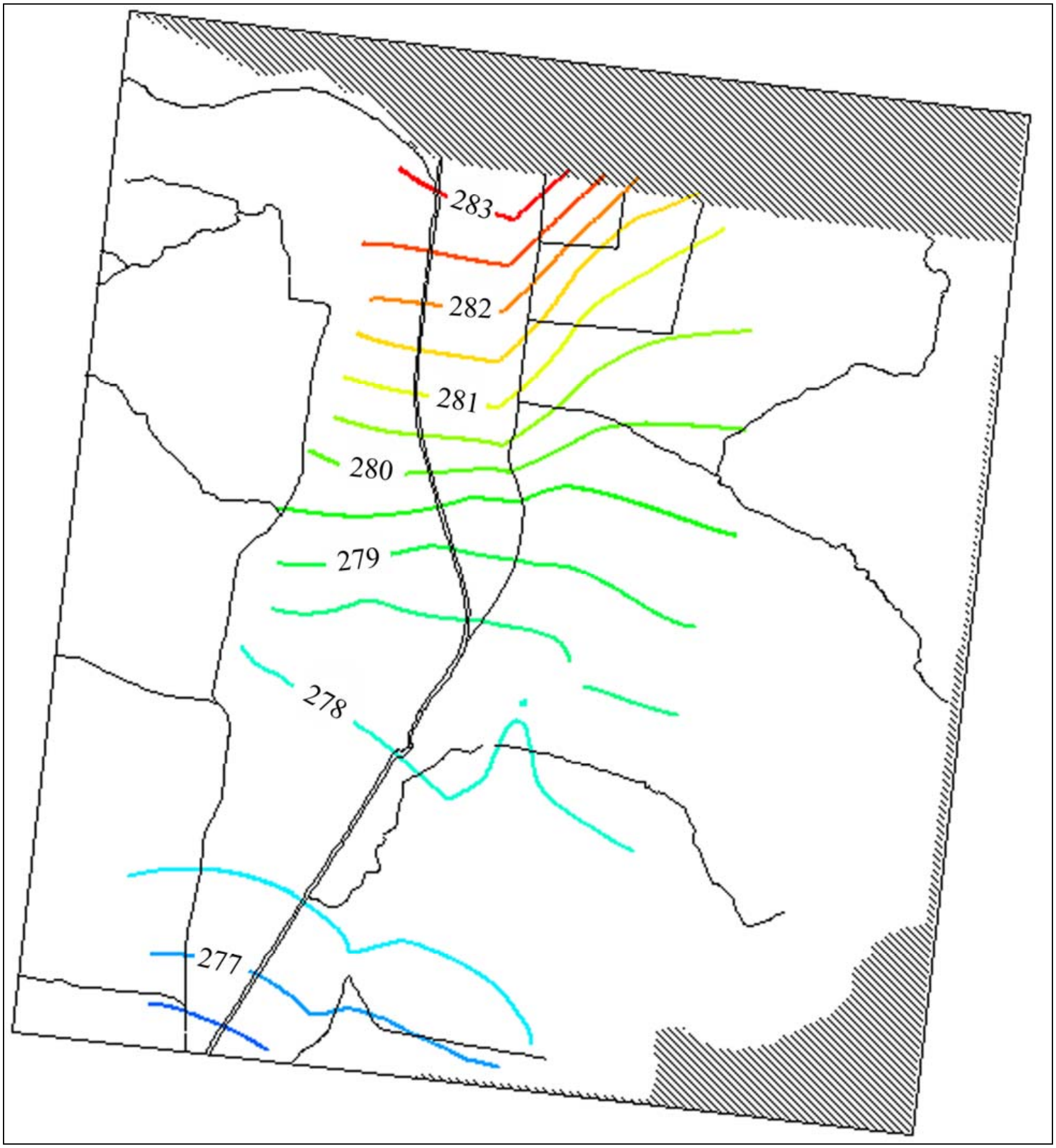

Figure 34 - Steady State Contours - Contour Interval 0.5 Meters

4.4 SWTP Transient Model

4.4.1 Model Development

Upon completion of a working steady state model a transient model, in which head and flow varies with time, of the study area was developed. In a transient model, input values for each parameter can vary over a specified number of stress periods. The SWTP transient model is divided into twelve stress periods to represent monthly changes over the annual cycle. Each stress period is divided into five equal time steps.

The initial heads for the transient model are taken from the final results of the steady state model to provide a reasonable starting point for calculating the hydraulic head. Head values from the transient model results are utilized to run the transient model a second time. This process is repeated for a third run and final transient results are accepted as final. The purpose of the repetition is to ensure that the results are not affected by fluctuations within the data.

Hydrologic data from 1968 was selected for the development of the transient model. This year was previously studied in detail by Norris and Eagon (1971) and includes a significant flooding event in May. Ground water levels were noted to exist at their seasonal lows on May 20, 1968, but rose quickly with heavy rains on the 23rd and 24th, with a recurrence interval of 50 to 100 years. Modeling this event provides an estimation of how ground water flow is affected by such events. Values for recharge and stream flow values are specific to 1968. Pumpage is assumed to remain a constant 52,504 m^3 (13.87 mgal) per day and is spread between six wells for a value of 8,750 m^3 per day for each well. Values for the transient model were set at 183.4 m/day for hydraulic conductivity (Feulner 1961) and 0.00142 for the hydraulic gradient used to calculated underflow (Norris and Eagon 1971).

The stage data from the Mad River is utilized to determine the transient changes in head elevation for both the river and lake layers. Values for both layers are set to increase and decrease at the same rate. While this does not realistically reflect the natural system there is insufficient information on lake stages and their hydrologic connection to the rivers. Stage elevations are back calculated from data available at the USGS website. Recent gage height and discharge data are plotted and a formula derived to back-calculate historical data from the gage located on the Mad River at Eagle City Road. The gage heights calculated for each month are summarized in Table 14. Calculations and the plotted data used to derive the historical gage heights are included in Appendix L.

Table 14
Initial recharge and elevation values applied to the SWTP transient model

Month	Recharge from precipitation (m/d)	Back-calculated gage heights (m)
January	0.000579	1.78
February	0.000135	1.78
March	0.001115	1.79
April	0.000576	1.79
May	0.003443	1.95
June	0.00089	1.83
July	0.000687	1.75
August	0.001073	1.77
September	0.000638	1.71
October	0.00031	1.70
November	0.00077	1.74
December	0.000688	1.83

The percent recharge in the transient model is variable through the year, depending on whether the data is from a depletion month or an accretion month as detailed by Norris and Eagon (1971) in their conceptual model for this area. During accretion months precipitation is added to storage only during the spring, when recharge is greater and evaporation and transpiration are limited. During depletion months, water is removed from storage due to lowered precipitation and increased evaporation and transpiration. Originally the percent recharge was set to 32 percent for accretion months and 10 percent for depletion months, but the values provided were increased during calibration, as indicated in Table 15, with a forty percent recharge rate for the first half of the year, and a twenty percent recharge for the second half of the year. This provides an average annual recharge of thirty percent, predominantly during the accretion period described by Norris and Eagon. The higher percentage of recharge during this time period also helps to account for recharge, which was not assigned a value in the upland areas. Illustrations of the SWTP input layers are included in Appendix M.

Table 15
Final transient recharge values for monthly precipitation

Month	Inches per month	Percent recharge	Inches of recharge	Daily recharge (m)
January	1.73	40	0.69	0.000579
February	0.38	40	0.15	0.000135
March	3.32	40	1.33	0.001115
April	1.66	40	0.66	0.000576
May	10.25	40	4.10	0.003443
June	2.56	40	1.02	0.000890
July	4.00	20	0.80	0.000687
August	6.34	20	1.27	0.001073
September	3.59	20	0.72	0.000638
October	1.80	20	0.36	0.000310
November	4.33	20	0.87	0.000770
December	4.00	20	0.80	0.000688

4.4.2 Calibration

As done with the steady state model, calibration is conducted with a trial and error approach to find the bet fit between the initial head and the final head in the sandpoint observation wells. The model parameters are also compared with the original estimates to keep them within realistic limits.

Each well is separately depicted in a hydrograph over each time step to compare the calculated head solution to the measured heads. Model calibration resulted in a lowered riverbed conductance, which increased the sensitivity of other parameters. Other changes include an increased hydraulic conductivity and increased monthly recharge. Hydrograph comparisons of the actual and measured water levels for each sandpoint are included in Appendix N. The results of the transient model are illustrated in the ground water contour map in Figure 35.

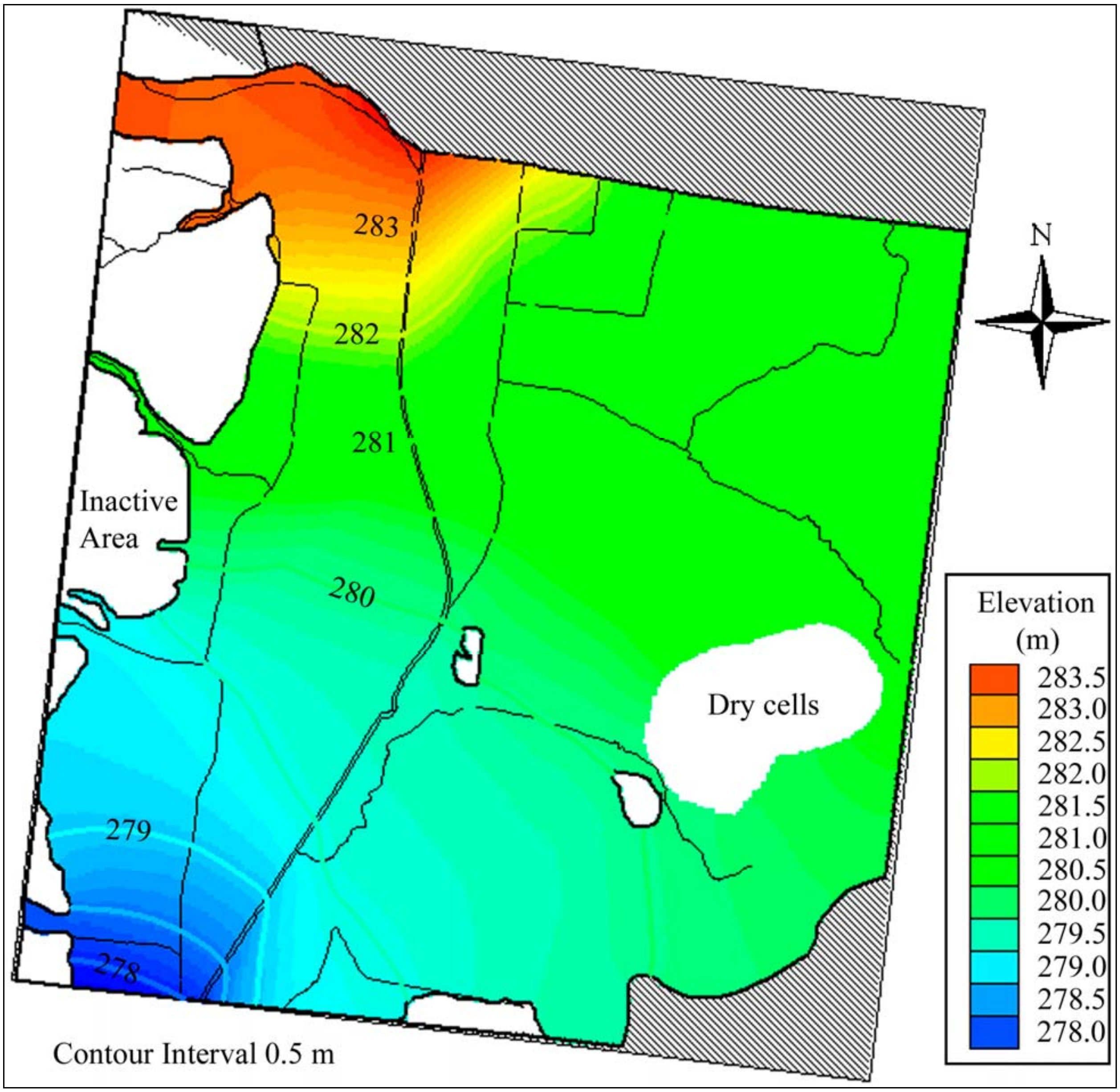

Figure 35 - Transient Ground Water Elevation Map – Contour Interval 0.5 meters

4.4.3 Sensitivity Analysis

Sensitivity analysis consists of a breakdown of the cell-to-cell budget terms to determine how changes to input variables affect results of the calibrated model. The model is run with parameter values systematically increased and decreased. Changes that produce significant variations in the model are said to be sensitive, while changes that produce little difference in the model are said to be insensitive.

Sensitivity analysis is similar to model calibration, except that the change in the piezometric heads is not limited to the sandpoints, but to all cells within the active model area. Heads at each cell from the calibrated model are compared with the heads from each parameter changes in the sensitivity runs. The differences in these values are calculated to obtain the change in head resulting from the changed parameter. The relative head difference and the absolute value of the head difference are averaged and plotted for comparison to changes in other parameters. For this analysis, sensitivity analysis is conducted for parameters values for hydraulic conductivity, recharge, hydraulic gradient and river bed conductance. Each parameter is increased and decreased up to one order of magnitude for a total of twenty-four model runs.

Results indicate that the model is most sensitive to riverbed conductance, less sensitive to hydraulic conductivity and hydraulic gradient and least sensitive to recharge. The riverbed conductance is more sensitive to decreases than increases in value and fails to run to completion if reduced more than half. The riverbed conductance is relatively insensitive to increases in value. Conversly the hydraulic conductivity and hydraulic gradient are more sensitive to increases and fail to complete if increased by more than double the original value. Both parameters are relatively insensitive to decreasing values. The recharge is the most stable parameter, with modeled heads inversely proportional to changes in value, perhaps due to the small geographic area being modeled. The results of the sensitivity analysis are included as Table 15. Graphs of the sensitivity analysis are included in Appendix O.

Table 15
Summary of sensitivity analysis

Parameter	Multiplier	0.1		0.25		0.5	
	Change in head (m)	Relative change	Absolute value of change	Relative change	Absolute value of change	Relative change	Absolute value of change
K	Maximum	1.28	2.28	0.14	1.68	-0.15	1.06
	Average	-0.65	0.76	-0.62	0.62	-0.46	0.46
Recharge	Maximum	0.36	0.36	0.23	0.23	0.10	0.10
	Average	0.33	0.33	0.20	0.20	0.09	0.09
k	Maximum	2.13	2.36	1.73	1.99	1.09	1.36
	Average	-0.30	0.79	-0.26	0.66	-0.20	0.45
Kriv	Maximum	--	--	--	--	283.07	283.07
	Average	--	--	--	--	3.79	3.79

Parameter	Multiplier	2		4		10	
	Change in head (m)	Relative change	Absolute value of change	Relative change	Absolute value of change	Relative change	Absolute value of change
K	Maximum	1.50	1.50	--	--	--	--
	Average	1.25	1.25	--	--	--	--
Recharge	Maximum	-0.27	0.37	-0.69	0.91	-1.81	2.41
	Average	-0.34	0.34	-0.83	0.83	-2.23	2.23
k	Maximum	283.31	283.31	--	--	--	--
	Average	1.37	1.67	--	--	--	--
Kriv	Maximum	-0.58	1.18	-0.70	1.77	-0.67	2.27
	Average	-0.85	0.85	-1.21	1.21	-1.45	1.45

4.5 SWTP Particle Tracking

Particle tracking was modeled with the MODPATH plug-in extension in Argus. A description and mathematical derivation of MODPATH is provided by Pollock (1994):

“Output from steady-state or transient MODFLOW simulations is used in MODPATH to compute paths for imaginary "particles" of water moving through the simulated ground-water system. In addition to computing particle paths, MODPATH keeps track of the time of travel for particles moving through the system. By carefully defining the starting locations of particles, it is possible to perform a wide range of analyses, such as delineating capture and recharge areas or drawing flow nets.

“The partial differential equation describing conservation of mass in a steady-state, three dimensional ground-water flow system can be expressed as,

$$\frac{d}{dx}(nv_x) + \frac{d}{dy}(nv_y) + \frac{d}{dz}(nv_z) = W$$

where v_x, v_y, and v_z are the principal components of the average linear ground-water velocity vector, n is porosity, and W is the volume rate of water created or consumed by internal sources and sinks per unit volume of aquifer.

“The finite difference approximation of equation 1 can be thought of as a mass balance equation for a finite-sized cell of aquifer that accounts for water flowing into and out of the cell, and for water generated or consumed within the cell. Figure 2-1 shows a finite-sized cell of aquifer and the components of inflow and outflow across its six faces.

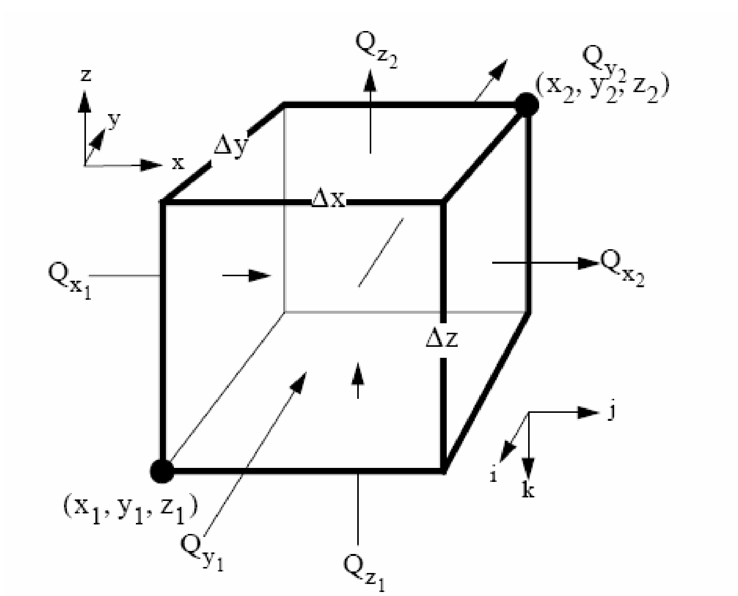

Figure 2-1. Finite-difference cell showing definitions of x-y-z and i-j-k

“The average linear velocity component across each face in cell (i,j,k) is obtained by dividing the volume flow rate across the face by the cross sectional area of the face and the porosity of the material in the cell.”

The particle paths computed by the program are traced forward in the direction of ground water flow or in reverse to recharge areas to determine the capture areas over a specified time. Based on modular flow results, the program ignores dispersion and is based solely on advection. The particle tracking for this model is completed with the transient flow results of the SWTP model.

Due to poor horizontal resolution at the 25 m grid scale, grid refinements are inserted near the Mad River to provide a finer scale of up to a 9 m resolution (Figure 36).

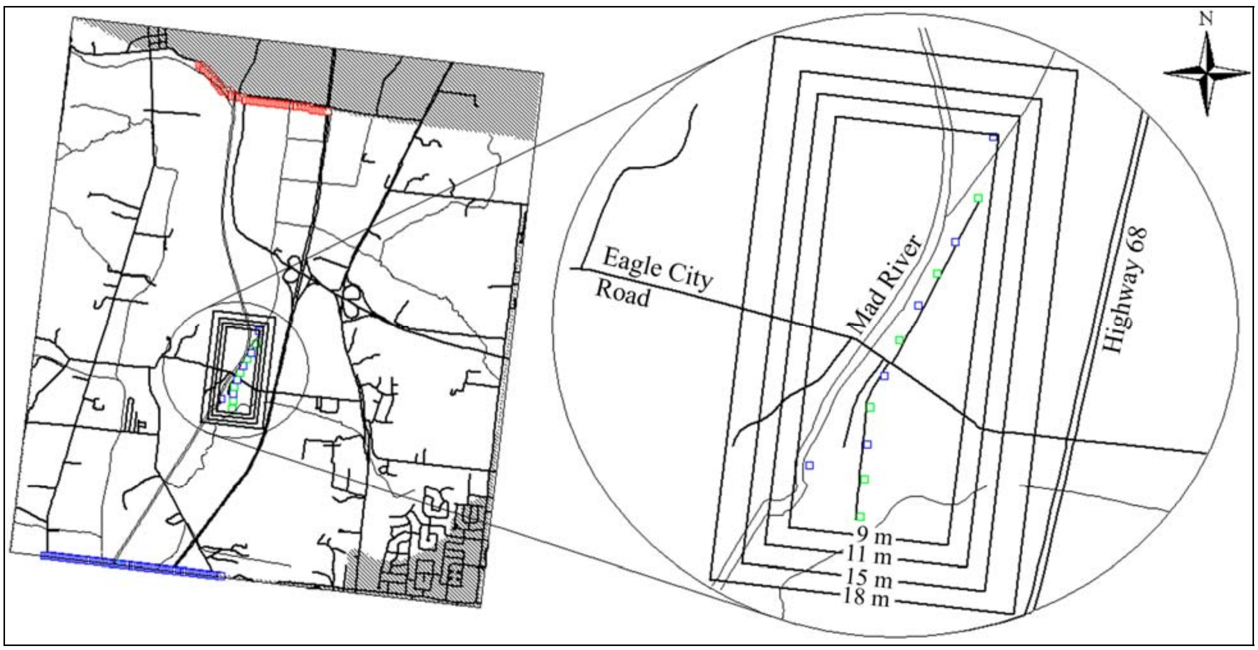

Figure 36 - Grid Refinement Values

4.6 SWTP Time of Travel Estimates

4.6.1 Reverse Particle Tracking

Reverse particle tracking is performed at each production well with an applied stress and traced back to its recharge area over the previous year with a total of 384 particles released. Of those, 320 remain active and only seventeen percent of the particles have travel times that were less than the average of 316 days. Modeling results indicated that the path lines run a minimum 187 days remained within the modeled area after one year of travel. The remainder stops at the lakes surrounding the well field area (Figure 37). Particle tracking is conducted on six wells (PW-3, PW-5, PW-7, PW-9, PW-11 and PW-12) and the results compare well with the previously determined extents of the one- and five-year times of travel for the aquifer (OEPA 1990).

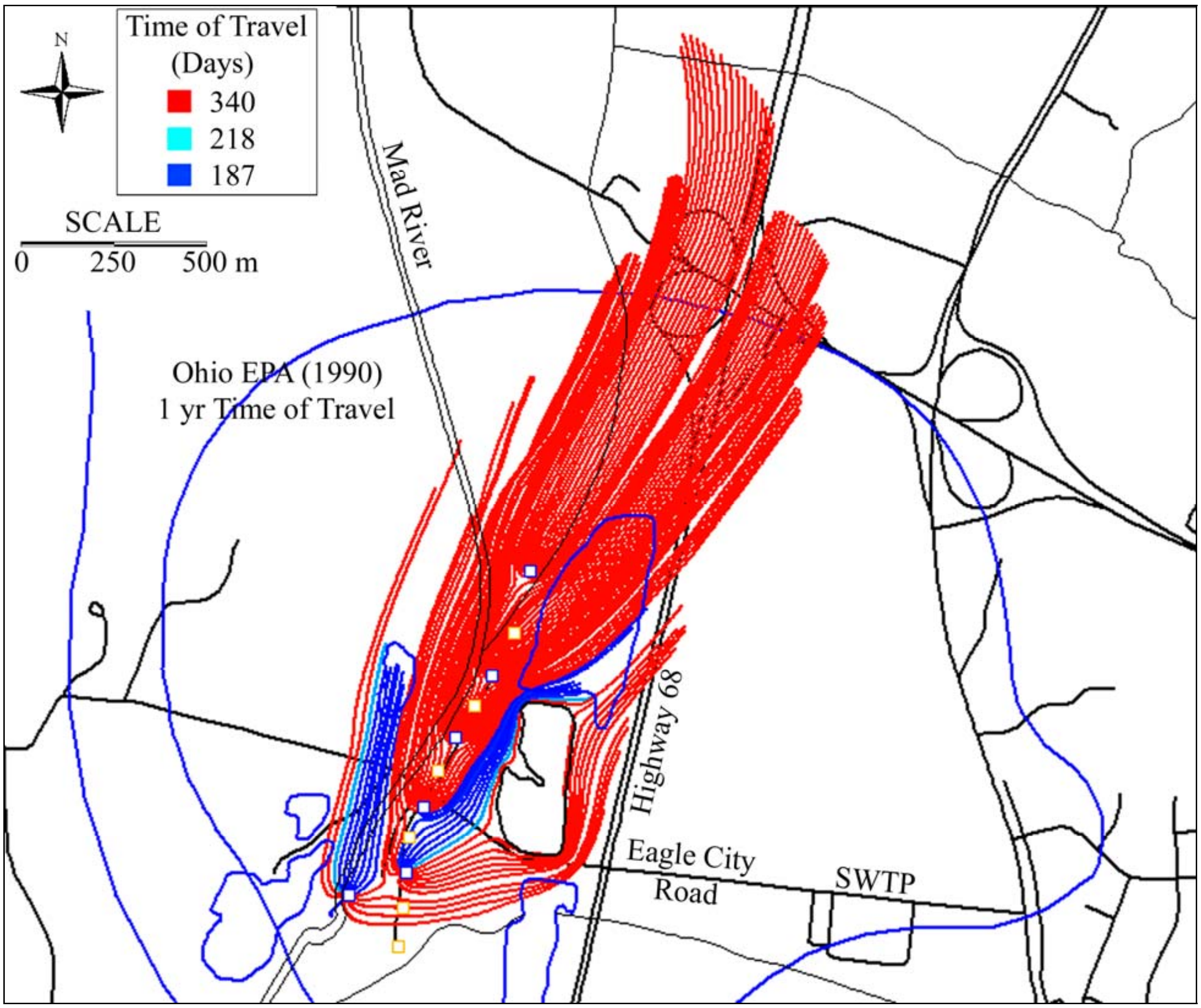

Figure 37 - Transient Reverse Particle Tracking Path lines – One Year Time of Travel

4.6.2 Forward Particle Tracking

Forward particle tracking is performed at sixty points along the Mad River and Moore Run through the well field area. Particle release locations are placed in the areas most likely to have the shortest travel times to each of the production wells, with a total of 960 particles released.

The flow paths for the 1968 transient model indicate travel times ranging from a minimum time of less than one day to a maximum of 132 days. The shortest flow path is less than one day for PW-12. The minimum flow paths for the others wells are 3.2 days for PW-11, 3.6 days for PW-7, 15.2 days for PW-9, 18.9 days for PW-5 and 82 days for PW-3. A map indicating the shortest flow paths from the Mad River and Moore Run to each well is included as Figure 38.

Sixty percent of the particles have travel times less than the 31-day average time of travel. This indicates that the majority of particles stop within the first month and that all particles stop before the May 1968 flooding event. Based on these results, forward tracking times are also run from the second week of May 1968 to simulate the path lines during a period of high flow in the Mad River.

Forward particle tracking is set to run for a period of one month, beginning on or about May 18th of 1968. Again, 960 particles are released, of which the majority stopped instantly. Over ninety-five percent of the particles had travel time less than the 0.6-day average. This indicates that MODPATH cannot compute the path of the particle based on the volume of flow during the May 1968 flooding event. The majority of particles are not removed influenced by pumping from the production wells and are not removed from the river. Only twelve particles remain active through the end of the month. Tracking times range from just over one day in PW-12 to three days in PW-11. No particles travel to the other production wells (Figure 39).

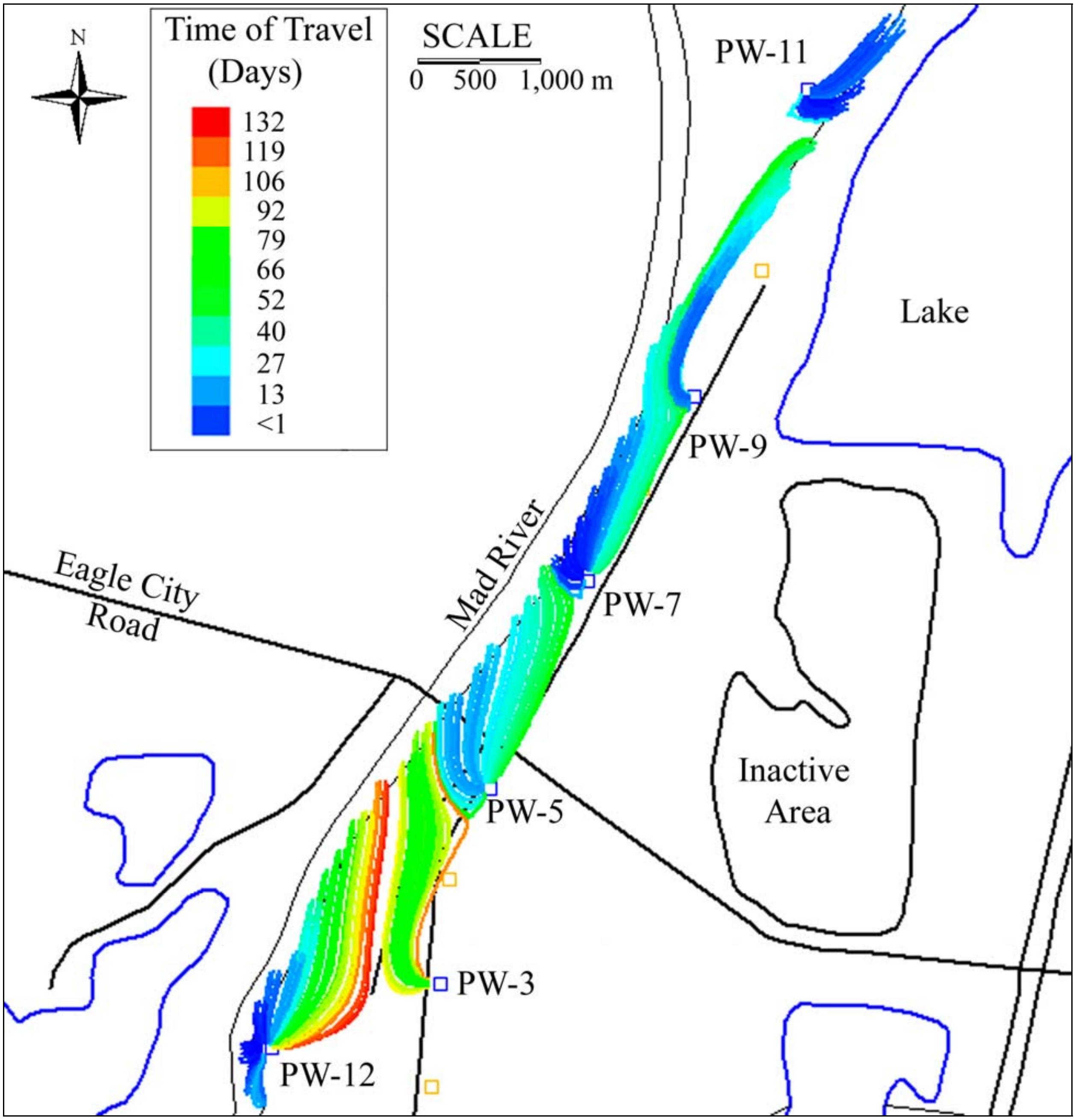

Figure 38 - Forward Particle Tracking Path Lines

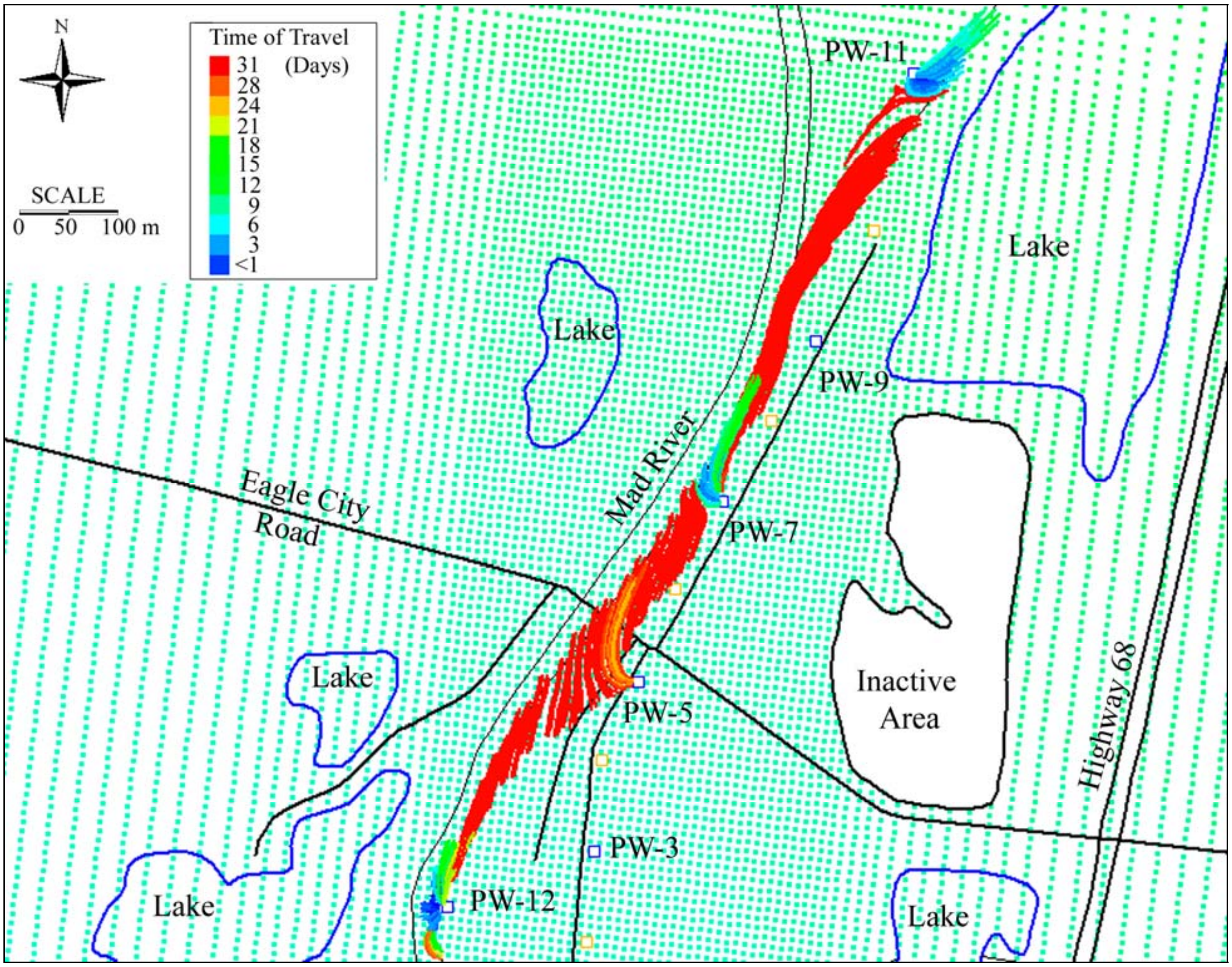

Figure 39 - Particle Tracking for May 1968

5.0 CONCLUSIONS

5.1 Limitations of the Model

A ground water model simulating a natural flow system is inherently limited by the assumptions made by the user during development. As a numerical approximation, it is understood that an exact representation of the natural system is not possible and that there is no single correct solution to a ground water flow problem. A working conceptual model is essential to ensure that the assumptions and simplifications utilized in the numerical model are reasonable.

In the SWTP model there are several assumptions that can have a large impact on the accuracy of the calibrated model, including boundary conditions and the nature of the aquifer. For example, the base of the model was set as a no-flow boundary at the bedrock surface, as based on previous studies (Dumouchelle et al. 1993, OEPA 1990). Variations in character of the aquifer resulting from the depositional setting were not modeled, although till is found interbedded within the valley train deposits in several locations (Markley 2001). A lack of data in this area and in the uplands to the east made it impossible to incorporate into the model.

Based on model calibration and sensitivity, the greatest potential source of this error lies with the values for riverbed conductance. Such values are extremely difficult to measure and vary with streambed scouring, vegetative growth and discharge. The recharge and hydraulic conductivity values are relatively insensitive and not considered as a significant source of error. Other parameters, such as underflow and specific storage, were determined directly from aquifer thickness and piezometric gradient. The MODPATH estimates of ground water flow paths do not account for contaminant transport by diffusion, dispersion, adsorption or other reductive processes.

5.2 Particle Tracking Analysis and Recommendations

Based on the May 1968 results, the area of highest concern is production well PW-12. Travel time from the Mad River to this most sensitive well is on the order of one day under both normal and flooding conditions. The wells closest to Mad River and Moore Run in the north well field also indicate short travel times are therefore also prone to contamination by surface water.

Under normal flow and pumping conditions the potential for contamination should be minimal due to a decrease in riverbed conductance resulting from silting and vegetative growth. The greatest potential for the introduction of contaminants would be during a flooding event, when the bed of the Mad River is scoured, the riverbed conductance is increased and the release of contaminants into the surface waters is at a maximum. However, this risk is offset by recharge to the storage of the aquifer and a lowered hydraulic gradient. More water is available to the production wells through recharge to storage and there is less demand for the infiltration of surface water from the Mad River. Also, contaminants are moved more quickly downstream by the increased water velocity and lowered hydraulic gradient.

The current study is not sufficient to determine if the reductive properties of riverbank filtration within the aquifer are adequate to remove contaminants during a worst case scenario, however several recommendations can be made:

- While the potential for contamination is greatest in production well PW-12 due to its close proximity to the Mad River, this well also provides the best location to determine the potential of surface water contaminants entering the well field. A plan should be developed to monitor the water quality of this well compared with surface water from the Mad River during both normal and flooding conditions. Careful monitoring could provide additional insight into the actual risk of contamination from surface water, serve as a base to determine the risk in other wells and determine the minimum distance from the Mad River for future production wells.

- Increased risk from surface contamination can be associated with the physical distance of each production well to Mad River or Moore Run. During periods of high flow, the production wells in the south well field, with the exception of PW-12, are least likely to introduce contaminants into the SWTP and may be used to minimize the risk of infiltration of surface water.

- The monitoring wells installed by the Miami Conservancy District and lake staff gages should be added to the monthly water level measurements currently collected by the SWTP. Modeling of this aquifer is limited in part by the locations of nearly all monitoring points on the opposite side of the Mad River from the production wells. Staff gages placed in the Mad River could also provide insight into the connection between the river, lakes and water table.

- The one- and five- year time of travel zones for the well field area should extend further to the north and should encompass all the surficial lakes that surround the well field. As the lithology the aquifer to the east is poorly understood, the boundaries in this area should not be altered without further investigation.

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APPENDIX A

SWTP MONTHLY PRECIPITATION TOTALS (1960 – 1990)

Springfield Water Treatment Plant
Monthly Precipitation Totals

	1960	1961	1962	1963	1964	1965	1966	1967	1968	1969
January		0.99	3.10	1.65	2.15	3.20	3.27	0.64	1.70	3.94
February		3.65	3.48	0.74	1.45	3.85	3.30	2.33	0.35	1.06
March		4.63	2.77	7.98	10.33	3.16	1.22	4.40	3.28	1.72
April		6.17	0.49	3.96	7.81	6.15	3.13	4.75	1.64	2.99
May		2.80	4.77	2.65	2.50	1.71	2.98	6.93	10.23	5.37
June		3.42	1.68	1.26	3.45	1.71	1.96	2.77	2.56	8.47
July	2.82	4.27	6.77	4.22	2.90	3.66	3.33	1.75	3.98	6.43
August	2.97	2.72	3.15	2.96	2.39	2.68	5.72	0.71	6.22	4.93
September	0.73	2.70	4.13	0.38	1.42	5.51	4.23	2.81	3.57	2.45
October	2.13	1.24	2.95	0.06	0.86	3.57	1.44	1.71	1.79	0.83
November	2.09	3.36	3.66	1.01	2.46	1.36	3.96	4.73	4.32	3.75
December	1.87	3.38	1.67	1.13	3.63	0.81	2.98	3.54	3.95	1.95

	1970	1971	1972	1973	1974	1975	1976	1977	1978	1979
January	1.17	1.74	1.19	1.53	3.05	4.65	3.10	1.17	4.09	3.99
February	1.14	3.51	0.79	1.32	1.69	4.37	1.81	1.39	0.24	2.77
March	2.21	1.98	3.46	4.41	2.92	3.51	2.29	3.05	2.11	1.28
April	7.03	0.77	4.70	4.21	3.53	3.07	1.54	4.86	3.74	4.17
May	6.79	3.96	5.03	5.08	4.69	1.28	3.20	2.17	3.34	3.74
June	4.33	6.44	2.51	7.63	4.12	4.57	6.56	1.56	3.65	3.17
July	3.50	4.57	3.09	4.45	0.72	5.82	2.33	2.06	3.79	5.79
August	1.23	1.83	5.20	3.38	6.35	4.54	3.19	5.45	8.71	7.45
September	2.09	4.83	5.26	2.87	4.31	3.23	2.41	2.69	0.45	5.58
October	2.43	2.47	2.36	2.65	1.29	2.67	2.87	3.55	3.10	1.74
November	1.57	1.74	5.58	4.82	2.82	1.35	0.74	2.73	1.41	3.69
December	1.99	4.83	3.16	2.83	2.66	3.62	0.54	4.28	4.01	1.83

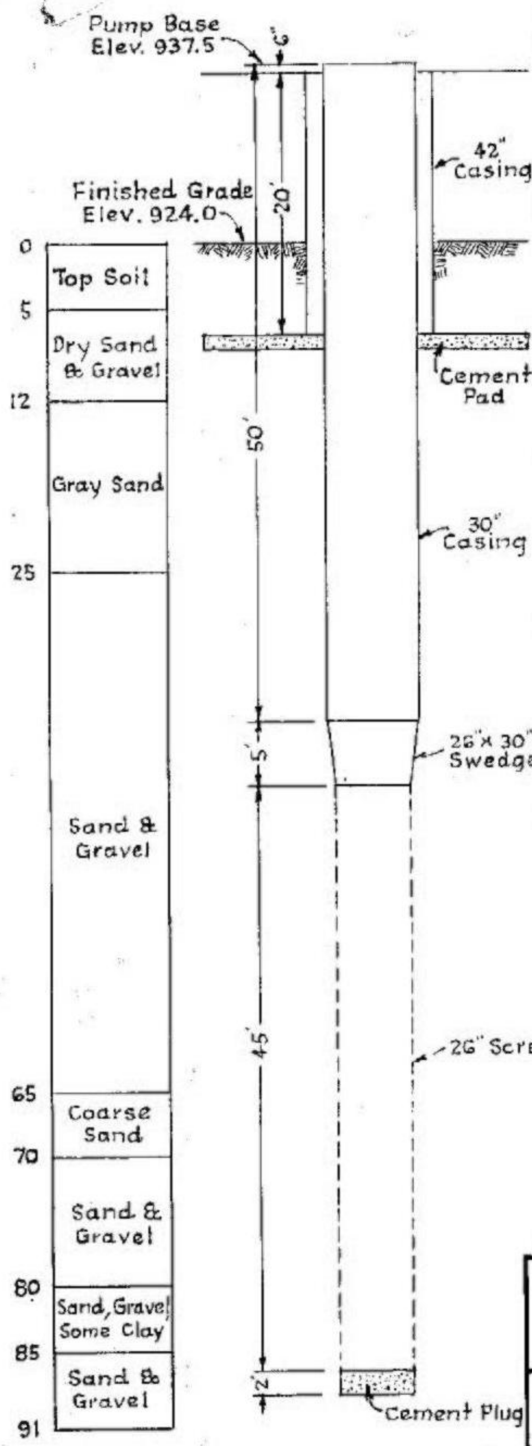
Springfield Water Treatment Plant
Monthly Precipitation Totals

	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989
January	1.75	0.55	4.91	1.01	0.80	1.44	1.11	1.37	1.11	2.16
February	1.57	2.93	2.47	0.83	1.89	0.84	2.59	0.22	4.49	2.59
March	3.85	0.94	5.06	1.35	3.36	4.05	2.05	2.10	2.42	4.77
April	3.09	5.79	1.58	3.23	3.16	1.43	3.81	1.77	1.57	4.60
May	4.27	10.06	3.19	7.07	4.08	4.93	2.02	2.23	1.75	6.11
June	9.22	5.32	3.80	1.66	1.95	1.97	4.23	4.02	2.53	6.45
July	4.94	4.20	1.89	3.21	2.24	3.09	6.60	3.39	3.92	5.19
August	7.76	1.64	2.35	1.82	3.73	5.13	2.15	0.68	2.82	5.19
September	1.77	5.98	1.81	1.44	3.64	0.52	2.02	1.12	5.58	3.16
October	3.21	3.48	1.28	4.89	3.11	1.90	7.53	1.60	2.30	0.96
November	2.27	2.53	4.20	4.93	4.69	9.81	2.93	1.87	5.01	2.38
December	1.26	3.09	3.54	2.24	4.36	3.08	2.84	3.16	2.20	0.85

	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999
January	0.96	1.56	2.62	3.52	2.36	2.31	3.70	1.83	3.59	3.79
February	1.92	1.56	0.52	1.94	1.20	1.14	0.65	1.31	2.25	2.45
March	1.23	2.38	2.58	1.98	1.38	1.61	1.03	3.13	1.38	1.30
April	1.88	2.10	2.90	2.98	3.72	3.78	6.46	0.81	6.43	3.81
May	7.55	2.48	2.43	2.92	2.64	7.57	8.30	4.01	5.92	1.25
June	4.86	1.77	3.95	5.09	3.45	4.17	6.52	6.68	6.42	2.84
July	9.62	1.31	7.35	6.53	4.05	3.59	7.04	3.73	2.86	3.37
August	2.87	3.38	5.12	0.85	3.24	4.70	0.16	5.46	1.12	1.13
September	4.18	3.03	1.46	4.49	1.28	1.45	5.96	1.36	1.65	1.37
October	4.98	1.55	1.98	1.52	0.83	3.63	1.58	0.94	3.69	0.96
November	1.80	0.83	2.86	2.17	2.80	2.37	3.26	2.43	1.36	1.71
December	6.39	2.61	0.85	1.26	2.40	1.91	3.16	1.80	2.65	1.88

APPENDIX B

SWTP PRODUCTION WELL BORING LOGS



MATERIAL:

Pit: 20' of 42"×3/8" Steel Casing, 50' of 30"×3/8" Steel Casing & 5' of 26"×30" Swedge.

Screen: 45' of 26" Stainless Steel Screen.

Cone: 26"×2' Steel Shoe with Cement Plug.

PUMP:

No.	36869	**Shop No.**	36869
Type	T. H. C.	**Size**	14"
Setting	70'	**Stages**	1
Suction	12"×10'	**Impellers**	Bronze
Discharge	12"	**Head**	
Tubing	2½"	**Press. B. P.**	
Shafting	1½"		

MOTOR:

Make	Westinghouse	**Type**	
Volts	440	**Cycle**	60
Phase	3	**Amp.**	
H. P.	75	**R. P. M.**	1760
Frame	445-P	**Serial**	2462V-121

WELL:

Capacity	3000 G.P.M.	**Static Level**	21'-7"
Guarantee	2800 G.P.M.	**P. Level**	30'-7"
Started	8-27-57	**Pressure**	
Finished	9-6-57	**Pumped**	3000 G.P.M.
Accepted		**Depth**	100'

REMARKS:

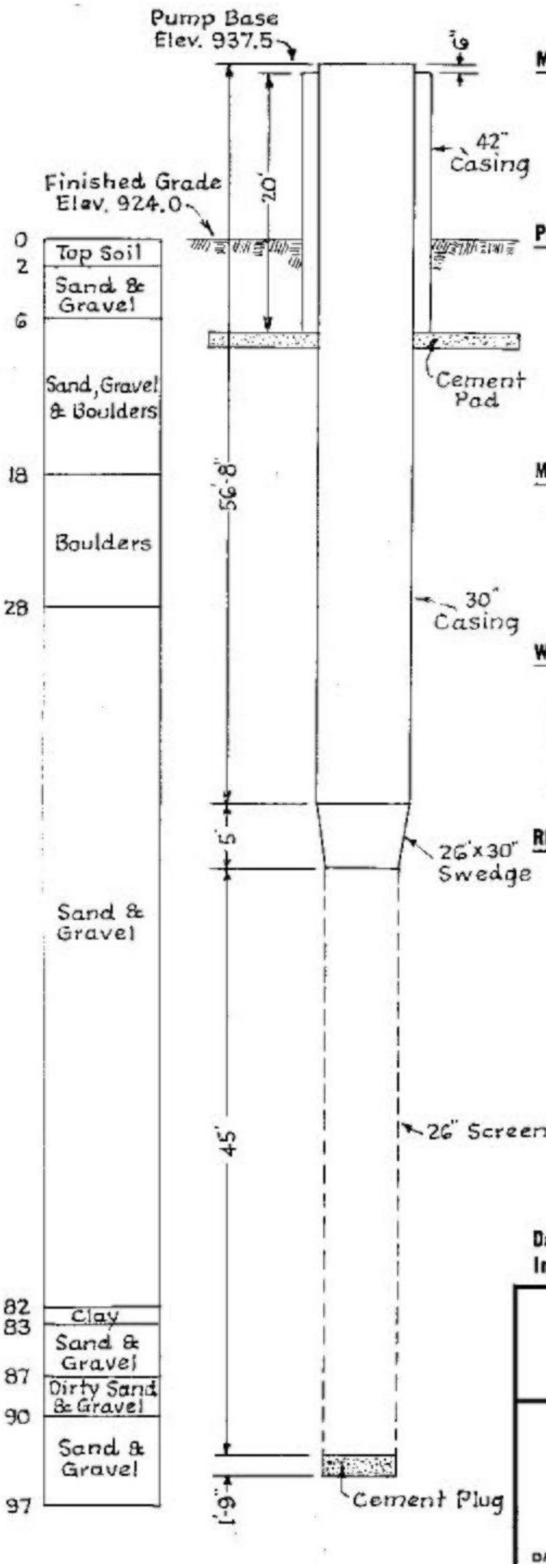
Used 40 T. of Pea Gravel Around Screen

Driller: Toledo Rogers
Installer: Chas. Webb

THE LAYNE-OHIO CO.
WATER SUPPLY CONTRACTORS
COLUMBUS OHIO

CITY OF SPRINGFIELD
SPRINGFIELD, OHIO

DRAWN BY O.L. MS APPROVED BY
WELL NO. 1 DRAWING NO. 1351



MATERIAL:

Pit: 20' of 42"×3/8" Steel Casing, 56'-8" of 30"×3/8" Steel Casing & 5' of 26"×30" Swedge.

Screen: 45' of 26" Stainless Steel Screen.

Cone: 26"× 1'-9" Steel Shoe with Cement Plug

PUMP:

No.	36876	**Shop No.**	36876
Type	T. H. C.	**Size**	14"
Setting	70'	**Stages**	1
Suction	12"× 10'	**Impellers**	Bronze
Discharge	12"	**Head**	
Tubing	2½"	**Press. B. P.**	
Shafting	1½"		

MOTOR:

Make	Westinghouse	**Type**	
Volts	440	**Cycle**	60
Phase	3	**Amp.**	
H. P.	75	**R. P. M.**	1760
Frame	445-P	**Serial**	3562 V-121

WELL:

Capacity	3000 G.P.M.	**Static Level**	20'
Guarantee	2800 G.P.M.	**P. Level**	28'-4"
Started	8-27-57	**Pressure**	
Finished	9-19-57	**Pumped**	3000 G.P.M.
Accepted		**Depth**	106'-8"

REMARKS:

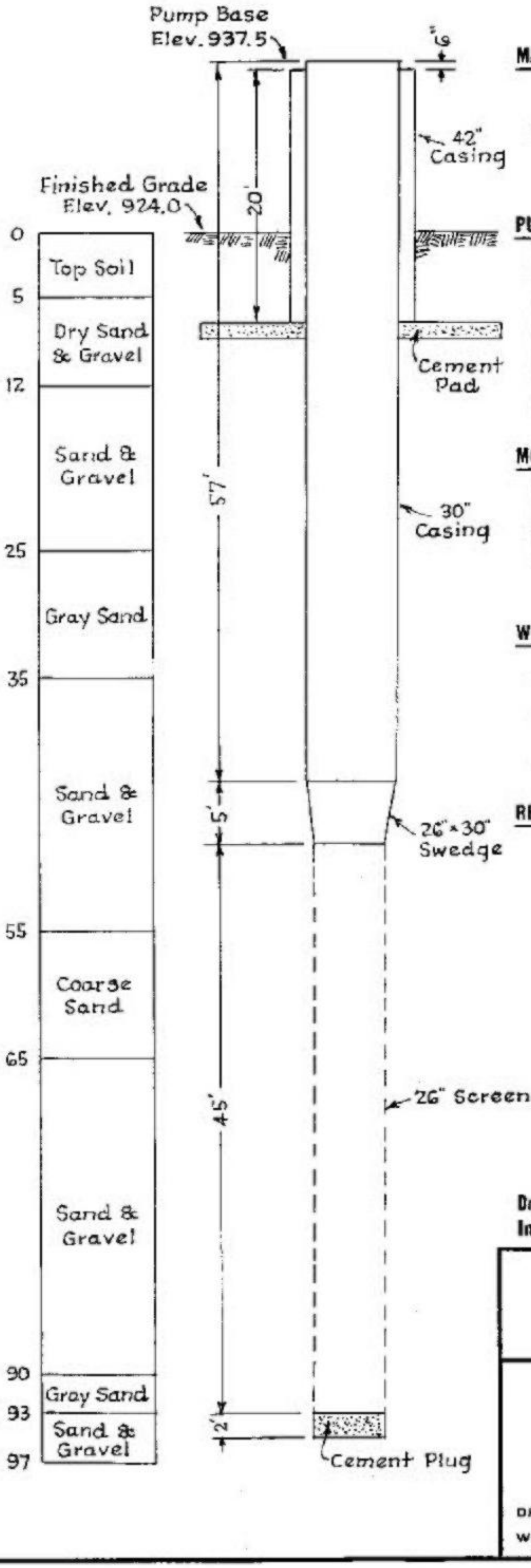
Air Line 82' Long.
Used 40T. of Pea Gravel
Around Screen.

Driller: Toledo Rogers
Installer: Chas. Webb

THE LAYNE-OHIO CO.,
WATER SUPPLY CONTRACTORS
COLUMBUS OHIO

CITY OF SPRINGFIELD
SPRINGFIELD, OHIO

DRAWN BY O. L. Mc APPROVED BY
WELL NO. 2 DRAWING NO. 1352



MATERIAL:

Pit: 20' of 42"×3/8" Steel Casing, 57' of 30"×3/8" Steel Casing & 5' of 26"×30" Swedge.

Screen: 45' of 26" Stainless Steel Screen.

Cone: 26"×2' Steel Shoe with Cement Plug.

PUMP:

No.	36871	**Shop No.**	36871
Type	T. H. C.	**Size**	14"
Setting	70'	**Stages**	1
Suction	12"×10'	**Impellers**	Bronze
Discharge	12"	**Head**	
Tubing	2½"	**Press. B. P.**	
Shafting	1½"		

MOTOR:

Make	Westinghouse	**Type**	
Volts	440	**Cycle**	60
Phase	3	**Amp.**	
H. P.	75	**R. P. M.**	1760
Frame	445-P	**Serial**	4262 V-121

WELL:

Capacity	3000 G.P.M.	**Static Level**	20'
Guarantee	2800 G.P.M.	**P. Level**	28'-4"
Started	9-19-57	**Pressure**	
Finished	9-30-57	**Pumped**	3000 G.P.M.
Accepted		**Depth**	107'

REMARKS:

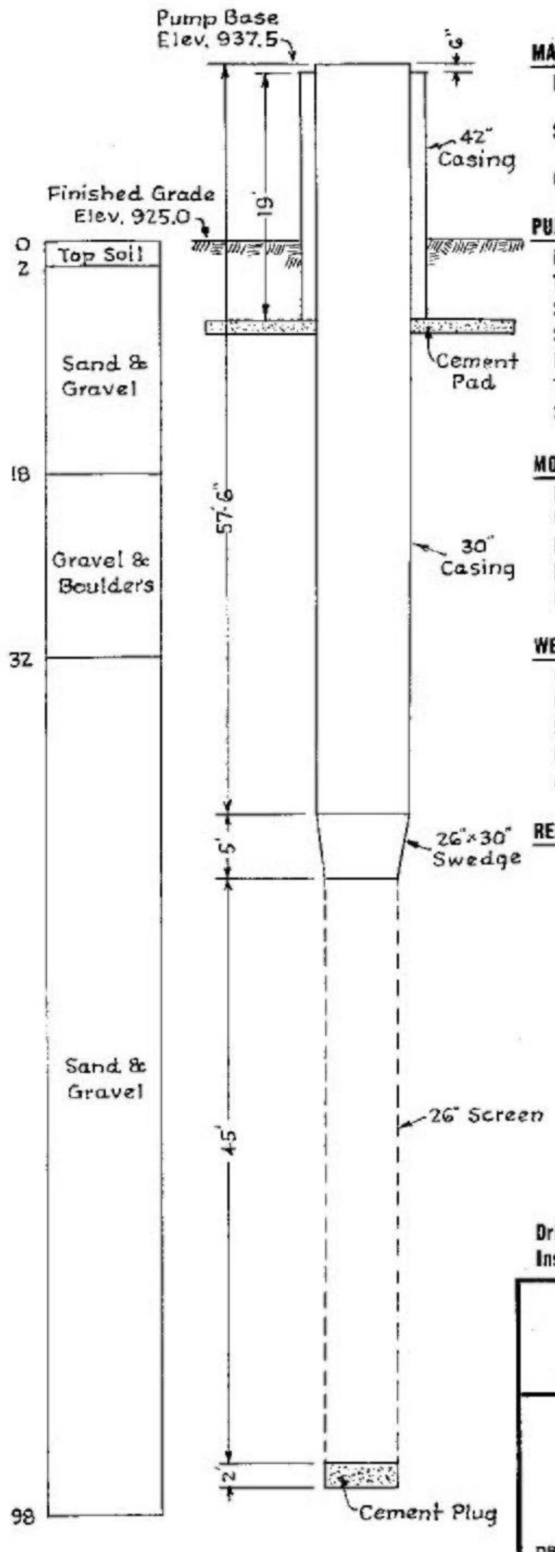
Air Line 82' Long.
Used 45 Tons of Pea Gravel Around Screen.

Driller: Toledo Rogers
Installer: Chas. Webb

THE LAYNE-OHIO CO.
WATER SUPPLY CONTRACTORS
COLUMBUS OHIO

CITY OF SPRINGFIELD
SPRINGFIELD, OHIO

DRAWN BY O. L. Mc — APPROVED BY
WELL NO. 3 — DRAWING NO. 1353



MATERIAL:

Pit: 19' of 42"×3/8" Steel Casing, 57'-6" of 30"×3/8" Steel Casing & 5' of 26"×30" Swedge.

Screen: 45' of 26" Stainless Steel Screen.

Cone: 26"×2' Steel Shoe with Cement Plug.

PUMP:

No.	36878	**Shop No.**	36878
Type	T.H.C.	**Size**	14"
Setting	70'	**Stages**	1
Suction	12"×10'	**Impellers**	Bronze
Discharge	12"	**Head**	
Tubing	2½"	**Press. B. P.**	
Shafting	1½"		

MOTOR:

Make	Westinghouse	**Type**	
Volts	440	**Cycle**	60
Phase	3	**Amp.**	
H. P.	75	**R. P. M.**	1760
Frame	445-P	**Serial**	4362 V-121

WELL:

Capacity	3000 G.P.M.	**Static Level**	20'
Guarantee	2800 G.P.M.	**P. Level**	28'-5"
Started	9-19-57	**Pressure**	
Finished	10-11-57	**Pumped**	3000 G.P.M.
Accepted		**Depth**	107'-6"

REMARKS:

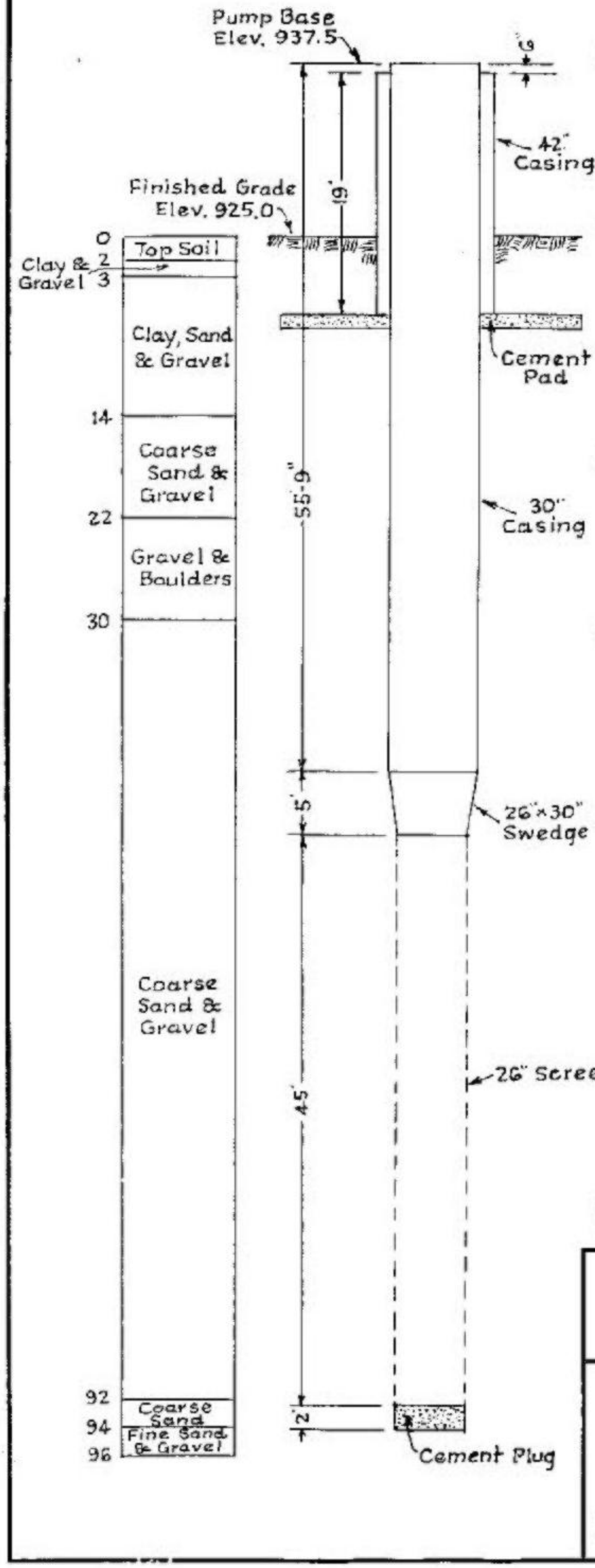
Air Line 82' Long.
Used 50 Tons of Pea Gravel Around Screen.

Driller: Toledo Rogers
Installer: Chas. Webb

THE LAYNE-OHIO CO.
WATER SUPPLY CONTRACTORS
COLUMBUS OHIO

CITY OF SPRINGFIELD
SPRINGFIELD, OHIO

DRAWN BY	O. L. M[c]	APPROVED BY	
WELL NO.	4	DRAWING NO.	1354



MATERIAL:

Pit: 19' of 42"×3/8" Steel Casing, 55'-9" of 30"×3/8" Steel Casing & 5' of 26"×30" Swedge.

Screen: 45' of 26" Stainless Steel Screen.

Cone: 26"×2' Steel Shoe with Cement Plug.

PUMP:

No.	36870	**Shop No.**	36870
Type	T. H. C.	**Size**	14"
Setting	70'	**Stages**	1
Suction	12"×10'	**Impellers**	Bronze
Discharge	12"	**Head**	
Tubing	2½"	**Press. B. P.**	
Shafting	1½"		

MOTOR:

Make	Westinghouse	**Type**	
Volts	440	**Cycle**	60
Phase	3	**Amp.**	
H. P.	75	**R. P. M.**	1760
Frame	445-P	**Serial**	3762 V-121

WELL:

Capacity	3000 G.P.M.	**Static Level**	19'-8"
Guarantee	2800 G.P.M.	**P. Level**	29'-10"
Started	5-9-57	**Pressure**	
Finished	6-1-57	**Pumped**	3000 G.P.M.
Accepted		**Depth**	105'-9"

REMARKS:

Air Line 82' Long.

Used 40 Tons of Pea Gravel Around Screen.

Driller: Reuben Sawyer

Installer: Chas. Webb

THE LAYNE-OHIO CO.

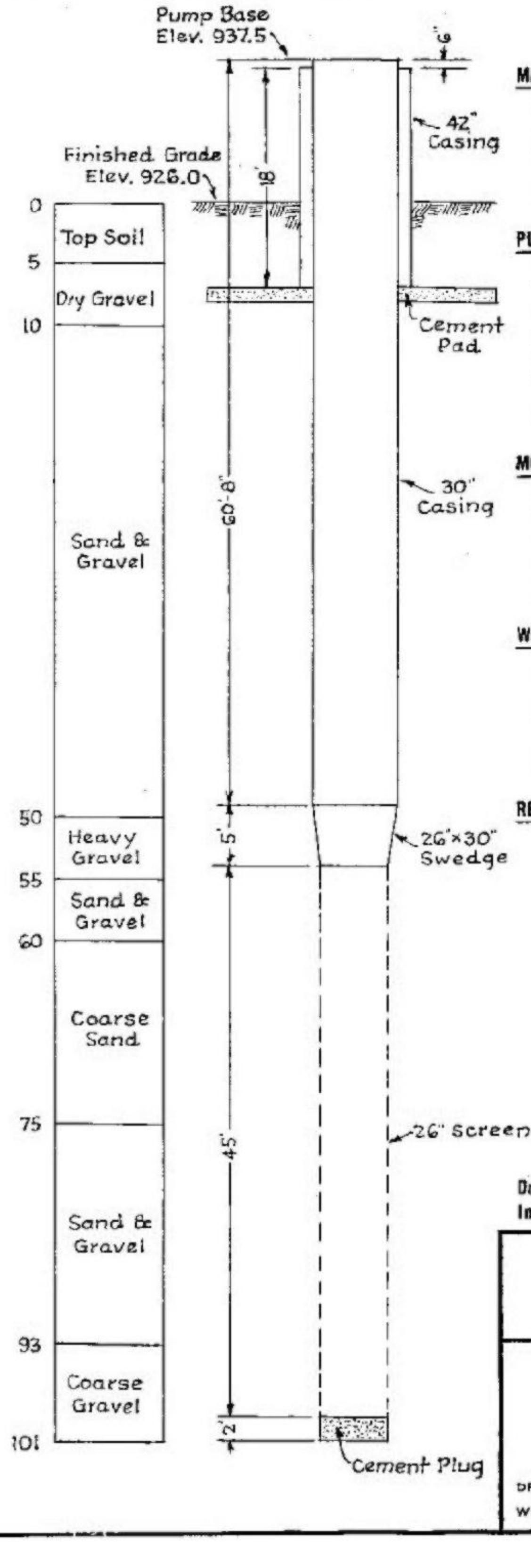
WATER SUPPLY CONTRACTORS

COLUMBUS OHIO

CITY OF SPRINGFIELD

SPRINGFIELD, OHIO

DRAWN BY	O. L. Mc.	APPROVED BY	
WELL NO.	5	DRAWING NO.	1355



MATERIAL:

Pit: 18' of 42"×3/8" Steel Casing, 60'-8" of 30"×3/8" Steel Casing & 5' of 26"×30" Swedge.

Screen: 45' of 26" Stainless Steel Screen.

Cone: 26"×2' Steel Shoe with Cement Plug.

PUMP:

No.	36877	**Shop No.**	36877
Type	T. H. C.	**Size**	14"
Setting	70'	**Stages**	1
Suction	12"×10'	**Impellers**	Bronze
Discharge	12"	**Head**	
Tubing	2½"	**Press. B. P.**	
Shafting	1½"		

MOTOR:

Make	Westinghouse	**Type**	
Volts	440	**Cycle**	60
Phase	3	**Amp.**	
H. P.	75	**R. P. M.**	1760
Frame	445-P	**Serial**	

WELL:

Capacity	3000 G.P.M.	**Static Level**	20'-2"
Guarantee	2800 G.P.M.	**P. Level**	30'-8"
Started	4-19-57	**Pressure**	
Finished	4-29-57	**Pumped**	3000 G.P.M.
Accepted		**Depth**	110'-8"

REMARKS:

Air Line 82' Long.

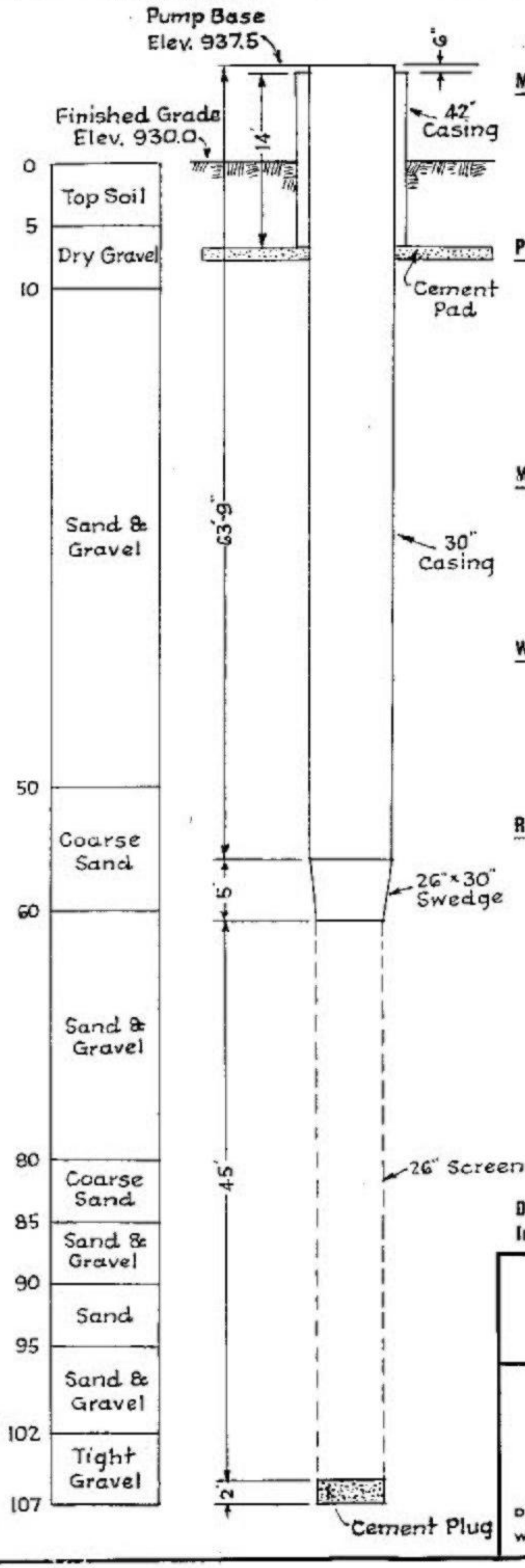
Used 40 Tons of Pea Gravel Around Screen.

Driller: Toledo Rogers
Installer: Elmer Hurles, Jr.

THE LAYNE-OHIO CO.
WATER SUPPLY CONTRACTORS
COLUMBUS OHIO

CITY OF SPRINGFIELD
SPRINGFIELD, OHIO

DRAWN BY	O. L. Mc	APPROVED BY	
WELL NO.	6	DRAWING NO.	1356



MATERIAL:

Pit: 14' of 42"×3/8" Steel Casing, 63'-9" of 30"×3/8" Steel Casing & 5' of 26"×30" Swedge.

Screen: 45' of 26" Stainless Steel Screen.

Cone: 26"×2' Steel Shoe with Cement Plug.

PUMP:

No.	36872	Shop No.	36872
Type	T.H.C.	Size	14"
Setting	70'	Stages	1
Suction	12"×10'	Impellers	Bronze
Discharge	12"	Head	
Tubing	2½"	Press. B. P.	
Shafting	1½"		

MOTOR:

Make	Westinghouse	Type	
Volts	440	Cycle	60
Phase	3	Amp.	
H. P.	75	R. P. M.	1760
Frame	445-P	Serial	

WELL:

Capacity	3000 G.P.M.	Static Level	19'-10"
Guarantee	2800 G.P.M.	P. Level	38'-9"
Started	3-22-57	Pressure	
Finished	4-6-58	Pumped	3000 G.P.M.
Accepted		Depth	113'-9"

REMARKS:

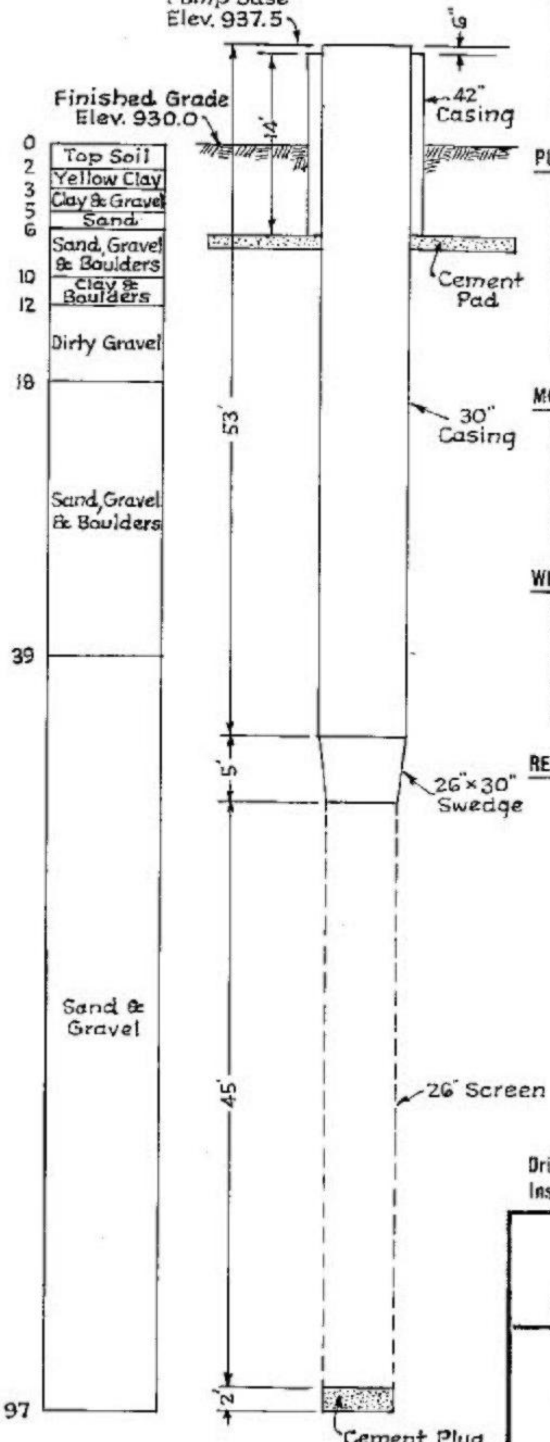
Air Line 82' Long.
Used 50 Tons of Pea Gravel Around Screen.

Driller: Toledo Rogers
Installer: Elmer Hurles, Jr.

THE LAYNE-OHIO CO.
WATER SUPPLY CONTRACTORS
COLUMBUS OHIO

CITY OF SPRINGFIELD
SPRINGFIELD, OHIO

DRAWN BY O. L. Mc   APPROVED BY
WELL NO. 7   DRAWING NO. 1357



MATERIAL:

Pit: 14' of 42"×3/8" Steel Casing, 53' of 30"×3/8" Steel Casing & 5' of 26"×30" Swedge.

Screen: 45' of 26" Stainless Steel Screen.

Cone: 26"×2' Steel Shoe with Cement Plug.

PUMP:

No.	36875	Shop No.	36875
Type	T.H.C.	Size	14"
Setting	70'	Stages	1
Suction	12"×10'	Impellers	Bronze
Discharge	12"	Head	
Tubing	2½"	Press. B. P.	
Shafting	1½"		

MOTOR:

Make	Westinghouse	Type	
Volts	440	Cycle	60
Phase	3	Amp.	
H. P.	75	R. P. M.	1760
Frame	445-P	Serial	

WELL:

Capacity	3000 G.P.M.	Static Level	19'-9"
Guarantee	2800 G.P.M.	P. Level	
Started	4-10-57	Pressure	
Finished	5-9-57	Pumped	3000 G.P.M.
Accepted		Depth	103'

REMARKS:

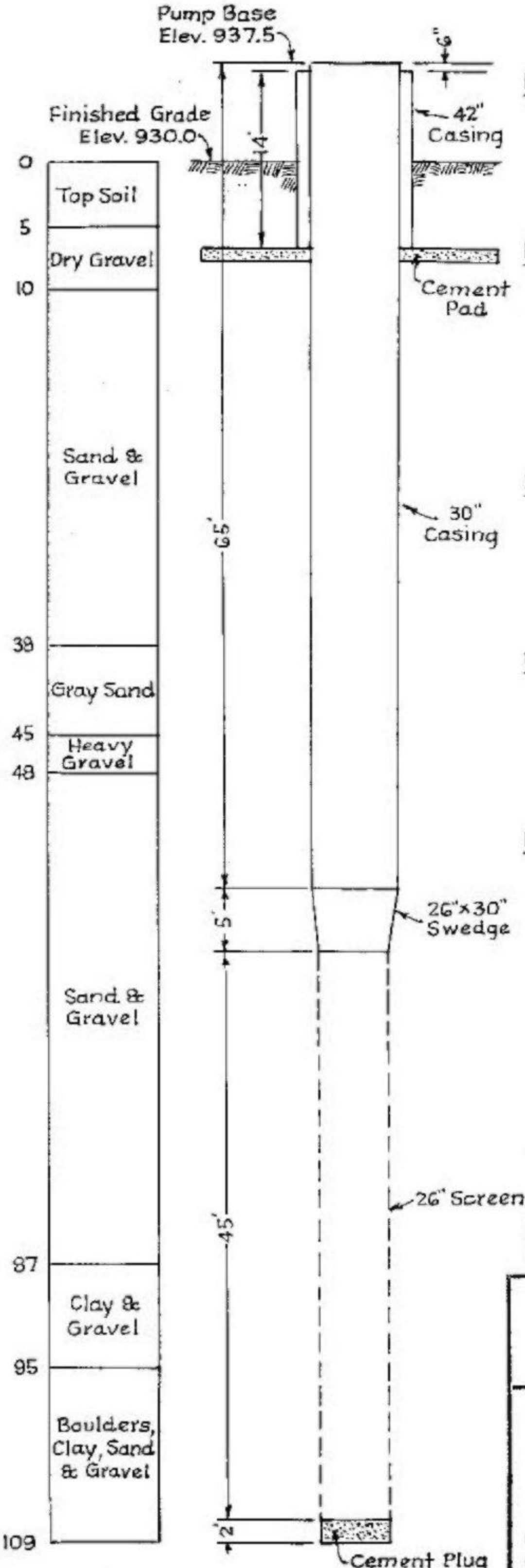
Air Line 82' Long.
Used 85 Tons of Pea Gravel Around Screen.

Driller: Reuben Sawyers
Installer: Elmer Hurles, Jr.

THE LAYNE-OHIO CO.,
WATER SUPPLY CONTRACTORS
COLUMBUS OHIO

CITY OF SPRINGFIELD
SPRINGFIELD, OHIO

DRAWN BY	O. L. McC	APPROVED BY	
WELL NO.	8	DRAWING NO.	1358



MATERIAL:

Pit: 14' of 42"×3/8" Steel Casing, 65' of 30"×3/8" Steel Casing & 5' of 26"×30" Swedge.

Screen: 45' of 26" Stainless Steel Screen.

Cone: 26"×2' Steel Shoe with Cement Plug.

PUMP:

No.	36873	Shop No.	36873
Type	T.H.C.	Size	14"
Setting	70'	Stages	1
Suction	12"×10'	Impellers	
Discharge	12"	Head	
Tubing	2½"	Press. B. P.	
Shafting	1½"		

MOTOR:

Make	Westinghouse	Type	
Volts	440	Cycle	60
Phase	3	Amp.	
H. P.	75	R. P. M.	1760
Frame	445-P	Serial	

WELL:

Capacity	3000 G.P.M.	Static Level	19'-4"
Guarantee	2800 G.P.M.	P. Level	28'-8"
Started	5-9-57	Pressure	
Finished	5-18-57	Pumped	3000 G.P.M.
Accepted		Depth	115'

REMARKS:

Air Line 82' Long.

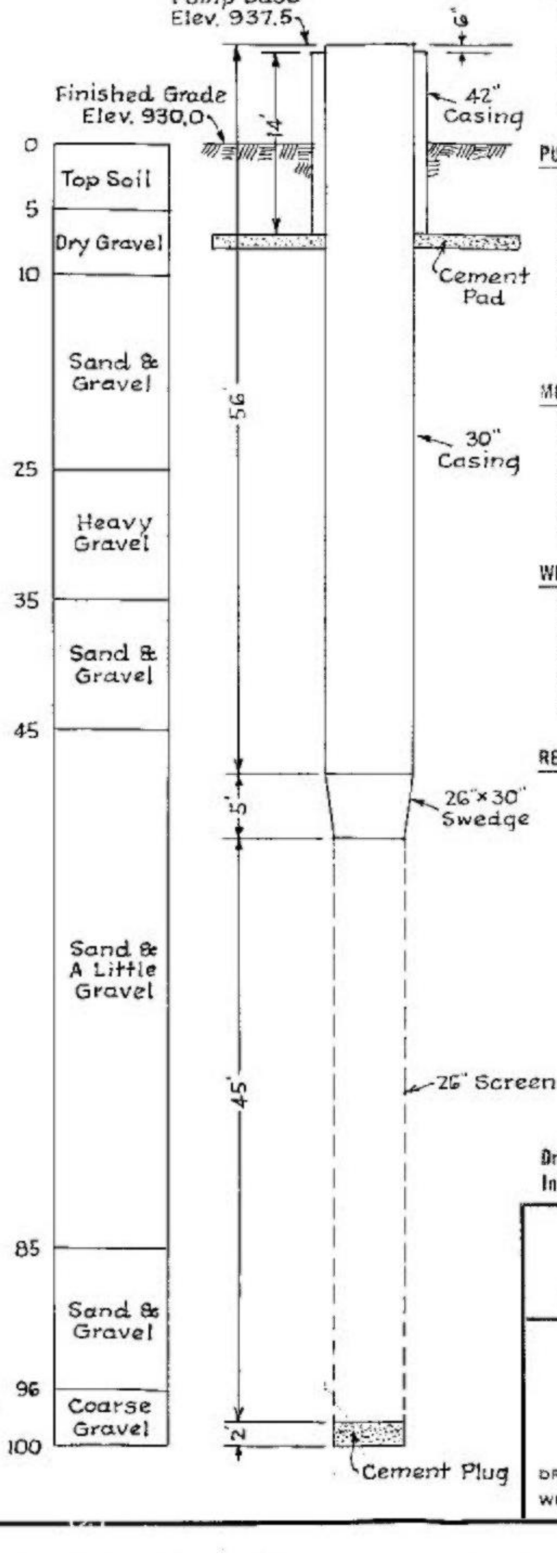
Used 40 Tons of Pea Gravel Around Screen.

Driller: Toledo Rogers
Installer: Elmer Hurles, Jr.

THE LAYNE-OHIO CO.
WATER SUPPLY CONTRACTORS
COLUMBUS OHIO

CITY OF SPRINGFIELD
SPRINGFIELD, OHIO

DRAWN BY O. L. Mc. APPROVED BY
WELL NO. 9 DRAWING NO. 1359



MATERIAL:

Pit: 14' of 42"×3/8" Steel Casing, 56' of 30"×3/8" Steel Casing & 5' of 26"×30" Swedge.

Screen: 45' of 26" Stainless Steel Screen.

Cone: 26"× 2' Steel Shoe with Cement Plug

PUMP:

No.	36874	Shop No.	36874
Type	T.H.C.	Size	14"
Setting	70'	Stages	1
Suction	12"× 10'	Impellers	Bronze
Discharge	12"	Head	
Tubing	2½"	Press. B. P.	
Shafting	1½"		

MOTOR:

Make	Westinghouse	Type	
Volts	440	Cycle	60
Phase	3	Amp.	
H. P.	75	R. P. M.	1760
Frame	445-P	Serial	

WELL:

Capacity	3000 G.P.M.	Static Level	18'-10"
Guarantee	2800 G.P.M.	P. Level	30'-4"
Started	4-30-57	Pressure	
Finished	5-8-57	Pumped	3000 G.P.M.
Accepted		Depth	106'

REMARKS:

Air Line 82' Long.
Used 43 Tons of Pea Gravel Around Screen.

Driller: Toledo Rogers
Installer: Elmer Hurles, Jr.

THE LAYNE-OHIO CO.
WATER SUPPLY CONTRACTORS
COLUMBUS OHIO

CITY OF SPRINGFIELD
SPRINGFIELD, OHIO

DRAWN BY O. L. McE. APPROVED BY
WELL NO. 10 DRAWING NO. 1360

.IF 7802.93
USE OR USE PEN
IF TRANSCRIBING
PRESS HARD

WELL LOG AND DRILLING REPORT

788726

Ohio Department of Natural Resources, Divison of Water
1939 Fountain Square Drive, Columbus, Ohio 43224 Phone (614) 265-6739

Permit Number________

COUNTY CLARK TOWNSHIP GERMAN SECTION/LOT No. 2 (CIRCLE ONE)

OWNER/BUILDER (CIRCLE ONE OR BOTH) CITY OF SPRINGFIELD, OHIO PROPERTY ADDRESS 201 EAGLE CITY ROAD (ADDRESS OF WELL LOCATION A)

LOCATION OF PROPERTY WEST OF U.S. ROUTE # 68 AND NORTH OF EAGLE CITY ROAD

CONSTRUCTION DETAILS

CASING Borehole Diameter 48 in.

1 Diameter 42 in. Length 62 ft. Wall Thickness .375 in.

2 Diameter 30 in. Length 62 ft. Wall Thickness .375 in.

Type: ☒ Steel ☐ Galv. ☐ PVC ☐ Other ____

Joints: ☐ Threaded ☒ Welded ☐ Solvent ☐ Other ____

Liner: Length ____ Type ____ Wall Thickness ____ in.

SCREEN

Type (wire wrapped, louvered, etc.) wire wrapped Material 304 SS

Length 45 ft. Diameter 30 in.

Set between 107 ft. and 62 ft. Slot 125

GROUT

Material Class I Portland Cement Volume used 65 cu. feet

Method of installation Tremie Pipe

Depth: placed from 50 ft. to 7

GRAVEL PACK (Filter Pack)

Material 1/8 x 1/4 quartz Volume used 14 cu. yds

Method of installation Poured

Depth: placed from 107 ft. to 57

Pitless Device ☐ Adapter ☐ Preassembled unit

Use of Well Potable Supply

☐ Rotary ☒ Cable ☐ Augered ☐ Driven ☐ Dug ☐ Other ____

Date of Completion October 11, 1994

WELL LOG*

INDICATE DEPTH(S) AT WHICH WATER IS ENCOUNTERED. #11 well

Show color, texture, hardness, and formation: sandstone, shale, limestone, gravel, clay, sand, etc.	From	To
Gravel and Clay	0'	10'
Gravel, Clay and Sand	10'	15'
Large Gravel, Clay and Sand	15'	20'
Large Gravel, Sand and Clay	20'	25'
Gravel, Sand and Clay	25'	30'
" " "	30'	35'
" " "	35'	40'
" " " Some large gravel	40'	47'
Gravel, Sand and Clay	47'	53'
Sand, Gravel and Clay, Medium Sand	53'	61'
Sand, Gravel & Clay Layers of Fine Sand	61'	66'
Sand, Gravel and Clay	66'	71'
Sand, Gravel & Clay-Some Coarse	71'	76'
Sand, Gravel and Clay	76'	81'
Sand, Gravel and Clay Some large stone	81'	88'
Sand, Gravel & Clay-Some fine sand	88'	94'
Gravel, Sand and Clay	94'	99'
Gravel, Sand and Clay	99'	104'
Gravel, Sand & Clay - Large rocks starting at 107 feet	104'	109'

If additional space is needed to complete well log, use next consecutively numbered form.

WELL TEST

☐ Bailing ☒ Pumping* ☐ Other ____

Test rate 3500 gpm Duration of test 24 h

Drawdown 12.56

Measured from: ☒ top of casing ☐ ground level ☐ Other ____

Static Level (depth to water) 16.25 ft. Date: ____

Quality (clear, cloudy, taste, odor) clear

*(Attach a copy of the pumping test record, per section 1521.05, ORC)

PUMP

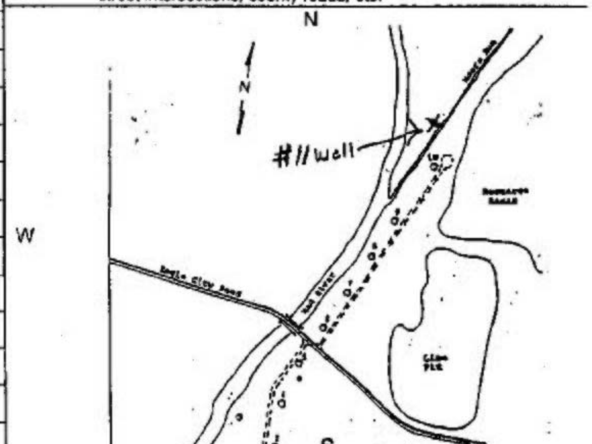
Type of pump ____ Capacity ____ gpm

Pump set at ____

Pump installed by ____

SKETCH SHOWING WELL LOCATION

Show distances well lies from numbered state highways, street intersections, county roads, etc.



I hereby certify the information given is accurate and correct to the best of my knowledge.

Drilling Firm The Ohio Drilling Company

Address P.O. Box 710

City, State, Zip Massillon, Ohio 44648

Signed Michael D. Berg

Date October 24, 1994

ODH Registration Number ____

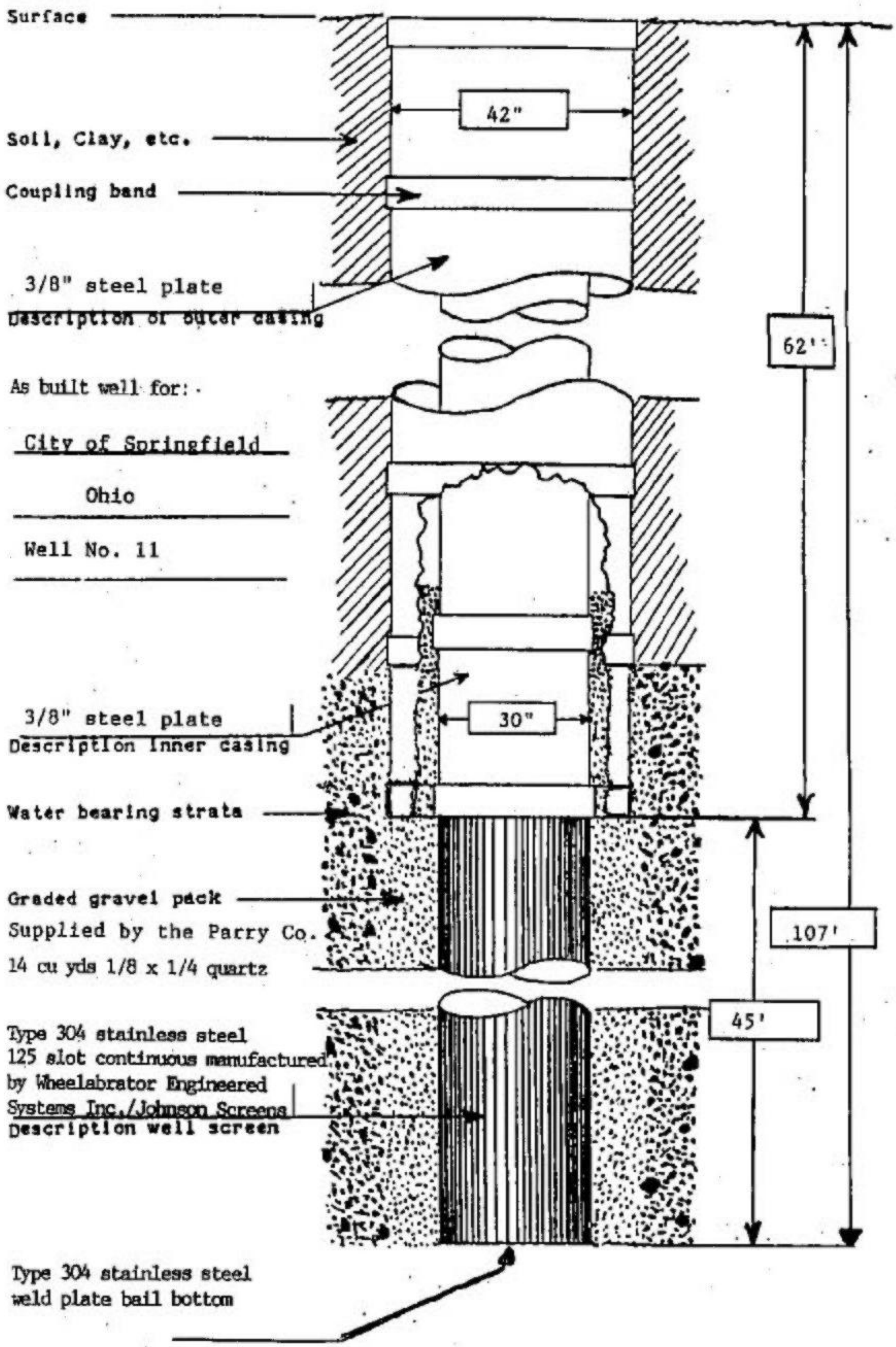
Completion of this form is required by section 1521.05, Ohio Revised Code. File within 30 days after completion of drilling.

THE OHIO DRILLING COMPANY

MASSILLON, OHIO

CITY OF SPRINGFIELD, OHIO

CONTRACT 2A WELL #11



DNR 7802.93
TYPE OR USE PEN
SELF TRANSCRIBING
PRESS HARD

WELL LOG AND DRILLING REPORT

Ohio Department of Natural Resources, Divison of Water
1939 Fountain Square Drive, Columbus, Ohio 43224 Phone (614) 265-6739

7881 ~~30~~

Permit Number

COUNTY CLARK TOWNSHIP GERMAN SECTION/LOT No. 2 (CIRCLE ONE)

OWNER/BUILDER (CIRCLE ONE OR BOTH) CITY OF SPRINGFIELD, OHIO PROPERTY ADDRESS 201 EAGLE CITY ROAD (ADDRESS OF WELL LOCATION A)

LOCATION OF PROPERTY WEST OF U.S. ROUTE #68 AND SOUTH OF EAGLE CITY ROAD

CONSTRUCTION DETAILS

CASING Borehole Diameter 48 in.
1 Diameter 42 in. Length ___ ft. Wall Thickness .375 in.
2 Diameter 30 in. Length ___ ft. Wall Thickness .375 in.
Type: 1 2 Steel 1 2 Galv. 1 2 PVC 1 2 Other
Joints: 1 2 Threaded 1 2 Welded 1 2 Solvent 1 2 Other
Liner: Length ___ Type ___ Wall Thickness ___ in.

SCREEN
Type (wire wrapped, louvered, etc.) wire wrapped Material 304 SS
Length 45 ft. Diameter 30 in.
Set between 106 ft. and 61 ft. Slot .200

GROUT
Material Class 1 Portland Cement Volume used 65 cu. feet
Method of installation Tremie Pipe
Depth: placed from 50 ft. to 7 ft.

GRAVEL PACK (Filter Pack)
Material 3/8 x 3/16 quartz Volume used 14 cu. yds
Method of installation Poured
Depth: placed from 106 ft. to 56 ft.

Pitless Device ☐ Adapter ☐ Preassembled unit
Use of Well Potable Supply
☐ Rotary ☐ Cable ☐ Augered ☐ Driven ☐ Dug ☐ Other
Date of Completion December 12, 1994

WELL LOG*

INDICATE DEPTH(S) AT WHICH WATER IS ENCOUNTERED.
Show color, texture, hardness, and formation: sandstone, shale, limestone, gravel, clay, sand, etc.

	From	To
Large Gravel and Clay	0'	10'
Large Gravel, Clay and Sand	10'	15'
Large Gravel, Sand and Clay	15'	20'
Boulders - Gravel and Clay	20'	25'
Large Gravel, Some Sand	25'	30'
Large Gravel and Sand	30'	35'
Gravel, large Gravel, Sand & Clay	35'	40'
Large Gravel, Gravel Sand and Clay	40'	52'
Gravel, Sand and Clay, Some Large Gravel	52'	59'
Gravel, Sand and Clay	59'	64'
Gravel, Sand and Clay	64'	69'
Coarse Sand, Some Gravel & Clay	69'	76'
Gravel, Coarse Sand and Clay	76'	82'
Gravel, Coarse Sand and Clay, Some Large Gravel	82'	87'
Gravel, Coarse Sand and Clay	87'	92'
Some Large Gravel, Coarse Sand and Clay	92'	96'
Gravel, Coarse Sand and Clay	96'	101'
Coarse Sand, Gravel, Some Clay Layers (thin)	101'	106'
Coarse Sand, Gravel, Some Clay Layers	106'	108' 6"

*If additional space is needed to complete well log, use next consecutively numbered form.

WELL TEST

☐ Bailing ☒ Pumping* ☐ Other
Test rate 4000 gpm Duration of test 24 hrs.
Drawdown 12.43 ft.
Measured from: ☒ top of casing ☐ ground level ☐ Other
Static Level (depth to water) 18.97 ft. Date: 1/12/95
Quality (clear, cloudy, taste, odor) clear

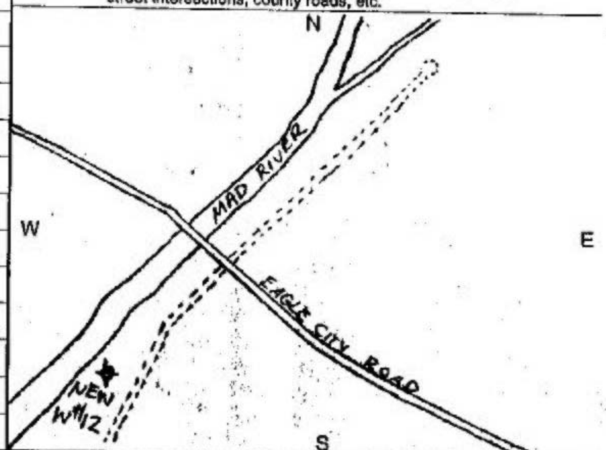
*(Attach a copy of the pumping test record, per section 1521.05, ORC)

PUMP

Type of pump ___ Capacity ___ gpm
Pump set at ___ ft.
Pump installed by ___

SKETCH SHOWING WELL LOCATION

Show distances well lies from numbered state highways, street intersections, county roads, etc.



I hereby certify the information given is accurate and correct to the best of my knowledge.

Drilling Firm The Ohio Drilling Company
Signed Thomas J. Perkins
Address P.O. Box 710
Date 2/15/95
City, State, Zip Massillon, Ohio 44648
ODH Registration Number

Completion of this form is required by section 1521.05, Ohio Revised Code - file within 30 days after completion of drilling.

ORIGINAL COPY TO - ODNR, DIVISION OF WATER, 1939 FOUNTAIN SQ. DRIVE, COLS., OHIO 43224

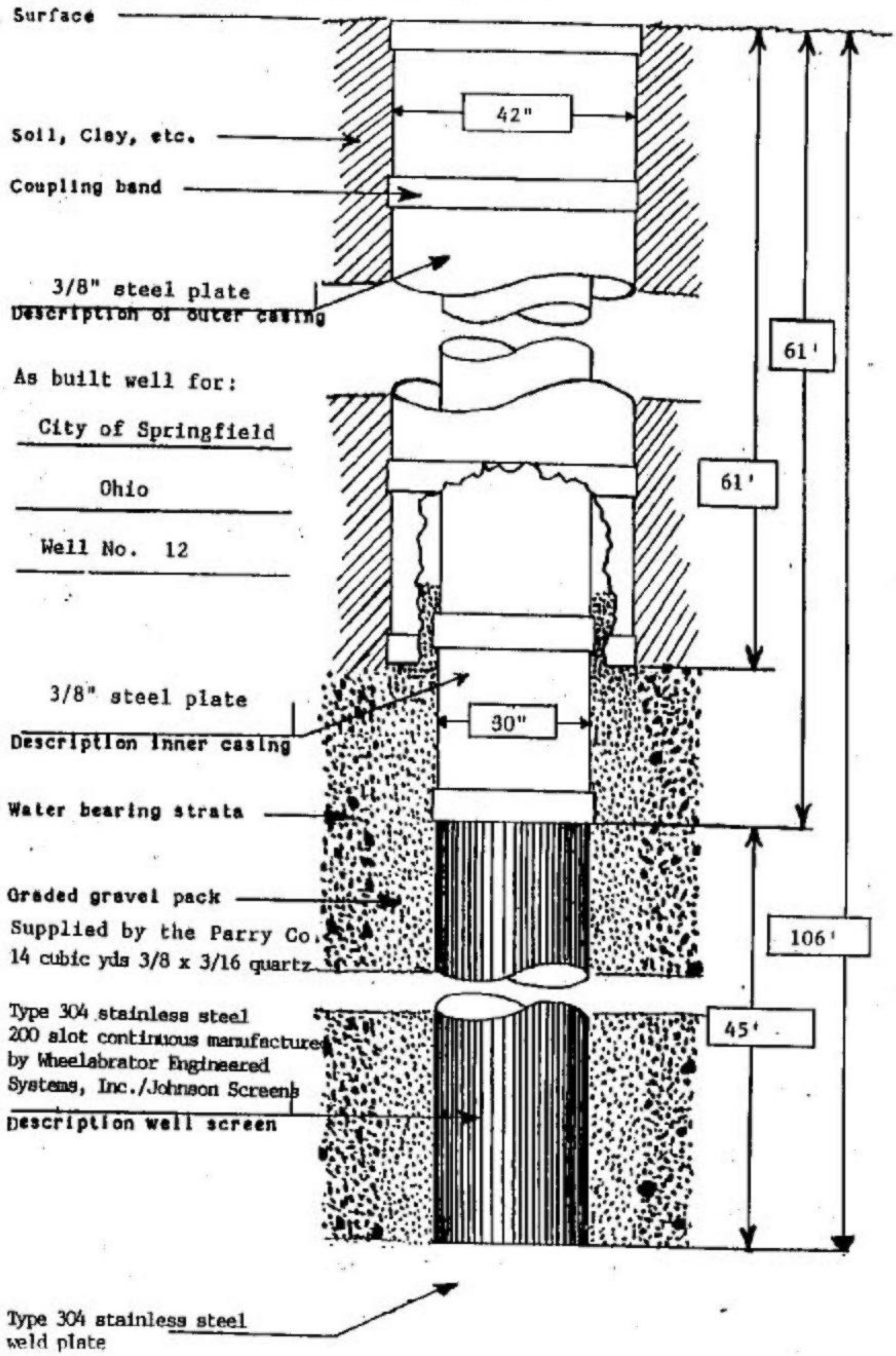
Blue - Customer's copy Pink - Driller's copy Green - Local Health Dept. copy

THE OHIO DRILLING COMPANY

MASSILLON, OHIO

CITY OF SPRINGFIELD, OHIO

CONTRACT 2A WELL #12



WELL LOG AND DRILLING REPORT

CUSTOMER'S COPY

State of Ohio
DEPARTMENT OF NATURAL RESOURCES
Division of Water
1562 W. First Avenue
Columbus, Ohio

PLEASE USE PENCIL OR TYPEWRITER. DO NOT USE INK.

CL-7 73

No. 252008

County: Clark. Township: ______ Section of Township: ______

Owner: Dept of Nat. Resources (Water Div.) Address: Columbus O.

Location of property: Springfield Ohio water works.

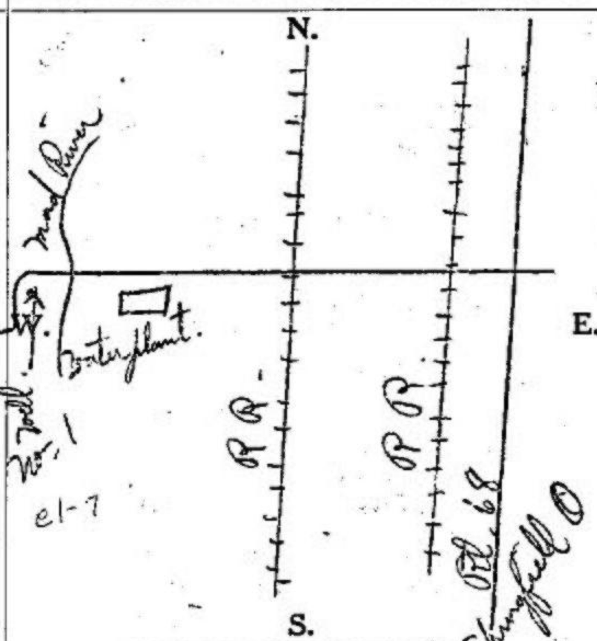
CONSTRUCTION DETAILS	BAILING OR PUMPING TEST
Casing diameter: 6" ID Length of casing: 50'	Pumping rate: ______ G.P.M. Duration of test: 6 hrs.
Type of screen: Slotted pipe Length of screen: 10'	Drawdown: 10 ft. Date: 9/4/60
Type of pump: None.	Developed capacity: 1200 GPH
Capacity of pump:	Static level—depth to water: 23 ft.
Depth of pump setting:	Pump installed by:
Date of completion:	

WELL LOG

Formations Sandstone, shale, limestone, gravel and clay	From	To
Loam & clay	0 Feet	5 Ft.
Clay & gravel	5	12
Gravel.	12	21
Sand & gravel.	21	29
Sand & gravel (water)	29	50

SKETCH SHOWING LOCATION

Locate in reference to numbered State Highways, St. Intersections, County roads, etc.



See reverse side for instructions

Drilling Firm: Don Weaver. Date: 9/9/60

Address: Xenia O. Signed: Don Weaver.

GAMMA RAY LOG

COUNTY *Clark*

WELL *CL-7*

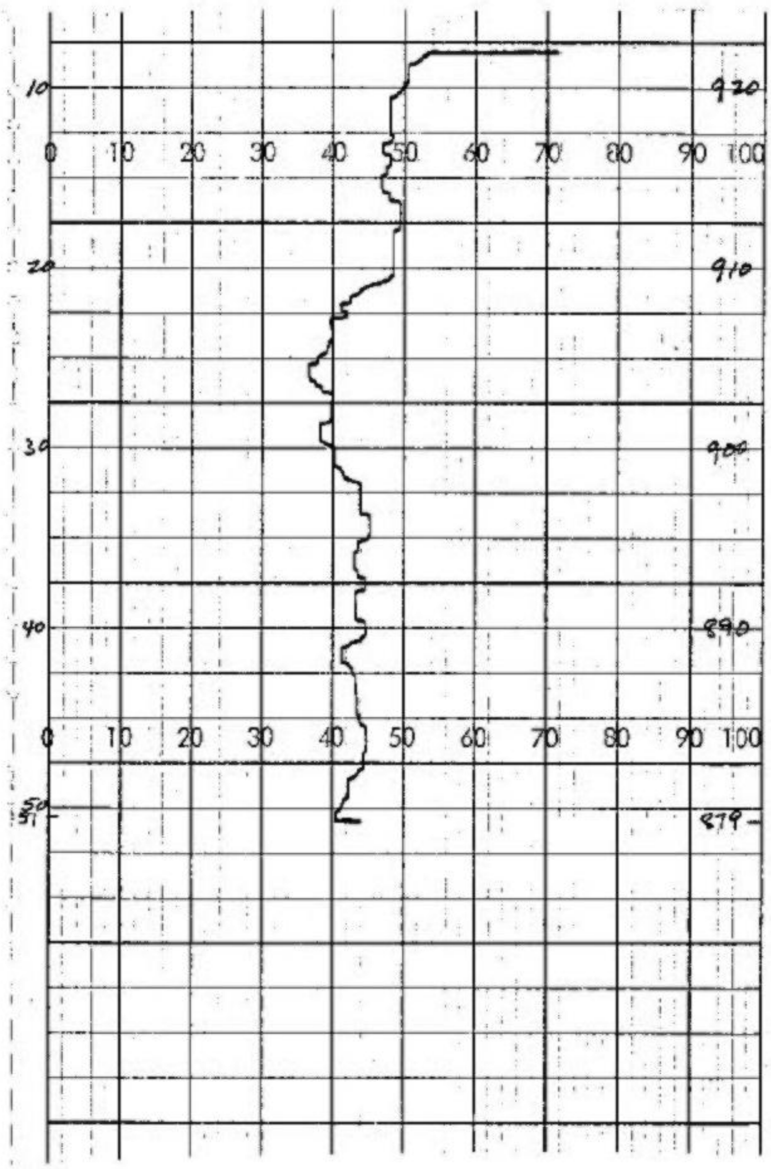
LOCATION *NW of Springfield near Eagle City*

LOGGED BY [illegible] DATE *9-20-66*

SCALE *.005* TIME CONSTANT *16*

DEPTH TO WATER

LENGTH OF CASING



APPENDIX C

SWTP HISTORIC SANDPOINT WATER LEVELS (1960 – 2000)

1960's Sandpoint Gauging Data												
	1	2	3	4	6	7	8	9	12	16	23	cl-7
07/09/60	8.83	12.16				23.58		23			21	
07/11/60	11.91	12.16				24.83		22.83			16.5	
07/12/60	10.5	12.25				24.83		22.91			17.66	
07/13/60	12.66	15				24.83		22.83			19.16	
07/14/60	12.75	12				24.91		22.83			18.58	
07/15/60		12				24.91		23			19.33	
07/19/60		12.16				24.5		22.83			19.12	
07/20/60		15.5				24.91		22.66			19.58	
07/22/60		15				24.91		22.66			19.58	
07/25/60		12.16				25.5		22.91			19.66	
08/02/60		15.5						23.25			20.33	
08/08/60		15.1						25.16			20.16	
08/15/60		15.16						25.83			20.12	
08/29/60		15.33						dry			20.33	
09/06/60		15.66						dry			20.58	
09/13/60	14.83	15.83	19.5	25.83	24	28	29	27.92	24.83	26.12	20.92	
09/30/60	15.48	18.15	16.32	26.04	24.68		29.77		25.63	26.24	22	26.29
10/03/60	15.53	17.23	19.95	26.12	24.82	28.55	29.04	27.97	25.66	25.82	21.96	
10/10/60	15.70	17.44	20.10	26.47	25.10	28.89	29.82	29.05	25.70	25.90	20.93	26.35
10/17/60	15.81	17.67	20.21	26.87	25.36	29.17	30.00	28.77	25.80	26.36	21.97	26.50
10/27/60	16.02	18.09	20.47	27.03	25.75	29.37	29.79	28.40	26.24	26.72	22.48	26.96
11/03/60	16.17	18.26	20.68	27.03	25.97	29.39	29.54	28.20	26.62	27.38	22.95	27.30
11/14/60	16.47	18.49	20.91	27.11	26.34	29.54	29.34	27.68	27.16	26.79	23.52	27.77
11/20/60	16.47	18.50	20.94	27.15	26.35	29.56	29.33	27.73	27.19	26.99	23.57	27.86
11/22/60	16.66	18.57	21.03	27.21	26.59	28.95	29.79	28.48	27.21	27.81	23.38	27.86
11/28/60	16.73	18.66	21.09	27.42	26.73	30.20	30.24	29.01	27.12	27.26	23.30	27.82
12/07/60	16.79	18.88	21.19	27.72	mud	30.55	30.73	29.63	27.22	27.94	23.38	27.96
12/15/60	16.86	19.14	21.35	28.02	mud	30.81	31.12	29.99	27.38	28.46	23.54	28.16
12/30/60	17.04	19.49	21.72	28.49	mud	31.22	30.96	30.23	27.70	28.03	23.86	28.53
01/04/61	17.10	19.55	21.75	28.49	mud	31.01	30.96	29.46	28.06	28.00	24.32	28.83
01/13/61	16.55	16.62	20.79	26.79	mud	30.16	29.09	28.08	27.59	25.63	23.11	29.27
01/18/61	16.65	16.54	20.80	26.70	mud	30.20	28.91	28.09	27.75	25.58	23.15	29.39
01/24/61	16.74	16.73	20.84	26.87	mud	30.37	29.32	27.68	27.82	26.01	23.18	29.46
02/01/61	16.87	16.84	21.00	27.17	mud	30.81	29.70	28.93	28.03	26.65	23.37	29.71
02/06/61	16.96	16.94	21.07	27.19	mud	31.09	29.98	29.23	18.16	26.86	23.46	29.89
02/17/61	17.10	16.97	20.53	27.37	mud	31.52	30.39	29.69	28.35	27.26	23.58	30.13
02/22/61	16.91	17.05	21.05	27.47	mud	31.56	30.43	29.64	28.17	27.24	23.39	30.04
02/27/61	16.36	16.80	20.93	27.48	mud	31.94	31.41	dry	27.69	26.06	22.74	29.64

03/03/61	15.42	17.00	20.77	27.77	mud	31.66	dry	dry	27.03	26.16	22.98	29.15
03/06/61	14.55	16.71	19.63	27.54	mud	31.45	31.19	30.26	26.67	26.54	21.63	28.91
03/15/61	11.92	15.56	19.25	26.41	mud	broke	29.77	29.10	25.03	24.75	20.04	27.39
03/23/61	11.45	14.79	18.98	25.64	mud	28.67	28.66	22.91	24.37	23.81	19.58	26.58
03/30/61	10.63	14.34	18.78	25.09	mud	27.67	27.85	27.10	23.73	23.13	19.04	25.80
04/04/61	11.49	14.16	18.90	24.27		26.99	27.28	26.64	23.52	22.56	18.96	25.41
04/14/61	11.32	13.64	18.76	24.25		26.69	27.07	26.63	22.99	21.83	18.34	24.90
04/19/61	10.18	13.17	18.18	23.92		26.10	26.60	26.10	22.34	21.29	17.66	24.32
04/28/61	6.83	7.89	12.98	17.99		22.08	19.04	19.17	18.80	16.92	14.20	20.86
05/13/61	6.76	4.71	12.61	15.48		17.80	17.80	16.66	15.97	13.63	11.87	17.30
05/25/61	7.29	5.34	13.35	15.90		17.53	17.90	16.90	15.74	13.35	11.72	16.97
06/06/61	7.20	4.86	12.50	15.18		18.42	17.45	16.66	16.85	14.19	12.76	18.18
06/13/61	6.72	7.27	14.69	17.55		18.75	18.66	17.11	16.18	14.18	13.00	16.68
06/23/61	7.32	7.47	14.26	16.38		17.43	18.30	17.46	15.54	12.51	11.51	16.69
06/29/61	7.81	6.29	14.46	16.58		17.74	18.68	17.99	15.79	13.00	11.74	16.93
07/07/61	8.39	6.29	14.45	16.54		18.09	18.36	17.11	16.40	13.85	12.29	17.52
07/28/61	9.08	6.10	14.11	16.51		18.43	18.40	17.40	16.85	13.99	12.78	17.96
08/21/61	9.28	7.12	15.20		15.91	18.69		17.46	17.12	14.19	13.09	18.21
09/20/61	10.69	9.24	16.93		18.01	20.30		18.81	18.91	16.02	14.90	20.01
10/11/61	11.83	10.62	18.03	20.44	19.14	21.52	21.53	20.01	20.09	16.96	16.10	21.19
10/31/61	12.63	10.88	18.98	21.64	20.32	22.74	22.74	21.29	21.06	18.21	16.98	22.22
11/07/61	13.14	12.86	19.67	22.53	21.32	23.75	23.69	22.35	21.88	19.30	17.62	23.12
11/27/61	13.13	13.31	19.82	22.99	21.73	24.06	24.06	22.60	21.99	19.28	17.68	23.34
12/15/61	13.06	14.04	20.14	23.72	22.26	24.80	24.90	23.64	22.45	20.42	18.14	23.91
01/05/62	13.03	13.62	20.30	23.90		25.34	25.14	24.02	22.92	21.15	18.58	24.42
01/23/62	11.09	14.13	19.50	24.16	22.23	25.32	25.94	25.14	21.98	20.89	17.39	23.76
02/14/62	10.29	11.78	18.20	22.08	19.96	23.19	25.49	24.31	20.12	18.26	15.72	21.69
02/27/62	8.59	10.56	17.53	20.07	19.66	22.95	21.62	21.58	19.56	16.75	14.98	21.28
03/15/62	6.91	5.50	13.55	14.66	15.59	17.69	15.14	14.91	16.03	13.17	11.81	17.37
03/27/62	6.40	3.82	12.49	13.38	12.93	15.41	14.75	13.47	13.99	11.32	10.03	15.14
04/12/62	6.70	4.00	12.76	13.78	12.65	15.28	15.19	15.66	14.07	10.93	10.24	15.10
04/27/62	7.42	4.35	13.17	13.93	13.35	15.71	15.23	13.75	14.81	11.40	10.98	15.72
05/11/62	7.89	5.05	13.65	15.00	13.90	16.49	16.60	14.88	15.04	12.10	11.04	16.02
05/25/62	8.47	6.76	14.91	17.04	15.09	17.99	19.26	18.71	17.88	15.20	13.67	19.01
06/21/62	9.58	7.94	15.94	17.85	16.84	19.33	19.22	17.91	17.65	15.38	13.55	17.82
07/20/62	11.00	6.51	14.67	15.97	16.90	18.97	17.87	16.94	18.12	14.81	14.11	19.02
08/16/62	10.69	8.18	16.06	18.54	17.35	19.90	20.54	19.51	17.88	15.20	13.67	19.01
09/12/62	11.51	9.85	17.45	19.76	18.69	20.92	20.81	19.30	19.41	16.21	15.29	20.49
12/18/62	12.46	14.09	20.43	23.50	21.76	24.19	24.37	23.13	21.78	19.76	17.41	23.18
01/18/63	12.08	15.03	20.65	25.00	22.70	25.62	27.14	27.03	22.02	20.39	17.38	23.72
02/18/63	13.21	16.19	21.14	26.20	24.17	27.26	27.97	27.16	23.72	22.86	19.10	25.49

03/18/63	6.96	2.36	10.61	11.53	13.30	14.20	12.02	10.59	13.34	7.57	9.17	14.16
05/20/63	6.26	3.37	12.28	13.19	11.78	14.42	14.27	12.64	13.29	10.00	9.49	14.20
06/18/63	7.30	4.65	13.10	14.94	13.54	16.35	16.87	16.38	14.50	11.59	10.44	15.55
07/17/63	9.18	5.72	13.69	16.23	15.58	18.01	17.89	16.75	16.38	13.72	12.26	17.44
07/25/63	9.52	5.90	13.87	16.34	15.75	18.10	17.81	16.52	16.70	13.91	12.62	17.70
07/26/63	9.57	5.95	13.91	16.36	15.80	18.14	17.87	16.61	16.74	14.21	12.69	17.74
09/16/63	11.54	9.66	17.10	19.42	18.58	21.11	21.53	20.44	19.02	16.35	14.75	20.17
10/22/63	12.66	12.16	18.92	22.38	20.78	23.53	24.04	23.08	20.95	19.07	16.53	22.32
11/18/63	13.76	13.54	19.98	23.38	22.21	24.55	24.44	23.09	22.55	19.43	18.23	23.83
12/18/63	14.56	15.03	20.82	24.89	23.77	26.32	25.91	25.58	23.73	22.02	19.21	25.17
01/21/64	14.94	15.75	21.11	25.84	25.25	27.86	27.87	27.22	24.62	23.38	19.92	26.25
02/18/64	15.55	16.51	21.36	26.55	26.85	28.84	28.26	27.32	26.13	24.14		27.72
03/16/64	9.98	7.37	13.95	15.85	23.39	22.48	17.25	16.91	21.51	16.11		22.72
04/21/64	4.56	0.42	8.86	9.33	12.30	14.11	10.02	9.36	13.27	7.55		14.19
05/18/64	5.50	1.97	11.04	11.54	10.31	12.73	12.13	10.24	12.07	7.72		12.84
07/10/64	8.43	3.53	12.25	13.43	13.39	15.76	15.19	14.10	14.68	11.20		15.51
07/27/64	8.82	3.63	12.38	13.51	13.65	16.01	15.45	14.67	14.91	11.28		15.74
08/18/64	9.02	4.27	12.88	14.26	14.24	16.59	15.16	15.62	15.32	11.84		16.17
09/22/64	9.93	4.72	13.30	14.66	14.86	16.99	16.22	14.95	16.09	12.46		16.90
10/20/64	10.44	5.89	14.24	15.85	15.44	17.58	17.03	15.50	16.67	13.07		17.50
11/17/64	11.02	8.12	16.00	17.87	16.86	19.01	18.37	17.05	17.90	14.13		18.80
12/21/64	11.38	10.64	17.85	20.65	18.81	21.40	22.16	21.14	19.03	16.00		20.28
01/25/65	10.92	12.13	18.82	21.89	20.19	22.63	22.90	21.49	20.00	17.53		21.48
02/15/65	9.09	11.94	18.05	21.74	19.68	22.27	22.58	21.00	19.53	16.99		21.12
03/18/65	7.78	8.92	16.07	18.85	16.89	19.93	20.49	19.38	17.15	15.46		18.68
04/19/65	6.30	6.63	14.44	16.19	14.90	17.47	17.82	16.74	14.89	11.94		16.31
05/19/65	5.83	3.04	11.89	12.51	11.51	14.00	13.38	11.80	12.92	9.38		13.87
06/16/65	6.63	3.63	12.50	13.13	12.18	14.55	13.89	12.20	13.67	9.92		14.52
07/21/65	8.55	4.94	13.55	14.78	13.98	16.35	16.56	15.87	14.90	10.92		15.79
08/17/65	9.35	6.35	14.60	16.29	15.17	17.67	17.92	16.95	15.93	12.87		16.94
09/20/65	10.06	7.61	15.62	17.28	16.27	18.38	17.97	16.26	17.11	13.30		18.06
11/16/65	10.56	11.08	18.34	20.86	18.49	20.99	22.18	21.35	18.38	15.38		19.68
12/21/65	11.76	12.84	19.80	22.25	20.19	22.59	22.80	21.37	20.35	17.83		21.64
01/18/66	10.57	13.58	19.76	23.34	20.28	23.17	24.80	24.22	19.87	17.73		
02/25/66	10.15	11.84	18.22	21.58	19.91	22.63	22.56	21.52	19.44	18.24		21.55
03/22/66	10.54	10.97	17.62	20.84	19.48	22.18	22.74	22.47	19.49	17.04		20.95
04/26/66	10.99	10.87	17.83	20.53	19.60	21.99	21.65	20.34	19.98	17.32		21.35
05/25/66	9.73	9.78	16.96	19.68	18.56	21.33	21.68	21.30	18.80	16.42		20.25
06/16/66	10.98	9.78	17.03	19.67	18.46	20.96	21.23	20.43	18.97	15.92		20.17
07/18/66	12.06	11.05	18.00	21.10	20.05	22.73	22.64	21.75	20.63	18.32		21.90
08/17/66	12.96	13.05	19.58	23.01	21.55	24.10	24.65	24.03	21.62	18.94		22.99

09/21/66	13.94	13.94	20.32	23.54	22.82	25.27	25.21	25.16	22.72	20.18	18.47	24.08
10/17/66	14.28	14.58	20.63	24.08	23.38	25.52	25.38	24.72	23.26	20.18	19.09	24.51
11/17/66	14.27	15.12	20.66	24.94	24.17	26.62	26.62	26.18	23.74	23.96	19.17	25.22
12/20/66	12.71	14.83	19.73	24.82	23.74	26.06	26.54	24.98	23.01	21.02	18.41	24.65
01/17/67	13.87	14.79	20.37	24.70	24.02	26.61	26.40	25.96	23.85	22.12	19.38	25.32
02/20/67	14.00	6.12	21.14	26.15	25.01	27.76	28.00	27.55	24.66	23.84	20.17	26.29
03/23/67	10.75	12.94	17.96	23.62	22.06	25.22	25.69	25.40	21.91	20.27	17.28	23.64
04/18/67	9.71	9.99	16.56	19.95	18.91	21.65	21.34	20.85	19.39	16.80	15.11	20.73
05/16/67	6.65	7.16	14.14	17.59	16.28	19.23	19.37	18.53	16.57	14.17	12.22	18.03
06/19/67	8.51	5.14	13.39	15.08	14.98	17.54	16.75	15.87	16.21	13.05	12.21	17.14
07/18/67	9.64	5.61	13.86	15.56	15.54	17.93	17.29	16.47	16.67	13.33	12.64	17.51
08/22/67	10.73	7.38	15.23	17.58	17.02	19.58	19.39	18.65	18.00	15.04	13.89	18.99
09/19/67	11.65	9.23	16.70	19.29	18.52	21.10	20.92	20.22	19.35	16.66	15.18	20.41
10/18/67	12.44	10.84	18.05	20.62	19.78	22.15	21.92	21.06	20.30	17.16	16.05	21.36
11/16/67	12.69	12.57	19.26	22.37	20.97	23.50	23.75	23.01	21.11	18.69	16.73	22.35
12/18/67	11.68	13.66	19.61	23.42	21.55	24.16	24.57	23.64	21.23	19.20	16.72	22.78
01/17/68	11.94	14.20	20.08	23.97	21.69	24.59	25.17	24.27	21.72	20.03	17.29	22.78
02/15/68	11.26	13.95	19.48	23.86	21.39	24.59	25.56	25.22	21.37	20.01	16.90	22.64
03/19/68	13.07	15.03	20.49	25.00	23.21	26.16	26.58	26.04	23.05	21.48	18.53	24.62
04/15/68	11.51	14.35	19.61	24.48	22.02	25.33	26.12	25.52	21.99	20.54	17.41	23.68
05/21/68	10.94	14.64	19.76	24.67	22.37	25.62	26.12	25.45	22.31	20.74	17.71	24.06
06/17/68	7.16	3.76	12.06	13.92	14.07	16.68	15.96	15.12	15.39	12.12	11.29	16.32
08/19/68	6.73	6.13	14.23	16.23	14.47	17.25	17.65	16.31	15.20	12.42	11.10	16.35
09/16/68	9.32	7.72	15.75	17.60	16.21	18.79	19.04	18.89	17.02	13.86	12.90	18.06
10/28/68	10.79	8.36	17.14	19.62	17.26	19.64	20.97	19.96	18.65	15.60	14.45	19.54
11/20/68	10.92	10.80	18.18	20.50	18.76	21.37	21.61	20.41	19.05	16.60	14.73	20.37
12/16/68	9.54	11.39	18.38	20.30	18.44	21.29	21.34	20.56	18.67	16.28	14.40	20.07
01/20/69	7.50	7.98	14.82	18.50	17.09	19.64	19.45	18.53	17.21	14.08	12.86	18.58
02/17/69	5.87	3.48	12.57	14.19	12.20	15.23	15.42	13.96	13.53	10.68	9.63	14.06
03/20/69	7.89	6.07	15.48	17.03	14.94	17.86	18.59	17.56	15.70	13.53	11.67	16.93
04/21/69	7.55	8.85	16.53	18.62	15.74	17.79	19.42	17.94	16.42	13.81	12.20	
05/20/69	7.37	8.11	15.83	18.50	16.31	19.31	19.25	18.15	16.90	14.12	12.59	18.26
06/16/69	8.77	7.54	15.12	18.91	16.01	18.79	19.64	17.87	16.85	14.03	12.75	18.00
07/28/69	6.59	6.13	14.33	17.54	14.80	17.53	18.55	16.60	15.67	17.52	9.83	16.53
08/18/69	6.10	5.03	12.90	16.63	12.56	15.61	17.86	15.86	14.07	15.83	9.05	16.50
09/23/69	8.61	7.10	15.38	17.05	15.18	17.81	18.36	17.07	16.64	17.62	10.70	16.97
10/21/69	9.82	8.58	16.50	18.57	16.76	19.25	19.71	18.55	17.29	18.96	11.86	18.34
11/17/69	10.66	10.68	18.13	20.53	18.35	20.86	21.37	19.78	18.96	19.65	13.00	19.80
12/17/69	10.85	12.45	19.45	22.18	19.57	22.28	23.22	22.26	20.24	20.96	13.58	20.88

1970's Sandpoint Gauging Data												
	1	2	3	4	6	7	8	9	12	16	23	cl-7
1/26/1970	11.80	14.21	20.52	24.04	21.50	24.43	25.39	24.64	21.40	19.66	16.95	22.91
2/17/1970	10.02	10.71	16.91	21.31	19.50	22.53	23.22	22.75	19.77	18.06	15.46	21.32
3/17/1970	11.56	13.58	18.18	23.10	20.15	23.96	25.17	24.46	21.31	21.38	17.88	21.73
4/21/1970	8.31	6.84	14.25	17.39	16.07	19.03	19.13	18.21	17.02	14.56	12.94	18.26
6/12/1970	5.37	2.97	11.47	13.44	11.25	14.43	15.40	14.59	12.45	9.65	8.58	13.53
7/28/1970	8.42	6.36	14.48	16.72	14.80	17.51	17.98	16.65	15.61	12.58	11.56	16.65
8/20/1970	9.62	8.57	16.23	19.02	16.76	19.64	20.83	20.26	17.13	14.47	12.89	18.33
9/24/1970	11.50	10.69	17.86	20.97	19.15	21.76	22.28	21.26	19.54	16.93	15.30	20.74
10/22/1970	12.50	12.47	19.28	22.51	20.69	23.30	23.73	22.75	20.85	18.47	16.52	22.14
11/19/1970	13.22	13.79	20.09	23.82	22.07	24.69	25.16	24.34	22.04	19.75	17.62	23.41
12/23/1970	13.85	15.03	20.76	25.07	23.82	26.37	26.59	26.29	23.37	21.18	18.81	24.93
1/22/1971	14.08	16.33	21.48	26.40	24.75	27.60	27.94	27.44	24.31	23.03	19.70	25.95
2/23/1971	12.00	11.06	16.23	23.37	24.14	26.33	25.69	25.38	23.88	20.68	18.53	24.68
3/23/1971	10.32	13.42	16.97	21.10	19.83	22.97	23.29	22.79	20.29	18.43	15.96	21.80
4/22/1971	11.52	11.61	18.16	22.06	20.51	23.56	23.96	23.52	20.96	19.23	16.67	22.35
5/18/1971	12.18	13.22	19.40	23.68	22.00	25.24	25.55	25.04	22.34	20.85	17.97	23.88
6/16/1971	13.60	13.09	19.17	23.89	23.47	26.57	26.54	26.66	23.84	22.34	19.41	25.33
7/22/1971	10.13	8.41	15.87	18.91	17.40	19.14	20.49	18.99	18.26	15.28	14.15	19.34
8/25/1971	11.52	9.16	16.29	20.05	18.99	21.71	22.14	21.47	19.68	17.01	15.50	20.84
9/23/1971	12.30	10.03	16.98	20.89	20.10	22.71	22.89	22.36	20.60	17.87	16.37	21.81
10/27/1971	13.02	11.74	18.25	22.40	21.55	24.11	24.24	23.79	21.78	19.21	17.45	23.04
11/17/1971	13.53	12.63	18.95	23.39	22.51	25.13	25.32	24.93	22.70	20.26	18.33	24.04
12/16/1971	12.22	13.43	18.97	23.75	22.66	24.69	24.24	22.19	21.81	19.00	17.22	23.41
1/20/1972	9.25	10.58	17.56	20.30	18.14	20.61	20.53	18.20	18.20	15.51	13.95	19.55
2/17/1972	9.32	10.76	18.21	20.21	17.79	20.24	20.15	17.73	17.94	14.96	13.69	
4/20/1972	5.54	5.94	13.47	16.33	13.59	16.56	16.85	14.52	14.26	11.31	10.12	15.59
5/17/1972	4.04	2.71	10.62	12.70	10.65	13.86	13.34	11.15	12.08	8.41	8.08	13.23
6/30/1972	6.34	0.18	5.05		7.75	10.72	13.60	12.36	10.60	4.98	8.11	14.35
7/27/1972	7.77	3.90	12.48	13.90	12.96	15.10	14.66	12.63	13.98	9.58	10.08	14.77
9/7/1972	7.79	4.47	13.03	14.94	12.77	15.66	15.29	13.22	14.37	10.37	13.69	15.24
10/19/1972	6.38	6.30	14.79	16.09	13.51	16.13	16.74	14.94	14.05	10.88	10.00	15.21
11/29/1972	4.96	2.80	11.56	12.72	10.58	13.44	13.33	11.09	12.05	8.52	8.29	13.02
2/7/1973	5.68	4.64	13.03	14.77	11.90	15.00	15.68	13.87	13.07	10.21	9.14	14.21
3/14/1973	6.86	6.79	14.58	16.63	13.81	16.62	17.14	15.07	14.60	11.24	10.51	15.77
4/25/1973	4.63	2.44	11.25	12.31	10.11	12.94	12.89	10.56	11.54	8.03	7.79	12.47
5/17/1973	5.84	3.23	12.04	13.07	11.16	13.82	13.55	11.21	12.49	8.84	8.69	13.40
6/13/1973	5.14	3.05	11.96	12.90	10.58	13.41	13.47	11.15	11.95	8.35	8.22	12.91
7/18/1973	5.58	2.85	11.92	12.71	10.49	13.31	13.40	11.22	12.07	8.34	8.38	12.92
8/16/1973	6.85	3.74	12.17	12.76	12.40	14.77	14.53	12.50	13.41	9.64	9.47	14.33

9/19/1973	7.98	5.34	13.70	14.64	13.82	16.26	16.46	14.82	14.67	10.97	10.65	15.62
10/24/1973	8.72	6.46	14.63	16.63	14.86	17.15	17.49	15.83	15.41	11.58	11.31	16.40
11/13/1973	8.85	7.28	15.40	17.12	15.26	17.44	17.42	15.46	15.70	12.10	11.60	16.73
1/17/1974	6.08	6.46	14.86	16.16	13.63	16.24	16.32	14.30	14.14	10.97	10.00	15.36
2/20/1974	5.95	4.00	12.60	13.90	11.76	14.46	14.42	12.27	12.89	9.40	9.00	13.88
3/18/1974	6.44	4.98	13.46	14.85	12.56	15.18	15.36	13.28	13.41	9.86	9.45	14.44
4/16/1974	5.65	6.53	13.14	15.03	11.22	14.76	15.59	13.06	13.07	11.42	10.13	13.18
5/23/1974	6.17	5.27	13.96	14.88	12.78	15.23	15.02	12.72	13.56	10.11	9.57	14.59
6/20/1974	7.56	5.79	14.26	15.61	13.82	16.15	15.92	13.80	14.57	10.81	10.57	15.53
7/16/1974	8.10	8.22	13.71	15.26	14.00	16.25	15.66	13.55	14.84	11.23	10.87	15.76
8/21/1974	9.09	6.20	14.64	16.28	14.82	16.95	16.55	14.61	15.54	11.55	11.47	16.41
9/19/1974	8.80	7.23	15.64	16.80	15.06	17.13	16.99	14.96	15.53	11.85	11.44	16.56
10/24/1974	9.16	8.56	16.79	18.05	15.92	18.11	18.27	16.35	16.15	12.66	12.01	17.30
11/19/1974	9.05	9.35	17.44	18.70	16.43	18.53	18.65	16.53	16.41	13.03	12.18	17.62
12/17/1974	8.56	9.43	17.46	18.62	15.79	18.14	18.44	16.29	15.75	12.56	11.47	17.09
1/23/1975	6.39	8.95	15.41	16.39	13.45	16.15	16.46	14.20	14.08	10.86	10.05	15.31
2/20/1975	5.38	4.32	12.63	14.25	11.88	14.68	14.78	12.76	12.81	9.65	8.86	14.00
4/22/1975	5.82	2.62	11.57	12.32	10.86	13.39	12.91	10.97	12.22	8.30	8.49	13.15
5/20/1975	6.07	2.94	11.85	12.66	11.35	13.81	13.28	11.39	12.63	8.85	8.88	13.57
6/17/1975	6.90	3.38	12.15	13.24	12.25	14.54	13.96	12.05	13.32	9.43	9.48	14.27
7/29/1975	6.38	2.83	11.81	12.86	11.35	13.74	13.48	11.54	12.71	8.79	9.01	13.58
9/22/1975	7.65	3.66	12.47	13.43	12.74	14.75	14.17	12.49	13.70	9.17	9.86	13.55
10/14/1975	7.88	3.88	12.65	13.67	13.00	15.06	14.45	12.84	13.97	9.81	10.12	13.80
11/18/1975	7.56	4.33	13.00	14.18	13.14	15.25	14.94	13.25	13.95	10.04	10.05	12.85
12/17/1975	6.32	4.65	13.03	14.63	12.91	15.14	15.22	13.44	13.46	9.68	9.42	13.56
2/24/1976	5.10	3.26	12.08	13.06	10.89	13.61	13.69	11.74	12.03	8.60	8.24	12.09
3/22/1976	6.38	5.53	14.22	15.24	12.79	15.36	15.68	13.64	13.49	10.13	9.52	13.57
4/19/1976	7.45	6.51	15.03	16.14	14.00	16.37	16.39	14.27	14.54	10.98	10.55	14.62
5/20/1976	8.16	7.80	16.07	17.43	15.17	17.49	17.59	15.42	15.48	12.19	11.36	15.65
6/30/1976	8.02	7.18	15.42	16.90	14.98	17.22	17.23	15.36	15.25	11.98	11.05	15.45
8/24/1976	9.65	7.85	16.05	17.65	16.06	18.16	18.04	16.31	16.37	12.88	12.33	16.47
9/21/1976	10.07	7.37	16.15	17.79	16.32	18.35	18.25	16.91	16.63	12.68	12.52	16.68
10/19/1976	10.20	8.54	16.57	18.13	16.60	18.52	18.45	16.66	16.85	13.21	12.73	16.92
11/18/1976	10.32	9.62	17.53	19.15	17.24	19.32	19.50	17.65	17.34	13.86	13.17	17.48
12/22/1976	10.84	10.72	18.55	20.17	18.32	20.46	20.58	18.60	18.42	14.81	12.95	18.46
2/15/1977	11.75		20.02		20.39	22.66			20.05	17.81	15.70	20.55
3/17/1977	10.85	13.25	20.05	22.99	20.72	23.21	23.60	22.11	20.14	18.13	15.70	20.83
5/25/1977	9.71	9.25	16.90	18.97	18.60	19.50	20.90	18.42	18.04	14.98	13.67	18.12
6/21/1977	11.02	9.57	17.03	19.79	17.81	20.84	20.60	18.80	18.79	16.02	14.67	19.05
7/20/1977	11.79	10.53	17.66	20.26	19.39	21.66	21.52	19.88	19.59	16.34	14.49	19.91
8/23/1977	12.46	12.09	19.07	20.36	20.46	22.59	19.53	19.68	20.35	17.25	16.10	20.72

10/19/1977	12.75	11.92	20.19	23.07	21.18	23.33	23.45	21.56	20.87	18.06	16.55	21.31
11/29/1977	13.30	14.02	21.02	24.35	22.44	25.06	25.20	22.76	22.02	19.42	17.59	22.51
1/4/1978	9.97	10.38	17.26	20.27	18.65	20.94	20.98	19.42	18.54	15.64	14.32	18.94
2/8/1978	9.99		18.39									18.81
3/20/1978	6.91	8.57	15.80	18.90	16.86	20.16	19.68	18.03	17.25	14.68	12.85	17.96
5/16/1978	5.52	4.28	12.82	14.55	12.56	15.44	15.50	13.81	13.59	10.43	9.70	13.81
6/27/1978	7.42	5.54	13.08	14.95	13.61	16.13	16.11	14.63	14.55	10.95	10.55	14.56
7/31/1978	8.49	4.34	13.85	16.29	13.71	16.91	17.13	16.72	15.44	11.76	11.40	15.08
9/27/1978	8.71	6.77	14.99	21.48	15.42	17.76	18.99	18.75	16.03	12.68	12.00	16.14
10/24/1978	9.59	8.47	16.09	16.70	16.46	18.81	17.57	14.01	16.80	13.31	12.65	17.00
11/29/1978	10.12	10.67	18.00	20.47	18.09	20.46	20.80	19.27	17.85	15.14	13.68	18.29
1/30/1979	7.52	7.72	15.70		15.05	17.71			15.40	12.53	11.57	16.22
2/28/1979	5.31	5.75	12.80	15.82	13.86	15.58	16.20	14.33	14.20	11.08	10.13	14.70
6/20/1979	7.17	4.46	12.94	14.58	13.09	15.59	15.57	15.34	14.14	12.64	10.19	14.16
7/30/1979	7.42	4.87	13.10	15.60	14.06	16.26	14.35	10.81		10.86	10.85	14.72
8/28/1979	6.15	4.45	12.91	15.40	12.36	15.06	12.88	11.01		10.35	9.42	13.05
10/1/1979	6.02	3.57	12.40	10.50	10.75	14.26	14.15	12.72		9.18	9.10	12.87

1980's Sandpoint Gauging Data													
	1	2	3	4	6	7	8	9	12	16	23	cl-7	cl20
1/23/1980	5.95	4.20	13.80	10.87	11.69	10.33	12.95	11.99		9.16	8.95	12.87	
3/26/1980	6.12		13.50	10.80		12.61	15.90	12.01		9.88	9.05	12.40	
4/30/1980	5.92	3.07	12.40	13.10	9.68	13.76	13.60	12.61		9.78	8.80	12.02	
9/12/1980	5.77	3.30	11.35		12.06	11.90				8.48	8.35	12.85	
12/5/1980	7.02	7.12	14.29		14.96	16.91				10.78	10.15	14.80	
1/14/1981	7.87	7.71	15.55		14.96	16.91				14.03	12.50	16.35	
3/10/1981	6.66	8.55	15.38		13.91	17.53				13.63	11.10	20.10	
4/7/1981	6.60	8.57	15.28		14.01	17.41				13.28	11.25	15.95	
5/7/1981	3.40	7.22	11.40		11.49	12.06				8.18	7.63	12.95	
6/3/1981	2.95	0.00	10.80		11.14	12.01				7.90	7.48	10.69	
7/28/1981	4.98	6.87	10.82		11.25	13.76				8.48	9.50	12.64	
8/31/1981	6.17	7.75			12.71	15.03				8.63	9.65	13.67	
12/1/1981	8.34	8.38			15.69	18.11				12.93	12.15	14.56	
1/4/1982	5.77	8.38			11.83	16.84				10.19	9.00		
2/24/1982	2.91	5.57			7.76	11.11				8.11	4.96	10.70	
6/8/1982	6.72	7.68			11.46	16.01				10.51	9.75	13.51	
7/1/1982	7.02	8.92			11.96	14.39				10.08	10.80	14.13	
8/6/1982	7.94	9.72			13.31	12.91					11.10	14.82	
9/14/1982	8.62	6.77			14.33	16.11				10.48	10.95	15.32	
10/11/1982	8.77	5.67			14.76	13.81				10.90	9.15	15.38	
11/2/1982	9.63	9.20			14.95	16.32				14.00	11.35	15.64	

12/15/1982	6.80	9.18			14.70	15.48				13.60	11.20	14.66	
1/9/1983	6.68	9.20			14.01	15.38				11.38	10.05	14.50	
2/1/1983	7.12	8.32			9.96	16.81				13.68	11.56	15.25	
3/2/1983	7.25	10.90		18.96	15.00	18.10				15.10	12.75	15.60	
3/30/1983	8.95	11.70		16.98	15.78						13.32	16.25	
5/2/1983	5.79	10.27		18.08	14.72	17.85	18.00	15.10		14.58	11.91	15.23	
6/1/1983	6.10	6.48		14.69	11.44	14.60	14.82	12.25		12.02	9.06	12.55	
7/1/1983	7.52	6.54			12.85	15.88	16.13	13.48		13.19	11.20	13.81	
7/18/1983													
8/1/1983	8.62	8.13			14.01	16.85		13.58		14.22	12.37	14.90	
9/1/1983	9.63	8.70			15.00	17.78		15.54		15.11	13.21	15.80	
9/30/1983	9.99	9.52			15.28	18.05		16.52		15.36	13.33	15.95	
11/1/1983	9.79	9.92		18.27	15.50	18.23	22.48	16.07		15.46	13.42	16.10	
12/1/1983	8.53	10.68		18.89	15.48	18.34	19.23	17.02		16.51	12.92	15.89	
12/30/1983	8.41	9.55			14.62	18.29				15.92	12.07	15.22	
2/1/1984	10.17	11.56		19.58	15.09	19.94	19.01	18.27		15.86	13.84	16.25	
3/1/1984	7.53			20.68	14.45	21.94	21.10	20.77		14.77		15.11	
3/30/1984	5.00	6.99		15.49		14.87	15.79	13.58		12.42	9.64	12.43	
5/1/1984	5.26	5.72		14.03	10.36	13.88	14.29	11.82		11.31	10.29	11.75	
6/1/1984	5.85	6.37		14.68	11.24	14.57	14.98	12.42		12.02	9.95	12.43	
6/29/1984	7.45	7.29			11.73	15.84		13.99		13.27	11.24		
9/5/1984	9.43	9.41			14.99	17.83		16.26		15.03	13.02	15.67	
10/1/1984	10.20	10.10			15.54	18.39		16.42		15.58	13.46	16.17	
11/1/1984	9.81			19.21	16.12	18.95	19.47	17.17		16.21	13.65	16.57	
12/3/1984	8.76	13.00		19.89	16.15	19.11	19.78	17.22		16.25	13.49	16.58	
12/31/1984	7.05	11.54		19.42	15.21	18.40	19.13	16.40		15.41	12.42	15.70	
2/1/1985	8.07				15.03	18.30				15.69	12.87	15.78	
2/28/1985	5.77	8.81		17.28	13.50	16.99	17.55	15.09		14.36	11.22	14.37	
4/1/1985	4.23	6.47		15.77	11.07	14.65	15.88	13.59		11.83	8.97	12.14	
5/1/1985	4.96	6.71		15.83	11.34	14.41	15.07	13.00		11.04	10.12	12.54	
5/31/1985	6.54	6.16		16.91	12.54	14.74	16.18	13.13		12.19	11.27	12.69	
7/1/1985	7.68	6.20			12.72	15.04		13.27		12.68	11.23	13.69	
8/1/1985	8.54	7.94			13.46	14.10		13.91		13.92	12.09	14.36	
9/1/1985	8.87	8.14			14.02	16.85		15.33		14.10	12.23	14.73	
10/1/1985	9.61	9.13			14.97	17.72		15.25		14.90	13.08	15.67	
11/1/1985	9.71	9.11			18.34	18.15	18.31	16.03		15.23	13.32	15.95	
12/2/1985	5.70	7.25		15.35	11.96	15.87	15.22	12.41		11.64	9.81	12.55	
12/30/1985	5.49	6.40		15.26	11.90	14.31	14.89	12.07			7.99	12.48	
1/31/1986	6.66	8.34		16.49	12.69	15.95	16.68	14.33		13.32	10.84	13.60	
4/1/1986	4.82	5.44		13.22	10.91	13.30	11.32	10.99		10.88	8.89	11.28	
5/1/1986	5.26	6.54		14.82	11.18	14.55	14.11	12.62		11.50	10.00	12.31	

6/2/1986	7.21	7.55		15.96	12.70	15.83	16.10	14.05		13.20	11.10	15.16	
7/1/1986	6.96	7.31			12.62	16.16		14.47		13.28	11.03	13.85	
8/1/1986	11.74	12.19			12.73	16.33		14.73		12.27	11.08	13.70	
9/2/1986	8.80	9.17			14.00	16.84		15.06		12.89	12.17	14.77	
10/2/1986	7.48	8.51			14.25	16.92				12.98	11.62	14.70	
10/31/1986	5.38	7.05			12.61	14.60		12.69		11.03	9.99	12.52	
12/1/1986	4.93	5.82			10.21	13.15				11.12	7.45	11.40	
1/2/1987	5.29	6.03		9.44	10.75	13.96	14.64	12.14		11.07	9.41	11.84	
2/2/1987	6.37	7.51		11.13	11.60	15.51	15.70	13.75		12.33	10.62	13.27	
3/2/1987	7.23	8.82		11.58	12.91	17.65	16.22	14.07		14.17	11.46	14.28	
4/1/1987	10.02	12.19		18.08	14.39	18.73	18.05	17.55		14.94	12.86	15.04	
5/4/1987		9.60		17.40	14.00	17.30	17.70	15.60		13.60	12.30	17.00	
6/1/1987	8.79	9.14		15.22	11.41	17.02	15.14	15.07		12.97	9.66	14.71	
7/10/1987	8.06	9.27		15.39	12.77	18.13	15.97	16.21		13.08	112.18	15.70	
8/3/1987	9.06	9.51			15.07	18.68		16.83		15.52	13.03	15.86	
9/1/1987	10.11	10.67			16.21	19.93		17.74		16.59	13.93	16.85	
10/1/1987	10.66	11.19			16.53	19.11		17.94		16.83	14.45	17.32	
10/30/1987	11.07	12.02		21.27	17.55	20.50	21.18	19.16		17.90	15.11	18.09	
12/1/1987	11.42	13.33		23.16	19.04	21.38	22.93	20.55		17.81	15.80	18.93	
1/5/1988	11.50	13.82		22.05	18.81	21.83	22.30	20.08		18.07	16.12	19.31	
2/1/1988	11.98	14.09		23.45	19.99	22.14	23.10	21.43		19.40	17.66	20.21	
3/1/1988	10.74	14.60		24.08	19.65	22.70	23.41	21.89		20.10	16.80	19.41	
4/1/1988	11.26	15.21		22.37	19.13	21.50	22.19	20.75		20.44	16.31	19.04	
5/2/1988	11.36	14.32		22.83	19.24	22.47	23.15	21.30		20.20	16.78	19.01	
6/1/1988	12.61	15.30			20.79					21.21	18.10	21.51	
7/1/1988	14.05		8.75		21.50	25.17			21.33	21.66	19.08	21.80	
August-88	14.85	15.25	8.56		21.09	24.25		20.75	19.54		18.05	21.30	
September-88	13.65		13.11		22.28				20.65	22.10	18.52	21.77	
October-88	18.59	17.79	17.40		16.31	24.70			21.04	21.74	18.40	21.10	
November-88	13.98	16.97	18.31	24.60	22.52	25.44	25.71	24.20	21.69	22.91	19.32	21.79	
December-88	11.65	16.31	18.96		21.05	24.25	24.95	23.37	20.22	21.71	17.80	20.44	
January-89	11.65	16.45	18.95		21.00	24.13	24.91	23.34	20.23	21.36	17.77	20.39	24.62
February-89	10.61	15.08	19.25	22.96	19.14	22.57	23.00	21.24	18.60	20.06	16.45	18.88	23.99
March-89	10.50	15.62	19.10	23.78	19.40	22.03	24.19	22.07	18.89	20.51	16.61	19.16	23.94
April-89	8.34	13.59	19.26	21.93	17.84	21.50	22.19	18.90	17.58	18.59	15.03	17.69	23.26
May-89	6.34	8.99		17.44	13.39	16.99	17.94	15.77	13.46	14.22	14.40	13.45	21.17
June-89	5.35	5.45	10.50	13.83	10.35	13.85	14.54	12.05	10.90	11.37	9.23	10.66	20.20
July-89	5.93	5.73	12.90	14.21	10.87	14.23	14.89	12.23	11.42	11.63	9.72	11.17	19.30
August-89	6.95	6.89	12.90	15.33	12.16	15.29	15.75	13.27	12.50	12.50	10.77	12.18	19.60
September-89	7.44	7.25	13.30	16.10	13.42	15.75	16.30	13.93	13.10	13.18	11.13	12.63	20.10

October-89	9.81				14.73	17.72		14.76	14.57	14.64		13.28	21.00
November-89	9.00	8.56		17.08	14.22	16.88	17.67	15.41	13.90	13.55	12.48	14.06	22.10
December-89	8.92	9.33			14.70	16.81	17.63	16.33	13.21	13.75	12.81	14.36	23.11

1990's Sandpoint Gauging Data													
	1	2	3	4	6	7	8	9	12	16	23	cl-7	cl20
January-90	8.92	11.81		19.93	15.95	19.09	19.35	17.21	13.81	15.80		15.48	23.86
February-90	8.33	10.92		19.05	15.00	18.42	18.63	16.35	12.93	14.72		14.90	24.21
March-90	5.65	10.40		14.30	11.10	13.40	14.76	11.89	10.75	10.95		10.70	20.43
April-90	6.89	12.45		15.05	12.89	11.60	15.46	12.93	10.09	11.15		11.58	20.86
May-90	6.82	12.62		15.33	12.82	15.21	16.62	12.86	10.50	11.69		11.90	20.90
June-90	5.30	5.23		13.79	10.73	10.73	12.79	10.80	8.40	8.85		10.22	19.45
July-90	6.38	7.80		12.60	11.15	11.83	13.15	10.61	11.73	9.65		10.91	19.15
August-90	6.15	8.15			10.90	11.48			8.51	10.05		10.46	18.45
September-90	7.72	9.81			12.31	13.21			11.39	13.07		12.74	20.19
October-90	8.19	10.15			13.05	16.49			11.81	13.49		13.34	21.00
November-90	7.02	7.65		14.35	12.85	15.82	16.71	16.40	11.15	12.62		12.61	21.75
December-90	7.05	8.75		16.85	13.35	16.40	16.95	14.05	11.45	13.25		13.05	21.90
January-91	6.21	6.34		14.62	10.90	11.52	12.40	9.38	7.98	16.00	8.90	7.64	20.71
February-91	5.84	5.23		14.73	10.32	13.10	13.80	11.61	10.42	10.61	9.13	10.25	19.09
March-91	5.76	5.02		13.61	9.81	13.42	13.83	10.83	10.45	10.00	9.11	10.24	18.76
April-91	5.41	9.56	12.81	11.10	5.71	13.05	13.71	13.34	10.00	9.63	9.77	9.90	17.95
May-91	5.80	5.31	12.80	12.51	9.95	12.60	13.90	10.30	10.40	9.63	9.11	10.31	19.25
June-91	7.39	6.15	12.72	12.35	11.62	14.64	15.87	12.31	11.62	10.03	10.44	11.70	20.00
July-91	8.24	6.09	12.43	12.06	12.56	15.49	15.52	13.54	12.71	12.00	11.32	12.62	20.97
August-91	9.12	6.73	12.77	16.35	13.61	16.55	16.49	14.79	13.71	12.14	11.98	13.28	22.35
September-91	9.52	7.72	12.79	15.93	13.73	16.63	15.76	15.26	13.91	12.68	12.64	13.57	23.41
October-91	9.56	8.25	12.39	16.68	14.14	16.93	17.44	15.46	13.98	13.00	12.42	13.87	23.31
November-91	9.72	9.32	13.54	17.33	14.82	17.57	17.35	15.70	14.46	13.13	12.78	14.45	23.61
December-91	9.77	10.45	12.56	18.55	15.56	18.35	17.46	15.92	14.99	13.87	13.24	15.50	23.95
January-92	9.84	11.39	11.62	19.52	16.19	18.74	19.44	16.79	15.34	15.12	14.66	15.53	24.28
February-92	9.66	12.07	12.66	21.22	16.70	19.48	20.46	18.27	15.70	15.90	14.26	16.02	24.49
March-92	10.02	12.42	12.70	20.58	17.22	19.98	20.75	18.71	16.16	16.21	14.39	16.44	24.67
April-92	9.67	12.14	12.87	20.33	16.99	19.88	20.73	18.44	15.98	16.26	14.17	16.40	24.80
May-92	8.22	10.31	12.92	18.76	15.10	18.22	17.98	16.79	14.55		12.78	14.82	24.32
June-92	9.13	10.56	12.94	18.91	15.60	18.53	18.92	16.33	15.14		13.47	15.03	23.97
July-92	8.43	8.99	13.03	18.96	14.22	17.42	18.23	15.98	13.19		12.67	14.32	23.63
August-92	6.51	5.32	13.01	13.68	10.67	13.85	14.48	12.75	11.04		9.72	10.95	22.89
September-92	7.46	6.42	12.08	14.66	12.00	14.85	14.70	12.22	12.08		10.72	11.99	22.13
October-92	8.43	7.16	12.88	15.49	12.98	15.85	14.92	13.54	13.01		11.53	9.01	22.25
November-92	8.67	7.64	12.85	16.56	13.58	16.37	15.43	14.20	13.44		11.97	13.34	22.51

December-92	8.55	7.44	12.70	16.22	13.61	16.53	15.14	13.98	13.77		12.19	13.63	22.52
January-93	7.58	7.68	12.80	15.89	12.88	15.68	16.08	13.36	12.65		11.16	12.66	22.43
February-93	6.07	6.15	11.97	14.41	10.71	14.11	14.80	12.17	10.85		11.59	10.95	21.73
March-93	6.55	7.15	11.81	15.55	11.69	14.95	15.33	13.04	11.61		10.19	11.71	21.52
April-93	5.79	5.77	11.61	14.05	10.18	13.67	14.22	11.85	10.51		9.21	10.56	20.47
May-93	5.70	5.63	11.47	13.92	9.97	13.57	14.25	11.67	10.36		9.12	10.45	20.29
June-93	6.79	6.58	11.14	14.81	11.58	14.64	15.05	12.45	11.60		10.26	11.60	20.49
July-93	6.50	5.77	10.57	15.03	11.50	14.53	14.66	12.01	11.63		10.09	14.19	20.85
August-93	6.80	5.68	10.28	14.99	10.90	13.80	14.32	11.95	11.10		9.90	13.70	19.95
September-93	8.42	7.92	10.27	15.52	12.89	15.89	16.03	13.87	13.01		11.62	12.95	21.24
October-93	8.79	7.77	7.59	16.01	13.38	16.15	16.43	14.23	13.30		11.77	13.18	21.97
November-93	8.90	8.20	7.70	16.52	13.81	16.53	16.74	14.24	13.57		12.05	15.30	22.77
December-93	8.12	7.47	7.69	15.80	12.84	15.64	15.90	13.50	12.72		11.22	13.10	22.56
January-94	7.52	7.71	7.78	15.84	12.62	15.52	15.77	13.14	12.48		11.01	12.49	22.06
February-94	5.54	5.90	5.07	14.29	10.20	14.08	14.50	11.70	11.40		9.32	12.00	21.60
March-94	6.43	7.04	1.42	15.29	11.62	14.88	15.64	11.62	11.60		10.16	11.90	21.09
April-94	6.94	7.56	1.66	15.61	12.22	15.37	15.92	13.54	12.10		10.64	12.20	21.49
May-94	6.30	6.57	1.77	15.41	11.33	14.56	15.76	12.18	11.42		10.02	14.01	21.03
June-94	7.37	6.97	1.98	15.31	12.24	15.32	15.56	13.24	12.32		10.92	14.94	21.27
July-94	7.49	6.90	2.14	15.11	12.34	14.83	15.76	12.41	12.63		10.77	15.09	21.03
August-94	8.66	7.34	1.42	16.65	13.31	16.04	15.60	13.53	13.28		11.74	13.10	22.48
September-94	9.11	7.97	1.49	17.10	13.74	16.46	15.98	14.31	13.59		12.09	13.50	22.30
October-94	9.63	8.43	1.73	17.49	14.24	16.90	16.24	14.67	14.11		12.61	16.67	23.35
November-94	9.77	9.02	1.90	17.86	14.73	17.43	17.96	15.68	14.42		12.83	17.00	23.52
December-94	9.65	9.38	2.12	17.69	14.40	17.52	17.84	15.17	14.49		12.89	17.07	23.90
January-95	9.29	9.29	2.26	17.69	14.85	17.38	17.26	14.90	14.36		12.75	16.90	24.01
February-95	8.49	9.57	1.55	17.69	14.57	17.29	17.67	15.30	14.05		12.38	16.73	23.87
March-95	8.50	9.29	1.47	15.90	14.61	17.40	17.66	15.04	14.62		12.30	16.80	23.95
April-95	8.07	8.14	1.72	15.55	13.95	16.79	17.37	14.80	13.51		11.96	16.39	23.55
May-95	7.22	8.01	1.99	15.94	13.17	16.17	16.46	13.32	12.85		11.27	15.63	22.36
June-95	5.42	4.45	1.98	13.58	11.01	13.18	14.68	10.58	10.28		9.04	12.95	21.88
July-95	6.79	5.86	2.12	14.14	12.34	14.82	14.03	12.37	11.93		10.56	13.06	20.09
August-95	7.60	7.03	2.58	15.03	12.39	15.32	15.60	13.56	12.27		10.85	14.89	21.49
September-95	7.35	6.18	2.00	14.29	11.69	14.77	14.97	12.84	11.85		10.56	11.80	21.00
October-95	9.45	7.35	2.21	15.73	12.99	15.60	16.02	13.53	12.90		12.44	12.77	21.92
November-95	9.78	7.52	2.26	15.99	13.09	15.79	16.40	14.09	13.32		12.94	13.22	22.32
December-95	9.92	7.60	2.20	16.29	12.96	15.65	16.52	14.52	13.46		13.12	15.22	22.54
January-96	7.80		2.40		13.40	16.10		11.06	12.45		11.50	15.55	22.80
February-96	6.72	7.21	2.43	14.14	11.23	12.88	13.74	12.14	10.82		8.50	14.60	21.72
March-96	6.40	7.01	2.40	13.98	11.00	14.39	14.77	8.67	10.68		8.36	14.37	21.07
April-96	6.11	6.52	1.60	14.71	11.02	14.35	14.89	8.97	11.15		9.65	13.80	20.75

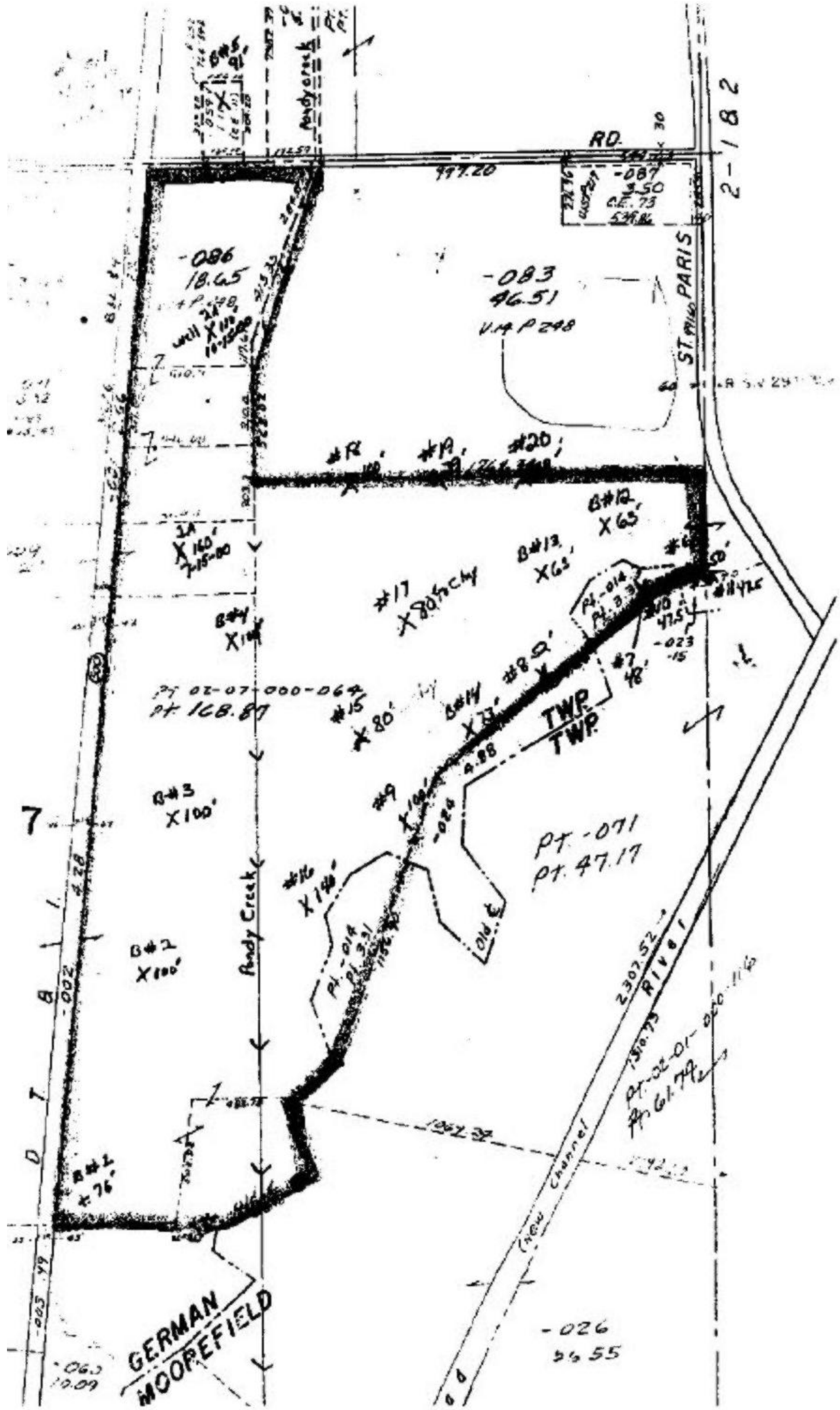
May-96	2.99		1.28	11.26		10.49	11.38	11.14	8.53		6.18	10.16	19.06
June-96	4.47		1.32	10.40	7.03	10.16	10.46	12.10	8.26		7.30	9.94	16.44
July-96	6.51	8.66	1.32	12.46	8.78	12.35	11.31	12.82	10.42		9.14	12.12	16.37
August-96	5.40	7.96	1.60	13.10	8.23	13.22	12.20	12.65	10.43		9.99	13.00	17.88
September-96	7.26	8.45	2.00	14.23	10.74	14.53	13.60	13.00	11.96		12.03	14.69	19.29
October-96	7.49	8.20	1.45	14.11	12.30	15.06	13.96	13.22	12.22		10.61	16.13	20.85
November-96	8.08	7.27	1.63	15.49	12.83	15.54	15.71		12.71		11.20	15.19	21.55
December-96	6.05	6.97	1.76	15.83	12.55	15.36	15.83		12.15		10.11	14.58	22.00
January-97	6.07	5.96	1.80	14.52	10.52	13.74	14.82	11.08	10.66		8.96	10.90	21.20
February-97	6.38	6.45	1.32	15.95	11.71	14.74	16.27	13.43	11.52		10.02	13.08	21.20
March-97	4.23	5.28	1.22	15.46	10.91	13.22	15.58	12.92	10.97		9.07	13.46	20.89
April-97	6.09	5.86	1.58	15.22	10.42	13.60	15.81	12.19	10.73		9.32	13.23	20.20
May-97	6.95	7.09	1.69	15.33	11.72	14.71	15.71	13.58	11.66		10.28	14.28	20.50
June-97			1.70			11.40		7.97	7.14		6.72	11.42	20.53
July-97	6.45	5.68	1.32	13.85	10.62	13.77	13.96	10.97	10.98		9.69	13.51	20.72
August-97	7.91	7.14	1.40		12.10	15.08		12.10	12.33		10.90	14.70	20.42
September-97	8.02	7.42	1.46	14.43	12.56	15.13	14.62	12.56	12.54		10.95	15.42	22.05
October-97	7.89	7.39	1.50	14.39	12.51	14.89	14.60	12.60	12.32		10.64	15.30	22.00
November-97	8.76	7.99	1.78	16.23	14.43	16.37	16.28	13.75	14.43		11.48	16.46	22.51
December-97	8.52	7.62	1.54	15.11	14.31	16.09	16.38	13.74	14.02		11.36	15.66	22.27
January-98	8.27	8.31	1.80	16.20	13.53	16.06	11.35	13.35	13.08		11.58	15.70	23.21
February-98	7.30	7.48	1.78	15.62	12.40	15.19	15.61	12.95	12.13		10.69	14.74	23.00
March-98	6.71	6.96	1.52	15.21	12.00	14.63	15.03	12.67	11.95		9.90	14.08	22.99
April-98	6.67	6.94	1.76	15.12	11.82	14.79	15.06	12.24	11.66		10.00		22.47
May-98	5.49	5.31	1.83			13.19		11.19	9.93		8.23	12.67	19.44
June-98	6.26	6.23	1.96	15.01	11.64	13.56	15.46	11.96	10.58		9.60	13.24	18.99
July-98	6.02	6.35	1.50			12.50		11.48	10.43		9.21	13.00	19.10
August-98	7.69	6.50	1.75		12.04	15.60		12.60	12.15		10.67	14.25	20.95
September-98	8.07	7.32	1.82		13.25	16.08		13.92	13.16		11.69	15.71	21.59
October-98	9.38	7.95	1.40	16.26	13.80	16.40	16.87	15.00	13.72		12.23	16.13	22.48
November-98	9.45	7.83	1.36	16.43	13.81	16.81	16.96	13.89	13.62		11.99	16.90	23.00
December-98	9.10	8.45	1.30	16.26	13.97	16.52	17.28	15.20	13.50		11.99	16.09	23.34
January-99	8.45	8.86	1.96	17.15	13.99	16.62	17.80	15.87	13.39		11.77	15.95	23.33
February-99	8.20	8.16	1.84	16.96	13.64	16.22	17.20	15.42	13.03		11.54	15.43	23.00
March-99	5.97	6.22	1.43	14.53	11.72	14.32	16.70	14.50	11.05		9.51	13.82	21.98
April-99	6.37	6.56	2.11	13.21	11.18	14.34	15.11	12.90	11.18		9.66	13.98	20.88
May-99	5.95	5.02	2.31	12.45	10.46	13.44	14.62	11.89	10.27		9.00	13.00	20.68
June-99	7.16	6.40	2.15	14.65	11.37	15.20	15.50	9.50	12.12		10.70		20.83
July-99	8.46	7.64	2.41	16.89	12.68	15.90	17.40	12.20	13.11		11.80	15.70	21.74
August-99	9.06	8.16	2.17		13.42	16.37	18.51	14.38	13.42		11.97	15.97	22.50
September-99	10.34	9.96	2.33		14.39	17.07		15.18	14.20		12.77	16.70	23.20

October-99	9.45	8.45	2.30	17.06	13.68	16.56	18.21	14.72	13.61		12.06	16.02	22.83
November-99	10.12	10.46	2.61	18.46	15.22	17.80	17.97	16.52	14.76		13.01	17.00	23.84
December-99	10.06	9.84	2.77	18.44	15.47	18.04	18.36	15.72	14.85		13.20	17.48	24.12

2000's Sandpoint Gauging Data													
	1	2	3	4	6	7	8	9	12	16	23	cl-7	cl20
January-00	10.02	10.66	2.68	19.06	15.97	18.33	19.20	17.17	14.96		13.25	17.62	24.62
February-00	9.40	11.34	2.72	19.54	15.94	18.80	19.68	17.04	15.24		13.78	18.05	24.98
March-00	8.65	11.05	2.75	19.03	15.58	18.21	19.04	16.81	14.64		12.82	17.45	24.21
April-00	7.74	9.96	2.86	18.57	14.63	17.40	18.80	16.52	13.79		12.01	16.51	23.72
May-00	6.14	6.10	2.89	14.44	10.78	13.94	14.75	12.33	10.80		9.56	13.56	21.47
June-00	6.70	7.43	2.93	15.78	11.81	14.72	15.91	13.63	11.62		10.09	14.22	20.89
July-00	7.65	7.69	3.02	15.92	11.96	15.45	15.97	13.87	12.45		10.86	14.96	21.02
August-00	8.26			16.21	13.23	15.86	16.43	14.25	12.85		11.22	15.38	21.59
September-00	8.75	8.16	2.46	16.53	13.40	16.11	16.62	14.18	13.17		11.73	15.72	21.91
October-00	7.77	8.04	2.60	16.64	13.16	15.89	16.69	14.36	12.67		11.10	15.33	22.25
November-00	8.20	8.29	2.66	16.50	13.45	16.16	16.76	14.46	13.11	15.60	11.56	15.71	23.40

APPENDIX D

BAISDEN EXCAVATING MAP AND SOIL GRAIN ANALYSIS



Baisden Core Samples - September 15, 2001																	
Boring	Depth	% Retain % Pass	Sieve Analysis – All samples passed the #4 seive														
			3	2.5	2	1.5	1	0.75	0.5	0.375	4	8	16	30	50	100	200
B-1 (Bedrock not Encountered)	9- 19	% R	0	5	3	7	8	8	13	16	6	10	8	7	4	2	0.5
		% P	100	95	92	85	77	69	56	40	34	24	16	9	5	3	2.5
	19-39	% R	0	0	9	7	11	7	9	4	12	9	7	9	10	2	1.4
		% P	100	100	91	84	73	66	57	53	41	32	25	16	6	4	2.6
	39-59	% R	0	0	8	4	5	6	9	6	13	11	8	11	12	3	1.4
		% P	100	100	92	88	83	77	68	62	49	38	30	19	7	4	2.6
	59-76	% R	0	0	4	4	6	6	6	6	17	15	10	11	10	3	0.4
		% P	100	100	96	92	86	80	74	68	51	36	26	15	5	2	1.6
B-2 (Bedrock not Encountered)	2-4.5	% R	0	0	0	2	9	5	9	8	16	12	9	11	10	3	1.5
		% P	100	100	100	98	89	84	75	67	51	39	30	19	9	6	4.5
	9- 19	% R	0	0	11	6	9	6	10	5	12	9	10	11	6	2	0.6
		% P	100	100	89	83	74	68	58	53	41	32	22	11	5	3	2.4
	19-39	% R	0	0	8	6	9	5	8	5	14	12	9	10	9	3	0.2
		% P	100	100	92	86	77	72	64	59	45	33	24	14	5	2	1.8
	39-59	% R	0	0	7	8	6	4	9	6	3	10	7	9	13	4	1.6
		% P	100	100	93	85	79	75	66	60	57	47	40	31	18	14	12
	59-79	% R	8	0	0	1	8	4	9	6	16	13	9	12	9	1	1.3
		% P	92	92	92	91	83	79	70	64	48	35	26	14	5	4	2.7
	79-99	% R	18	4	9	5	7	5	9	6	12	8	6	4	3	1	1
		% P	82	78	69	64	57	52	43	37	25	17	11	7	4	3	2
B-3 (Bedrock not Encountered)	2-4.5	% R	11	0	3	2	10	8	12	6	11	8	6	7	6	3	2.3
		% P	89	89	86	84	74	66	54	48	37	29	23	16	10	7	4.7
	9- 19	% R	0	10	2	4	9	10	11	6	13	8	5	7	9	3	0.7
		% P	100	90	88	84	75	65	54	48	35	27	22	15	6	3	2.3
	19-39	% R	0	6	3	3	10	6	10	6	11	10	7	11	11	3	1.2
		% P	100	94	91	88	78	72	62	56	45	35	28	17	6	3	1.8
	39-59	% R	0	0	8	1	4	4	7	5	12	10	9	13	18	6	0.7
		% P	100	100	92	91	87	83	76	71	59	49	40	27	9	3	2.3
	59-79	% R	0	0	4	6	6	4	10	7	17	12	11	12	7	2	1
		% P	100	100	96	90	84	80	70	63	46	34	23	11	4	2	1
	79-99	% R	0	0	8	2	11	8	11	7	15	9	7	4	9	4	0.6
		% P	100	100	92	90	79	71	60	53	38	29	22	18	9	5	4.4

B-4 (Bedrock not Encountered)	3.5-10	% R	6	0	0	8	6	6	10	6	14	11	9	8	7	3	1.4
		% P	94	94	94	86	80	74	64	58	44	33	24	16	9	6	4.6
	10-20	% R	0	4	1	8	8	7	11	6	16	13	9	7	6	1	1
		% P	100	96	95	87	79	72	61	55	39	26	17	10	4	3	2
	20-40	% R	0	0	5	6	9	4	7	5	13	10	8	9	16	4	1.3
		% P	100	100	95	89	80	76	69	64	51	41	33	24	8	4	2.7
	40-60	% R	0	0	5	6	9	4	7	5	13	10	8	9	16	4	1.3
		% P	100	100	95	89	80	76	69	64	51	41	33	24	8	4	2.7
	60-80	% R	0	0	4	6	3	4	9	6	14	14	13	14	8	2	0.4
		% P	100	100	96	90	87	83	74	68	54	40	27	13	5	3	2.6
	80-100	% R	0	12	0	5	6	4	9	5	14	12	9	9	9	2	1.3
		% P	100	88	88	83	77	73	64	59	45	33	24	15	6	4	2.7
B-5 (Bedrock at 92')	6- 20	% R	0	0	7	9	6	7	12	7	15	11	7	8	5	2	1.2
		% P	100	100	93	84	78	71	59	52	37	26	19	11	6	4	2.8
	20-24	% R	0	7	7	4	9	9	9	6	13	9	5	10	8	1	1.2
		% P	100	93	86	82	73	64	55	49	36	27	22	12	4	3	1.8
	27-40	% R	0	0	0	0	0	0	1	1	0	1	1	5	68	15	2.4
		% P	100	100	100	100	100	100	99	98	98	97	96	91	23	8	5.6
	40-60	% R	0	0	0	0	2	3	6	4	13	13	12	13	18	10	2.2
		% P	100	100	100	100	98	95	89	85	72	59	47	34	16	6	3.8
	60-73	% R	0	0	0	1	2	2	5	3	10	11	12	15	25	9	1.4
		% P	100	100	100	99	97	95	90	87	77	66	54	39	14	5	3.6
	73-80	% R	0	0	0	2	3	3	3	3	8	8	9	9	15	15	8.9
		% P	100	100	100	98	95	92	89	86	78	70	61	52	37	22	13
	80-92	% R	0	0	0	0	2	2	5	6	20	21	16	12	9	3	1.3
		% P	100	100	100	100	98	96	91	85	65	44	28	16	7	4	2.7
B-6 (Bedrock at 42.5')	5-7.5	% R	0	0	0	1	7	12	15	8	16	11	7	7	7	4	1.5
		% P	100	100	100	99	92	80	65	57	41	30	23	16	9	5	3.5
	10-12	% R	0	0	0	5	5	7	19	7	18	10	7	7	6	5	0.9
		% P	100	100	100	95	90	83	64	57	39	29	22	15	9	4	3.1
	20-40	% R	0	0	7	1	6	8	11	7	23	14	7	7	5	1	0.3
		% P	100	100	93	92	86	78	67	60	37	23	16	9	4	3	2.7
	40-42.5	% R	0	0	0	9	9	9	14	8	19	13	7	5	3	1	0.7
		% P	100	100	100	91	82	73	59	51	32	19	12	7	4	3	2.3

B-7 (Bedrock at 47.3')	2.5-7	% R	0	0	0	2	3	4	7	5	14	13	12	10	14	7	2.9
		% P	100	100	100	98	95	91	84	79	65	52	40	30	16	9	6.1
	10-15	% R	0	8	0	4	6	8	9	5	12	11	10	11	10	3	0.8
		% P	100	92	92	88	82	74	65	60	48	37	27	16	6	3	2.2
	20-40	% R	0	0	3	4	7	8	9	7	17	12	8	12	7	4	0.6
		% P	100	100	97	93	86	78	69	62	45	33	25	13	6	2	1.4
	40-47	% R	0	0	7	3	10	10	12	8	20	11	5	4	4	1	1.4
		% P	100	100	93	90	80	70	58	50	30	19	14	10	6	5	3.6
B-8 (Bedrock at 52.75')	3- 10	% R	0	0	0	7	10	6	9	7	13	11	9	9	7	4	2
		% P	100	100	100	93	83	77	68	61	48	37	28	19	12	8	6
	10-20	% R	0	0	4	7	14	8	13	6	13	11	9	6	4	2	0.7
		% P	100	100	96	89	75	67	54	48	35	24	15	9	5	3	2.3
	20-40	% R	12	13	5	11	0	5	10	6	14	10	5	4	3	0	0.7
		% P	88	75	70	59	59	54	44	38	24	14	9	5	2	2	1.3
	40-50	% R	6	0	3	5	6	4	7	6	16	14	9	12	7	1	1.4
		% P	94	94	91	86	80	76	69	63	47	33	24	12	5	4	2.6
B-9 (Bedrock not Encountered)	4- 10	% R	0	0	0	4	13	5	12	7	15	10	9	9	8	2	1.7
		% P	100	100	100	96	83	78	66	59	44	34	25	16	8	6	4.3
	10-20	% R	0	0	0	0	8	10	12	7	17	11	7	8	11	6	0.9
		% P	100	100	100	100	92	82	70	63	46	35	28	20	9	3	2.1
	20-40	% R	0	0	3	3	7	7	13	6	19	14	8	8	8	2	0.6
		% P	100	100	97	94	87	80	67	61	42	28	20	12	4	2	1.4
	40-60	% R	7	0	0	2	9	9	14	7	14	8	6	7	10	3	0.8
		% P	93	93	93	91	82	73	59	52	38	30	24	17	7	4	3.2
	60-76.5	% R	0	0	0	0	3	4	9	6	20	20	16	11	6	2	0.5
		% P	100	100	100	100	97	93	84	78	58	38	22	11	5	3	2.5
B-10 (Bedrock at 47.5')	1- 10	% R	0	0	0	0	3	5	8	5	14	12	11	12	14	8	2.5
		% P	100	100	100	100	97	92	84	79	65	53	42	30	16	8	5.5
	10.5-20	% R	14	5	0	6	13	6	10	6	13	8	6	5	5	1	0.7
		% P	86	81	81	75	62	56	46	40	27	19	13	8	3	2	1.3
	20-40	% R	0	0	0	5	5	7	10	8	22	14	8	9	7	3	0.6
		% P	100	100	100	95	90	83	73	65	43	29	21	12	5	2	1.4
	40-47.5	% R	0	0	0	0	6	4	8	7	22	18	13	10	7	2	0.9
		% P	100	100	100	100	94	90	82	75	53	35	22	12	5	3	2.1

B-11 (Bedrock at 48.5')	3- 10	% R	0	0	0	1	7	7	14	7	15	9	7	8	12	5	2.8
		% P	100	100	100	99	92	85	71	64	49	40	33	25	13	8	5.2
	11.5- 14	% R	0	0	8	0	17	8	12	6	12	9	6	7	10	3	0.2
		% P	100	100	92	92	75	67	55	49	37	28	22	15	5	2	1.8
	14- 20	% R	0	0	0	1	3	7	10	3	22	13	8	7	17	5	1.5
		% P	100	100	100	99	96	89	79	76	54	41	33	26	9	4	2.5
	20- 28	% R	0	3	16	8	14	7	13	6	15	8	4	2	3	0	0.2
		% P	100	97	81	73	59	52	39	33	18	10	6	4	1	1	0.8
	28- 40	% R	0	10	0	4	5	5	9	6	15	11	8	11	12	2	0.4
		% P	100	90	90	86	81	76	67	61	46	35	27	16	4	2	1.6
	42- 48.5	% R	5	5	3	1	7	6	11	7	17	13	9	8	4	2	0.8
		% P	95	90	87	86	79	73	62	55	38	25	16	8	4	2	1.2
B-12 (Bedrock at 62.75')	3- 10	% R	0	0	0	12	1	4	5	4	14	20	11	9	8	4	1.4
		% P	100	100	100	88	87	83	78	74	60	40	29	20	12	8	6.6
	10- 20	% R	0	6	0	3	10	8	14	8	16	10	7	7	6	2	1.1
		% P	100	94	94	91	81	73	59	51	35	25	18	11	5	3	1.9
	20- 40	% R	12	0	0	10	8	6	11	8	16	10	6	6	4	1	0.8
		% P	88	88	88	78	70	64	53	45	29	19	13	7	3	2	1.2
	40- 60	% R	0	0	5	13	8	7	12	7	18	11	5	6	5	1	0.5
		% P	100	100	95	82	74	67	55	48	30	19	14	8	3	2	1.5
	60- 63	% R	0	8	0	4	9	7	14	8	20	14	7	3	2	1	0.2
		% P	100	92	92	88	79	72	58	50	30	16	9	6	4	3	2.8
B-13 (Bedrock at 63')	2- 10	% R	0	0	3	3	4	6	10	8	18	11	8	9	10	4	1.7
		% P	100	100	97	94	90	84	74	66	48	37	29	20	10	6	4.3
	10- 20	% R	0	0	0	7	12	10	15	7	17	11	7	6	5	1	0.7
		% P	100	100	100	93	81	71	56	49	32	21	14	8	3	2	1.3
	20- 40	% R	0	0	11	12	9	5	12	8	17	9	5	5	4	2	0.1
		% P	100	100	89	77	68	63	51	43	26	17	12	7	3	1	0.9
	40- 60	% R	0	0	0	3	3	5	7	7	19	15	9	12	16	2	0.9
		% P	100	100	100	97	94	89	82	75	56	41	32	20	4	2	1.1
	60- 63	% R	0	0	0	2	6	6	11	9	23	21	12	5	2	1	0.4
		% P	100	100	100	98	92	86	75	66	43	22	10	5	3	2	1.6

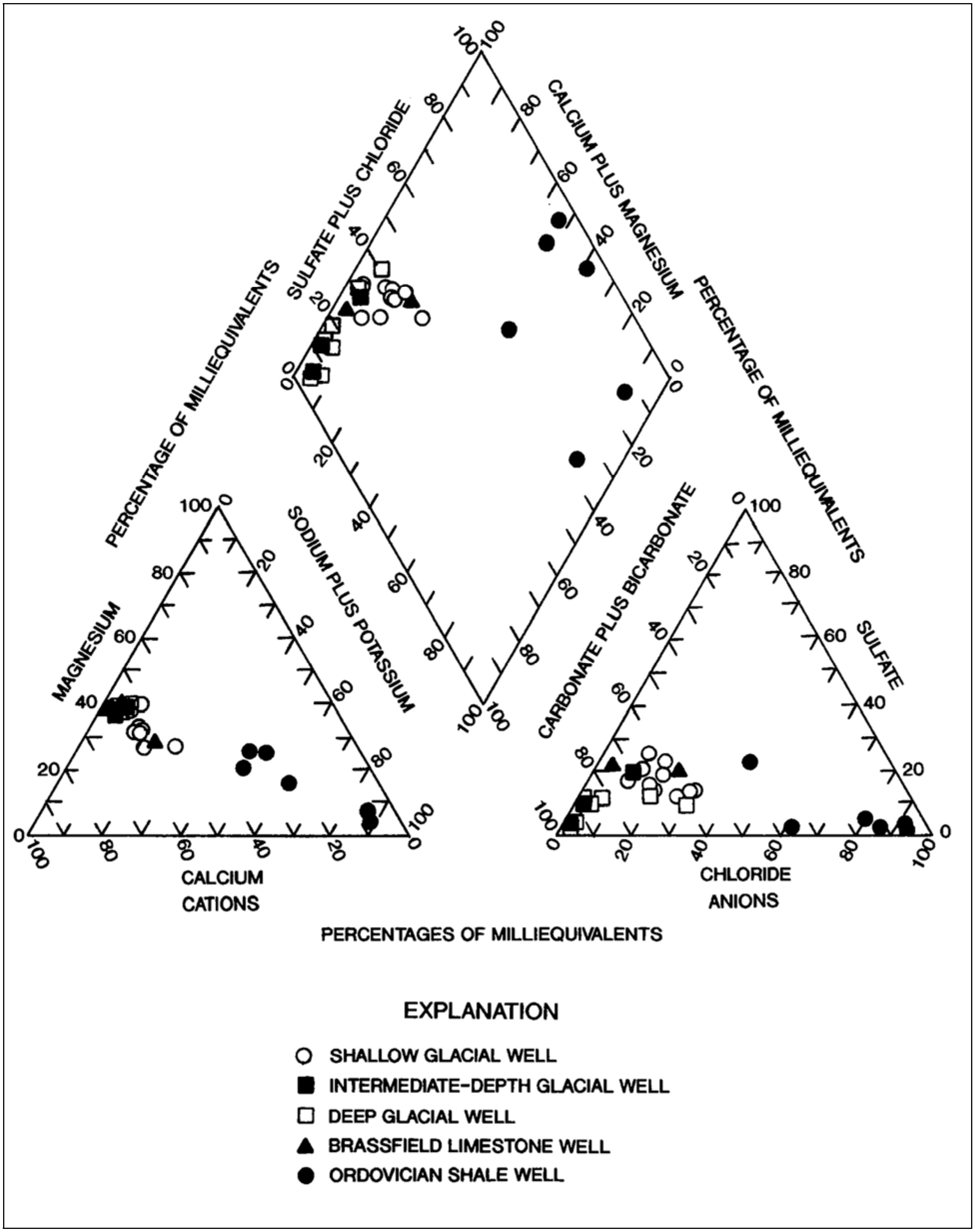
B-14 (Bedrock at 73')	3- 10	% R	0	0	0	11	8	4	14	7	15	11	7	8	7	2	1.8
		% P	100	100	100	89	81	77	63	56	41	30	23	15	8	6	4.2
	10-20	% R	0	0	4	11	10	9	14	7	15	10	6	5	5	1	0.9
		% P	100	100	96	85	75	66	52	45	30	20	14	9	4	3	2.1
	20-40	% R	0	6	5	12	15	8	14	6	13	8	4	4	2	1	0.7
		% P	100	94	89	77	62	54	40	34	21	13	9	5	3	2	1.3
	40-60	% R	0	0	6	11	10	7	11	7	17	11	7	5	4	2	0.2
		% P	100	100	94	83	73	66	55	48	31	20	13	8	4	2	1.8
	60-73	% R	0	0	0	3	0	0	2	0	4	10	28	34	13	2	0.6
		% P	100	100	100	97	97	97	95	95	91	81	53	19	6	4	3.4
B-15 (Bedrock not Encountered)	3- 10	% R	0	6	0	7	11	9	10	6	13	9	6	6	6	3	1.8
		% P	100	94	94	87	76	67	57	51	38	29	23	17	11	8	6.2
	10-20	% R	0	0	0	11	10	9	13	7	15	9	7	7	7	2	0.5
		% P	100	100	100	89	79	70	57	50	35	26	19	12	5	3	2.5
	20-62	% R	0	0	5	0	6	7	15	8	21	15	8	6	5	2	0.2
		% P	100	100	95	95	89	82	67	59	38	23	15	9	4	2	1.8
	62-75	% R	0	0	0	0	8	2	4	1	6	5	6	28	32	5	0.6
		% P	100	100	100	100	92	90	86	85	79	74	68	40	8	3	2.4
	75-80	% R	0	7	2	5	9	6	9	6	16	14	9	7	6	1	1.1
		% P	100	93	91	86	77	71	62	56	40	26	17	10	4	3	1.9
	80-100	% R	0	0	0	0	0	0	0	0	0	0	0	0	1	10	15
		% P	100	100	100	100	100	100	100	100	100	100	100	100	99	89	75
B-16 (Bedrock not Encountered)	5- 10	% R	0	0	0	5	2	5	7	6	18	15	9	11	14	4	0.8
		% P	100	100	100	95	93	88	81	75	57	42	33	22	8	4	3.2
	20-50	% R	0	0	0	4	12	6	13	7	9	20	8	8	8	3	0.2
		% P	100	100	100	96	84	78	65	58	49	29	21	13	5	2	1.8
	52-80	% R	0	0	0	4	4	5	10	8	22	18	11	9	5	1	1
		% P	100	100	100	96	92	87	77	69	47	29	18	9	4	3	2
	80-100	% R	0	10	3	3	6	4	7	4	11	11	11	12	12	3	1
		% P	100	90	87	84	78	74	67	63	52	41	30	18	6	3	2
	100-120	% R	21	0	0	2	0	2	2	2	6	9	9	14	18	9	2.5
		% P	79	79	79	77	77	75	73	71	65	56	47	33	15	6	3.5
	120-140	% R	0	0	0	0	8	4	4	3	9	10	11	18	21	8	1.4
		% P	100	100	100	100	92	88	84	81	72	62	51	33	12	4	2.6

B-17 (Bedrock not Encountered)	6- 20	% R	0	0	0	19	7	8	8	5	12	11	9	8	5	2	1.6
		% P	100	100	100	81	74	66	58	53	41	30	21	13	8	6	4.4
	20-40	% R	0	15	0	3	8	5	7	5	16	13	8	6	8	3	1.1
		% P	100	85	85	82	74	69	62	57	41	28	20	14	6	3	1.9
	40-45	% R	0	0	0	0	0	0	0	0	0	4	7	27	49	7	1.8
		% P	100	100	100	100	100	100	100	100	100	96	89	62	13	6	4.2
	45-60	% R	0	0	0	4	4	7	12	8	20	13	7	8	11	3	0.6
		% P	100	100	100	96	92	85	73	65	45	32	25	17	6	3	2.4
	60-80	% R	0	0	4	8	7	4	10	6	18	13	10	8	6	2	1.2
		% P	100	100	96	88	81	77	67	61	43	30	20	12	6	4	2.8
	80-100	% R	0	0	0	0	0	0	0	0	0	0	0	0	1	7	3.6
		% P	100	100	100	100	100	100	100	100	100	100	100	100	99	92	88
B-18 (Bedrock not Encountered)	3- 10	% R	0	0	0	5	8	7	10	7	14	11	8	7	8	3	3.1
		% P	100	100	100	95	87	80	70	63	49	38	30	23	15	12	8.9
	10-35	% R	0	0	3	14	15	5	10	7	15	11	6	5	5	1	0.9
		% P	100	100	97	83	68	63	53	46	31	20	14	9	4	3	2.1
	37-40	% R	0	0	0	0	2	0	3	2	6	6	7	21	42	7	0.9
		% P	100	100	100	100	98	98	95	93	87	81	74	53	11	4	3.1
	40-57	% R	0	0	0	2	9	6	9	7	19	14	9	10	9	3	0.8
		% P	100	100	100	98	89	83	74	67	48	34	25	15	6	3	2.2
	57-65	% R	0	0	0	3	4	3	6	4	12	16	15	16	12	4	1.7
		% P	100	100	100	97	93	90	84	80	68	52	37	21	9	5	3.3
	65-100	% R	0	6	5	4	9	5	11	7	17	12	8	7	5	1	1.1
		% P	100	94	89	85	76	71	60	53	36	24	16	9	4	3	1.9
B-19 (Bedrock not Encountered)	3- 10	% R	0	11	0	2	8	3	8	5	14	10	7	8	9	4	1.9
		% P	100	89	89	87	79	76	68	63	49	39	32	24	15	11	9.1
	10-20	% R	0	5	3	6	6	7	10	6	12	11	8	9	10	2	1.5
		% P	100	95	92	86	80	73	63	57	45	34	26	17	7	5	3.5
	20-40	% R	0	0	0	2	9	7	11	8	19	15	9	8	8	2	0.6
		% P	100	100	100	98	89	82	71	63	44	29	20	12	4	2	1.4
	40-60	% R	0	8	0	2	1	2	8	5	17	14	11	10	13	5	1.6
		% P	100	92	92	90	89	87	79	74	57	43	32	22	9	4	2.4
	60-79	% R	0	0	0	5	7	5	7	6	17	13	10	12	12	3	0.7
		% P	100	100	100	95	88	83	76	70	53	40	30	18	6	3	2.3

B-20 (Bedrock at 67')	3- 20	% R	0	0	5	10	15	7	12	7	13	9	8	7	5	0	1.2
		% P	100	100	95	85	70	63	51	44	31	22	14	7	2	2	0.8
	20-40	% R	0	0	6	8	10	6	9	6	15	13	11	8	4	2	0.6
		% P	100	100	94	86	76	70	61	55	40	27	16	8	4	2	1.4
	40-60	% R	0	0	0	3	9	6	10	6	15	12	10	14	10	3	0.3
		% P	100	100	100	97	88	82	72	66	51	39	29	15	5	2	1.7
	60-68	% R	0	0	14	1	7	4	9	6	15	12	7	7	12	3	1
		% P	100	100	86	85	78	74	65	59	44	32	25	18	6	3	2

APPENDIX E

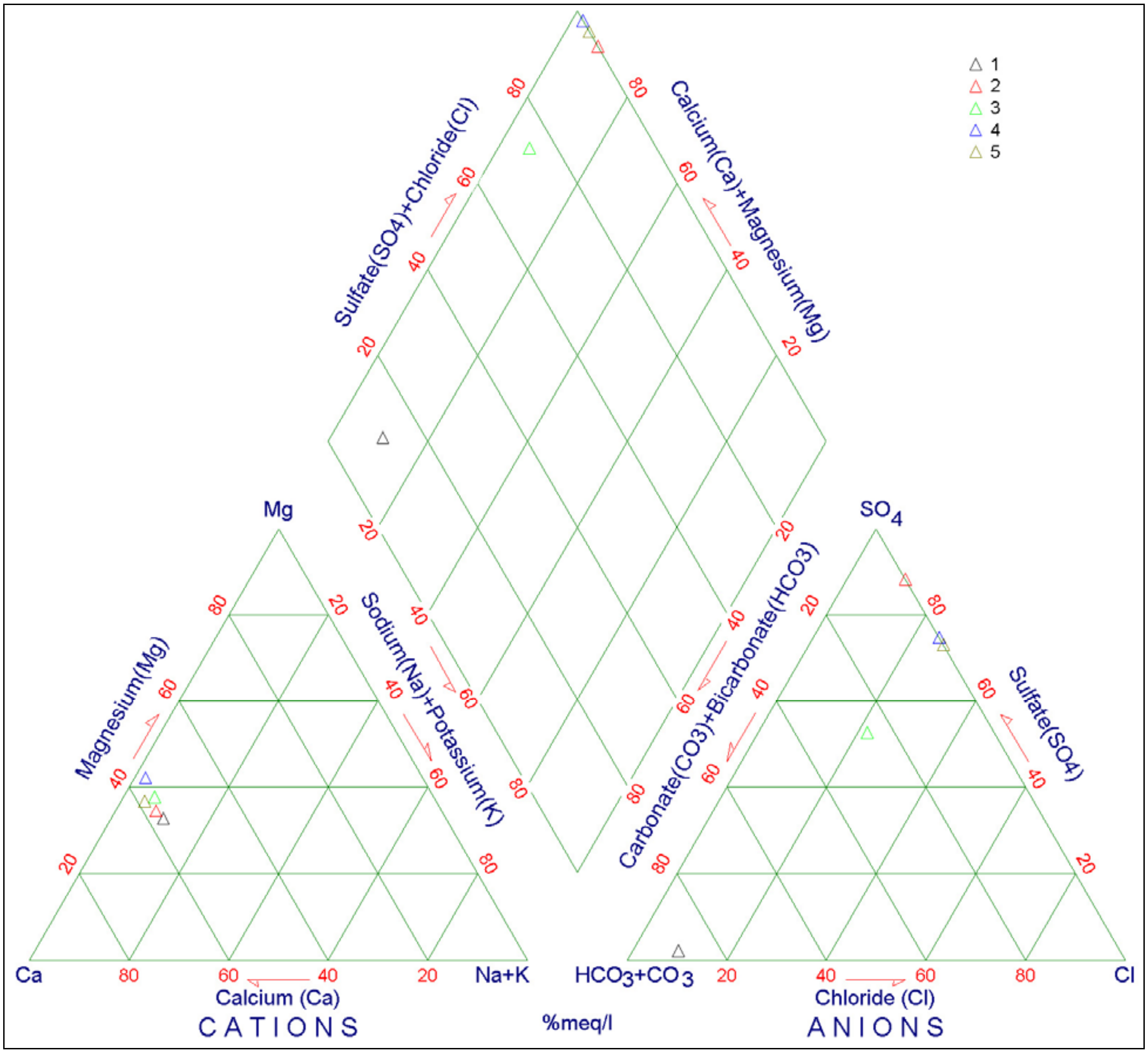
SWTP GEOCHEMICAL DATA PIPER DIAGRAMS



From Dumouchelle et al. 1993

Water Samples from Limestone and Dolomite Wells (Results in ppm)

Parameter	Well 1	Well 2	Well 3	Well 4	Well 5
Total Solids	328.0	460.0	400.0	498.0	470.0
Total Alkalinity	288.0	275.0	345.0	430.0	335.0
Calcium	60.0	85.0	81.0	100.0	92.0
Magnesium	21.0	31.0	33.0	46.0	35.0
Na + K	21.0	23.0	17.0	7.0	14.0
Chloride	3.0	7.0	4.0	5.0	9.0
Sulfate	1.0	71.0	13.0	20.0	33.0
Total Hardness	238.0	359.0	337.0	440.0	373.0
pH	7.7	7.3	7.3	7.2	7.2
Total Iron	0.15	0	2.7	0.6	0.4

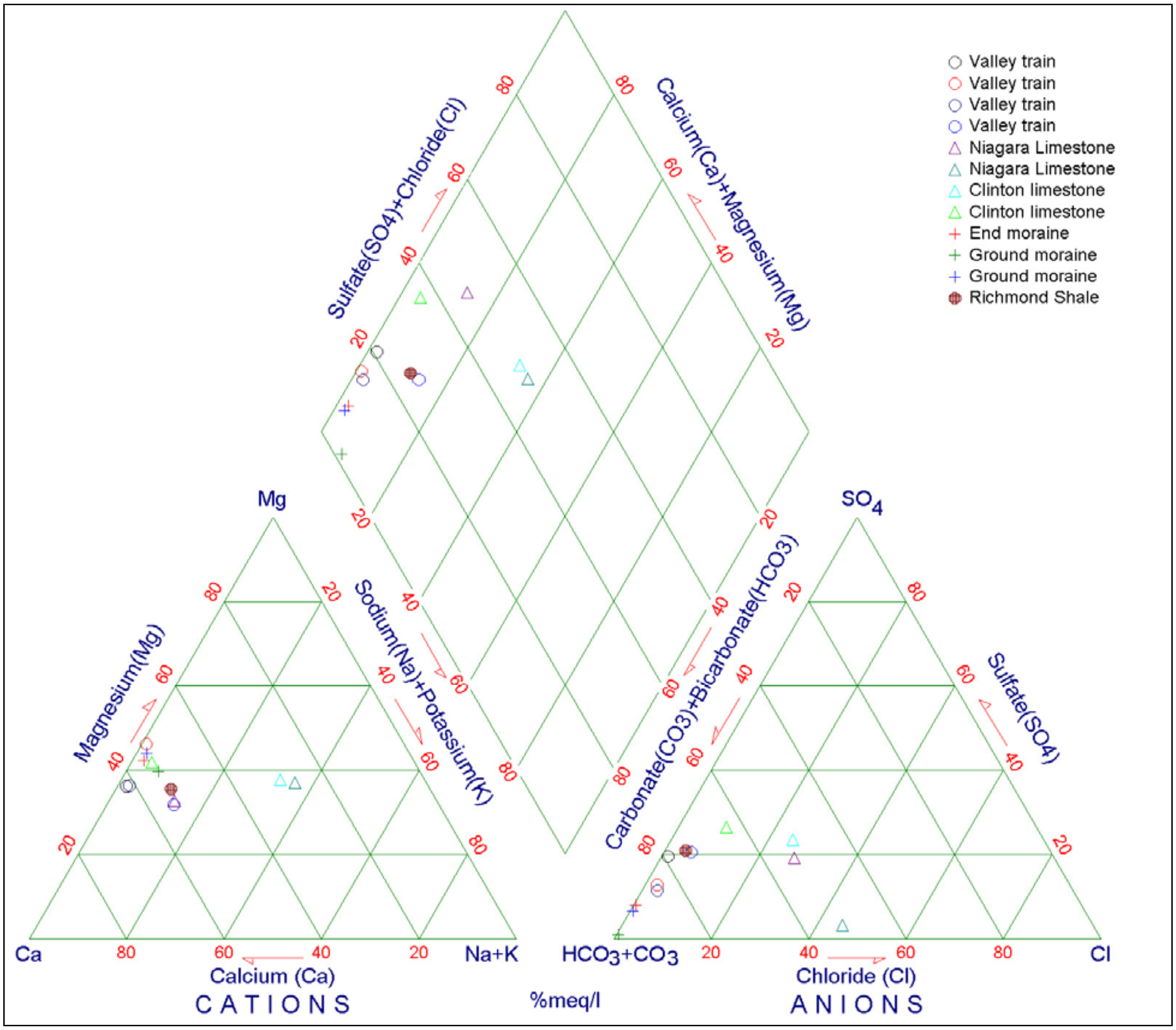


Piper diagram based on analytical results from bedrock well data by Harker and Bernhagen 1943

Water Samples from Consolidated and Unconsolidated Wells (Results in ppm)

Parameter	Valley Train 1	Valley Train 2	Valley Train 3	Valley Train 4	Niagara 1	Niagara 2
Total Solids	442	402	298	419	397	520
Specific Conductance	705	698	479	728	637	974
Calcium	110	85	48	100	57	42
Magnesium	30	45	17	36	21	35
Na + K	5.7	2.3	23	6.9	37	109
Chloride	3.8	7.0	8.5	9.0	55	155
Sulfate	77	49	42	44	52	15
Total Hardness	398	397	190	398	229	249
pH	7.7	7.6	7.3	7.4	8.1	7.8
Total Iron	7.1	1.1	0.50	3.4	3.2	10
Carbonate	0	0	0	0	12	0
Bicarbonate	396	411	192	415	160	302

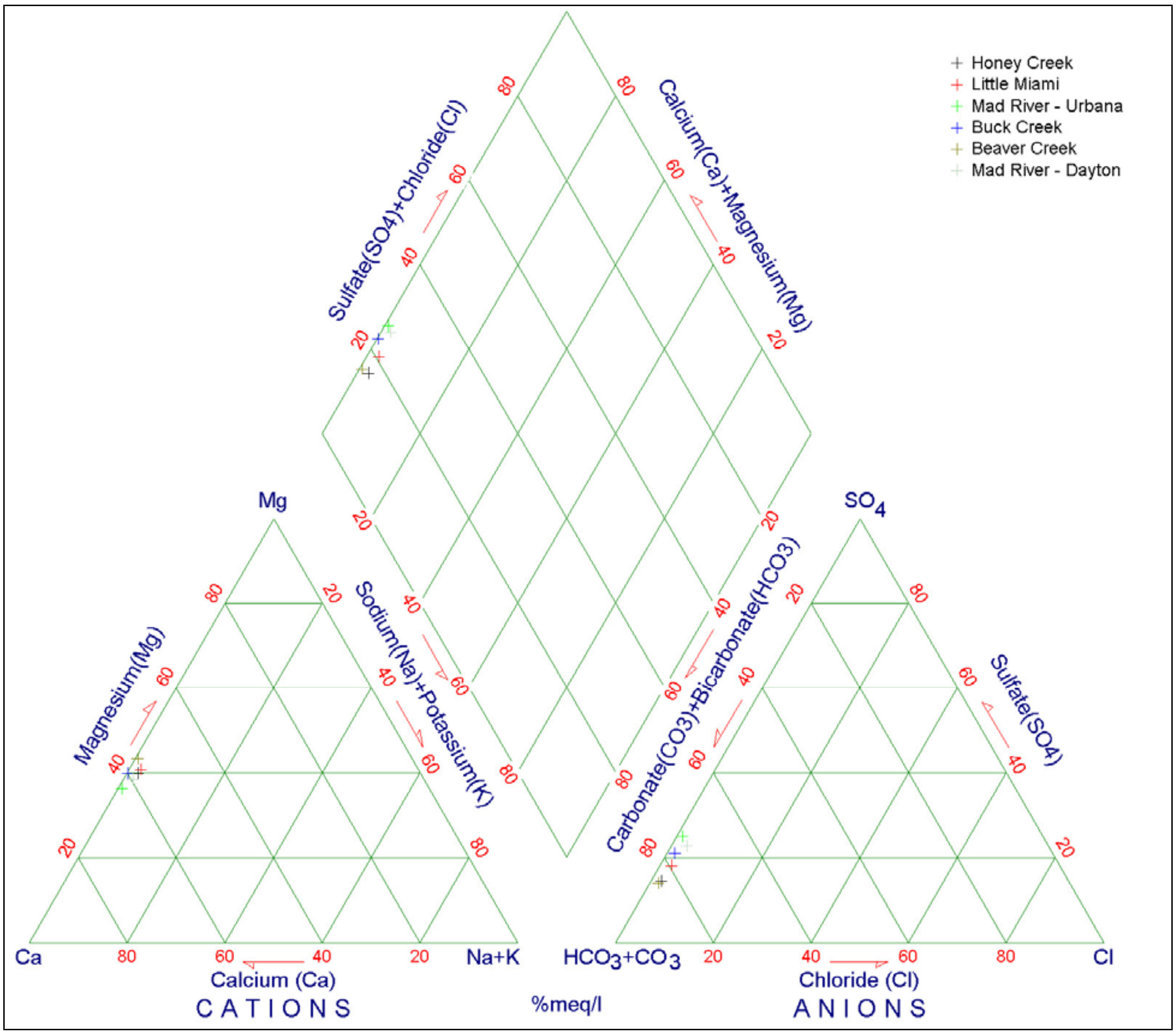
Parameter	Clinton 1	Clinton 2	End Moraine	Ground Moraine 1	Ground Moraine 2	Richmond Shale
Total Solids	646	594	353	363	356	380
Specific Conductance	1,010	1,030	642	641	641	624
Calcium	119	53	80	76	79	69
Magnesium	56	41	37	34	39	28
Na + K	18	114	6.2	18	5.7	28
Chloride	39	97	1.4	1.0	1.9	9.0
Sulfate	142	123	28	3.6	23	60
Total Hardness	527	301	352	329	357	287
pH	7.4	8.3	7.9	7.6	7.4	7.6
Total Iron	11	1.6	3.6	5.4	2.6	4.0
Carbonate	0	14	0	0	0	0
Bicarbonate	434	314	406	436	416	272



Piper diagram based on analytical results from aquifer well data by Norris et al. 1952

Water Samples from Surface Waters (Results in ppm)

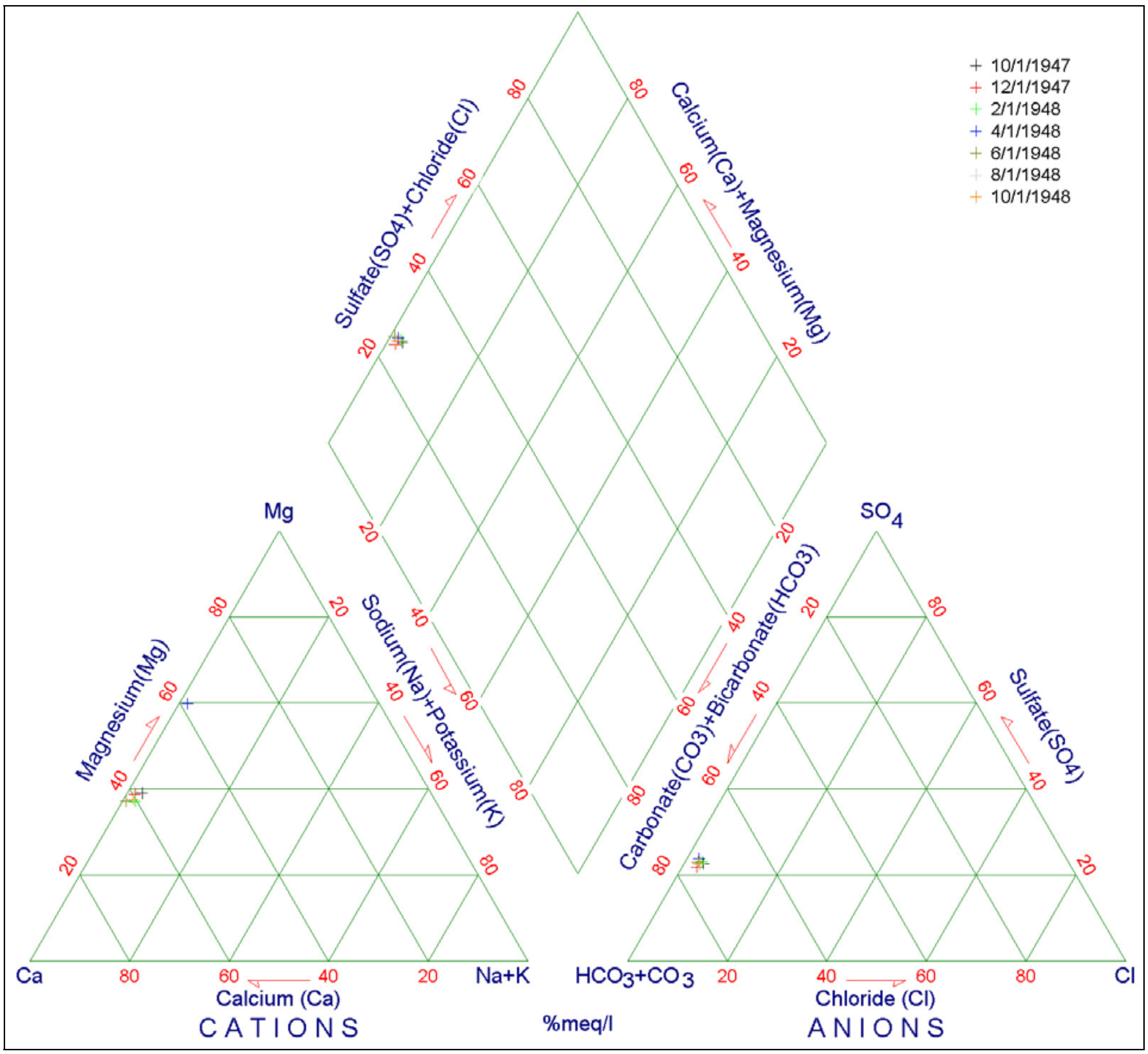
Parameter	Honey Creek	Little Miami	Mad River – Urbana	Buck Creek	Beaver Creek	Mad River - Dayton
Total Solids	359	--	397	404	347	406
Spec.Conductance	593	607	640	642	592	646
Calcium	79	79	83	87	77	84
Magnesium	33	35	36	35	36	31
Na + K	5.7	4.1	2.3	0.6	1.1	10
Chloride	5.1	6	3.4	4.2	4.5	9.8
Sulfate	45	58	90	72	45	79
Total Hardness	333	341	355	361	340	337
pH	8.0	8.1	7.8	8.1	8.2	7.8
Bicarbonate	330	337	312	336	347	312



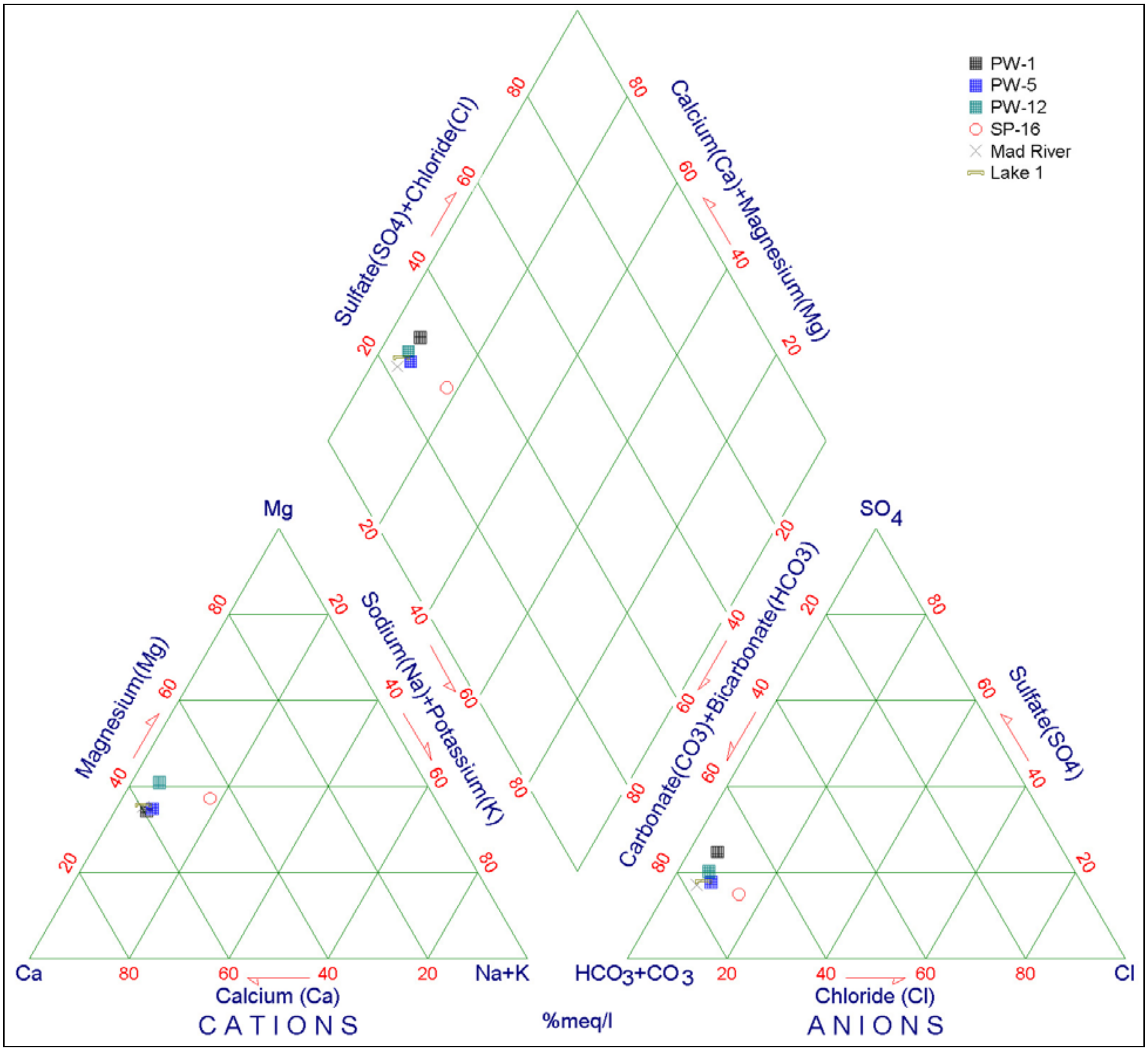
Piper diagram based on analytical from stream data with geographical variations by Norris et al. 1952

Water Samples from Mad River near Urbana (Results in ppm)

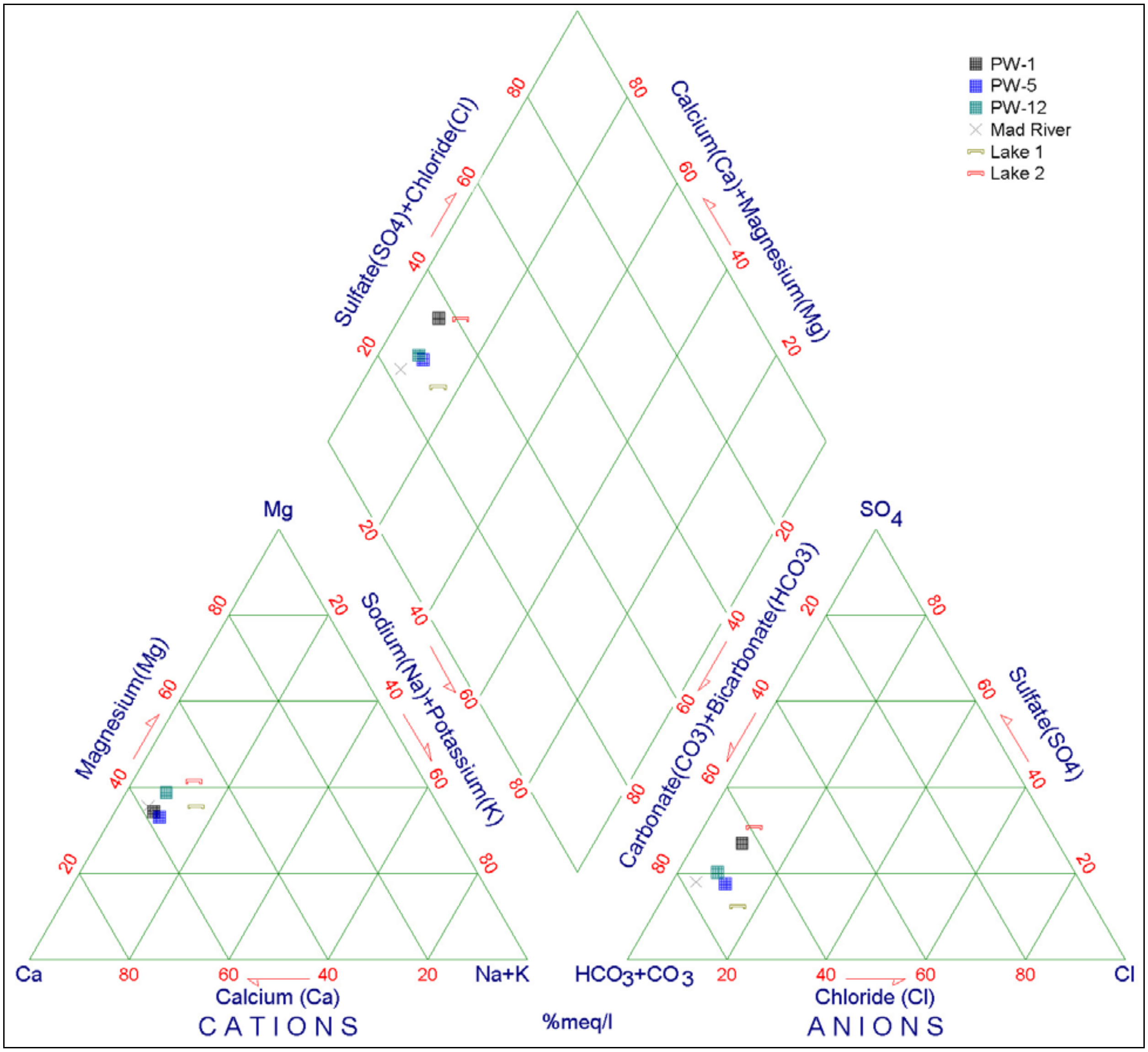
Parameter	10/1/47	12/1/47	2/1/48	4/1/48	6/1/48	8/1/48	10/1/48
Total Solids	453	435	456	393	414	421	420
Spec.Conductance	694	703	719	627	688	680	681
Calcium	91	94	97	86	94	90	88
Magnesium	37	37	36	31	34	36	35
Na + K	8.8	4.9	6.7	7.1	1.6	3.0	8.4
Chloride	11	8.5	9.8	6	7	8.2	11
Sulfate	85	81	88	77	82	80	81
Total Hardness	379	387	890	342	374	373	363
pH	8.0	7.9	7.7	7.8	7.9	8.0	7.9
Bicarbonate	351	356	356	304	337	338	336



Piper diagram of stream data analytical over time in the Mad River near Urbana by Norris et al. 1952



Piper diagram based on analytical collected near the SWTP on April 16, 2002.



Piper diagram based on analytical collected near the SWTP on May 14, 2002.

APPENDIX F

SWTP PUMP TEST REPORTS

Data Set: G:\My Thesis\Data\Pump test\Pump Test Results 1 - Revised.aqt
Title: Pump Test 1
Date: 09/11/05
Time: 13:16:03

PROJECT INFORMATION

Company: Brendan Merk
Client: Springfield Water Plant
Project: Pumping Test 1
Location: Springfield, OH
Test Date: April 16, 2002
Test Well: PW-1

AQUIFER DATA

Saturated Thickness: 115. ft
Anisotropy Ratio (Kz/Kr): 1.

PUMPING WELL DATA

Number of pumping wells: 1

Pumping Well No. 1: PW 1

X Location: 0. ft
Y Location: 0. ft

Partially Penetrating Well
Depth To Top Of Screen: 41.5 ft
Depth To Bottom Of Screen: 86.5 ft

No. of pumping periods: 2

Pumping Period Data

Time (min)	Rate (gal/min)	Time (min)	Rate (gal/min)
0.	2400.	1.5	0.

OBSERVATION WELL DATA

Number of observation wells: 1

Observation Well No. 1: PW-2

X Location: 300. ft
Y Location: 0. ft

Partially Penetrating Well
Depth To Top Of Screen: 48.17 ft
Depth To Bottom Of Screen: 88.17 ft

No. of observations: 25

Observation Data

Time (min)	Displacement (ft)	Time (min)	Displacement (ft)	Time (min)	Displacement (ft)
0.05	-0.0024	0.5	0.057	0.95	0.1236
0.1	-0.0008	0.55	0.0642	1.	0.1333
0.15	0.0032	0.6	0.0731	1.1	0.1397
0.2	0.0064	0.65	0.0843	1.2	0.1533
0.25	0.009	0.7	0.0915	1.3	0.1581
0.3	0.0193	0.75	0.0955	1.4	0.1662
0.35	0.0313	0.8	0.1077	1.5	0.1718
0.4	0.0361	0.85	0.1148		
0.45	0.0458	0.9	0.118		

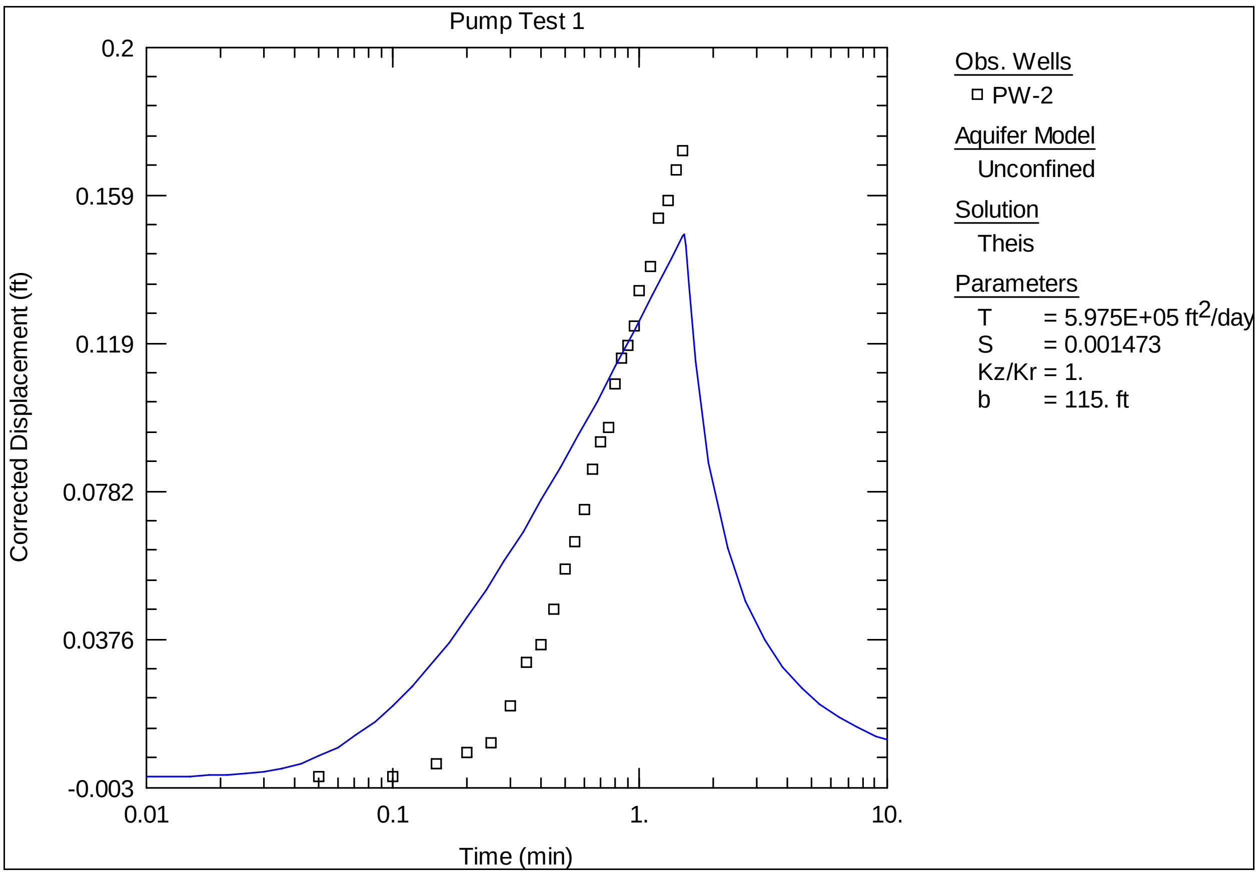
SOLUTION

Aquifer Model: Unconfined
Solution Method: Theis

VISUAL ESTIMATION RESULTS

Estimated Parameters

Parameter	Estimate	
T	5.975E+05	ft^2/day
S	0.001473	
Kz/Kr	1.	
b	115.	ft



Pump Test 1
0.2
0.159
0.119
0.0782
0.0376
-0.003
Corrected Displacement (ft)
0.01
0.1
1.
10.
Time (min)
Obs. Wells
PW-2
Aquifer Model
Unconfined
Solution
Theis
Parameters
T = 5.975E+05 ft2/day
S = 0.001473
Kz/Kr = 1.
b = 115. ft

Data Set: G:\My Thesis\Data\Pump test\Pump Test Results 2.aqt
Title: Pump test 2
Date: 09/11/05
Time: 13:18:54

PROJECT INFORMATION

Company: Brendan Merk
Client: Springfield Water Plant
Project: Pumping Test 2
Location: Springfield, Ohio
Test Date: April 16, 2002
Test Well: Pumping well 1

AQUIFER DATA

Saturated Thickness: 115. ft
Anisotropy Ratio (Kz/Kr): 1.

PUMPING WELL DATA

Number of pumping wells: 1

Pumping Well No. 1: PW 1

X Location: 0. ft
Y Location: 0. ft

Partially Penetrating Well
Depth To Top Of Screen: 41.5 ft
Depth To Bottom Of Screen: 86.5 ft

No. of pumping periods: 2

Pumping Period Data

Time (min)	Rate (gal/min)	Time (min)	Rate (gal/min)
0.	2400.	8.2	0.

OBSERVATION WELL DATA
Number of observation wells: 1

Observation Well No. 1: PW 2

X Location: 300. ft
Y Location: 0. ft

Partially Penetrating Well
Depth To Top Of Screen: 48.17 ft
Depth To Bottom Of Screen: 88.17 ft

No. of observations: 25

Observation Data

Time (min)	Displacement (ft)	Time (min)	Displacement (ft)	Time (min)	Displacement (ft)
0.05	0.0063	0.5	0.0562	0.95	0.1244
0.1	0.0032	0.55	0.0648	1.	0.1284
0.15	0.0048	0.6	0.0762	1.1	0.1421
0.2	0.0046	0.65	0.0811	1.2	0.1469
0.25	0.0152	0.7	0.0851	1.3	0.1581
0.3	0.0191	0.75	0.0945	1.4	0.1629
0.35	0.0263	0.8	0.1074	1.5	0.1718
0.4	0.0377	0.85	0.1074		
0.45	0.048	0.9	0.1132		

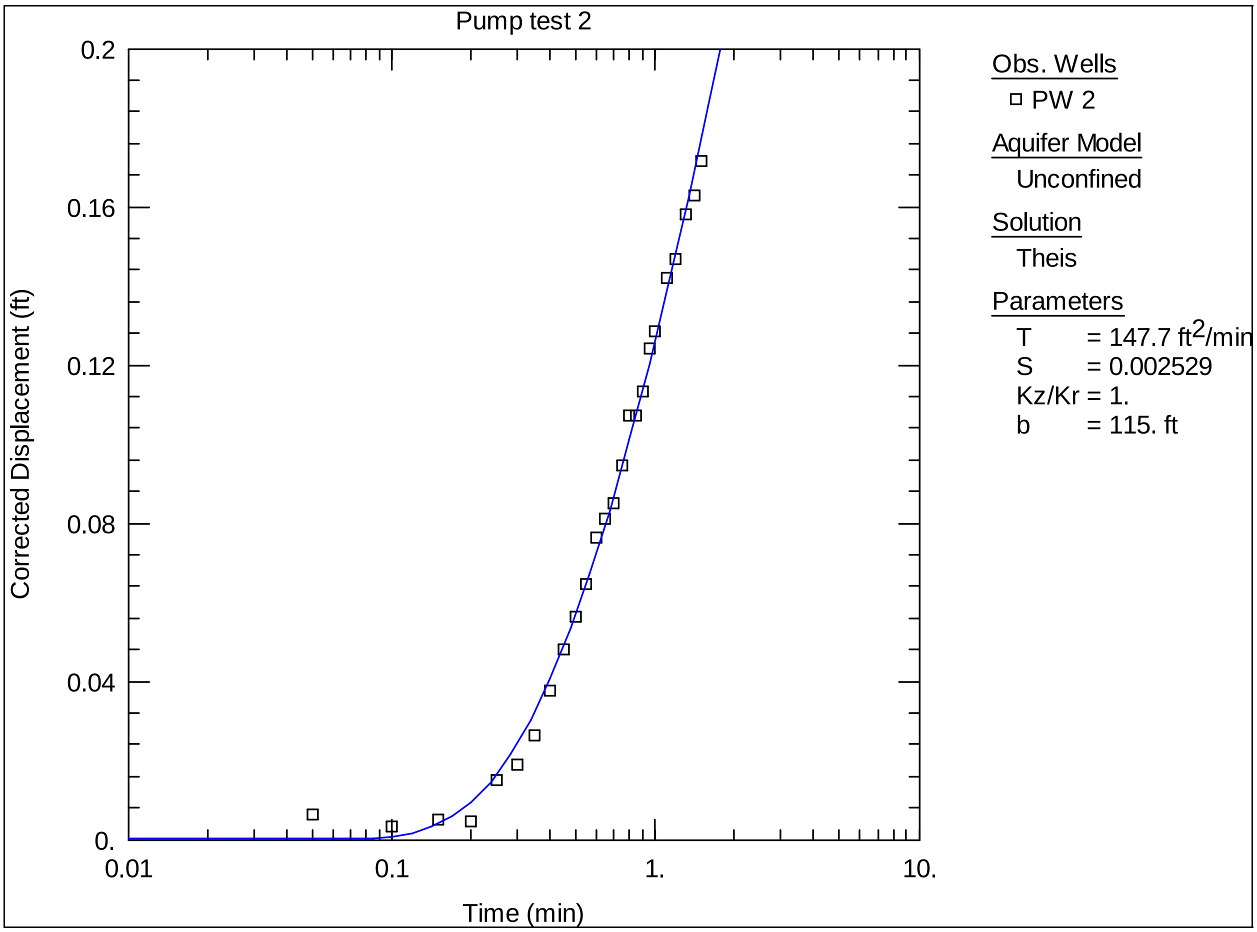
SOLUTION

Aquifer Model: Unconfined
Solution Method: Theis

VISUAL ESTIMATION RESULTS

Estimated Parameters

Parameter	Estimate	
T	147.7	ft^2/min
S	0.002529	
Kz/Kr	1.	
b	115.	ft

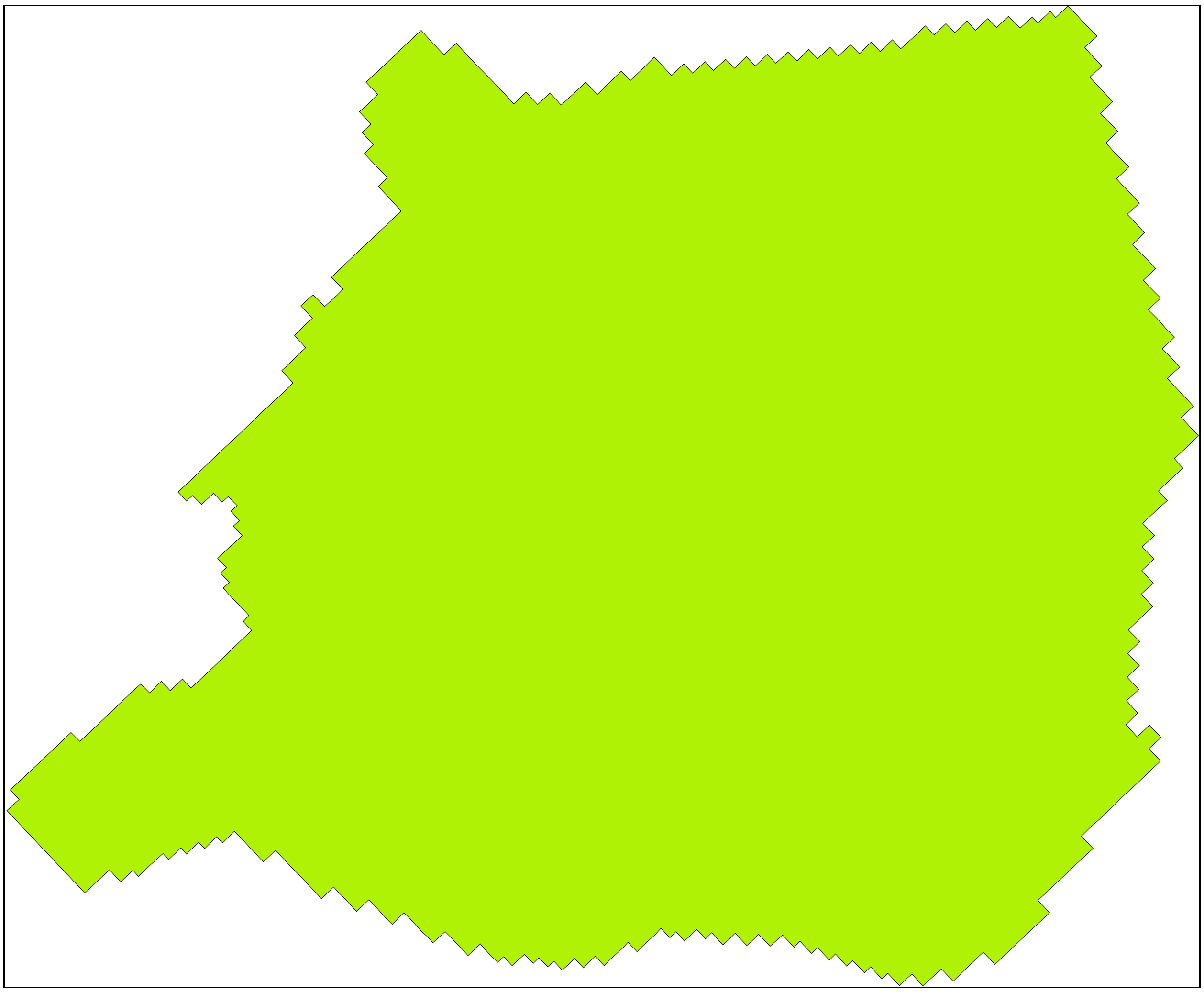


Pump test 2
Corrected Displacement (ft)
0.2
0.16
0.12
0.08
0.04
0.
0.01
0.1
1.
10.
Time (min)
Obs. Wells
PW 2
Aquifer Model
Unconfined
Solution
Theis
Parameters
T = 147.7 ft2/min
S = 0.002529
Kz/Kr = 1.
b = 115. ft

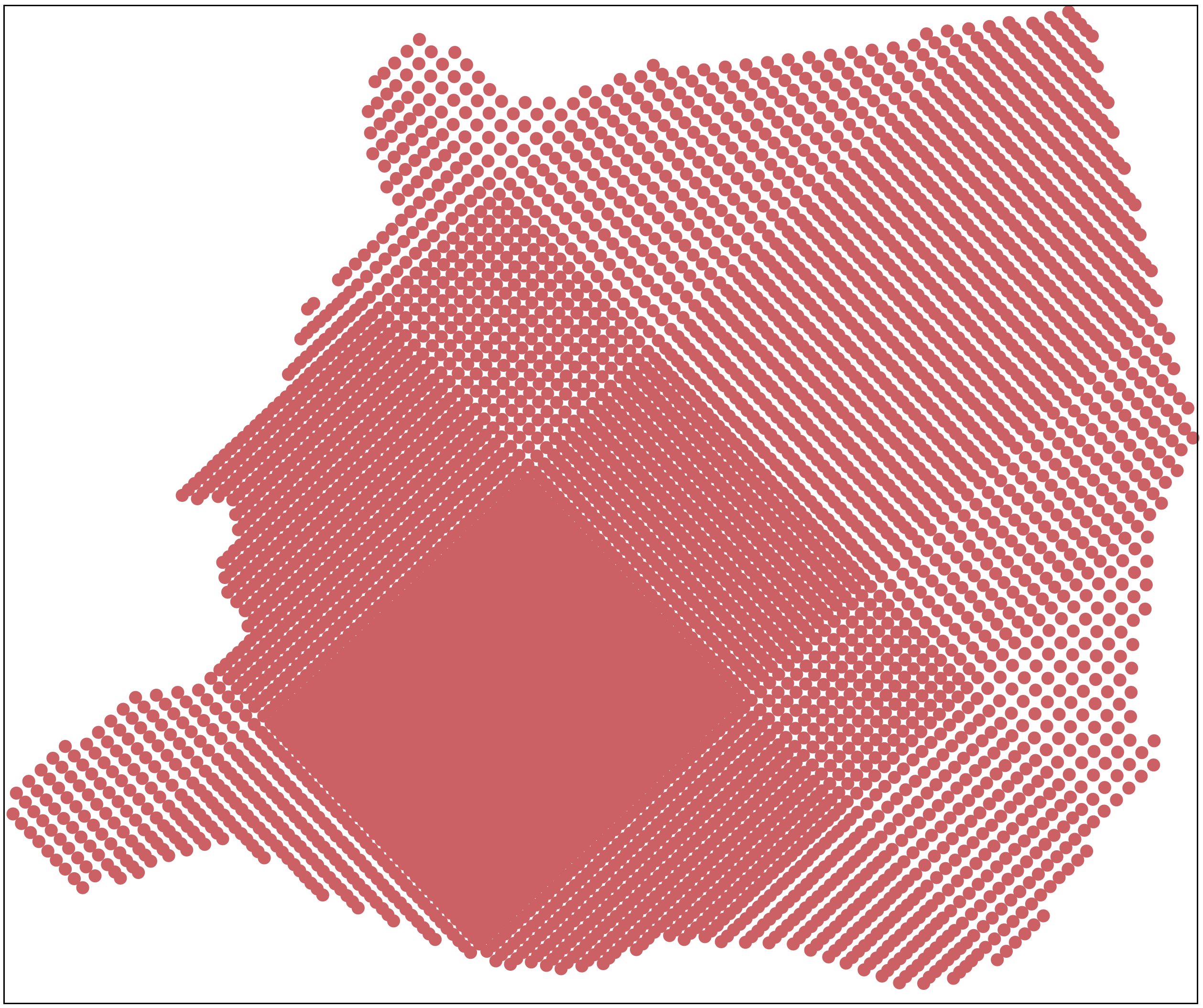
APPENDIX G

WPAFB MODEL GIS COVERAGES FROM DUMOUCHELLE ET AL. 1993

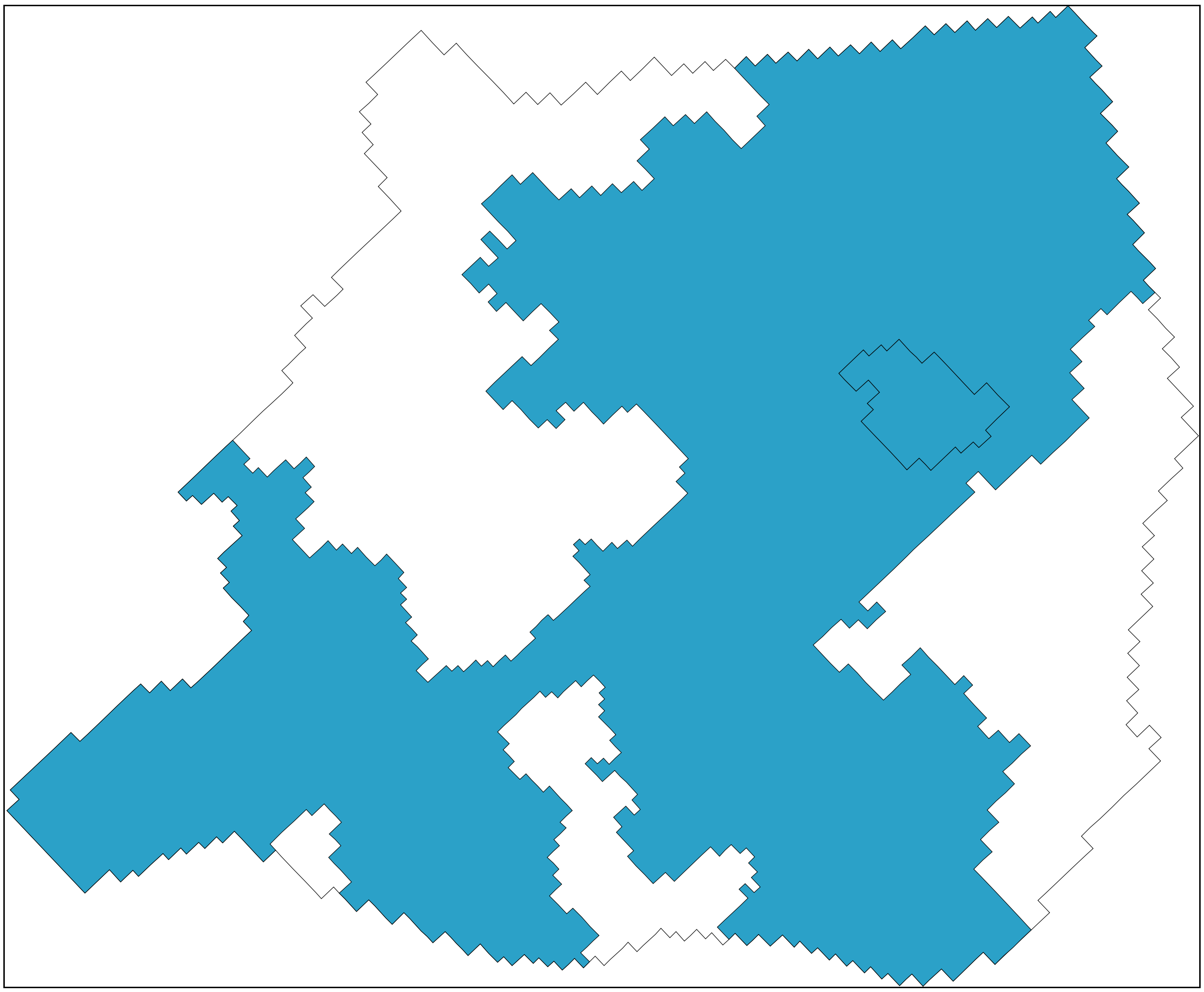
Dumouchelle et al. 1993 ArcView coverages	
Layer Name	Description
A1 polls	Outline of modeled area boundary, shaded.
A1 pts	Center points marked for each cell in the model.
A2pol2	Outline of modeled layer 2, shaded.
A3pols	Outline of modeled layer 3, shaded.
Boundpts	Interior model boundary lines.
Contact	Silurian / Ordovician contact contour.
Gridplot, Gridpol	Model grid.
Gslinewri	Cross-Section locations.
Histwell	Wells.
Land	Topography.
Municip	Municipal boundaries.
Pwell	Production wells.
Rockpts	Bedrock points (based on potable well locations).
Roads	Roads.
Rock	Bedrock contours.
Simclp2	Ground water flow simulation.
Soils	Soil types.
Starea	Outline of modeled area boundary.
Swat	Surface water features.
Wells	Private potable well locations.
Wpwt	Ground water contours



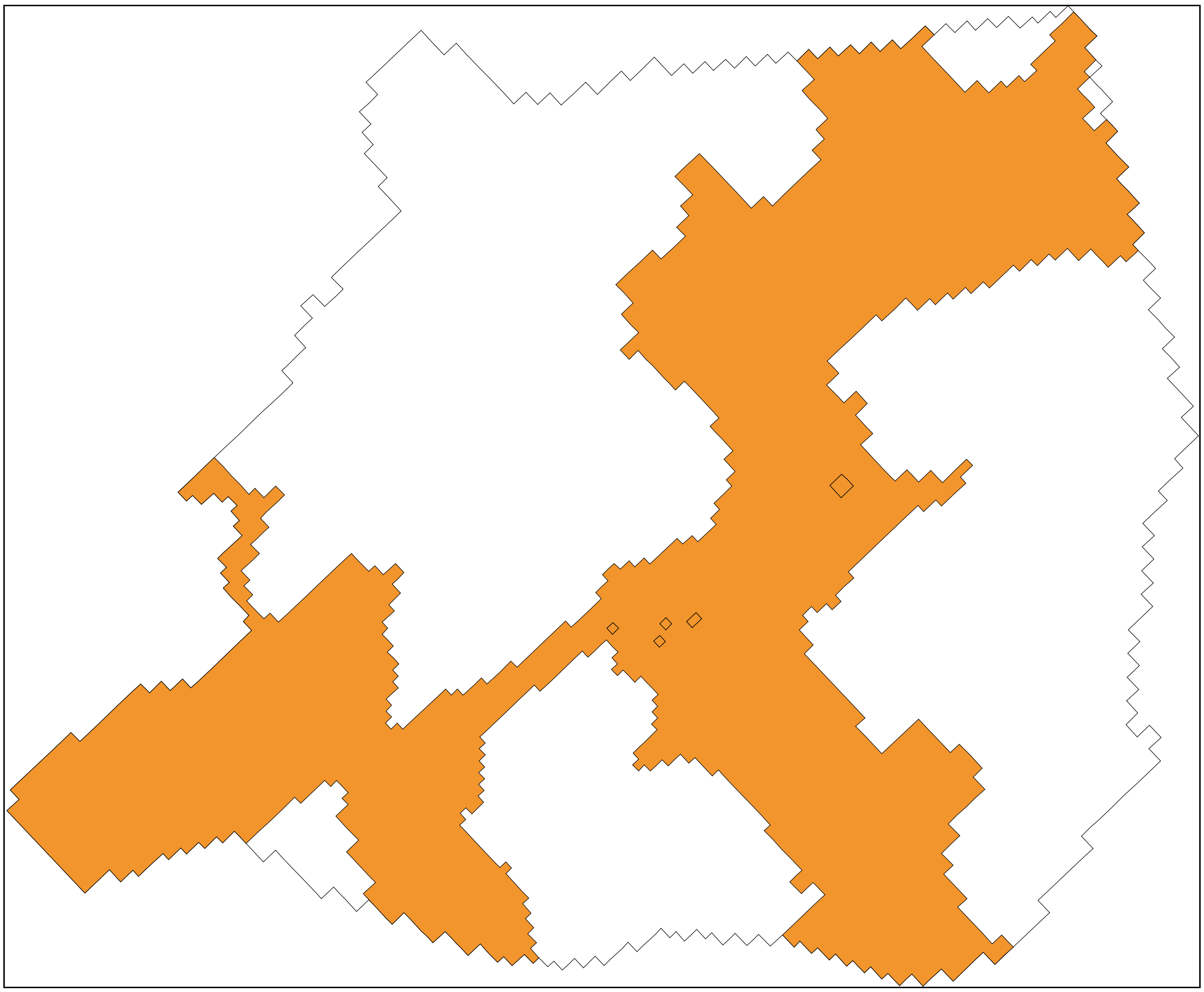
A1 polls (ArcGIS Coverage from Dumouchelle et al. 1993)



A1 pts (ArcGIS Coverage from Dumouchelle et al. 1993)



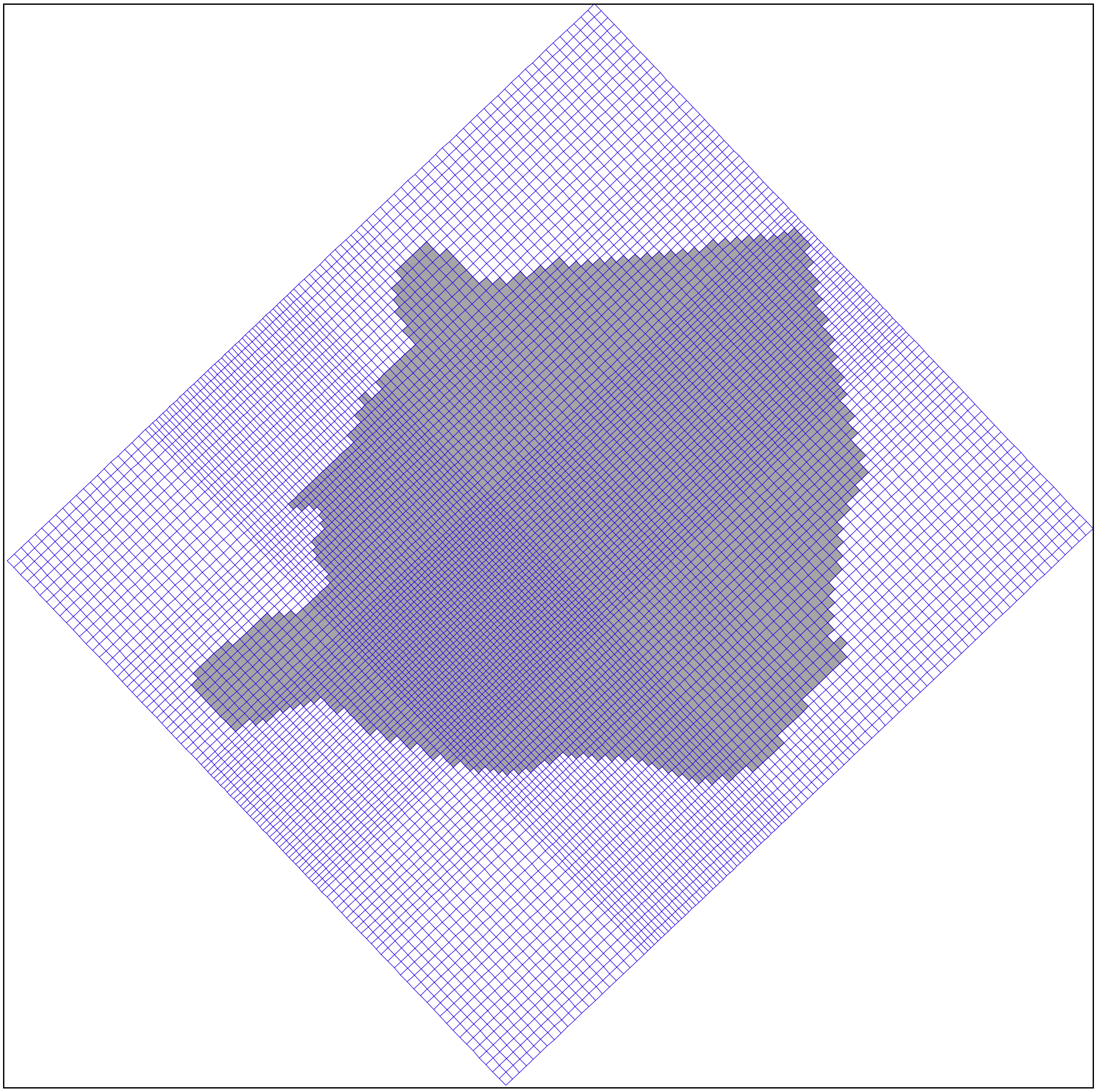
A2pol2 (ArcGIS Coverage from Dumouchelle et al. 1993)



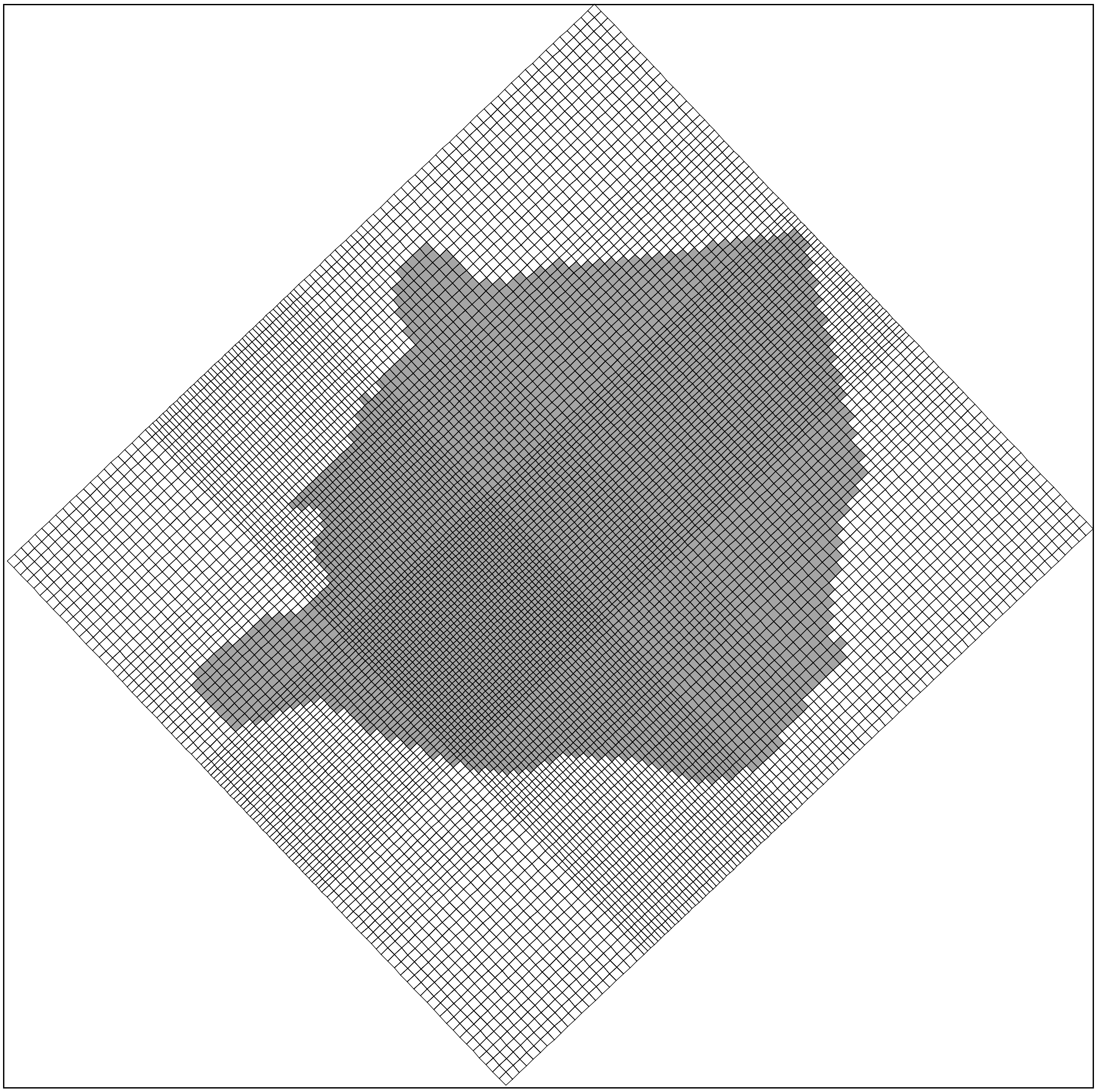
A3pols (ArcGIS Coverage from Dumouchelle et al. 1993)

Boundpts (ArcGIS Coverage from Dumouchelle et al. 1993)

Contact (ArcGIS Coverage from Dumouchelle et al. 1993)

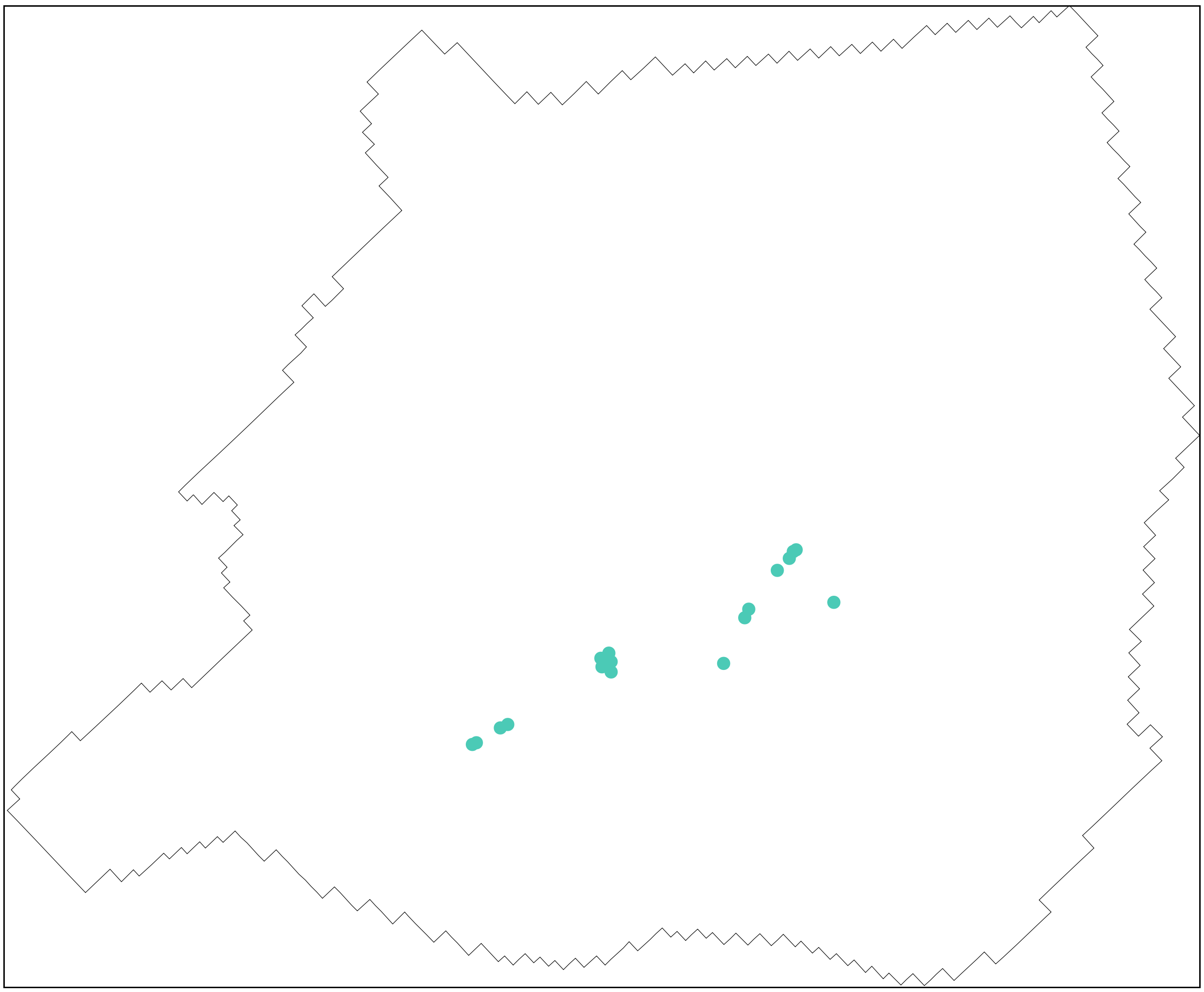


Gridplot (ArcGIS Coverage from Dumouchelle et al. 1993)

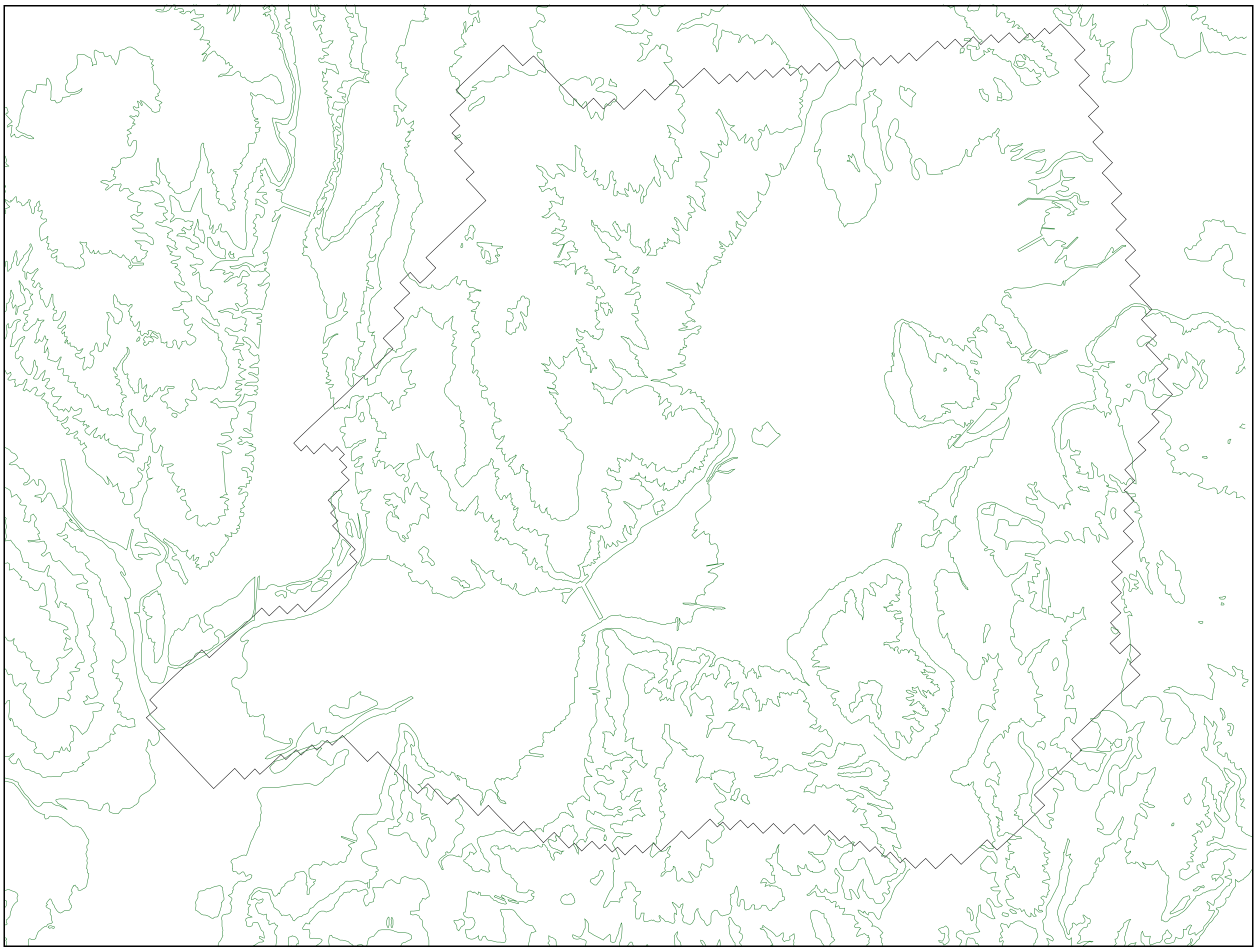


Gridpol (ArcGIS Coverage from Dumouchelle et al. 1993)

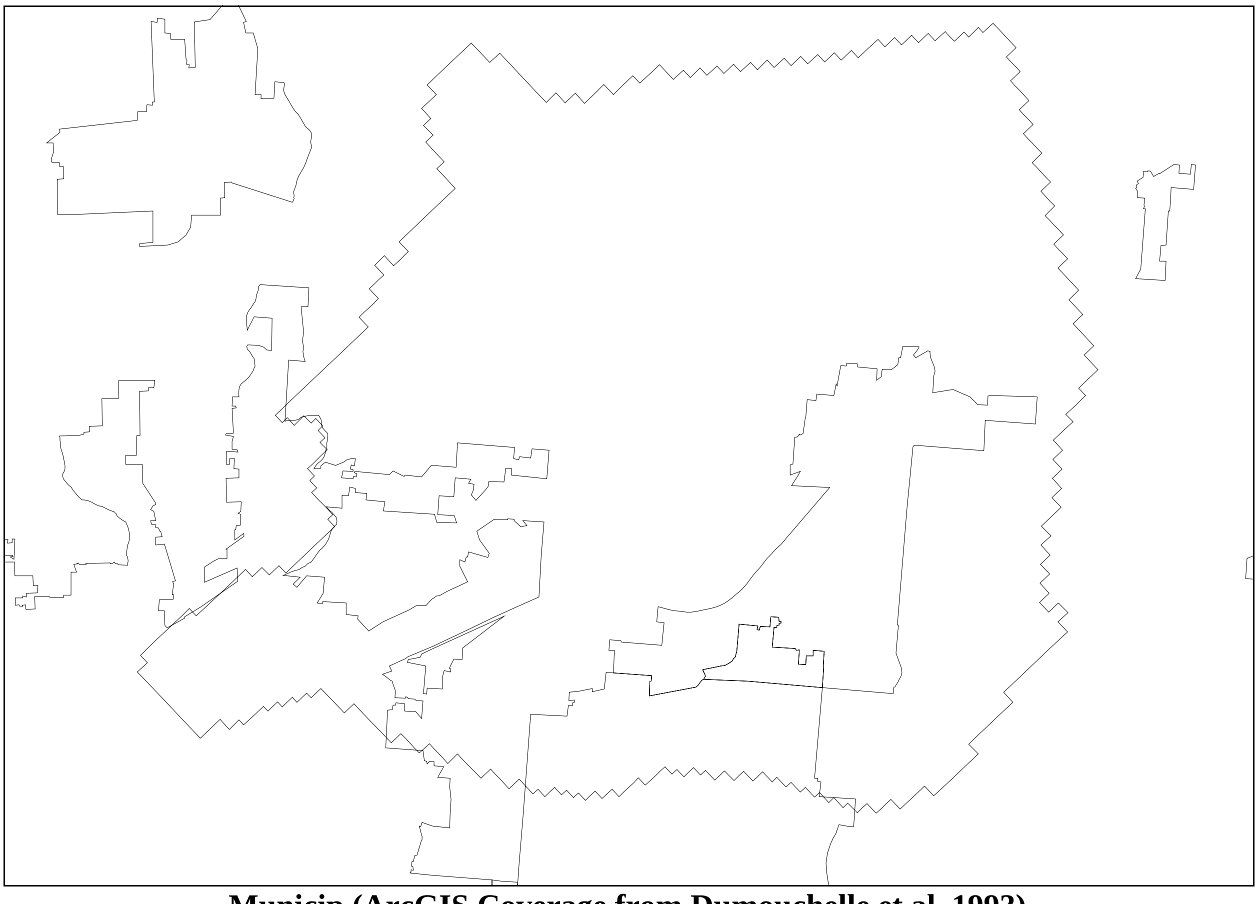
Gslinewri (ArcGIS Coverage from Dumouchelle et al. 1993)



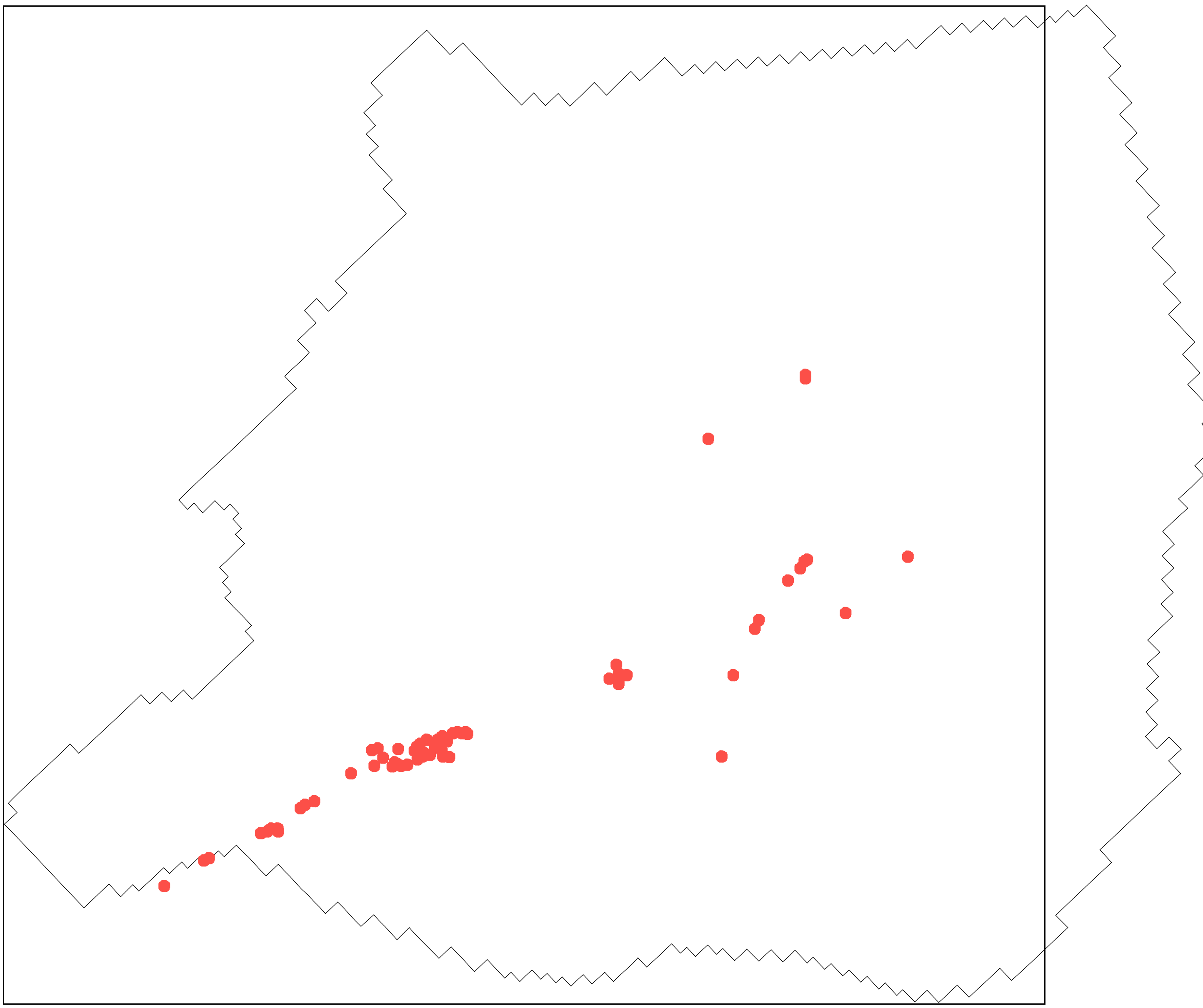
Histwell (ArcGIS Coverage from Dumouchelle et al. 1993)



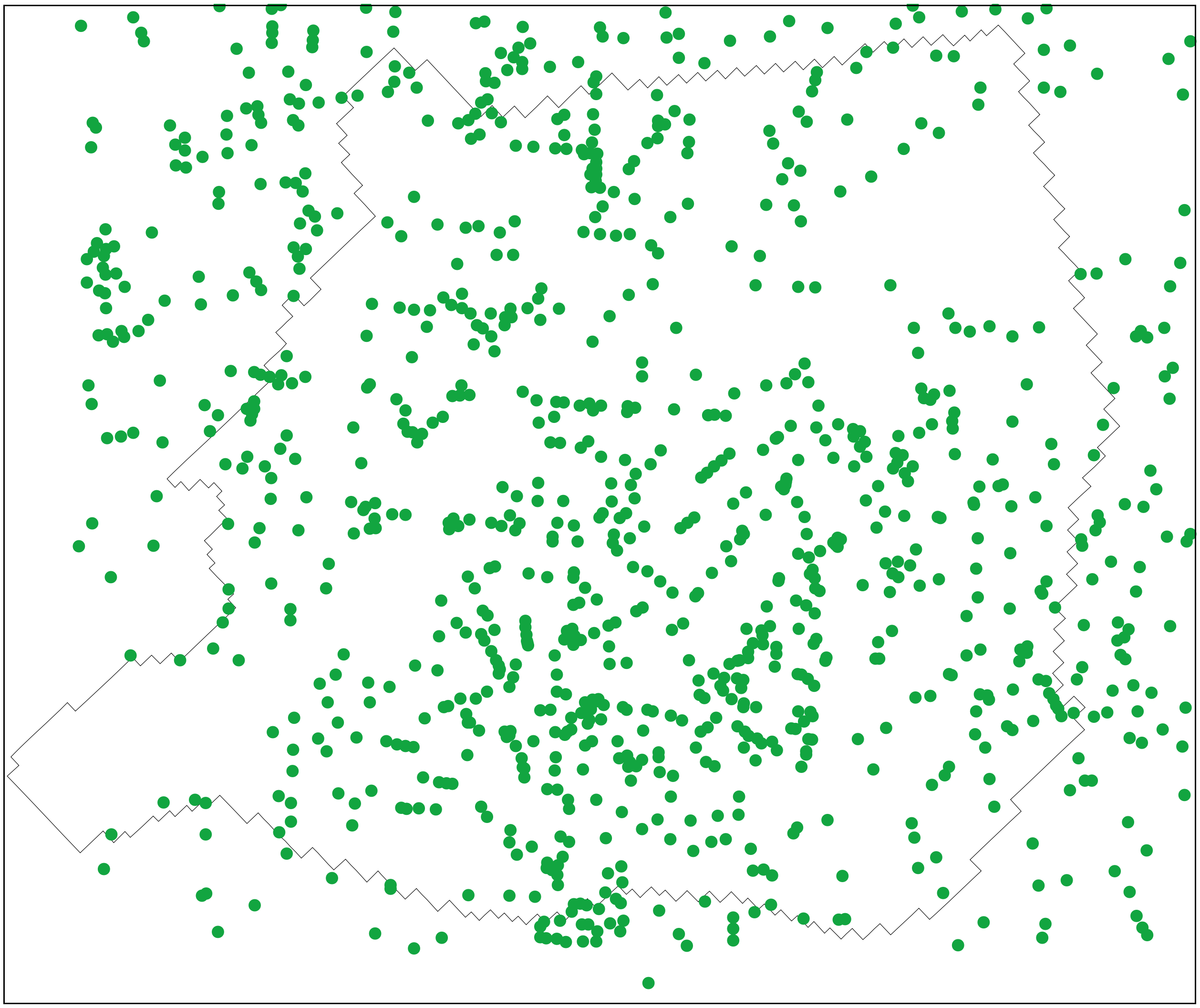
Land (ArcGIS Coverage from Dumouchelle et al. 1993)



Municip (ArcGIS Coverage from Dumouchelle et al. 1993)

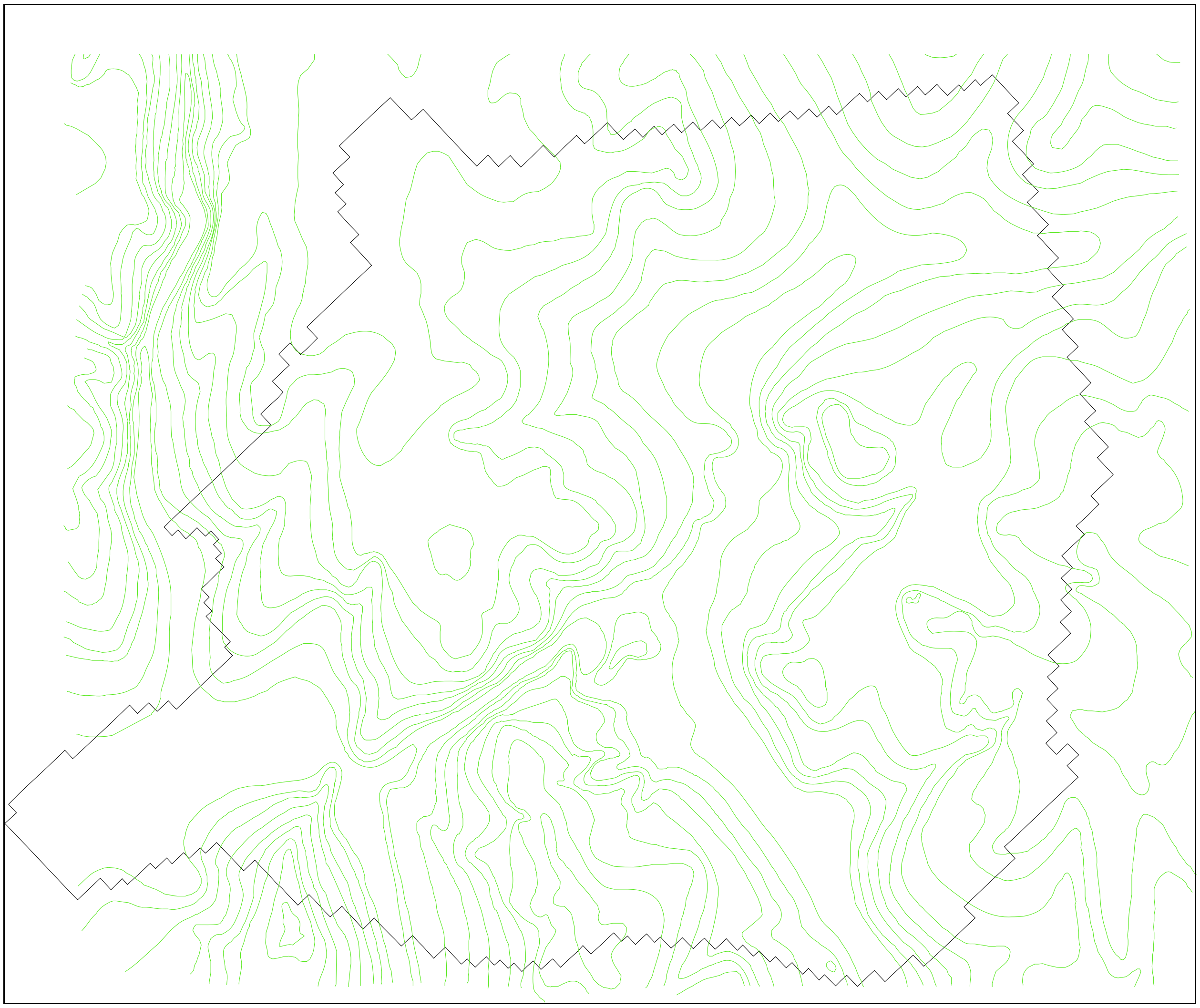


Pwell (ArcGIS Coverage from Dumouchelle et al. 1993)



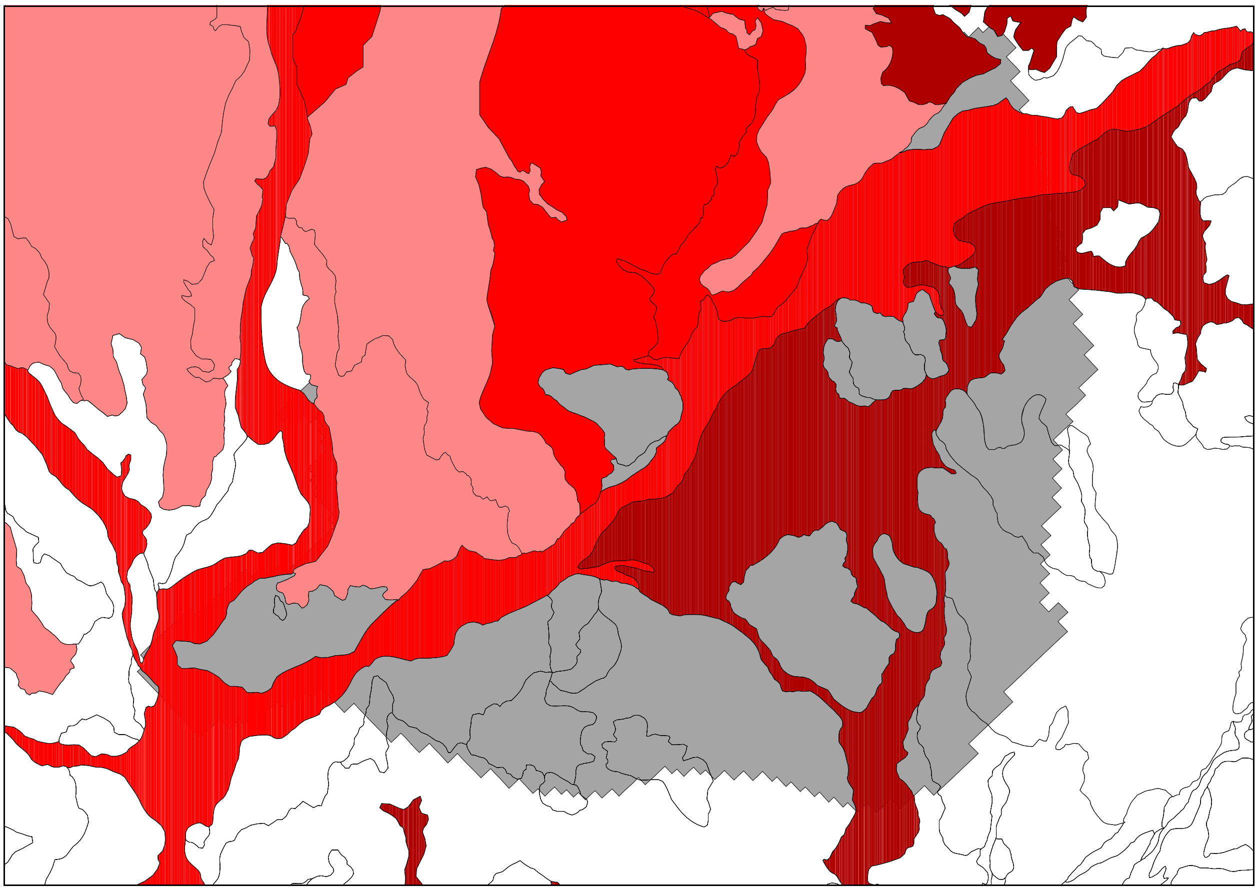
Rckpts (ArcGIS Coverage from Dumouchelle et al. 1993)

Roads (ArcGIS Coverage from Dumouchelle et al. 1993)



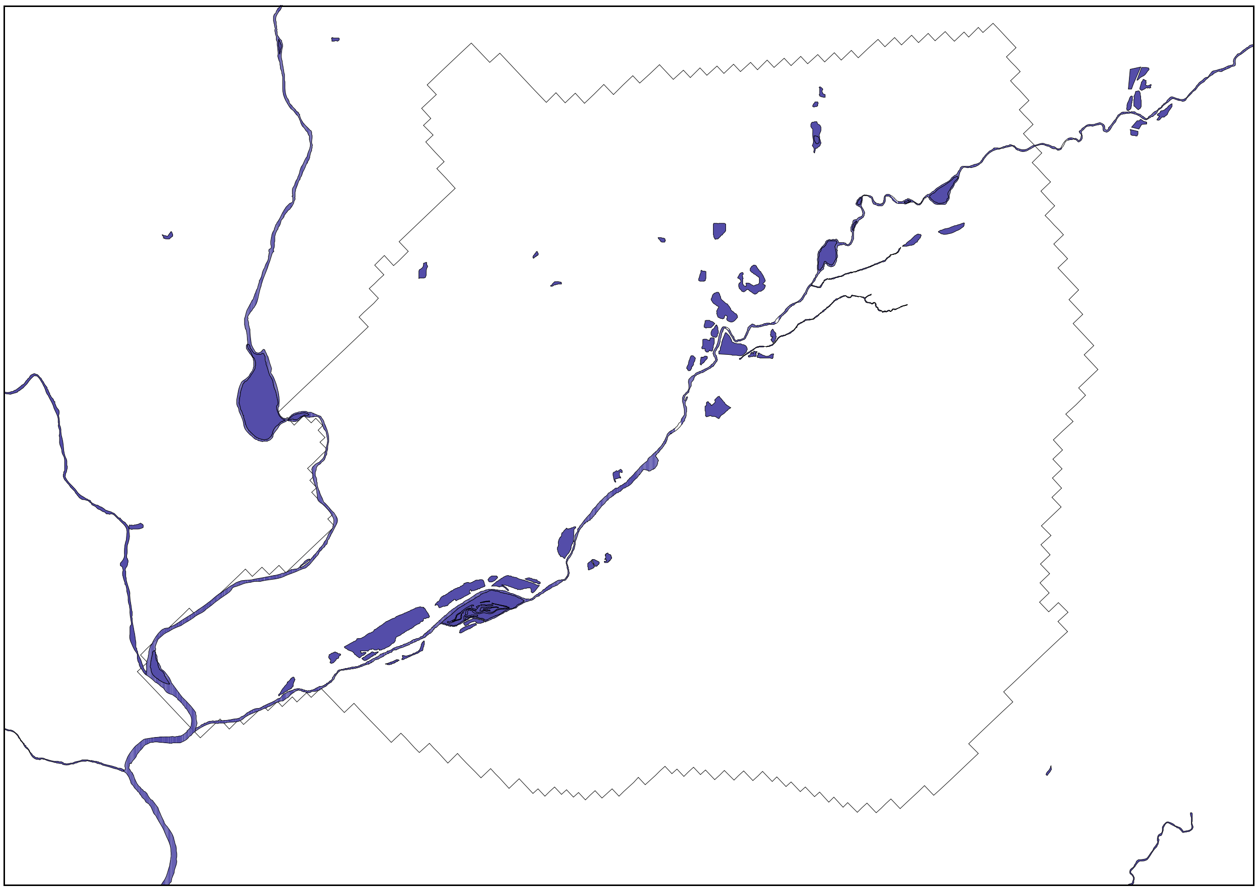
Rock (ArcGIS Coverage from Dumouchelle et al. 1993)

Simclp2 (ArcGIS Coverage from Dumouchelle et al. 1993)

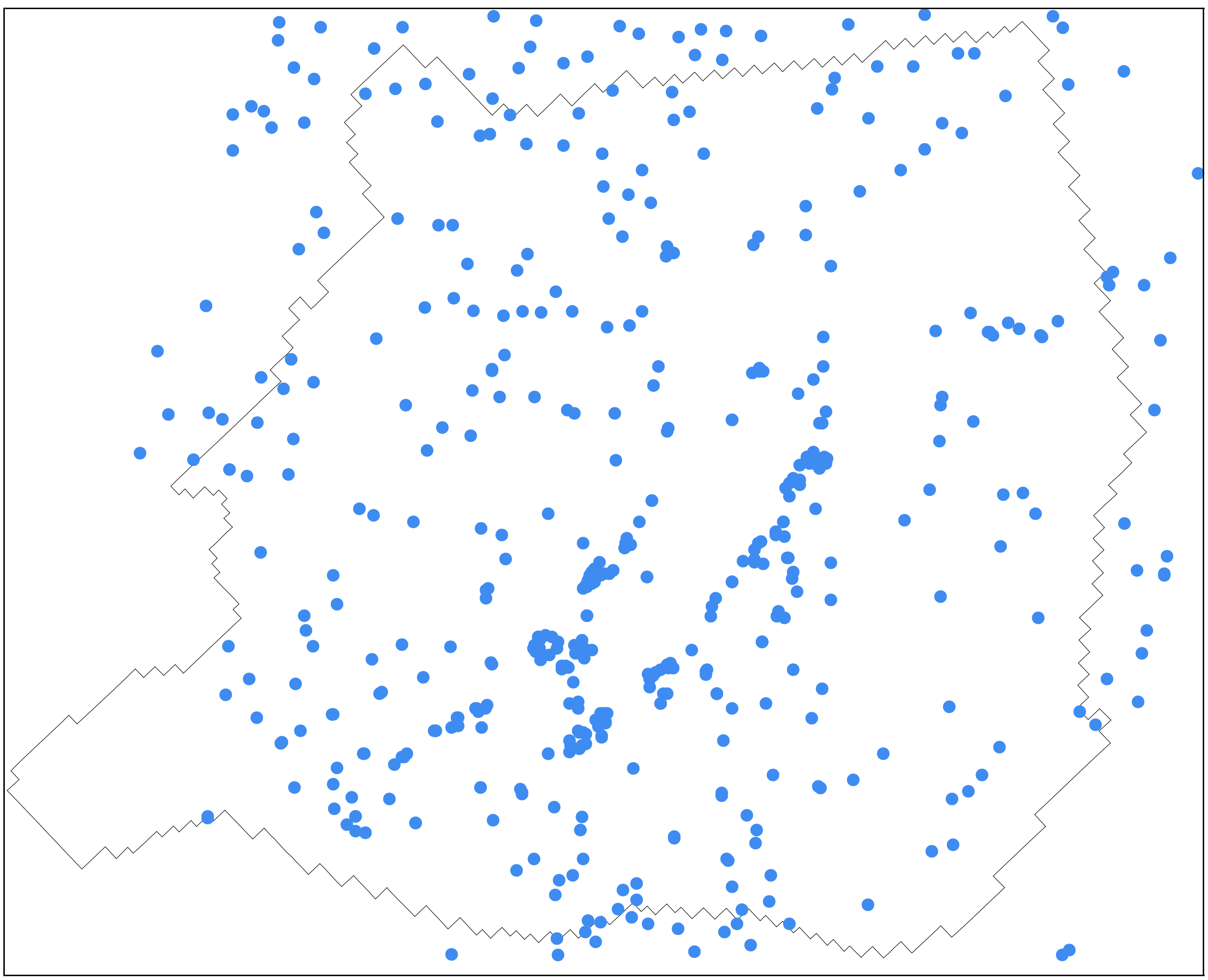


Soils (ArcGIS Coverage from Dumouchelle et al. 1993)

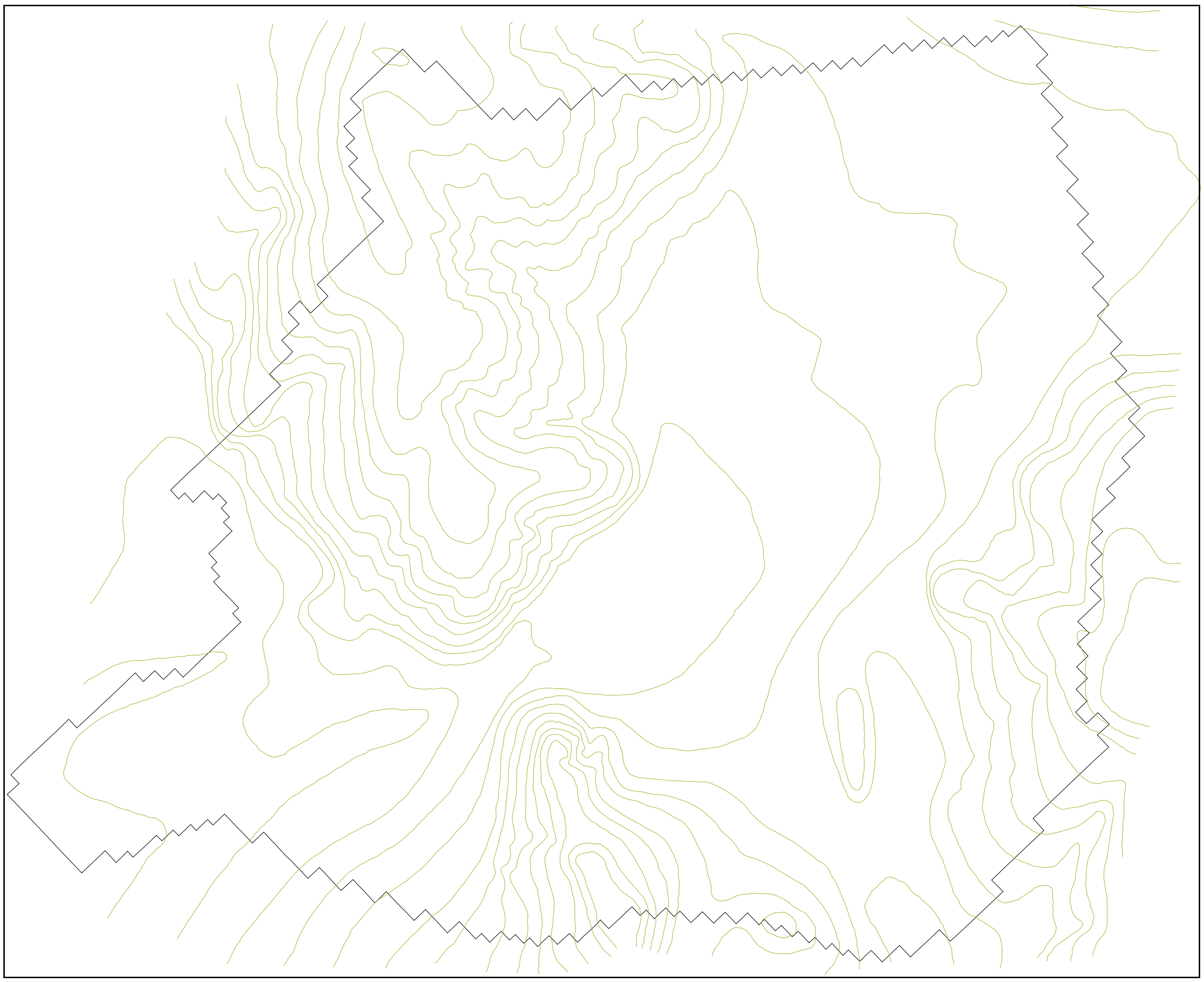
Starea (ArcGIS Coverage from Dumouchelle et al. 1993)



Swat (ArcGIS Coverage from Dumouchelle et al. 1993)



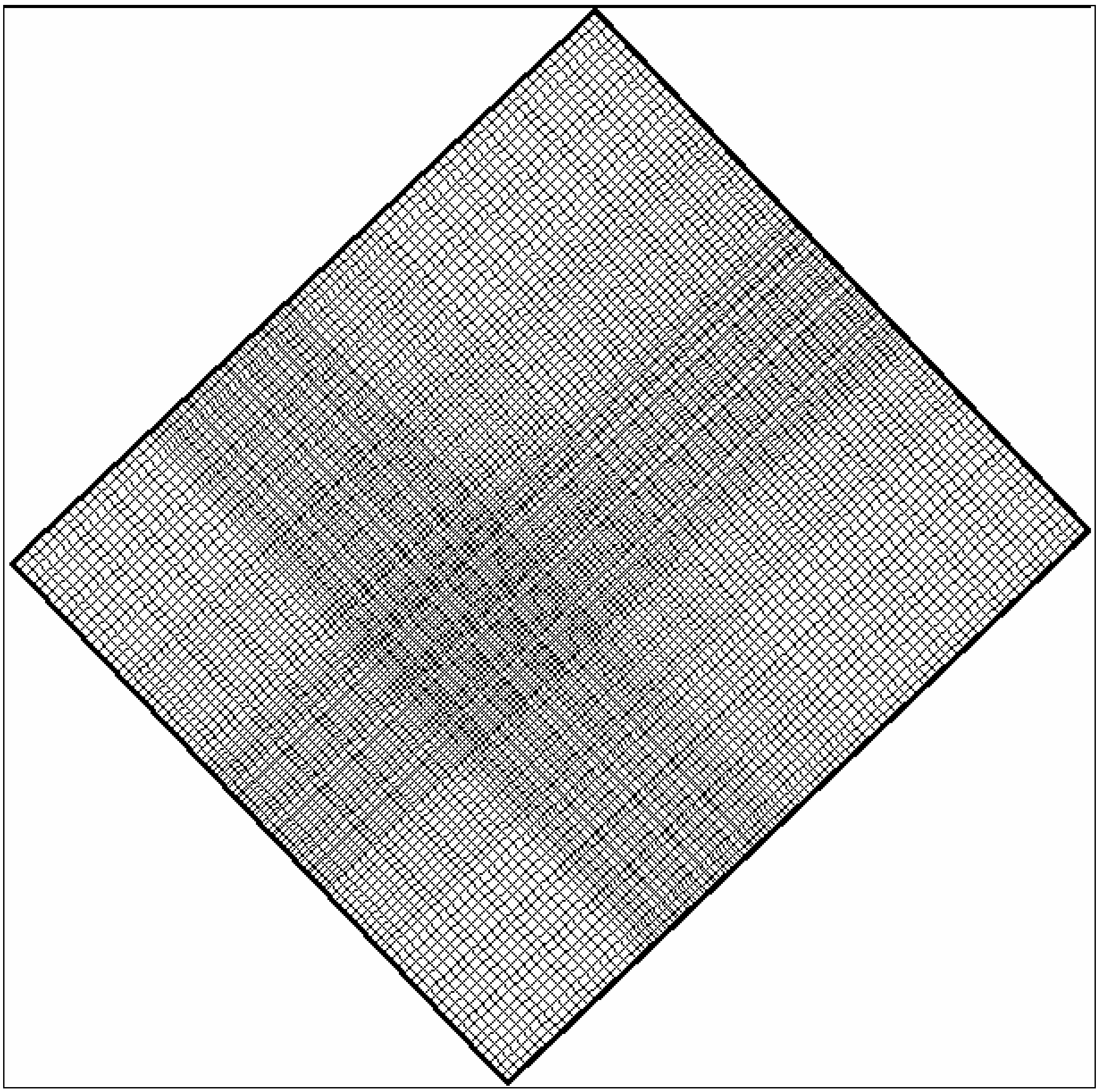
Wells (ArcGIS Coverage from Dumouchelle et al. 1993)



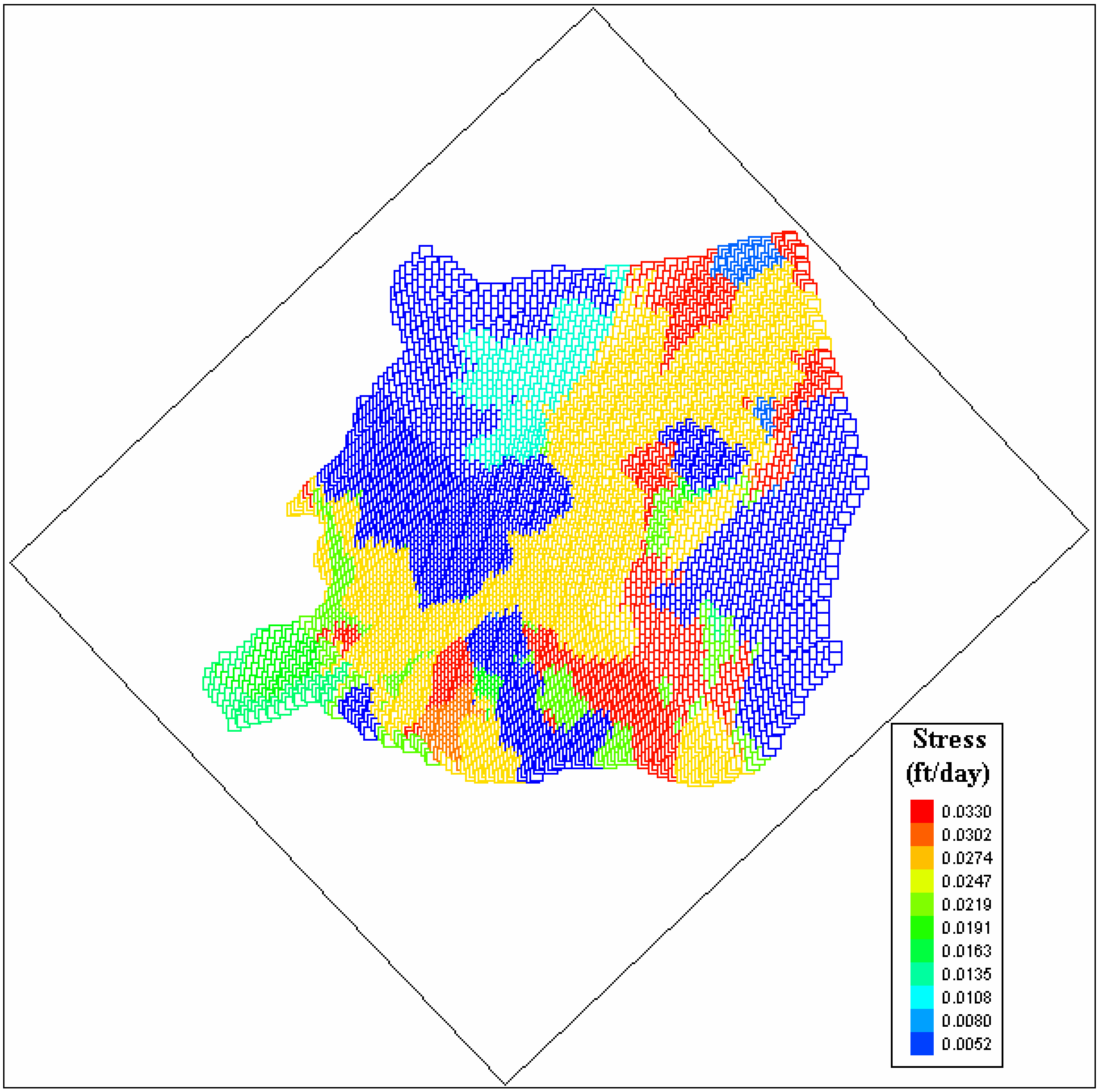
Wpwt (ArcGIS Coverage from Dumouchelle et al. 1993)

APPENDIX H

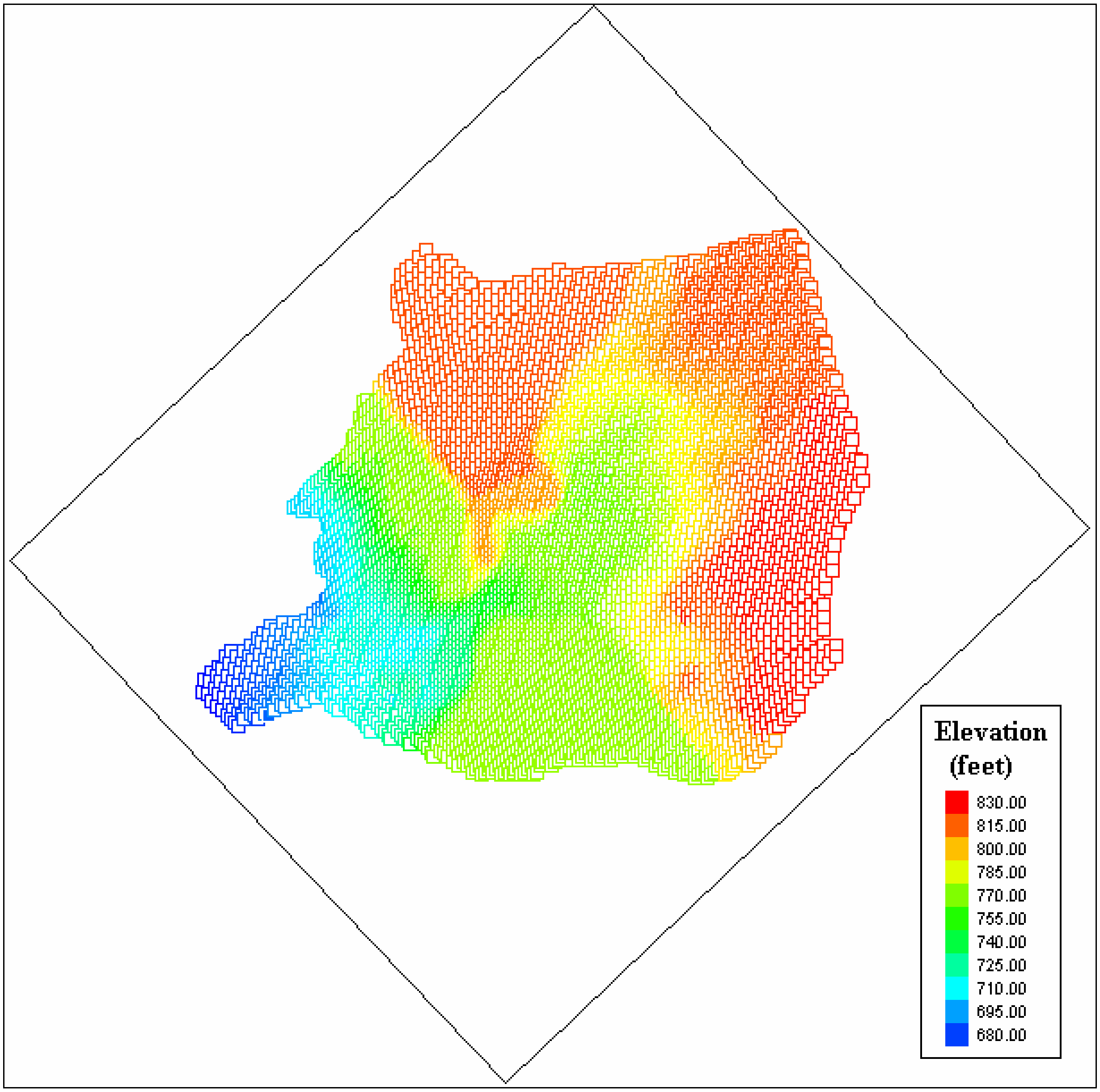
WPAFB MODFLOW INPUT PARAMETERS



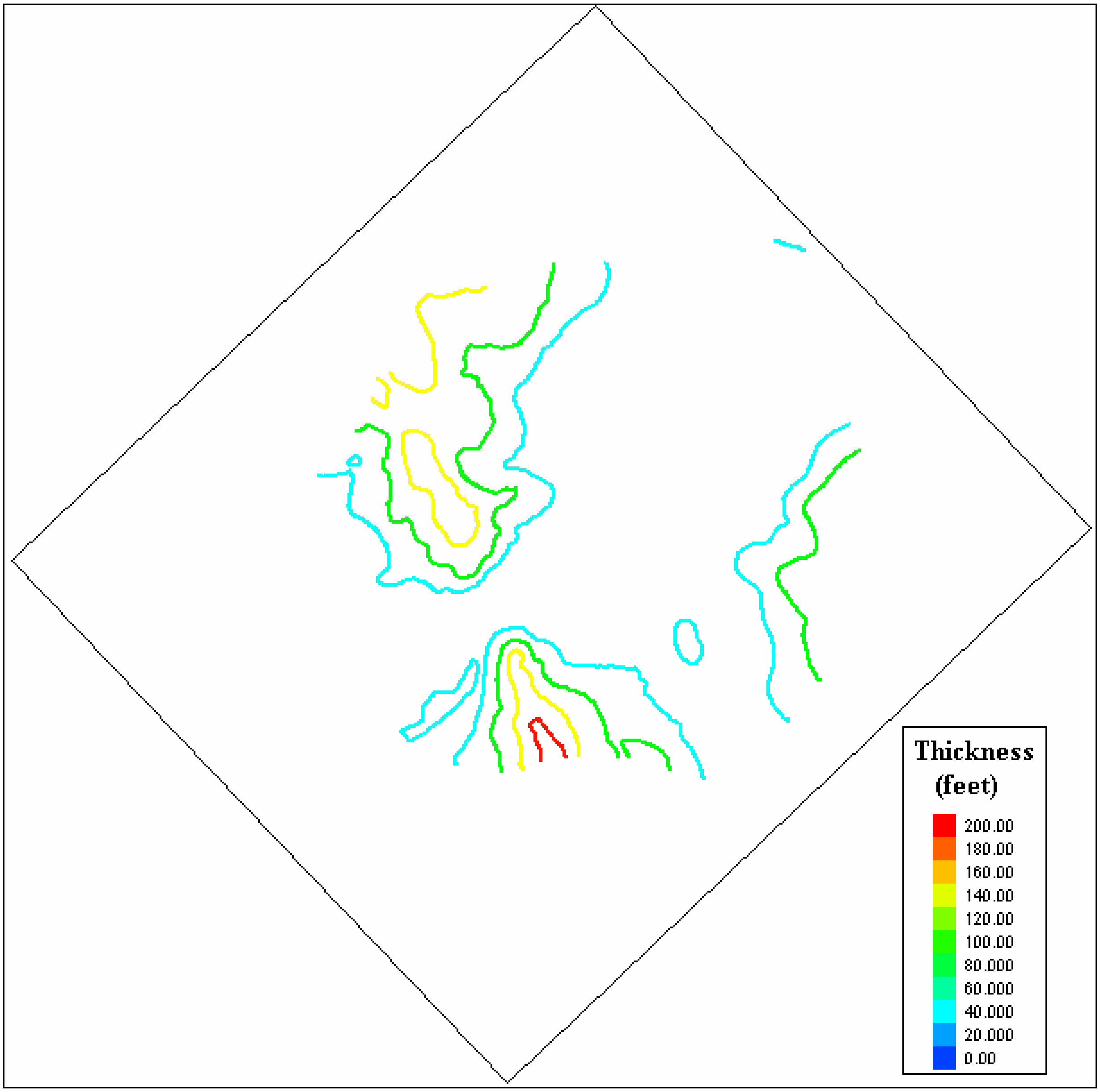
Grid and Domain Outline (Adapted from Dumouchelle et al. 1993)



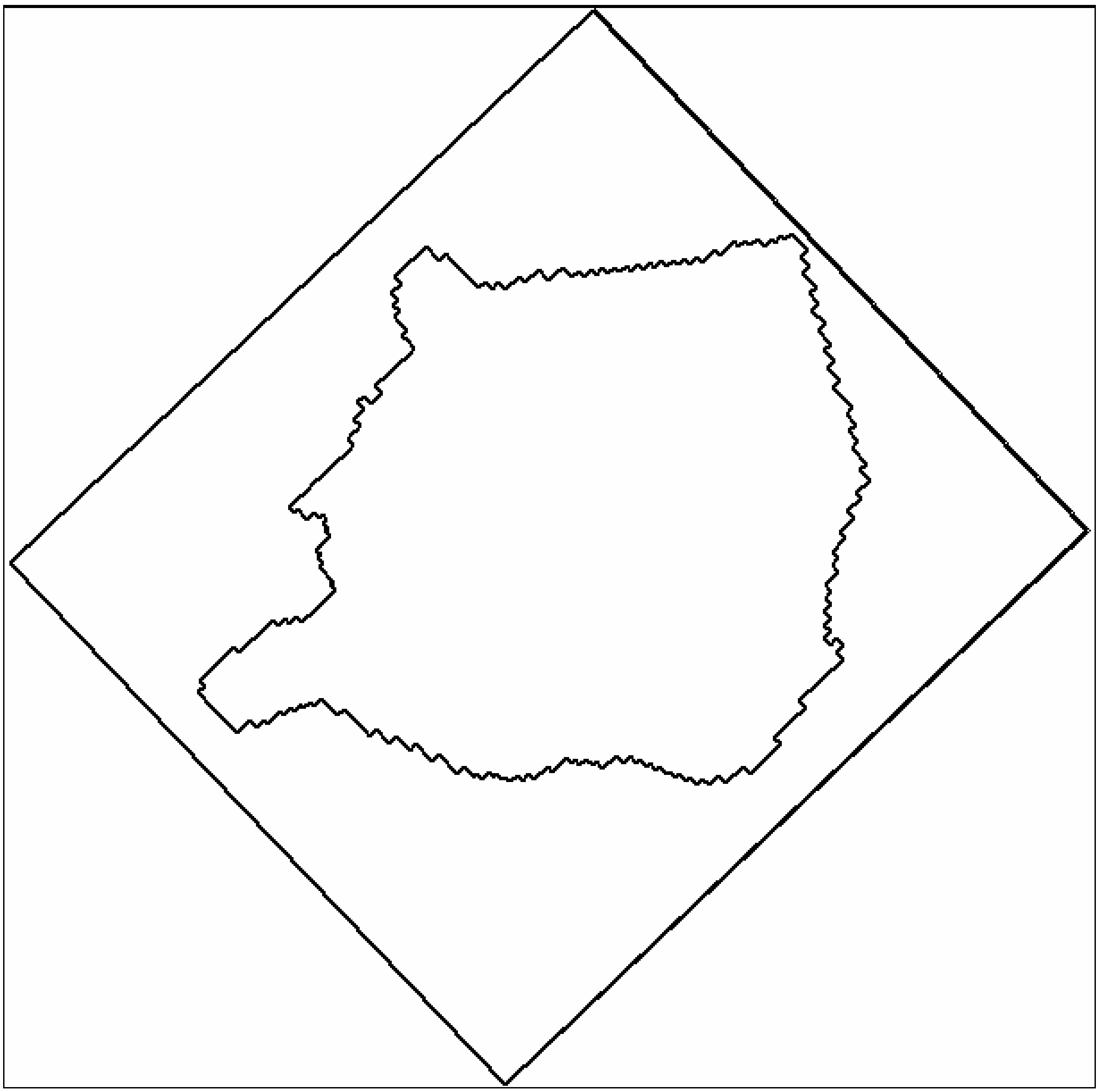
Recharge (Adapted from Dumouchelle et al. 1993)



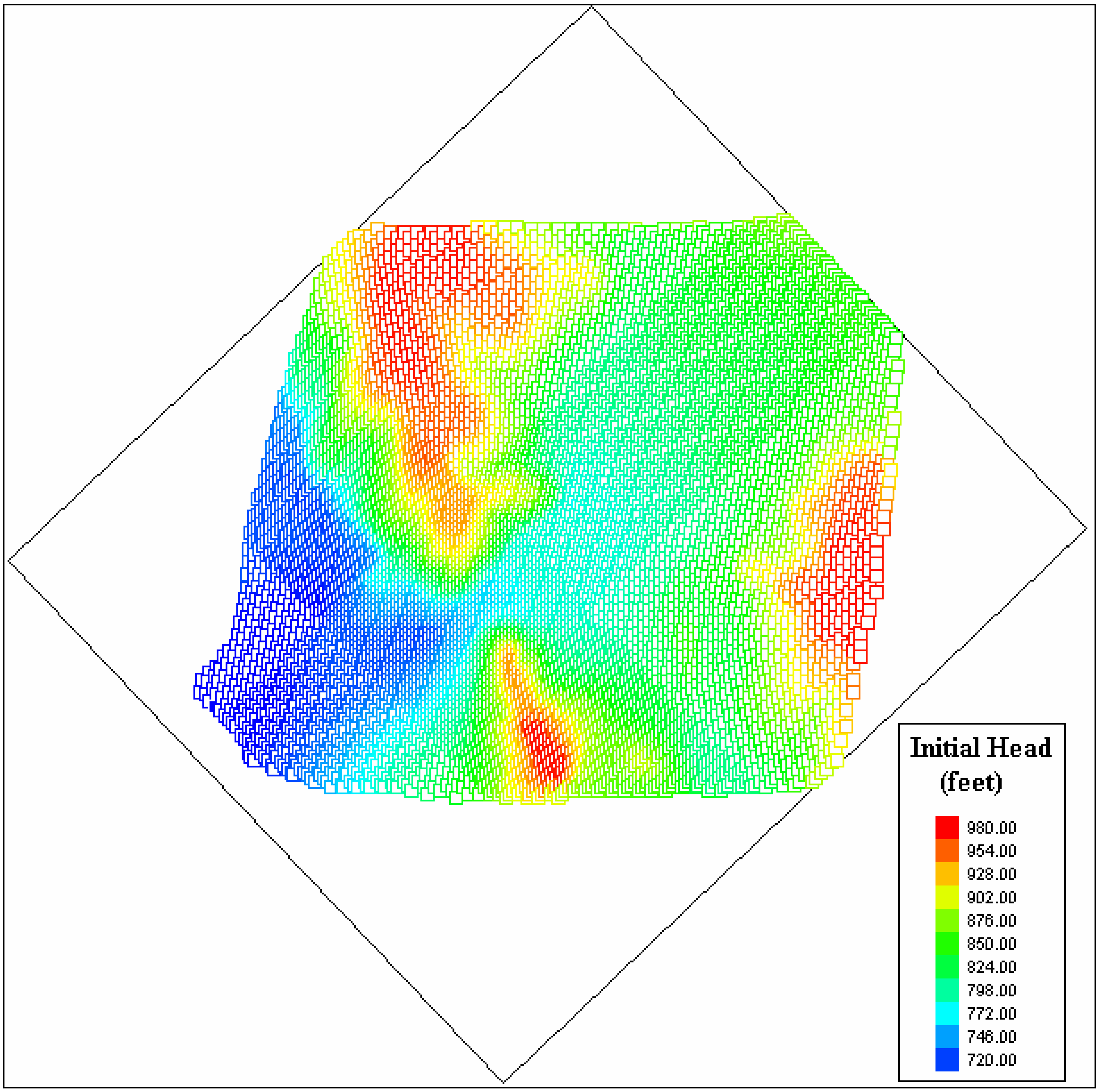
Bottom Elevation (Adapted from Dumouchelle et al. 1993)



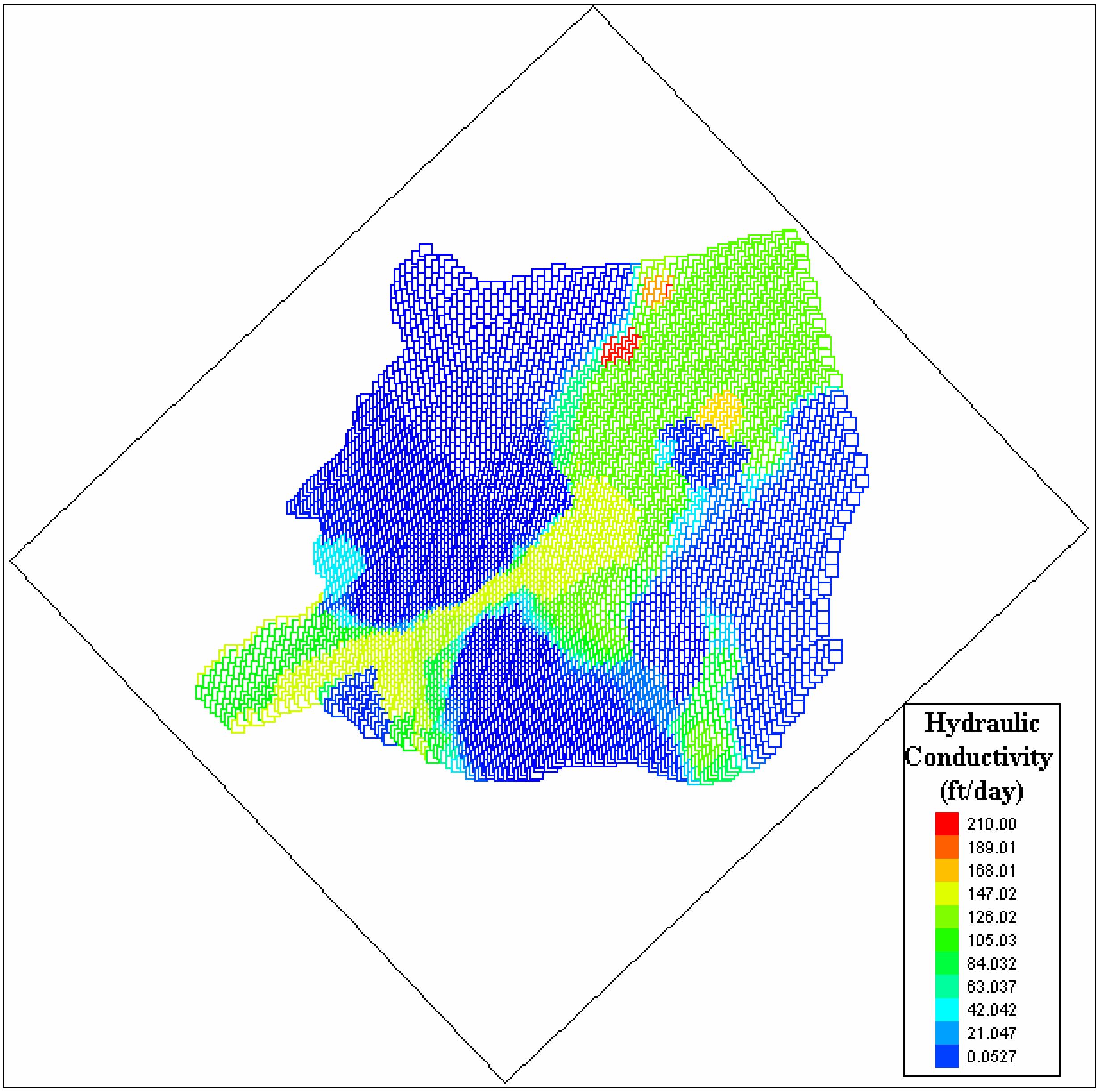
Thickness (Adapted from Dumouchelle et al. 1993)



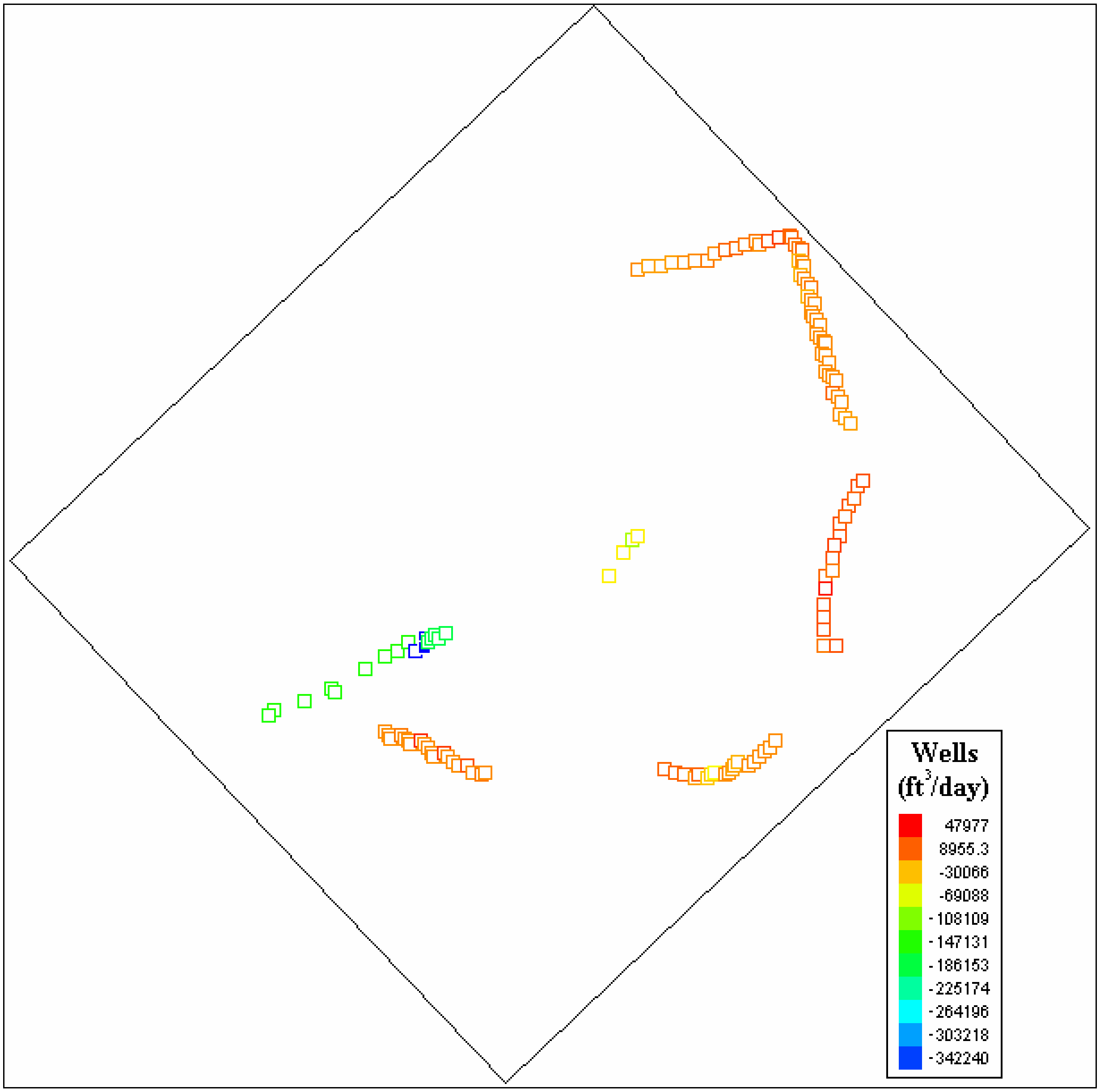
Added Inactive Area (Adapted from Dumouchelle et al. 1993)



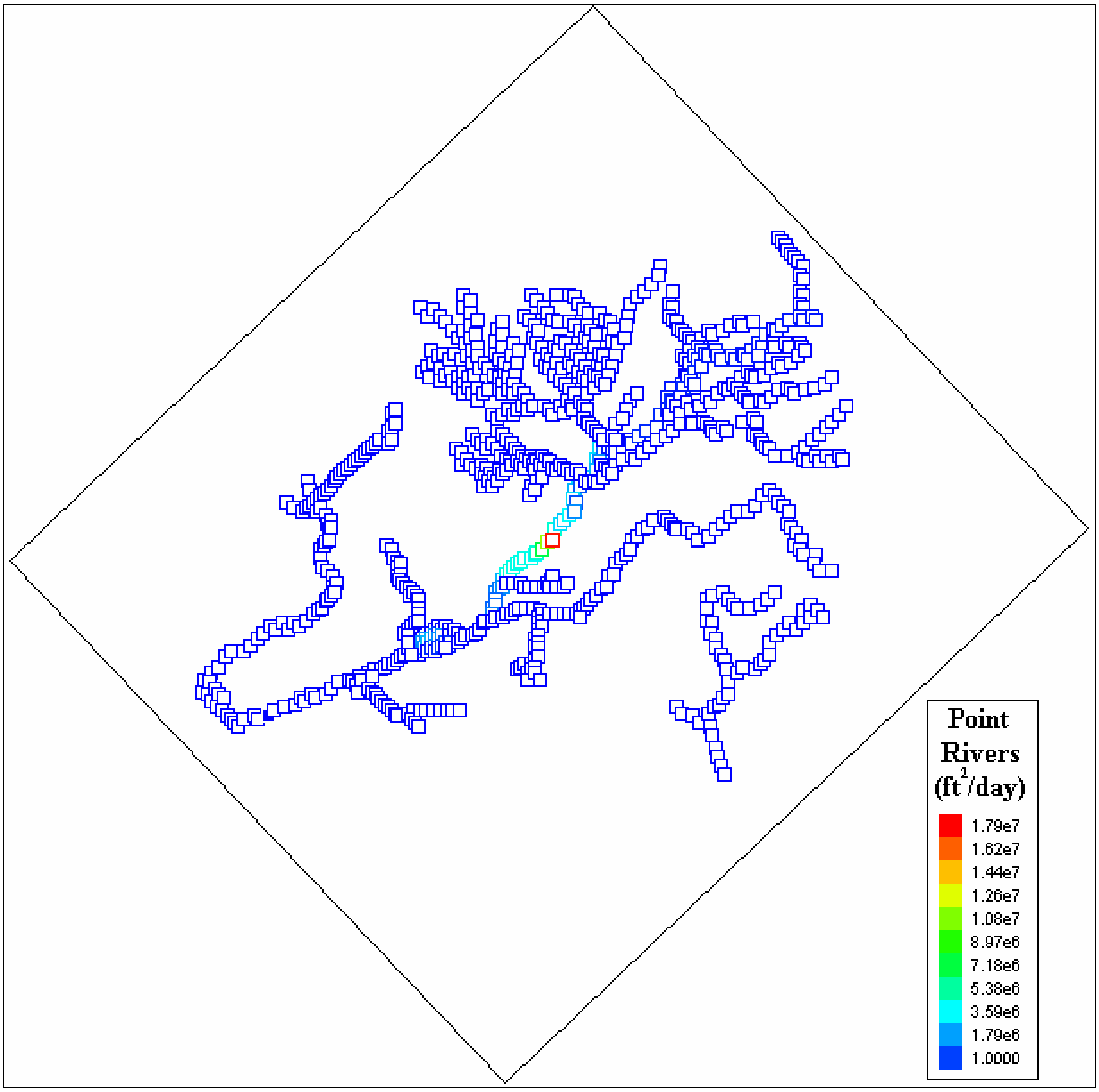
Initial Head (Adapted from Dumouchelle et al. 1993)



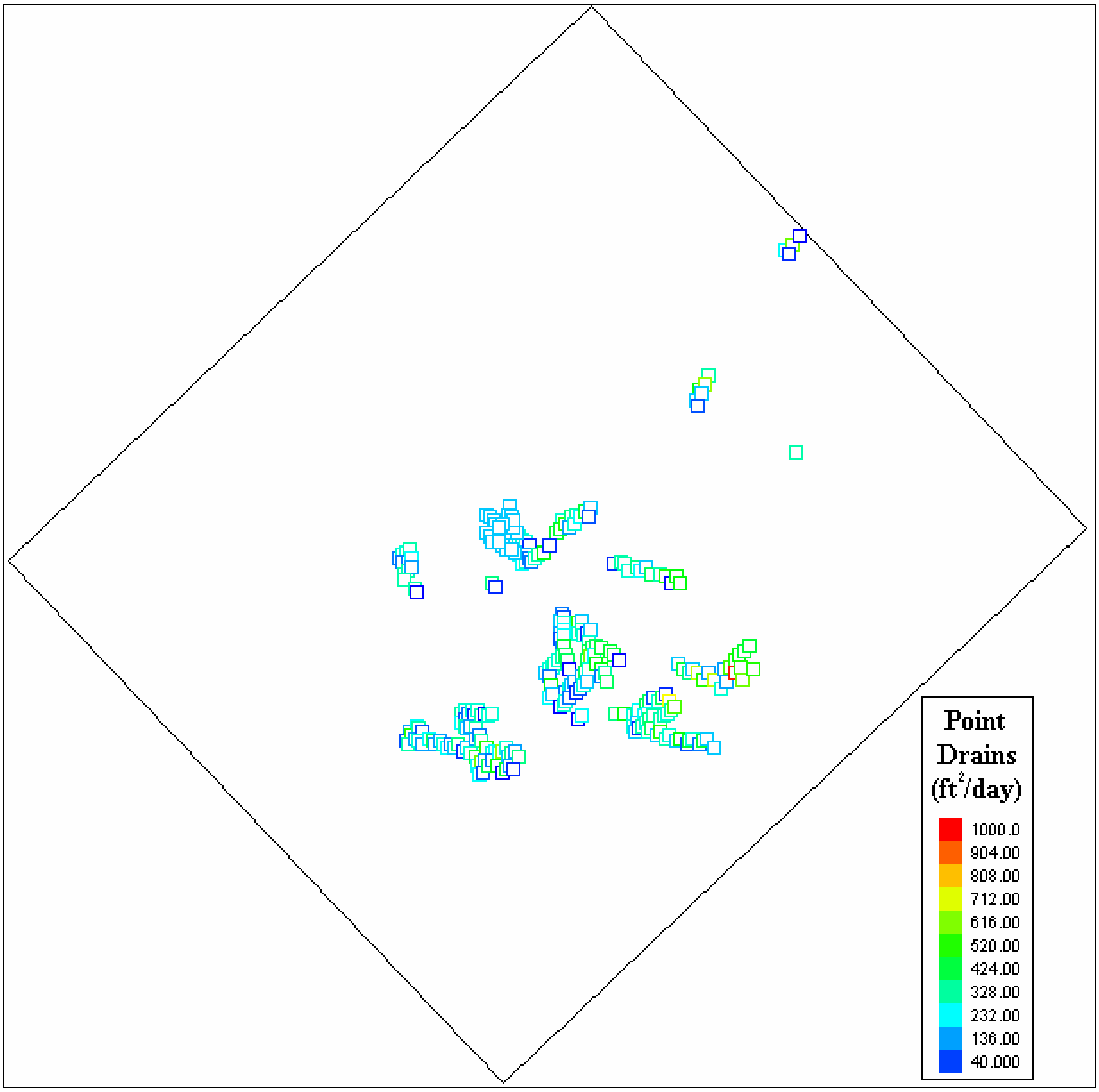
Hydraulic Conductivity (Adapted from Dumouchelle et al. 1993)



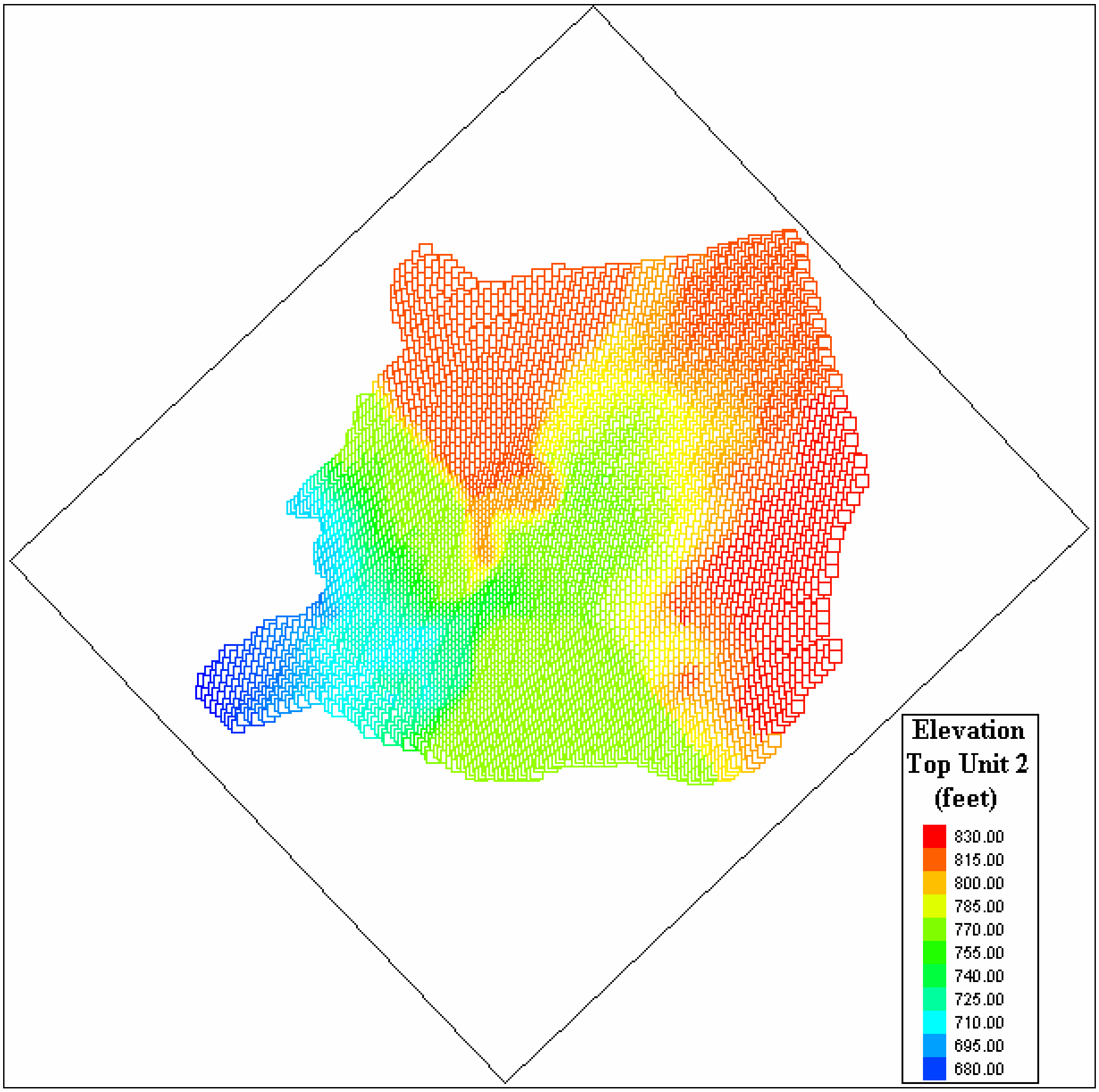
Well Stress (Adapted from Dumouchelle et al. 1993)



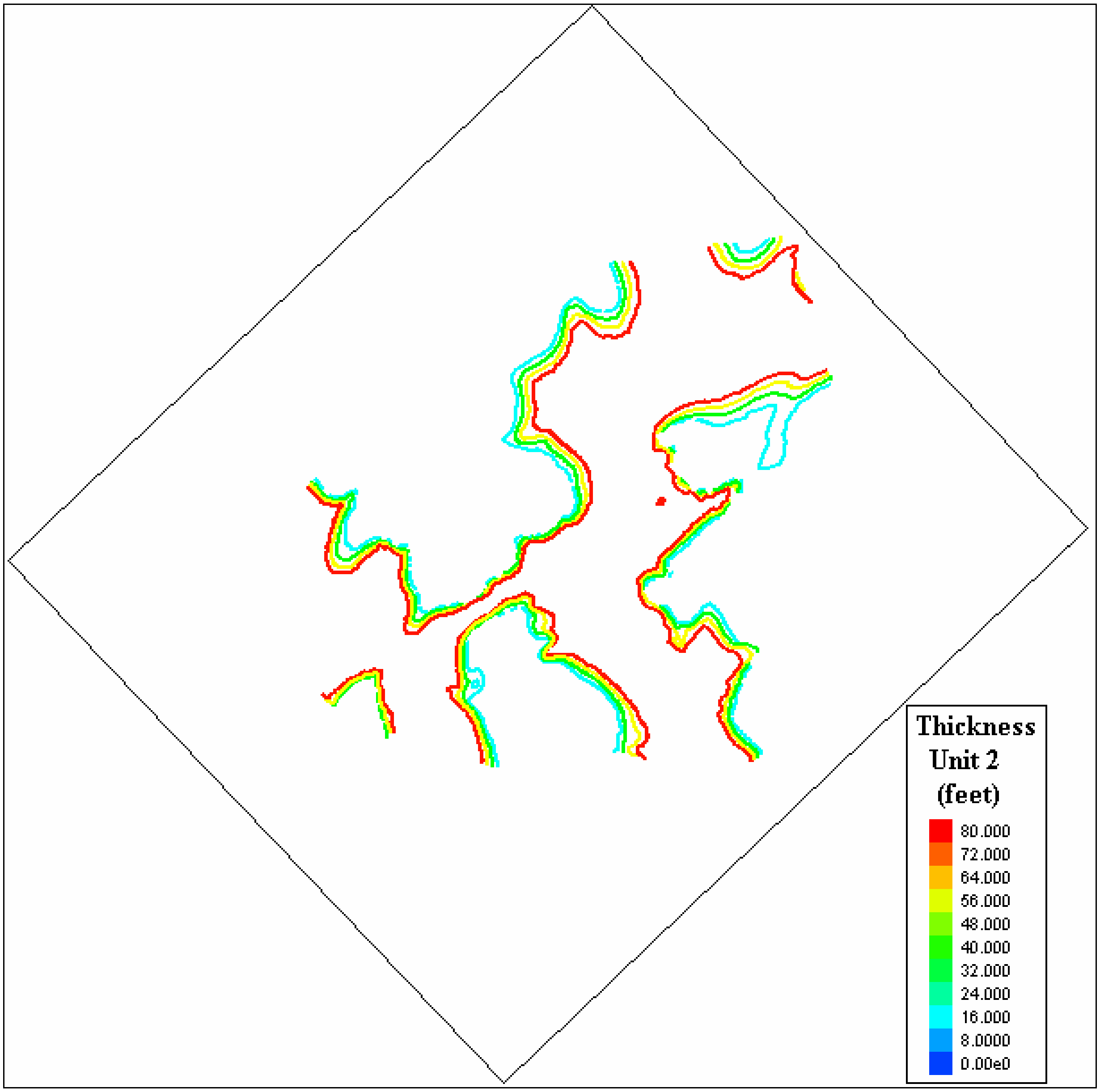
Point River Conductance (Adapted from Dumouchelle et al. 1993)



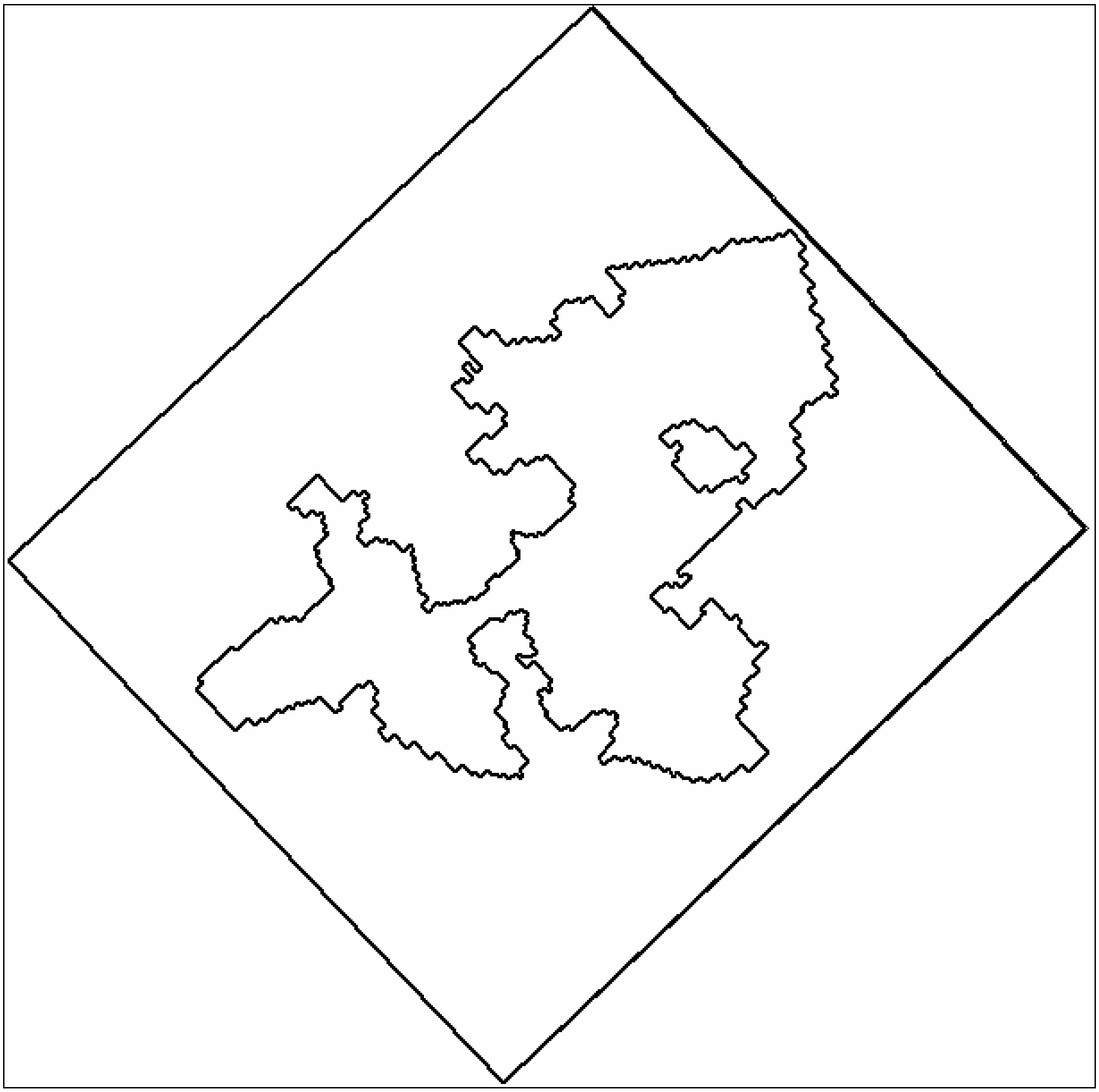
Point Drain Conductance (Adapted from Dumouchelle et al. 1993)



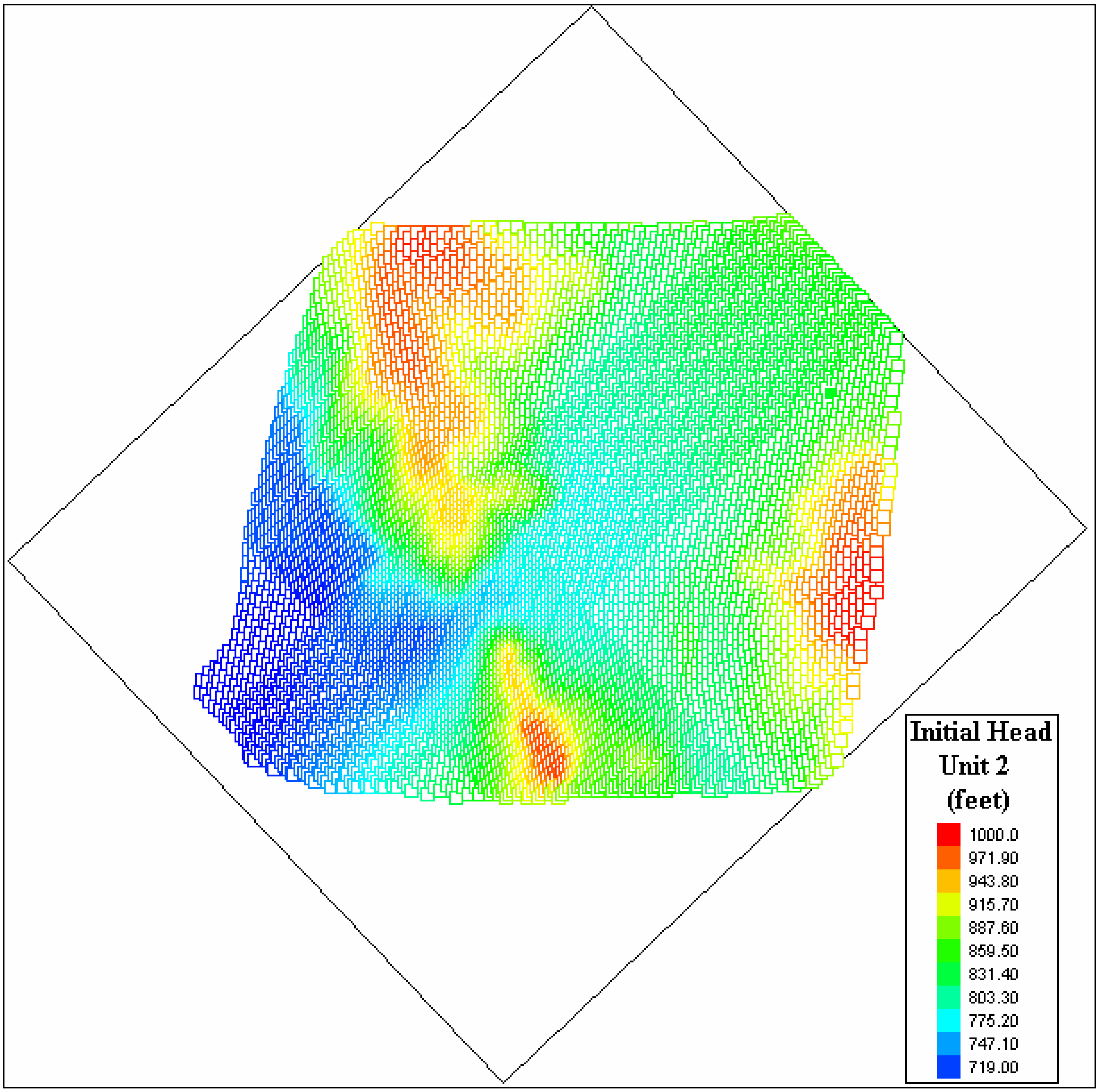
Elevation Top Unit 2 (Adapted from Dumouchelle et al. 1993)



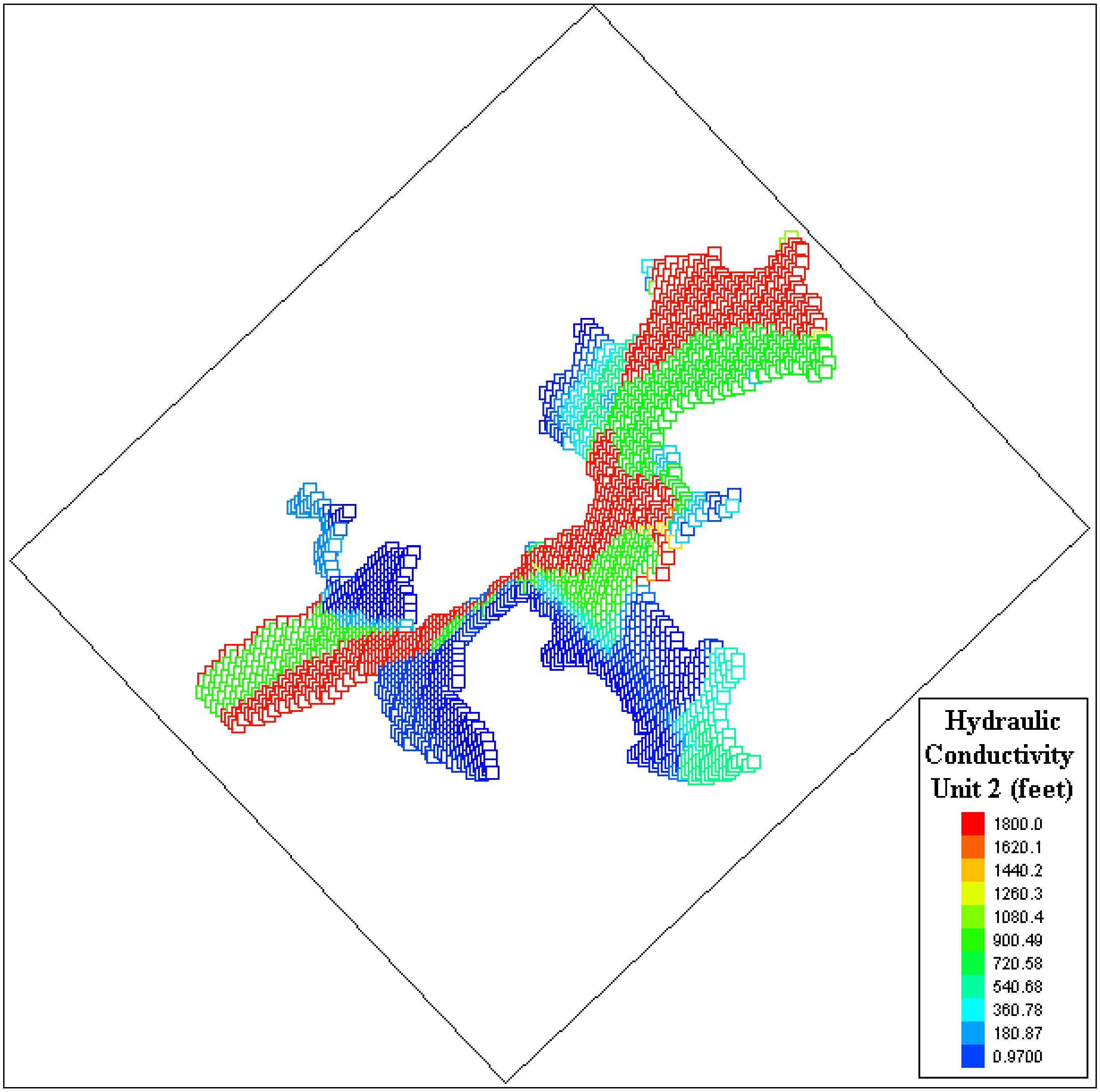
Thickness Unit 2 (Adapted from Dumouchelle et al. 1993)



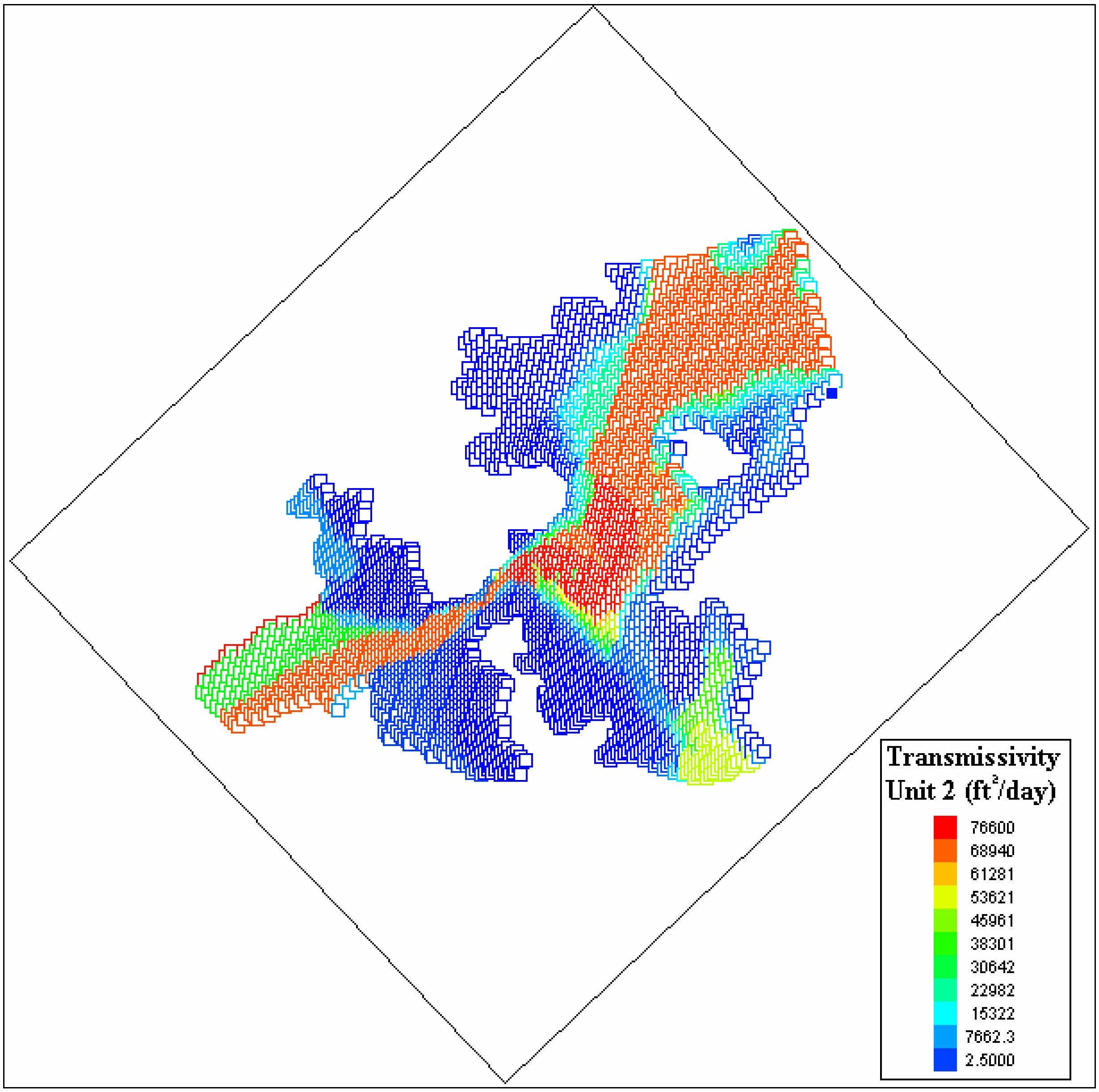
Added Inactive Area Unit 2 (Adapted from Dumouchelle et al. 1993)



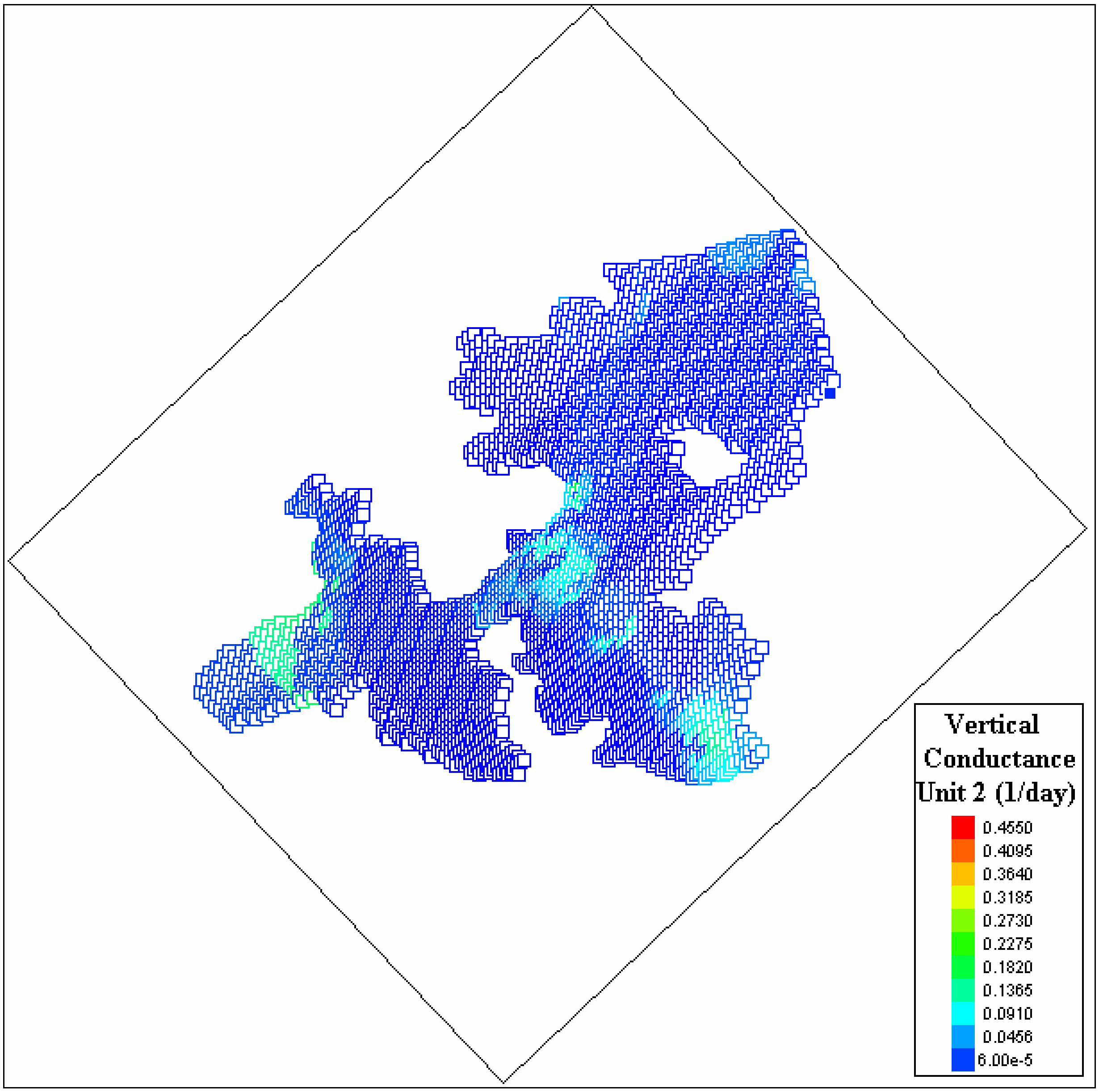
Initial Head Unit 2 (Adapted from Dumouchelle et al. 1993)



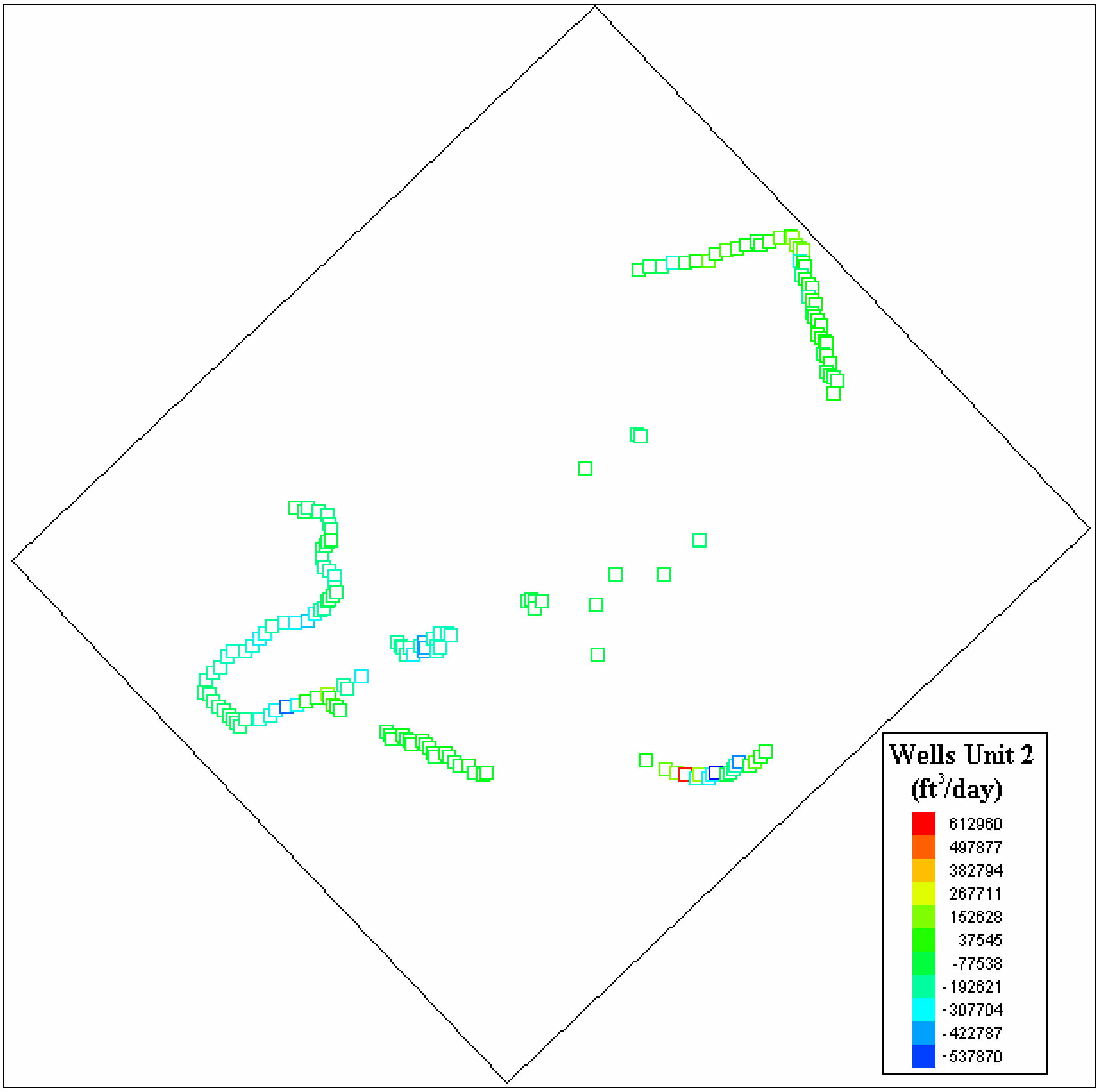
Hydraulic Conductivity Unit 2 (Adapted from Dumouchelle et al. 1993)



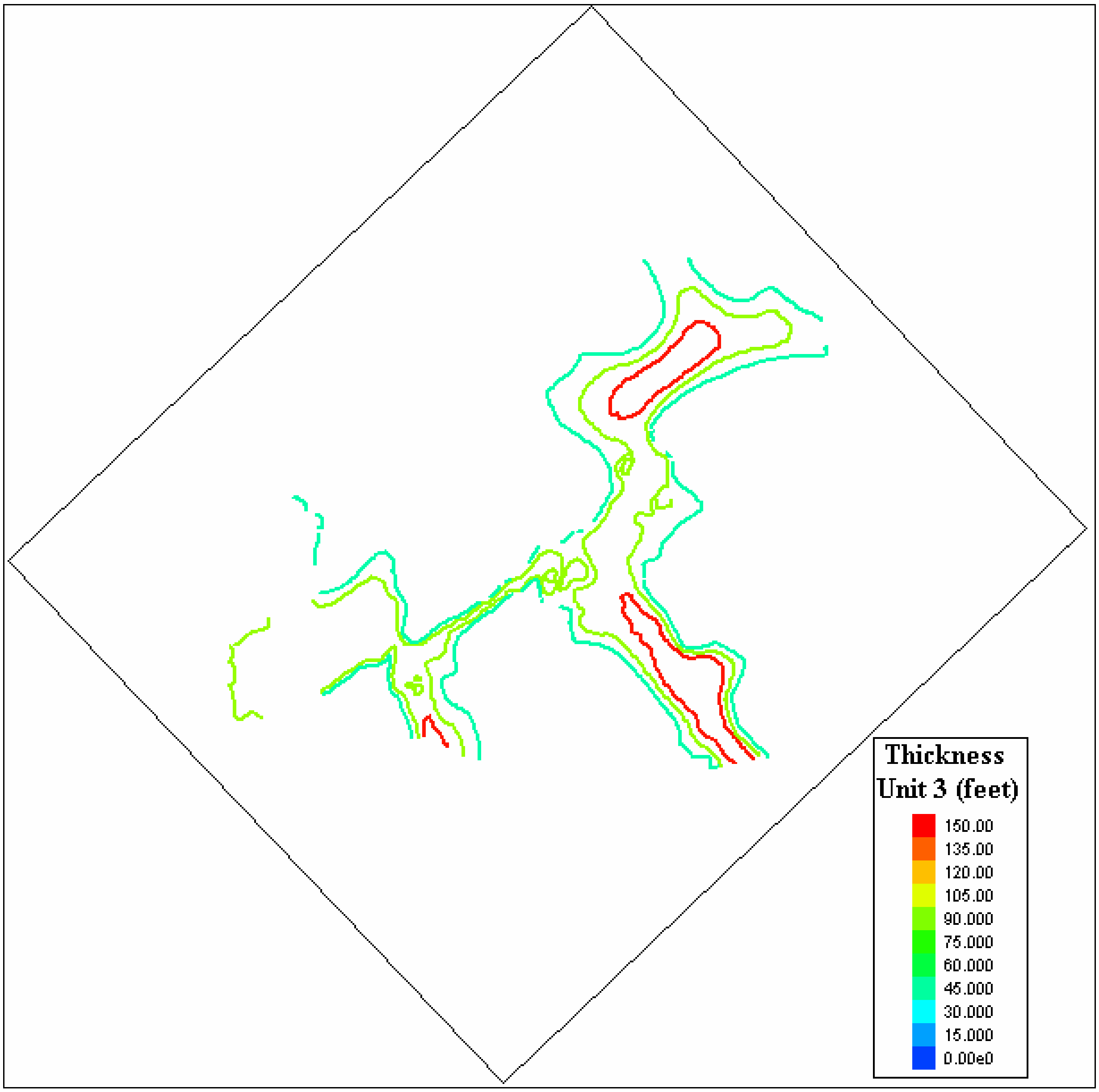
Transmissivity Unit 2 (Adapted from Dumouchelle et al. 1993)



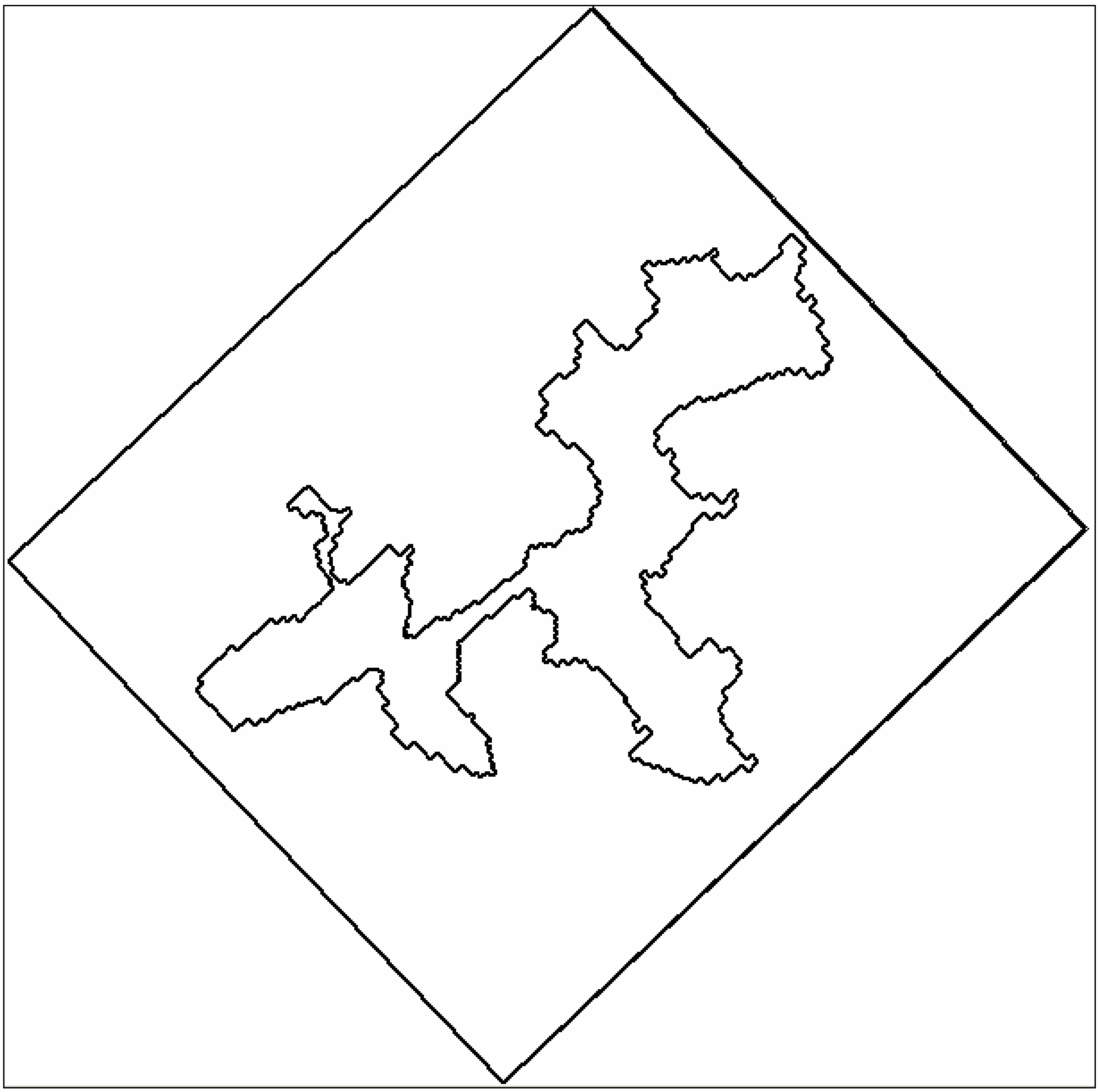
Vertical Conductance Unit 2 (Adapted from Dumouchelle et al. 1993)



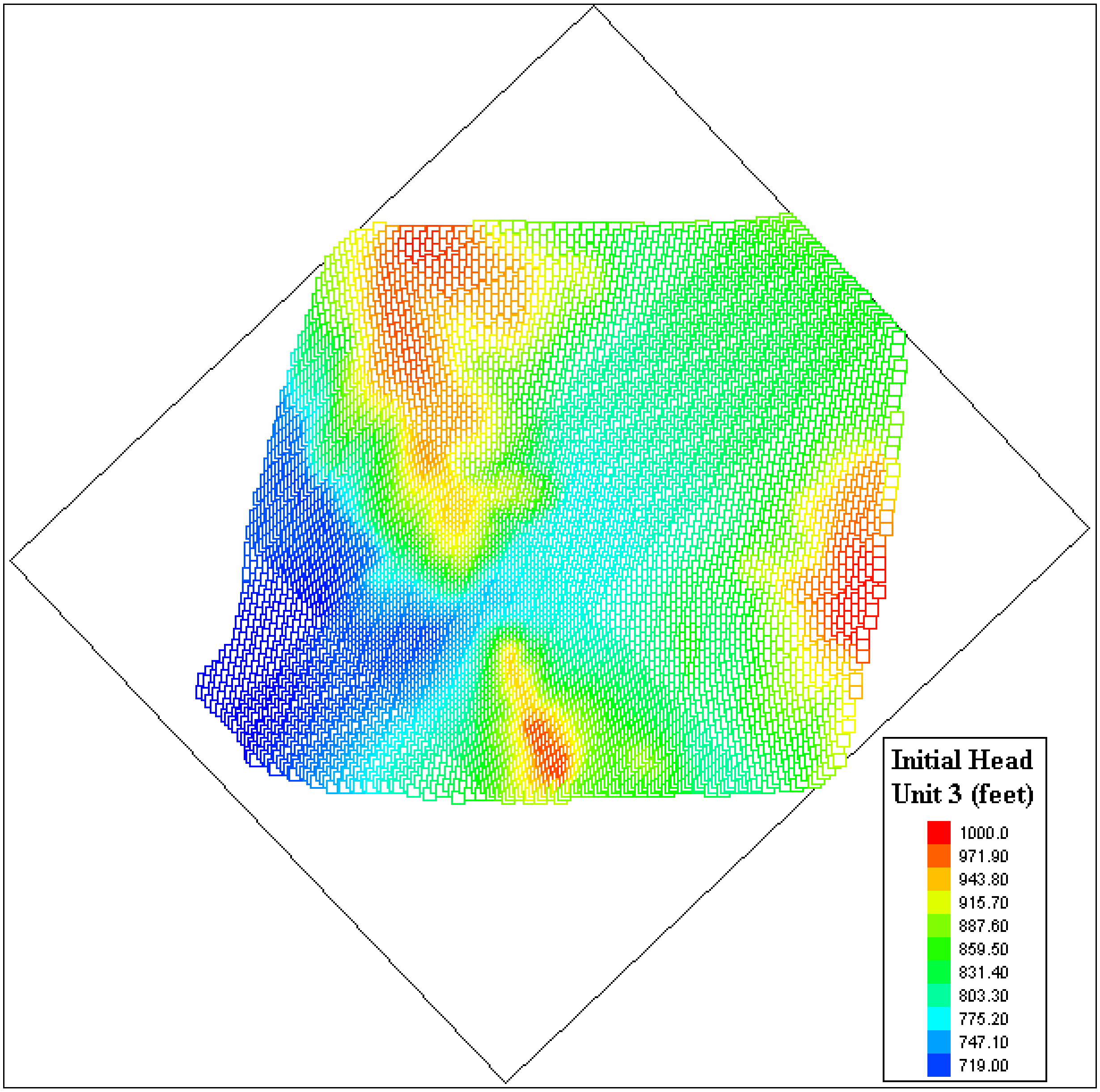
Wells Unit 2 (Adapted from Dumouchelle et al. 1993)



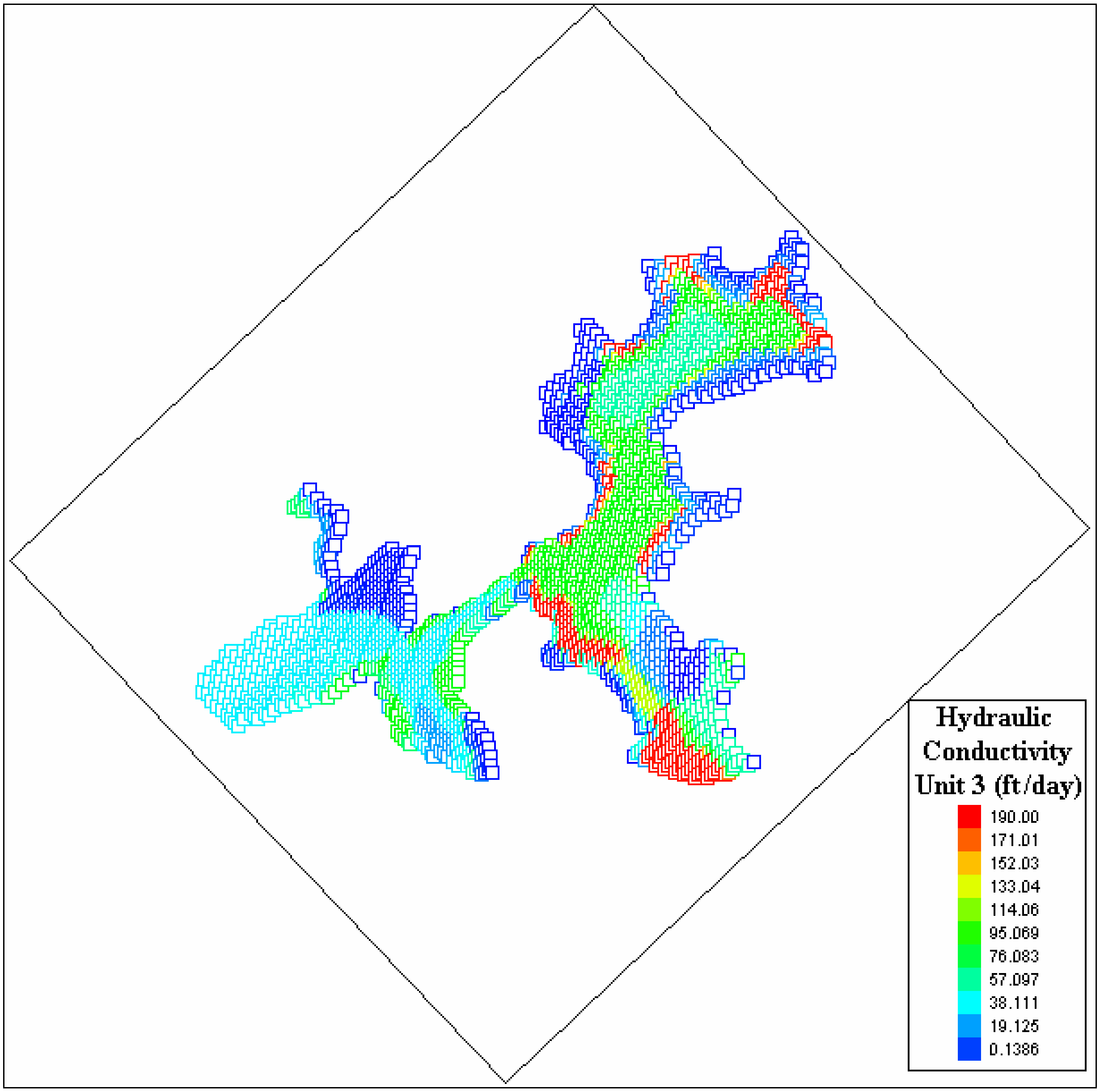
Thickness Unit 3 (Adapted from Dumouchelle et al. 1993)



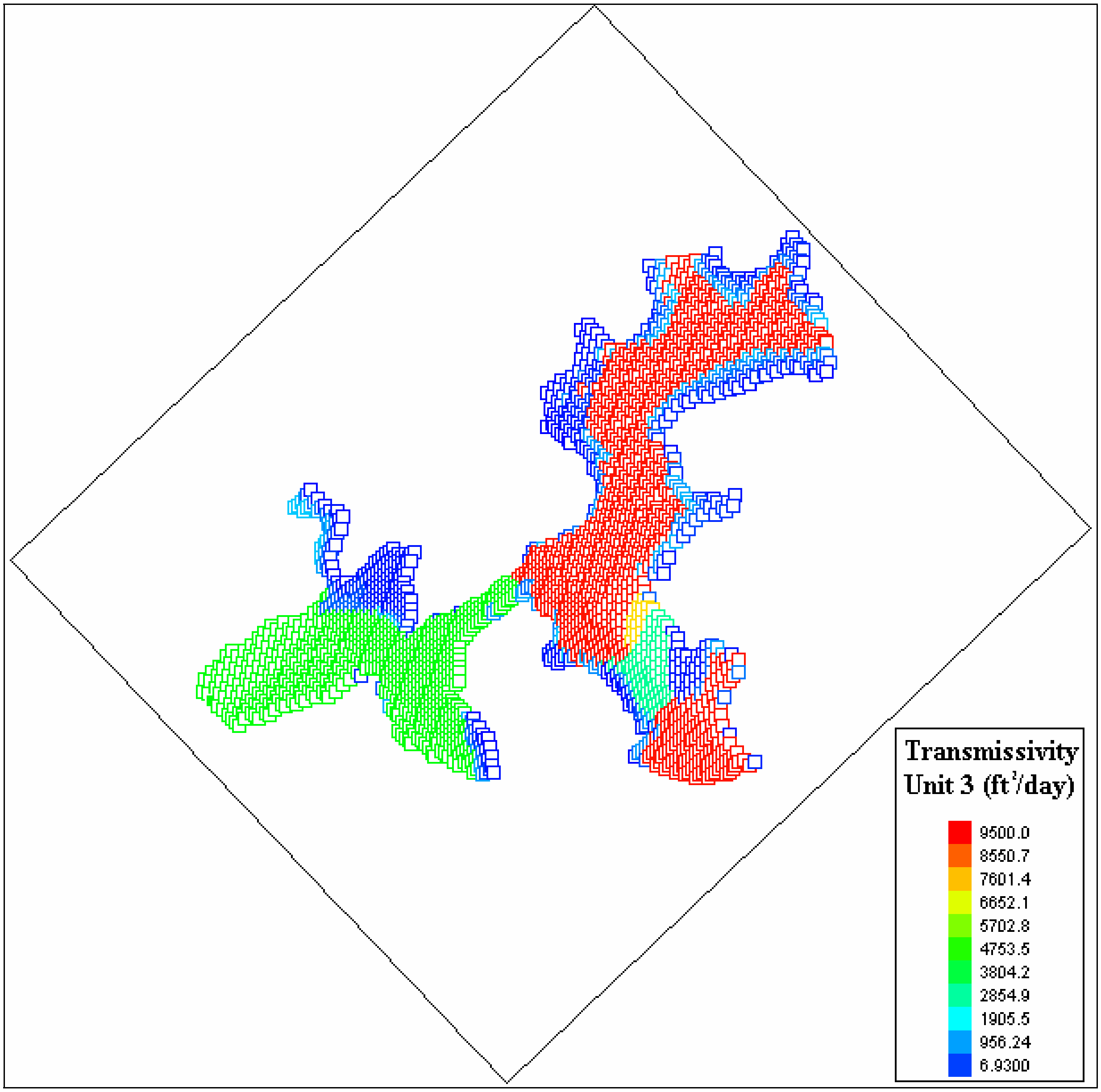
Added Inactive Area Unit 3 (Adapted from Dumouchelle et al. 1993)



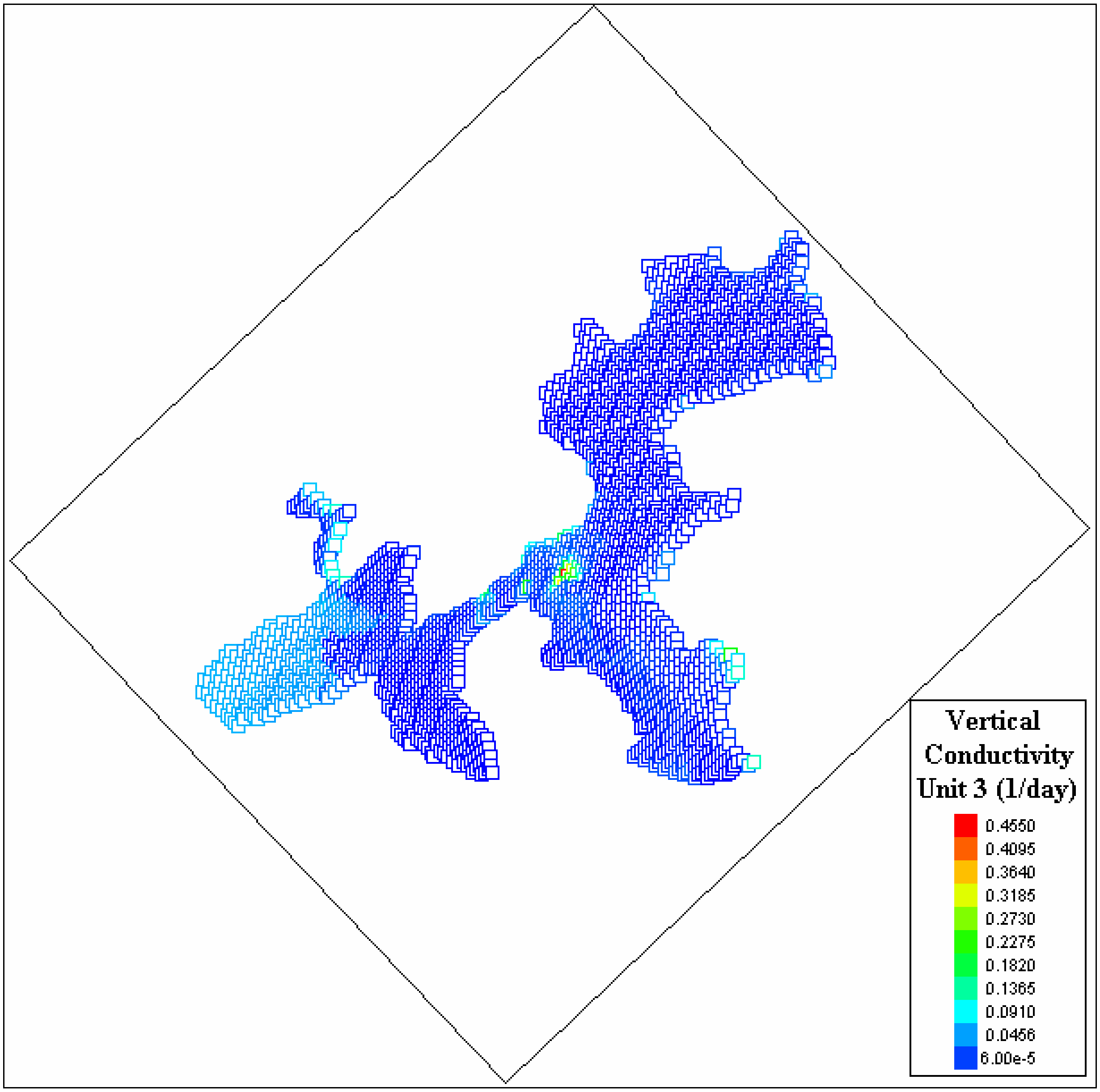
Initial Head Unit 3 (Adapted from Dumouchelle et al. 1993)



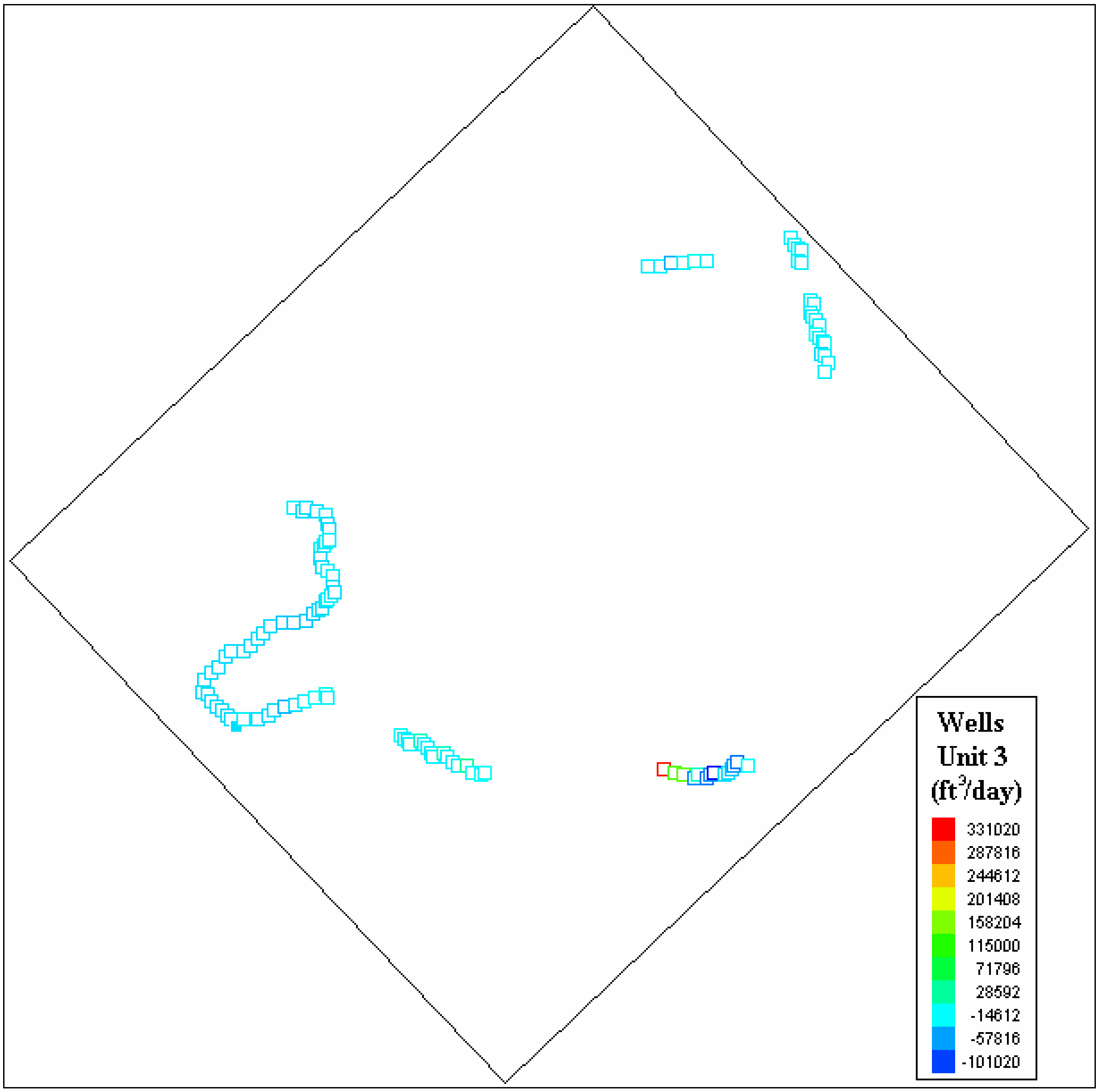
Hydraulic Conductivity Unit 3 (Adapted from Dumouchelle et al. 1993)



Transmissivity Unit 3 (Adapted from Dumouchelle et al. 1993)



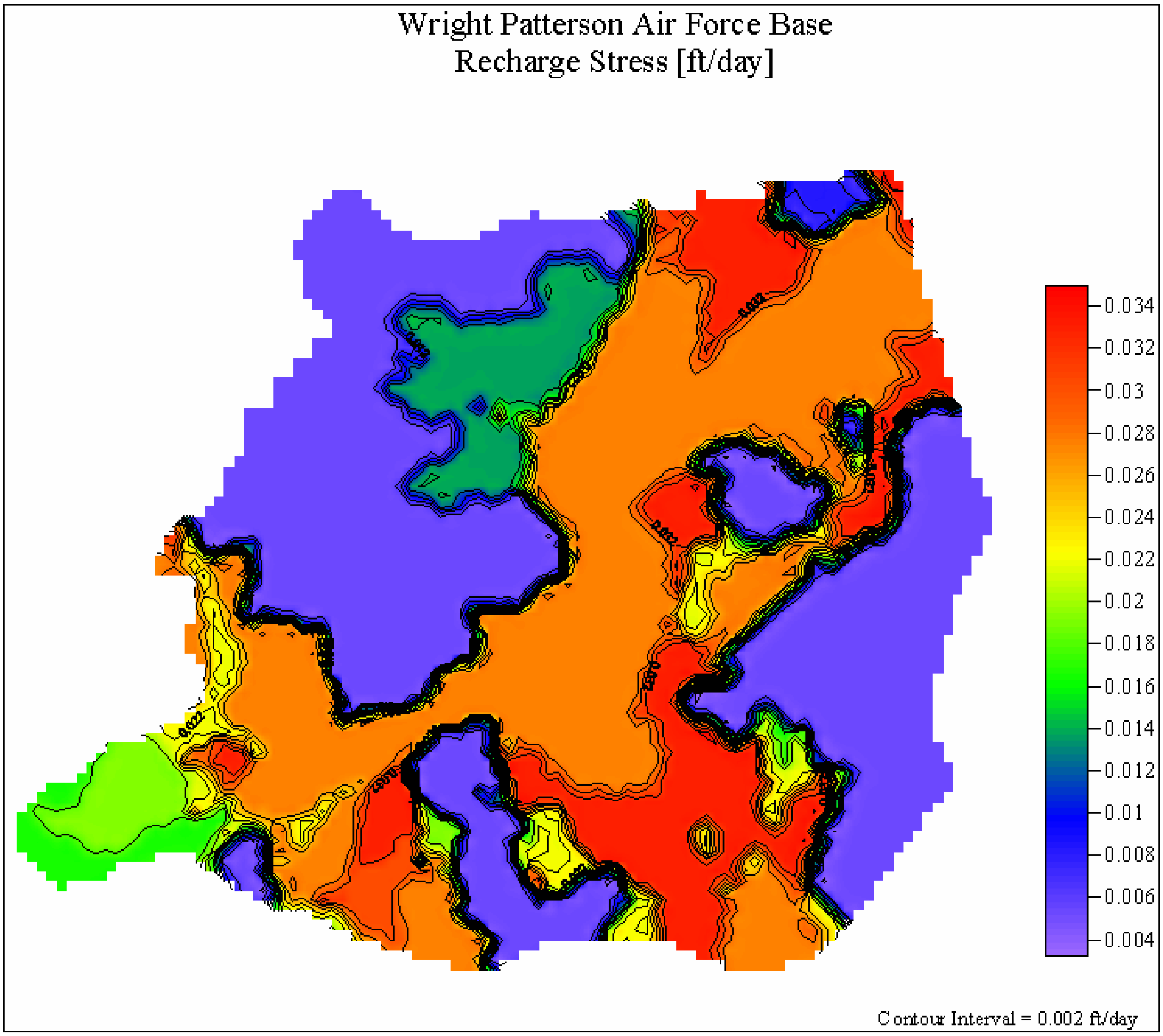
Vertical Conductance Unit 3 (Adapted from Dumouchelle et al. 1993)

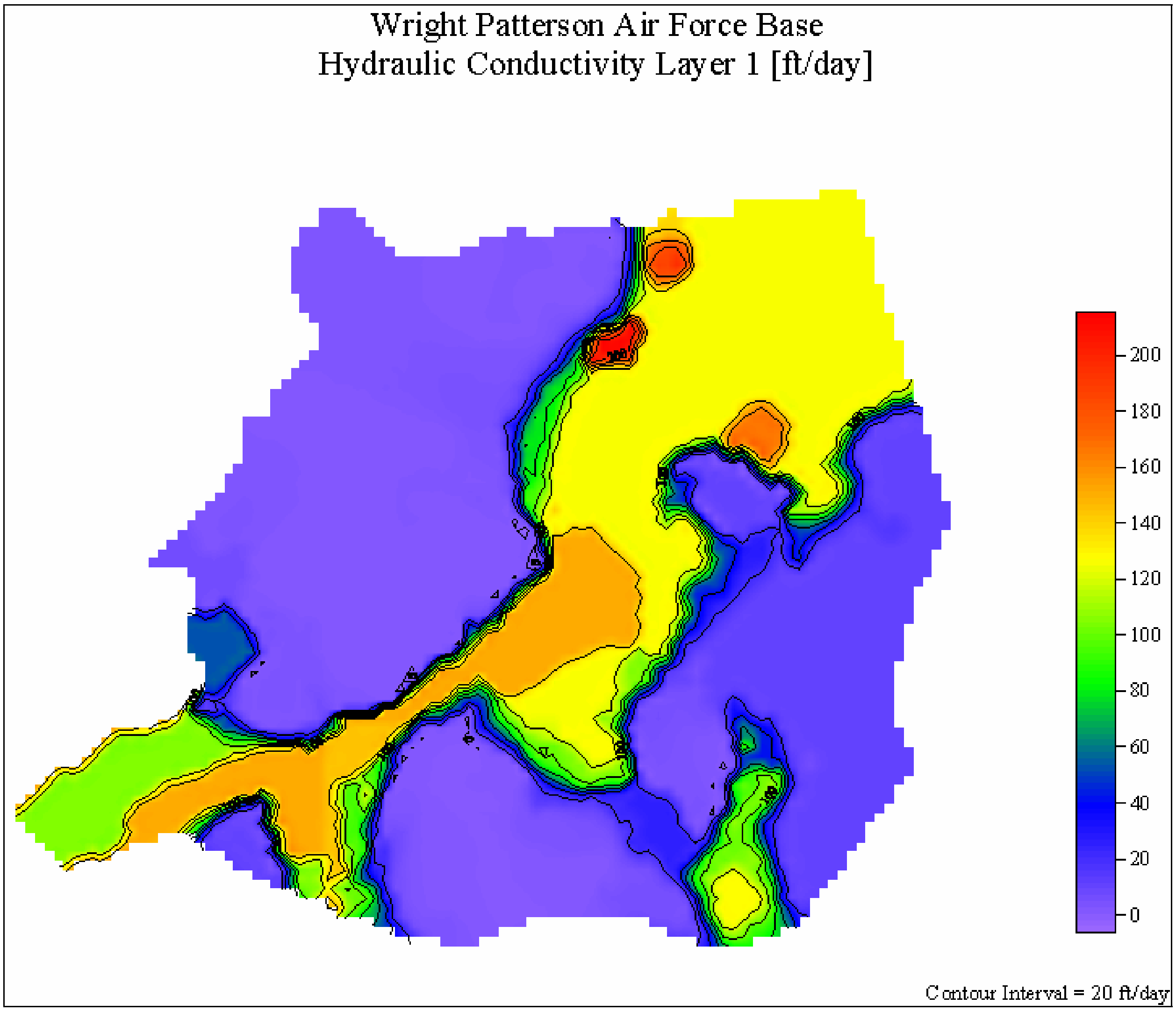


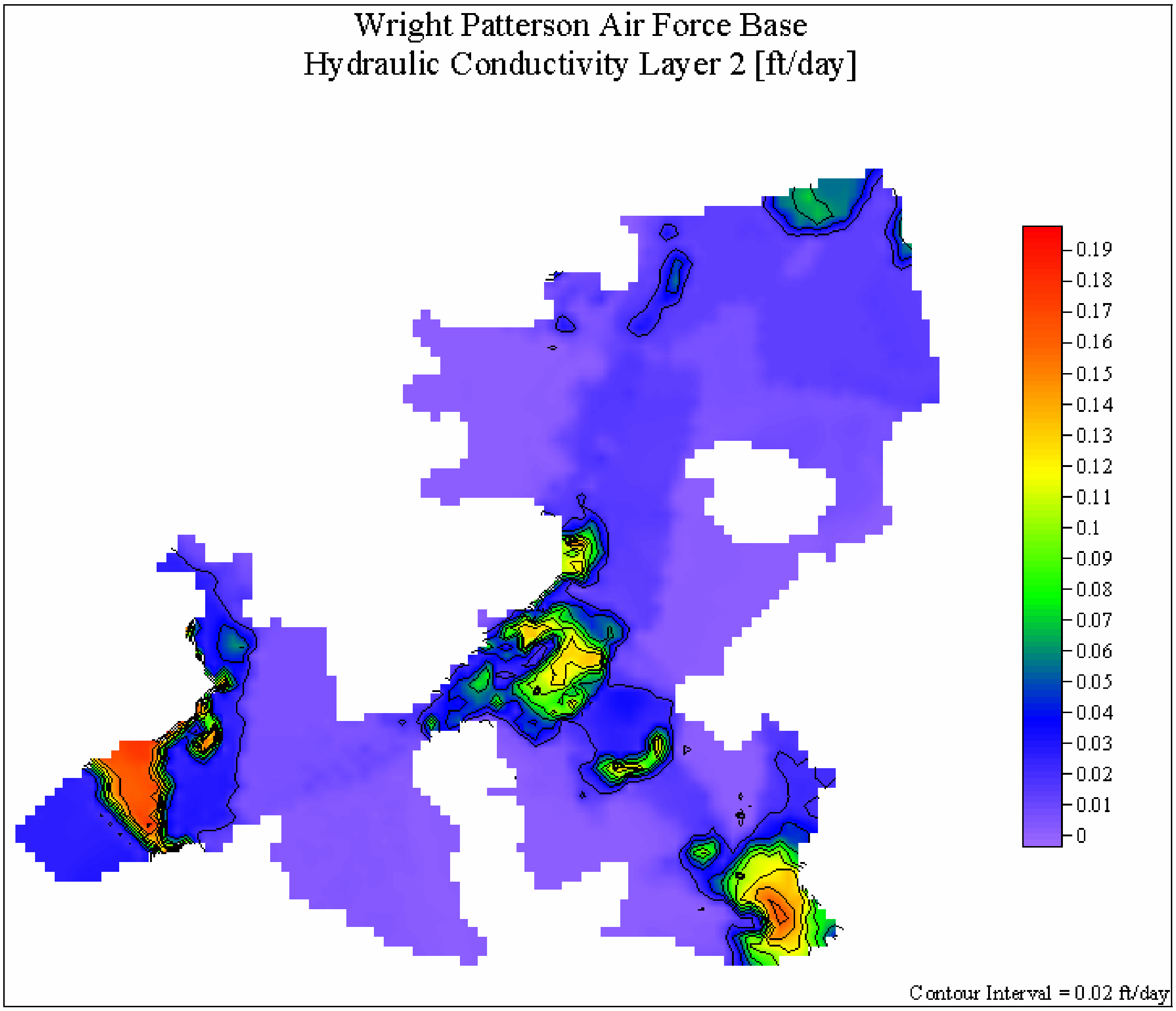
Well Conductance Unit 3 (Adapted from Dumouchelle et al. 1993)

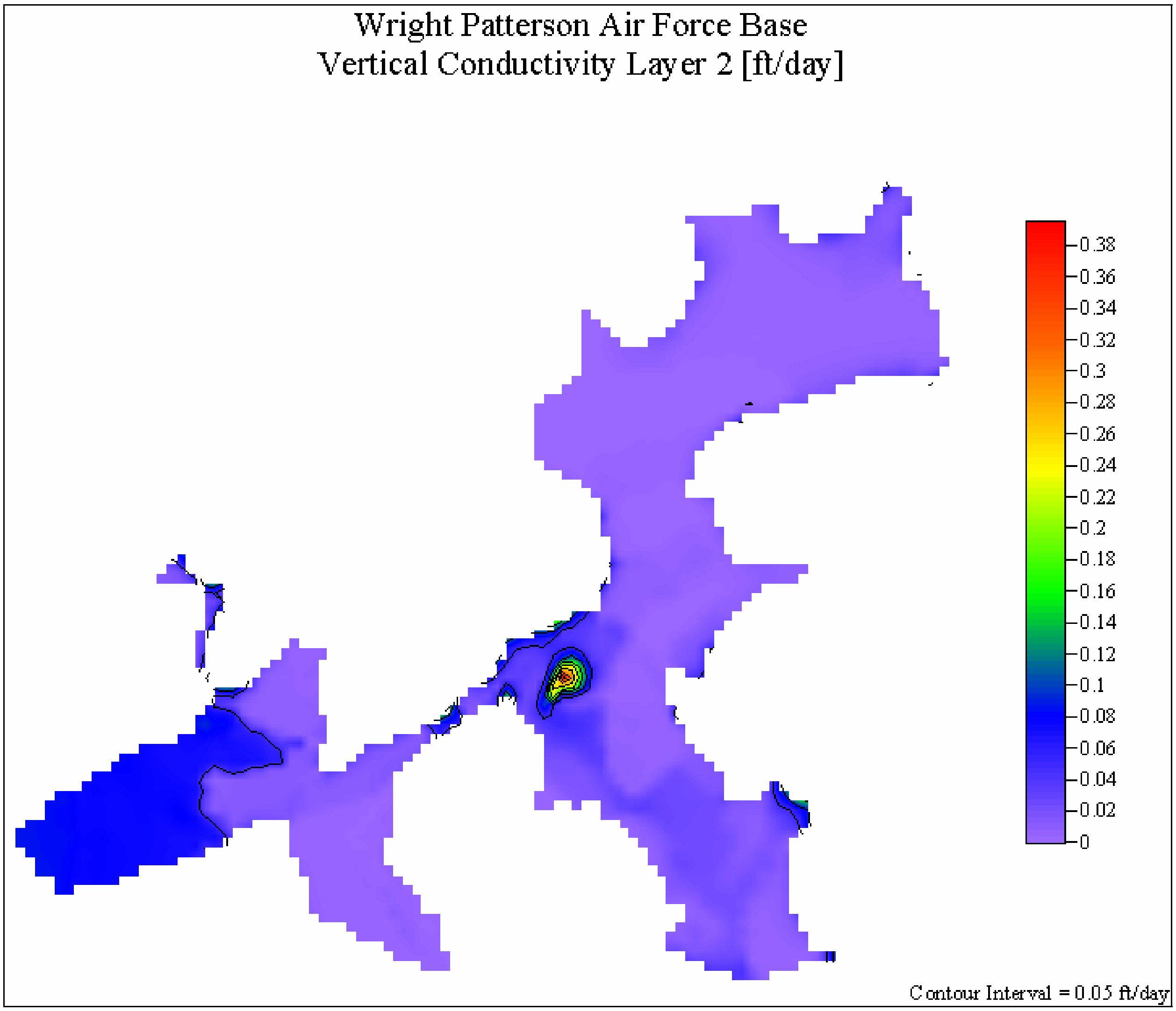
APPENDIX I

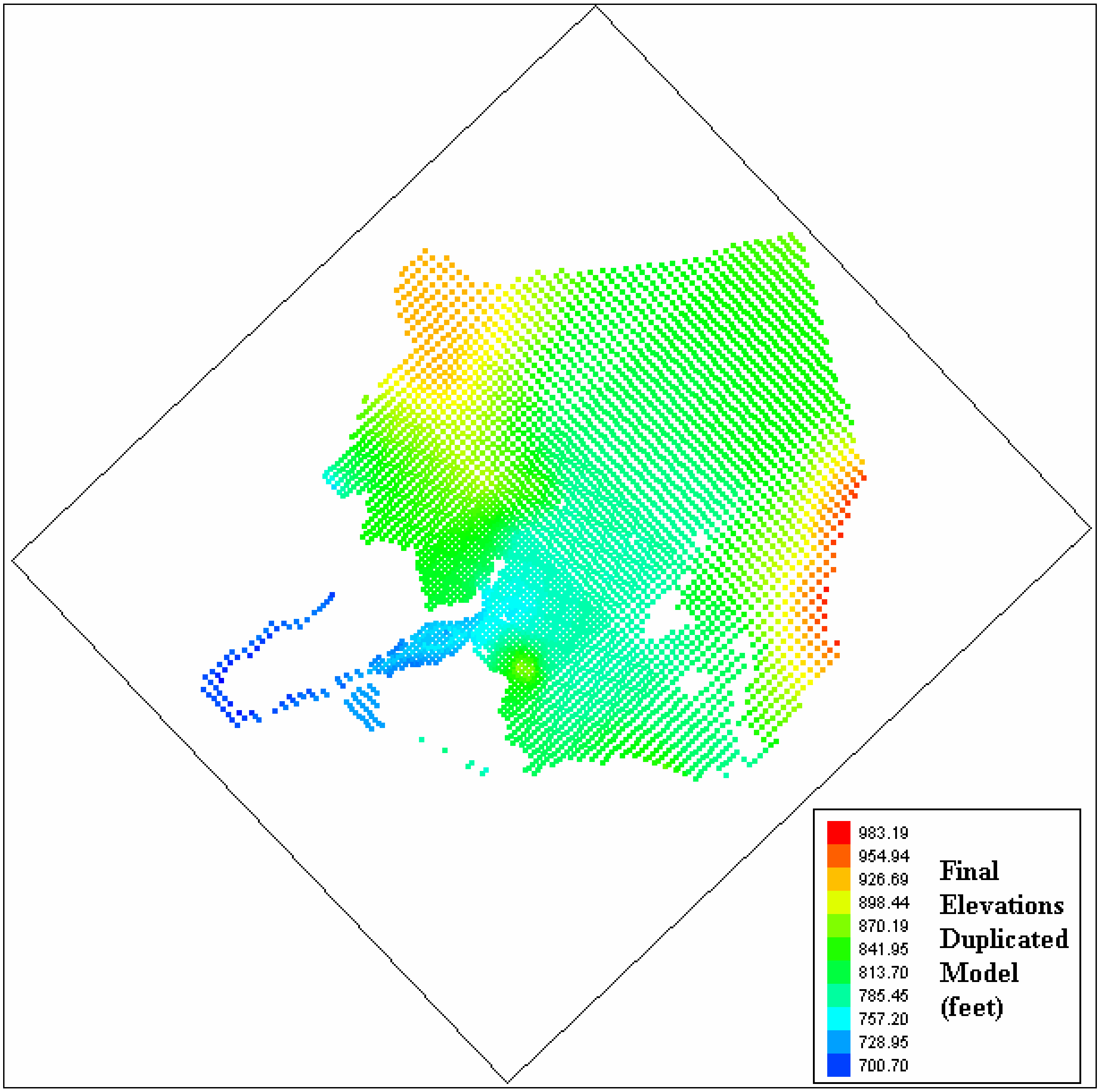
WPAFB MODFLOW OUTPUT CONTOUR MAPS


Wright Patterson Air Force Base
Recharge Stress [ft/day]
0.034
0.032
0.03
0.028
0.026
0.024
0.022
0.02
0.018
0.016
0.014
0.012
0.01
0.008
0.006
0.004
Contour Interval = 0.002 ft/day


Wright Patterson Air Force Base
Hydraulic Conductivity Layer 1 [ft/day]
200
180
160
140
120
100
80
60
40
20
0
Contour Interval = 20 ft/day


Wright Patterson Air Force Base
Hydraulic Conductivity Layer 2 [ft/day]
0.19
0.18
0.17
0.16
0.15
0.14
0.13
0.12
0.11
0.1
0.09
0.08
0.07
0.06
0.05
0.04
0.03
0.02
0.01
0
Contour Interval = 0.02 ft/day


Wright Patterson Air Force Base
Vertical Conductivity Layer 2 [ft/day]
0.38
0.36
0.34
0.32
0.3
0.28
0.26
0.24
0.22
0.2
0.18
0.16
0.14
0.12
0.1
0.08
0.06
0.04
0.02
0
Contour Interval = 0.05 ft/day



Final Elevations of the Dulicated WPAFB Model

APPENDIX J

SWTP UNDERFLOW CALCULATIONS

Gaging station: Tremont City
Drainage area: 264 square miles = 683,756,832 square meters
Annual precipitation (1968): 43.59 inches = 3.63 feet = 1.11 meters
Total precipitation = 683,756,832 m^2 * 1.11 m = 758,970,084 m^3
Recharge (Total precipitation at 30%): 227,691,025 m^3
Average stream flow (1966 – 1970): 230.52 $ft.^3/s$ = 6.53 m^3/s = 205,854,402 m^3/y
Recharge – stream flow = 21,836,623 m^3/y

Gaging station: St. Paris Pike
Drainage area: 310 square miles = 802,896,280 square meters
Annual precipitation (1968): 43.59 inches = 3.63 feet = 1.11 meters
Total precipitation = 802,896,280 m^2 * 1.11 m = 891,214,871 m^3
Recharge (Total precipitation at 30%): 267,364,461 m^3
Average stream flow (1966 – 1970): 270.26 $ft.^3/s$ = 7.65 m^3/s = 241,342,229 m^3/y
Recharge – stream flow – well loss = 9,442,128 m^3/y

Gain in recharge = 267,364,461 m^3 - 227,691,025 m^3 = 39,065,110 m^3/y

Loss to stream flow = 241,342,229 m^3 - 205,854,402 m^3 = 35,487,827 m^3/y

Loss to production wells = 12,000,000 gal/d = 16,580,105 m^3/y

Input totals: Gain in recharge + Upstream underflow = 39,065,110 m^3/y + 21,836,623 m^3/y
= 57,410,471 m^3 /y

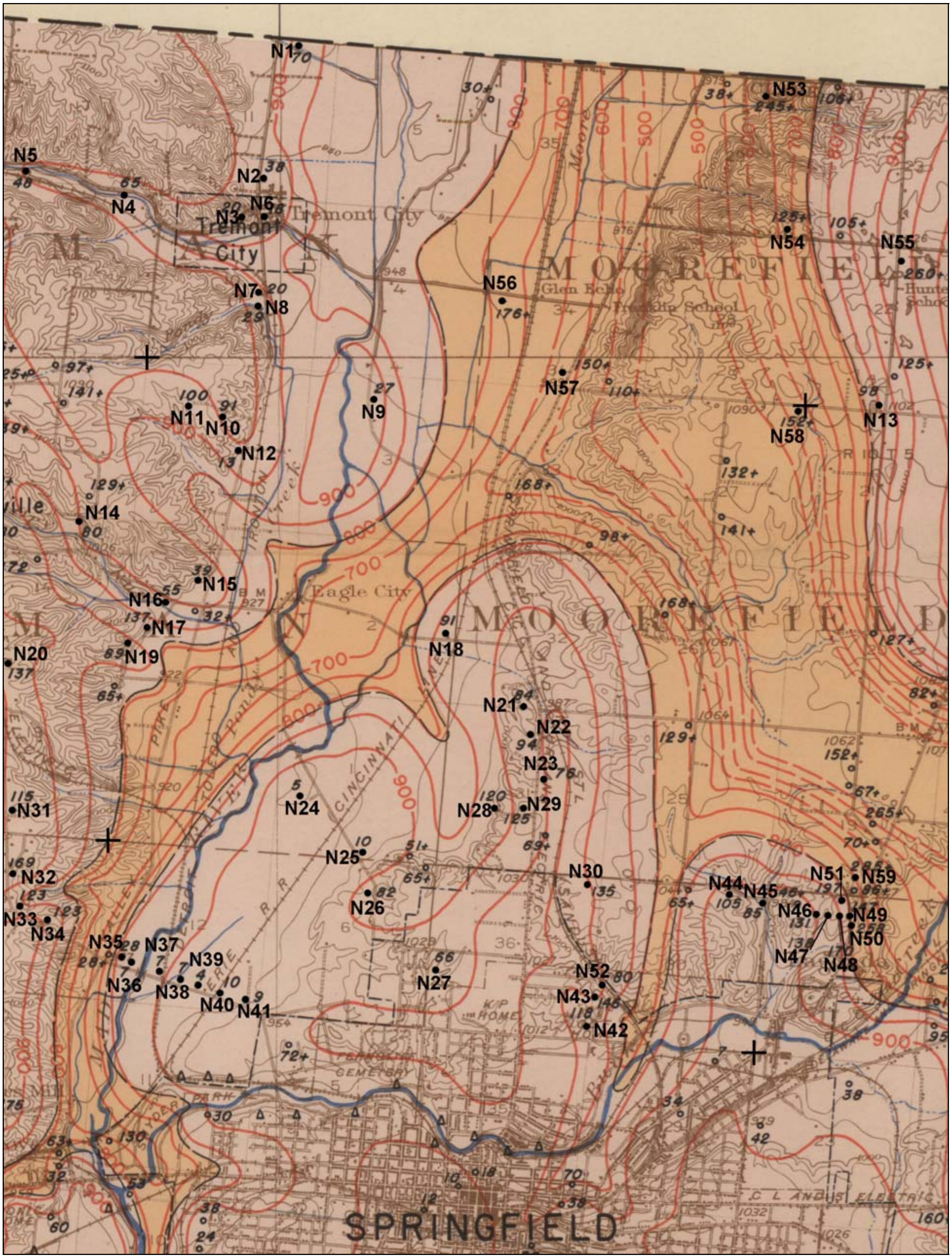
Output totals: Loss to stream flow + loss to wells + downstream underflow
= 35,487,827 m^3/y + 16,580,105 m^3/y + 9,442,128 m^3/y
= 57,410,471 m^3/y

APPENDIX K

SWTP BEDROCK RESOURCES MAPS

Bedrock Topography of the Springfield Area Bedrock Elevations from Norris et al. 1952						
Assigned Name	Estimated x - coordinate (meters)	Estimated y - coordinate (meters)	Estimated Surface Elevation (feet)	Indicated Depth to Bedrock (feet)	Estimated Bedrock Elevation (feet)	Estimated Bedrock Elevation (meters)
N1	258,395	4,434,450	960	70	890	271
N2	258,014	4,433,132	955	38	917	279
N3	257,781	4,432,752	990	20	970	296
N4	256,633	4,433,011	990	65	925	282
N5	256,669	4,433,279	1,000	48	952	290
N6	258,006	4,432,753	959	18	941	287
N7	257,930	4,431,995	955	20	935	285
N8	257,916	4,431,861	950	29	921	281
N9	259,038	4,430,893	935	27	908	277
N10	257,544	4,430,760	1,019	91	928	283
N11	257,209	4,430,880	1,040	100	940	286
N12	257,685	4,430,421	970	13	957	292
N13	264,024	4,430,686	1,000	98	902	275
N14	256,090	4,429,763	1,005	80	925	282
N15	257,249	4,429,142	960	39	921	281
N16	256,921	4,428,929	940	55	885	270
N17	256,736	4,428,682	950	137	813	248
N18	259,677	4,428,533	933	91	842	257
N19	256,537	4,428,526	970	89	881	268
N20	255,351	4,428,361	1,080	137	943	287
N21	260,426	4,427,779	1,020	84	936	285
N22	260,485	4,427,502	1,020	94	926	282
N23	260,605	4,427,044	1,025	76	949	289
N24	258,194	4,426,952	920	5	915	279
N25	258,795	4,426,367	935	10	925	282
N26	258,838	4,425,956	970	82	888	271
N27	259,482	4,425,168	1,000	66	934	285
N28	260,113	4,426,771	990	120	870	265
N29	260,395	4,426,763	1,025	125	900	274
N30	261,010	4,425,977	1,035	135	900	274
N31	255,351	4,426,889	1,065	115	950	289
N32	255,343	4,426,260	1,065	169	896	273
N33	255,396	4,425,928	1,055	123	932	284
N34	255,663	4,425,778	1,040	123	917	279
N35	256,388	4,425,392	908	28	880	268
N36	256,491	4,425,339	907	7	900	274
N37	256,759	4,425,233	904	7	897	273
N38	256,964	4,425,152	907	7	900	274
N39	257,133	4,425,082	912	4	908	277
N40	257,351	4,425,003	915	10	905	276

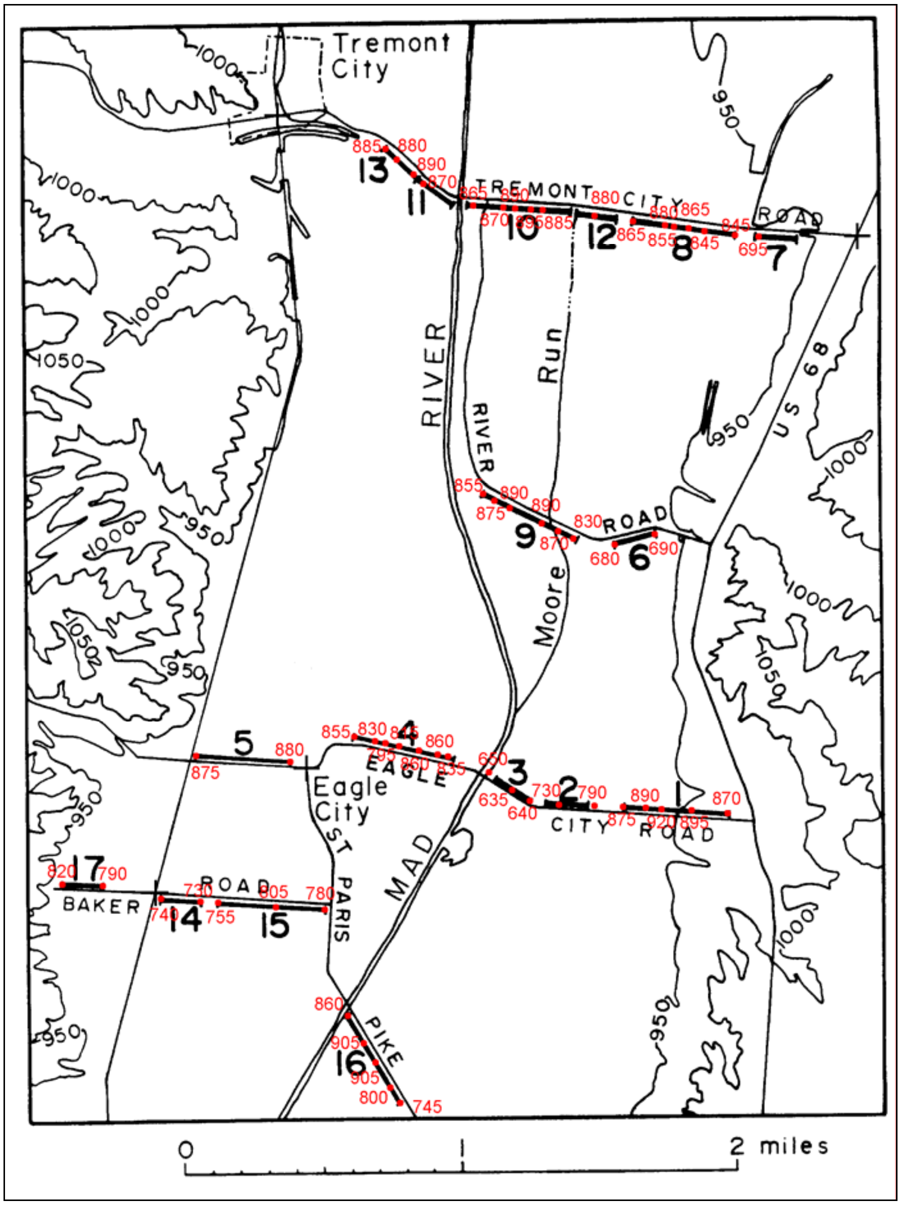
Bedrock Topography of the Springfield Area Bedrock Elevations from Norris et al. 1952						
Assigned Name	Estimated x - coordinate (meters)	Estimated y - coordinate (meters)	Estimated Surface Elevation (feet)	Indicated Depth to Bedrock (feet)	Estimated Bedrock Elevation (feet)	Estimated Bedrock Elevation (meters)
N41	257,601	4,424,934	919	9	910	277
N42	260,955	4,424,565	1,005	118	887	270
N43	261,047	4,424,854	1,015	146	869	265
N44	262,406	4,425,836	1,030	105	925	282
N45	262,732	4,425,744	995	85	910	277
N46	263,257	4,425,614	1,035	131	904	275
N47	263,376	4,425,600	1,025	138	887	270
N48	263,489	4,425,589	1,045	170	875	267
N49	263,585	4,425,586	1,040	147	893	272
N50	263,600	4,425,493	1,010	258	752	229
N51	263,516	4,425,748	1,050	197	853	260
N52	261,123	4,424,974	985	80	905	276
Wells Not Extending to Bedrock						
N53	262,997	4,433,813	1,050	245	805	245
N54	263,169	4,432,473	1,090	125	965	294
N55	264,289	4,432,121	1,126	260	866	264
N56	260,333	4,431,839	952	176	776	237
N57	260,910	4,431,108	969	150	819	250
N58	263,225	4,430,653	1,090	152	938	286
N59	263,659	4,425,971	1,020	285	735	224



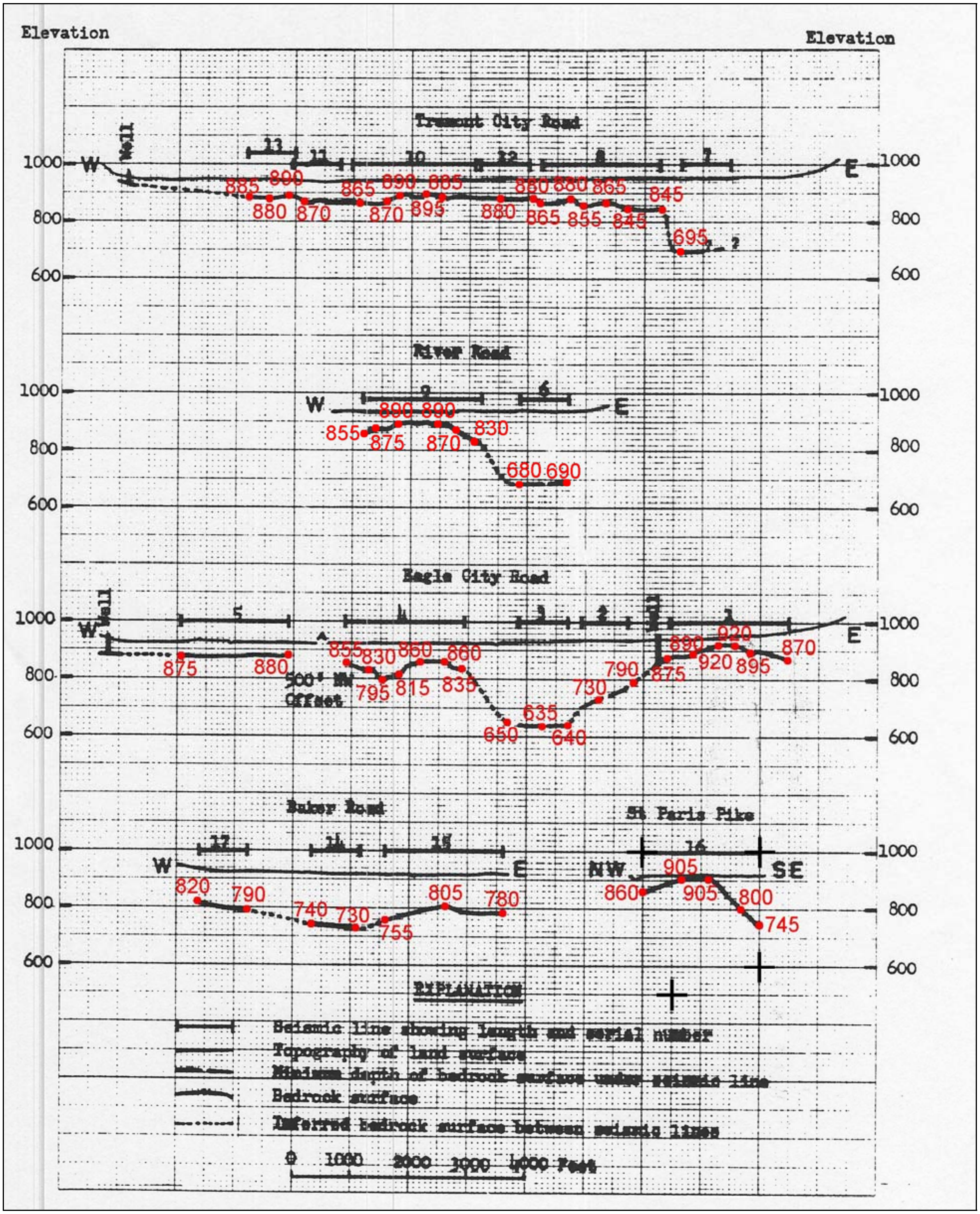
Bedrock Topography – Adapted from Norris et al. 1952

Bedrock Topography of the Springfield Area Bedrock Elevations from USGS Seismic Study - 1965			
Estimated x - coordinate (meters)	Estimated y - coordinate (meters)	Estimated Bedrock Elevation (feet)	Estimated Bedrock Elevation (meters)
Tremont City Road			
258,587	4,432,452	885	270
258,650	4,432,390	880	268
258,743	4,432,294	890	271
258,797	4,432,240	870	265
259,078	4,432,096	865	264
259,253	4,432,079	870	265
259,321	4,432,073	890	271
259,411	4,432,062	895	273
259,480	4,432,053	885	270
259,776	4,432,005	880	268
260,000	4,431,966	865	264
260,183	4,431,934	880	268
260,235	4,431,924	855	261
260,318	4,431,910	865	264
260,411	4,431,888	845	257
260,585	4,431,859	845	257
260,720	4,431,845	695	212
River Road			
259,056	4,430,389	855	261
259,123	4,430,347	875	267
259,213	4,430,305	890	271
259,389	4,430,206	890	271
259,481	4,430,156	870	265
259,568	4,430,107	830	253
259,804	4,430,061	680	207
260,039	4,430,113	690	210
Eagle City Road			
257,327	4,428,911	875	267
257,872	4,428,852	880	268
258,247	4,428,983	855	261
258,364	4,428,952	830	253
258,422	4,428,940	795	242
258,505	4,428,916	815	248
258,615	4,428,886	860	262
258,723	4,428,857	860	262
258,783	4,428,841	835	254
259,016	4,428,741	650	198
259,143	4,428,632	635	193
259,245	4,428,562	640	195
259,412	4,428,533	730	222

Bedrock Topography of the Springfield Area Bedrock Elevations from USGS Seismic Study - 1965			
Estimated x - coordinate (meters)	Estimated y - coordinate (meters)	Estimated Bedrock Elevation (feet)	Estimated Bedrock Elevation (meters)
Eagle City Road			
259,613	4,428,518	790	241
259,783	4,428,505	875	267
259,909	4,428,492	890	271
260,004	4,428,479	920	280
260,173	4,428,465	895	273
260,384	4,428,441	870	265
Baker Road			
256,521	4,428,182	820	250
256,752	4,428,162	790	241
257,084	4,428,072	740	225
257,314	4,428,046	730	222
257,415	4,428,034	755	230
257,747	4,427,994	805	245
258,029	4,427,970	780	238
St. Paris Pike			
258,132	4,427,338	860	262
258,222	4,427,170	905	276
258,283	4,427,051	905	276
258,360	4,426,902	800	244
258,412	4,426,810	745	227



Seismic Refraction Locations – Adapted from Hassemer et al. 1965



Seismic Refraction Cross-Sections – Adapted from Hassemer et al. 1965

Bedrock Topography of the Springfield Area Bedrock Elevations from Brockman and Swinford (2001)						
Assigned Name	Estimated x - coordinate (meters)	Estimated y - coordinate (meters)	Estimated Surface Elevation (feet)	Indicated Depth to Bedrock (feet)	Estimated Bedrock Elevation (feet)	Estimated Bedrock Elevation (meters)
Urbana West Quadrangle						
SW1	258,750	4,434,576	958	33	925	282
SW2	259,318	4,434,573	951	56	895	273
SW3	256,077	4,434,471	1,110	154	956	291
SW4	256,767	4,434,538	1,070	148	922	281
SW5	256,797	4,434,094	1,065	152	913	278
SW6	257,118	4,434,522	1,064	144	920	280
SW7	258,396	4,434,532	965	70	895	273
SW8	257,519	4,433,262	1,010	68	942	287
SW9	256,747	4,433,447	1,050	152	898	274
SW10	256,570	4,433,717	1,070	149	921	281
SW11	256,460	4,433,637	1,030	120	910	277
SW12	256,381	4,433,422	1,000	90	910	277
SW13	256,288	4,433,421	1,030	85	945	288
SW14	256,285	4,433,344	1,005	75	930	283
SW15	256,139	4,433,277	995	71	924	282
SW16	255,580	4,432,894	1,050	89	961	293
SW17	256,473	4,433,063	987	58	929	283
SW18	256,762	4,433,021	980	60	920	280
SW19	257,275	4,432,770	1,020	85	935	285
SW20	257,408	4,433,183	1,010	84	926	282
SW21	257,220	4,433,070	1,046	110	936	285
SW22	257,694	4,432,712	990	51	939	286
SW23	257,554	4,433,171	975	64	911	278
SW24	257,737	4,432,751	1,010	42	968	295
SW25	257,859	4,432,627	955	13	942	287
SW26	257,843	4,432,748	970	21	949	289
SW27	256,809	4,432,126	84	66	946	288

Bedrock Topography of the Springfield Area Bedrock Elevations from Swinford and Shrake (1993)				
Assigned Name	Estimated x - coordinate (meters)	Estimated y - coordinate (meters)	Estimated Bedrock Elevation (feet)	Estimated Bedrock Elevation (meters)
Springfield Quadrangle - Area North of Water Treatment Plant				
SW29	257,910	4,430,848	931	284
SW30	256,056	4,431,068	965	294
SW31	255,992	4,430,768	965	294
SW32	256,307	4,429,874	946	288
SW33	256,376	4,430,015	932	284
SW34	257,563	4,429,922	916	279
SW35	258,065	4,429,821	905	276
SW36	258,231	4,430,386	905	276
SW37	260,542	4,429,310	859	262
SW38	257,507	4,429,699	917	280
SW39	257,337	4,429,602	924	282
SW40	257,407	4,429,422	922	281
SW41	257,410	4,429,177	922	281
SW42	257,379	4,429,024	886	270
SW43	256,910	4,429,254	910	277
SW44	256,749	4,429,157	955	291
SW45	256,590	4,429,202	936	285
SW46	256,497	4,429,239	955	291
SW47	255,926	4,429,429	900	274
SW48	256,716	4,428,614	863	263
SW49	257,117	4,428,857	903	275
SW50	257,188	4,428,842	905	276
SW51	257,272	4,428,713	884	269
SW52	260,509	4,428,372	913	278
SW53	260,670	4,428,415	952	290
SW54	261,898	4,428,640	979	298

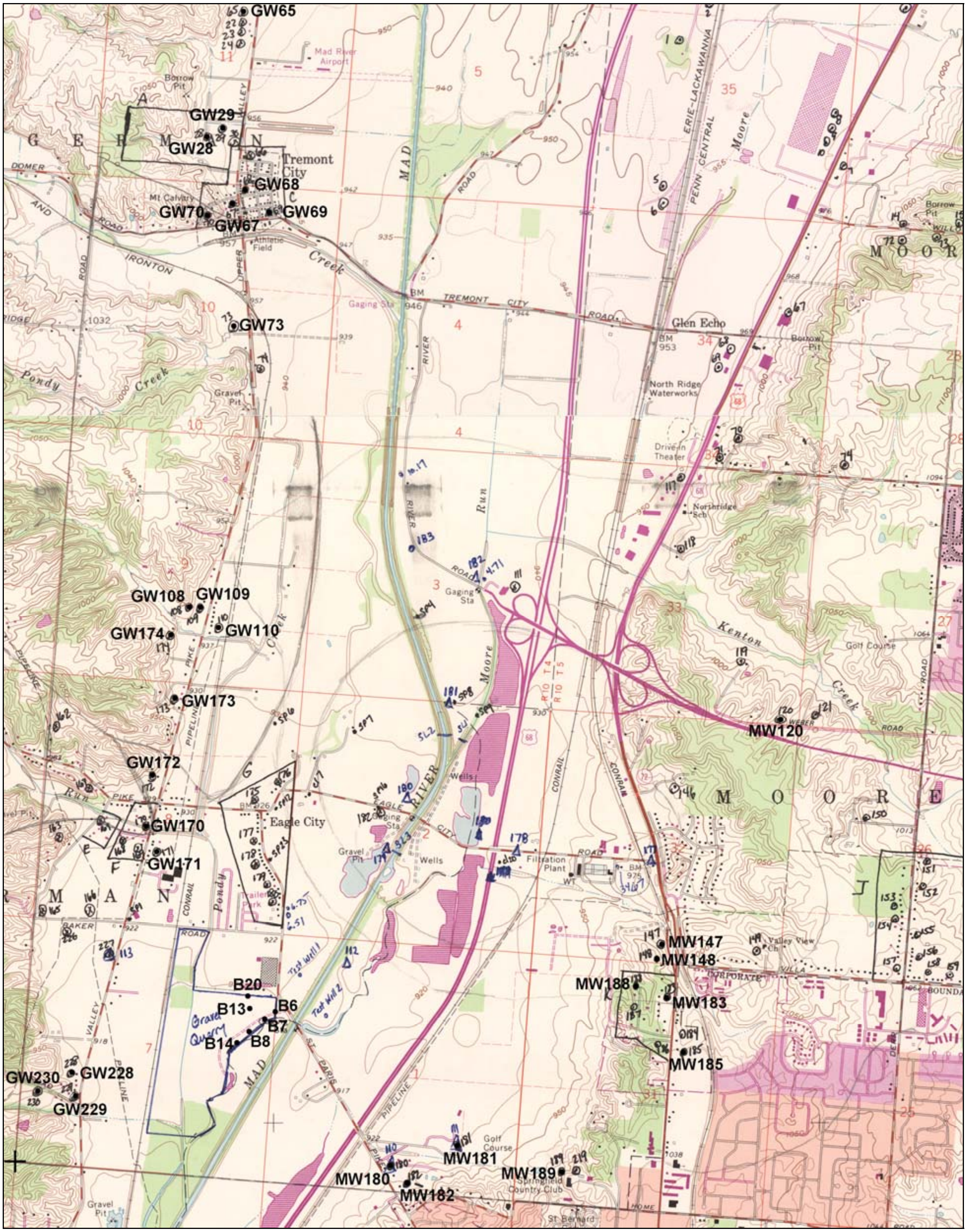
Bedrock Topography of the Springfield Area Bedrock Elevations from Swinford and Shrake (1993)				
Assigned Name	Estimated x - coordinate (meters)	Estimated y - coordinate (meters)	Estimated Bedrock Elevation (feet)	Estimated Bedrock Elevation (meters)
Springfield Quadrangle - Area South of Water Treatment Plant				
SW55	255,896	4,427,756	875	267
SW56	255,675	4,427,766	918	280
SW57	255,320	4,428,452	934	285
SW58	255,259	4,427,127	925	282
SW59	256,033	4,427,308	910	277
SW60	263,049	4,426,230	851	259
SW61	262,762	4,426,282	880	268
SW62	262,595	4,425,973	902	275
SW63	260,569	4,426,420	936	285
SW64	259,183	4,426,518	910	277
SW65	256,279	4,426,370	875	267
SW66	255,251	4,426,360	943	287
SW67	255,386	4,426,273	944	288
SW68	255,421	4,425,766	919	280
SW69	255,386	4,425,564	898	274
SW70	255,565	4,425,293	844	257
SW71	256,081	4,425,721	900	274
SW72	262,663	4,425,919	924	282
SW73	263,220	4,425,467	899	274
SW74	263,204	4,425,243	912	278
SW75	262,872	4,425,218	939	286
SW76	261,092	4,424,839	864	263
SW77	261,048	4,425,019	905	276
SW78	259,516	4,425,172	944	288
SW79	257,666	4,424,846	909	277
SW80	257,393	4,424,830	916	279
SW81	257,080	4,424,969	906	276
SW82	257,084	4,425,076	904	276
SW83	256,008	4,425,143	872	266
SW84	255,822	4,425,202	801	244
SW85	255,714	4,425,041	865	264
SW86	255,364	4,425,258	915	279
SW87	255,371	4,425,098	849	259
SW88	255,622	4,424,860	893	272
SW89	255,317	4,424,696	987	301
SW90	255,624	4,424,500	929	283
SW91	255,395	4,424,406	869	265
SW92	255,372	4,424,229	940	287
SW93	255,619	4,424,153	900	274

Bedrock Topography of the Springfield Area Bedrock Elevations from Brockman and Swinford (2001)				
Assigned Name	Estimated x - coordinate (meters)	Estimated y - coordinate (meters)	Minimum Bedrock Elevation (feet)	Minimum Bedrock Elevation (meters)
Urbana West Quadrangle - Wells Not Extending To Bedrock				
SW94	255,764	4,424,212	895	273
SW95	256,448	4,424,817	839	256
SW96	260,923	4,424,559	877	267
SW97	262,233	4,424,143	938	286
SW98	261,874	4,423,635	928	283
SW99	257,205	4,423,846	880	268
SW100	256,198	4,423,625	775	236
SW101	255,512	4,424,021	945	288
SW102	255,746	4,423,937	917	280
SW103	255,562	4,423,889	927	283
SW104	255,500	4,423,817	855	261
SW105	255,384	4,423,623	831	253
SW106	255,673	4,423,364	928	283
SW107	255,812	4,435,037	1001	305
SW108	256,413	4,434,565	980	299
SW109	257,498	4,434,924	1042	318
SW110	258,534	4,434,475	931	284
SW111	261,101	4,434,328	862	263
SW112	262,693	4,434,660	940	287
SW113	262,572	4,434,445	944	288
SW114	263,150	4,434,013	921	281
SW115	262,959	4,434,043	953	290
SW116	262,433	4,434,173	878	268
SW117	262,344	4,433,977	931	284
SW118	262,324	4,433,824	931	284
SW119	261,432	4,434,197	929	283
SW120	261,339	4,434,206	929	283
SW121	261,029	4,434,034	921	281
SW122	260,839	4,433,785	930	283
SW123	259,696	4,434,471	922	281
SW124	258,580	4,434,146	926	282
SW125	256,310	4,434,294	974	297
SW126	255,873	4,433,860	938	286
SW127	257,917	4,433,173	916	279
SW128	261,845	4,433,263	896	273
SW129	261,804	4,433,137	936	285
SW130	262,286	4,432,521	929	283
SW131	261,890	4,432,956	937	286
SW132	261,768	4,433,080	936	285
SW133	260,690	4,432,838	923	281

Bedrock Topography of the Springfield Area Bedrock Elevations from Brockman and Swinford (2001)				
Assigned Name	Estimated x - coordinate (meters)	Estimated y - coordinate (meters)	Minimum Bedrock Elevation (feet)	Minimum Bedrock Elevation (meters)
Urbana West Quadrangle - Wells Not Extending To Bedrock				
SW134	260,706	4,432,729	913	278
SW135	261,489	4,431,968	910	277
SW136	262,244	4,432,448	913	278
SW137	262,495	4,432,451	920	280
SW138	261,112	4,431,774	915	279
SW139	260,732	4,431,731	873	266
SW140	258,030	4,431,697	860	262
Springfield Quadrangle - Wells Not Extending To Bedrock				
SW141	261,119	4,429,691	838	255
SW142	259,251	4,429,102	820	250
SW143	257,937	4,428,552	826	252
SW144	262,214	4,428,055	892	272
SW145	260,525	4,427,215	899	274
SW146	263,095	4,427,633	903	275
SW147	260,600	4,426,191	927	283
SW148	263,057	4,425,322	926	282
SW149	262,696	4,425,518	920	280
SW150	262,291	4,425,820	943	287
SW151	261,692	4,424,817	790	241
SW152	258,044	4,424,374	853	260

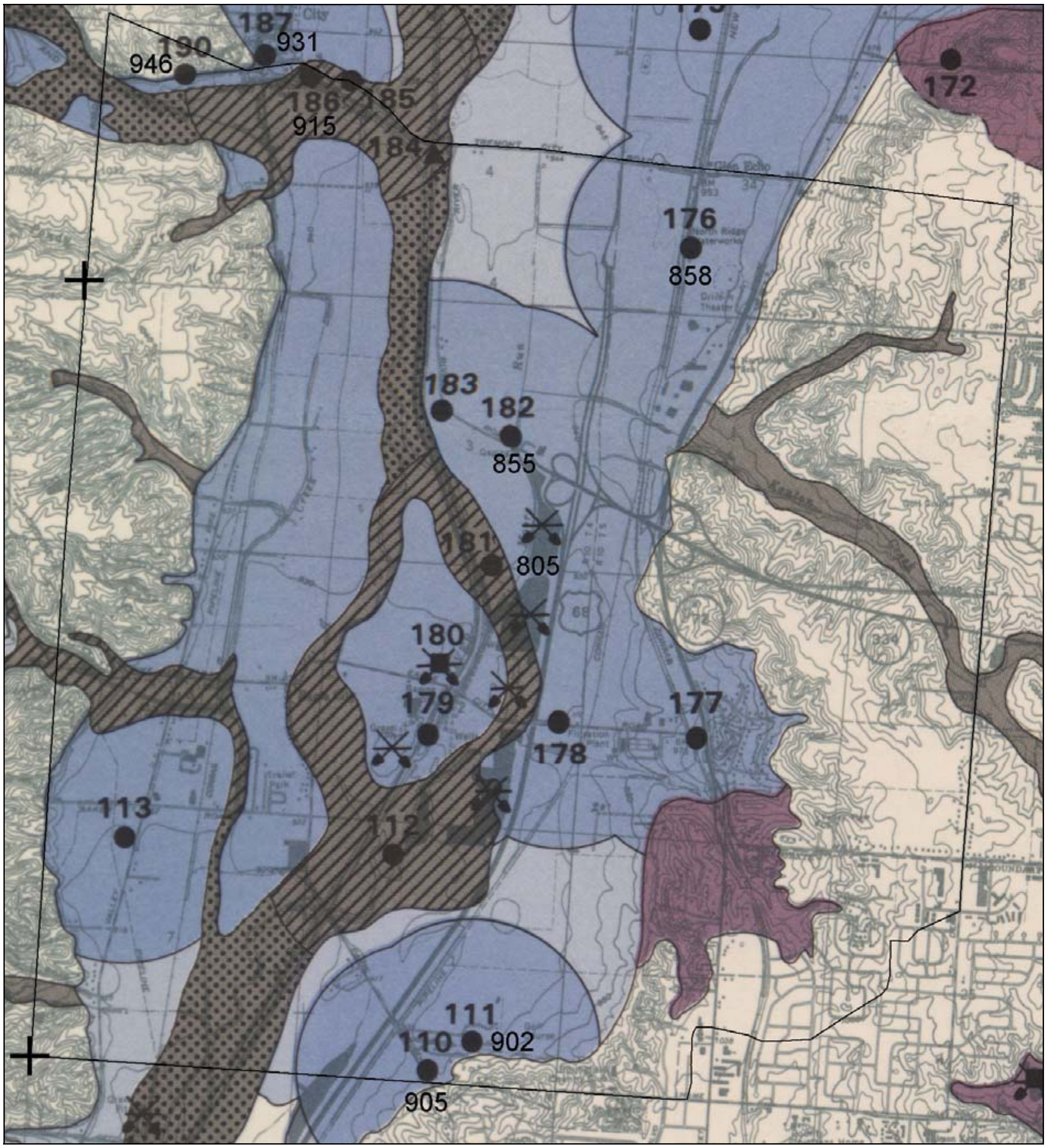
Bedrock Topography Map of the Springfield and Urbana West Quadrangles
Adapted from Swinford and Shrake (1993) and Brockman and Swinford (2001)

Bedrock Topography of the Springfield Area Bedrock Elevations from Well Logs						
Assigned Name	Estimated x - coordinate (meters)	Estimated y - coordinate (meters)	Estimated Surface Elevation (feet)	Indicated Depth to Bedrock (feet)	Estimated Bedrock Elevation (feet)	Estimated Bedrock Elevation (meters)
German Township ODNR Well Logs						
GW28	257,714	4,433,231	959	45	914	278
GW29	257,821	4,433,265	958	38	920	280
GW65	257,975	4,434,042	968	40	928	283
GW67	257,887	4,432,787	965	21	944	288
GW68	257,951	4,432,875	950	30	920	280
GW69	258,113	4,432,722	948	18	930	283
GW70	257,727	4,432,717	999	51	948	289
GW73	257,876	4,431,976	957	30	927	282
GW108	257,539	4,430,154	950	15	935	285
GW109	257,609	4,430,142	937	11	926	282
GW110	257,714	4,430,004	934	33	901	275
GW170	257,217	4,428,713	920	56	864	263
GW171	257,269	4,428,561	925	54	871	265
GW172	257,265	4,429,054	939	44	895	273
GW173	257,420	4,429,560	939	10	929	283
GW174	257,417	4,429,973	960	46	914	278
GW228	256,686	4,427,129	925	30	895	273
GW229	256,693	4,426,986	933	14	919	280
GW230	256,444	4,427,028	947	26	921	281
Moorefield Township ODNR Well Logs						
MW120	261,367	4,429,295	1,040	133	907	276
MW147	260,557	4,427,868	980	50	930	283
MW148	260,507	4,427,760	1,010	69	941	287
MW188	260,363	4,427,582	1,007	100	907	276
MW183	260,573	4,427,488	1,000	94	906	276
MW185	260,669	4,427,139	1,030	115	915	279
MW189	259,849	4,426,380	995	65	930	283
MW180	258,765	4,426,407	927	30	897	273
MW182	258,868	4,426,271	930	9	921	281
MW181	259,179	4,426,635	928	30	898	274
Baisden Quarry Well Logs						
B6	258,009	4,427,499	921	43	878	268
B7	257,941	4,427,461	920	47	873	266
B8	257,785	4,427,367	920	51	869	265
B13	257,917	4,427,558	920	63	857	261
B14	257,672	4,427,330	920	73	847	258
B20	257,821	4,427,623	920	67	853	260



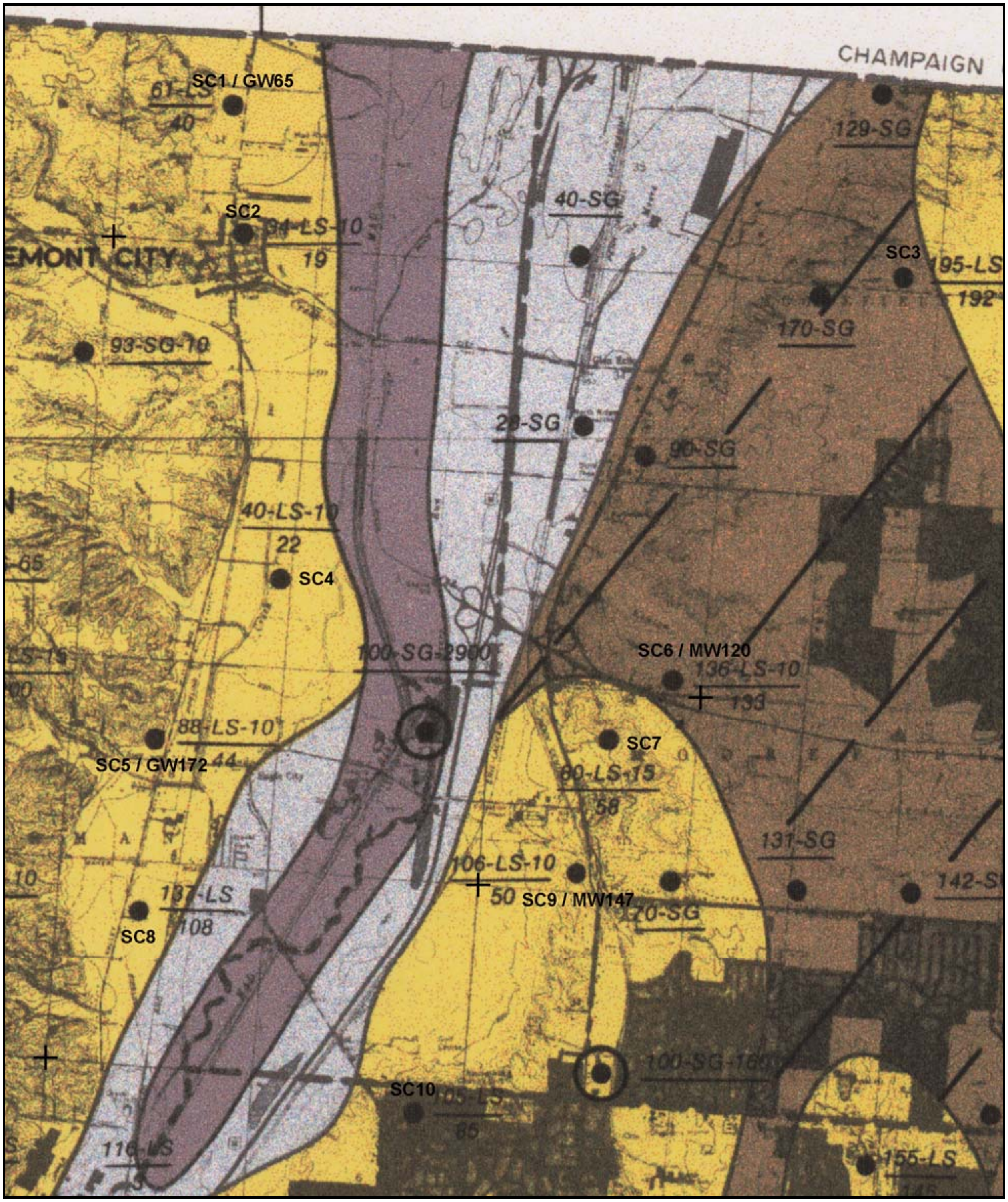
ODNR Well Log Locations – Adapted from USGS Springfield and Urbana West Quadrangles

Bedrock Topography of the Springfield Area Bedrock Elevations from Struble 1987						
Assigned Name	Estimated x - coordinate (meters)	Estimated y - coordinate (meters)	Estimated Surface Elevation (feet)	Indicated Depth to Bedrock (feet)	Estimated Bedrock Elevation (feet)	Estimated Bedrock Elevation (meters)
SG190	257,469	4,432,659	975	29	946	288
SG187	257,958	4,432,718	950	19	931	284
SG186	258,224	4,432,627	948	33	915	279
SG176	260,600	4,431,441	947	89	858	261
SG182	259,418	4,430,294	930	75	855	261
SG181	259,220	4,429,478	930	125	805	245
SG111	259,003	4,426,557	932	30	902	275
SG110	258,718	4,426,388	935	30	905	276



Sand and Gravel Resources of Clark County – Adapted from Struble (1987)

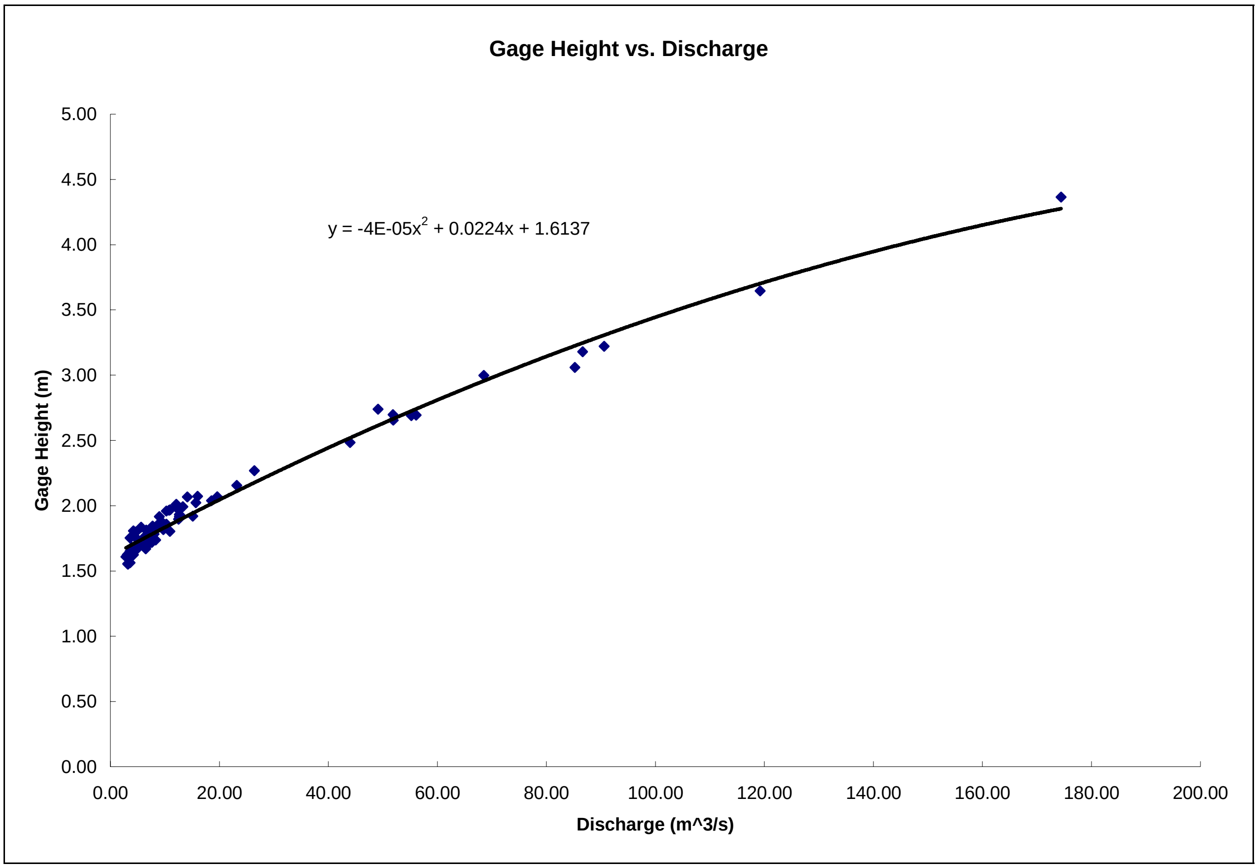
Bedrock Topography of the Springfield Area Bedrock Elevations from Schmidt 1982						
Assigned Name	Estimated x - coordinate (meters)	Estimated y - coordinate (meters)	Estimated Surface Elevation (feet)	Indicated Depth to Bedrock (feet)	Estimated Bedrock Elevation (feet)	Estimated Bedrock Elevation (meters)
SC1	257,975	4,434,042	968	40	928	283
SC2	257,986	4,433,055	949	19	930	283
SC3	263,150	4,432,436	1,120	192	928	283
SC4	258,190	4,430,273	931	22	909	277
SC5	257,265	4,429,054	939	44	895	273
SC6	261,367	4,429,295	1,040	133	907	276
SC7	260,716	4,428,921	1,010	58	952	290
SC8	256,985	4,427,751	922	108	814	248
SC9	260,557	4,427,868	980	50	930	283
SC10	259,199	4,426,055	1,020	85	935	285



Ground Water Resources of Clark County – Adapted from Schmidt (1982)

APPENDIX L

SWTP GAGE HEIGHT CALCULATIONS



Plot of Recent Mad River Gage Height and Discharge Data from the USGS

Location	USGS 03267900 - Mad River at St. Paris Pike at Eagle City, Ohio - Latitude 39°57'51", Longitude 83°49'54" NAD27		
Drainage area (sq. mi.)	310		
Gage datum	904.66 feet above sea level NGVD29		
Date	Discharge Measurements flow (ft^3/s)	Discharge Measurements flow (m^3/s)	Back calculated gage height (m)
1/1/1968	202	5.72	1.74
1/2/1968	202	5.72	1.74
1/3/1968	198	5.61	1.74
1/4/1968	189	5.35	1.73
1/5/1968	180	5.10	1.73
1/6/1968	180	5.10	1.73
1/7/1968	177	5.01	1.72
1/8/1968	171	4.84	1.72
1/9/1968	171	4.84	1.72
1/10/1968	168	4.76	1.72
1/11/1968	162	4.59	1.72
1/12/1968	160	4.53	1.71
1/13/1968	162	4.59	1.72
1/14/1968	165	4.67	1.72
1/15/1968	162	4.59	1.72
1/16/1968	152	4.30	1.71
1/17/1968	154	4.36	1.71
1/18/1968	152	4.30	1.71
1/19/1968	152	4.30	1.71
1/20/1968	152	4.30	1.71
1/21/1968	165	4.67	1.72
1/22/1968	202	5.72	1.74
1/23/1968	314	8.89	1.81
1/24/1968	230	6.51	1.76
1/25/1968	195	5.52	1.74
1/26/1968	180	5.10	1.73
1/27/1968	168	4.76	1.72
1/28/1968	362	10.25	1.84
1/29/1968	700	19.82	2.04
1/30/1968	1480	41.91	2.48
1/31/1968	818	23.16	2.11
Average	265.32	7.51	1.78

Location	USGS 03267900 - Mad River at St. Paris Pike at Eagle City, Ohio - Latitude 39°57'51", Longitude 83°49'54" NAD27		
Drainage area (sq. mi.)	310		
Gage datum	904.66 feet above sea level NGVD29		
Date	Discharge Measurements flow (ft^3/s)	Discharge Measurements flow (m^3/s)	Back calculated gage height (m)
2/1/1968	626	17.73	2.00
2/2/1968	682	19.31	2.03
2/3/1968	522	14.78	1.94
2/4/1968	424	12.01	1.88
2/5/1968	371	10.51	1.84
2/6/1968	336	9.51	1.82
2/7/1968	315	8.92	1.81
2/8/1968	294	8.33	1.80
2/9/1968	276	7.82	1.79
2/10/1968	256	7.25	1.77
2/11/1968	245	6.94	1.77
2/12/1968	233	6.60	1.76
2/13/1968	227	6.43	1.76
2/14/1968	224	6.34	1.75
2/15/1968	218	6.17	1.75
2/16/1968	215	6.09	1.75
2/17/1968	209	5.92	1.74
2/18/1968	198	5.61	1.74
2/19/1968	198	5.61	1.74
2/20/1968	201	5.69	1.74
2/21/1968	193	5.47	1.73
2/22/1968	190	5.38	1.73
2/23/1968	190	5.38	1.73
2/24/1968	187	5.30	1.73
2/25/1968	182	5.15	1.73
2/26/1968	179	5.07	1.73
2/27/1968	179	5.07	1.73
2/28/1968	179	5.07	1.73
2/29/1968	179	5.07	1.73
Average	273.38	7.74	1.78

Location	USGS 03267900 - Mad River at St. Paris Pike at Eagle City, Ohio - Latitude 39°57'51", Longitude 83°49'54" NAD27		
Drainage area (sq. mi.)	310		
Gage datum	904.66 feet above sea level NGVD29		
Date	Discharge Measurements flow (ft^3/s)	Discharge Measurements flow (m^3/s)	Back calculated gage height (m)
3/1/1968	179	5.07	1.73
3/2/1968	176	4.98	1.72
3/3/1968	174	4.93	1.72
3/4/1968	171	4.84	1.72
3/5/1968	174	4.93	1.72
3/6/1968	174	4.93	1.72
3/7/1968	171	4.84	1.72
3/8/1968	171	4.84	1.72
3/9/1968	174	4.93	1.72
3/10/1968	171	4.84	1.72
3/11/1968	168	4.76	1.72
3/12/1968	174	4.93	1.72
3/13/1968	171	4.84	1.72
3/14/1968	168	4.76	1.72
3/15/1968	171	4.84	1.72
3/16/1968	190	5.38	1.73
3/17/1968	236	6.68	1.76
3/18/1968	209	5.92	1.74
3/19/1968	201	5.69	1.74
3/20/1968	209	5.92	1.74
3/21/1968	259	7.33	1.78
3/22/1968	290	8.21	1.79
3/23/1968	284	8.04	1.79
3/24/1968	276	7.82	1.79
3/25/1968	385	10.90	1.85
3/26/1968	1100	31.15	2.27
3/27/1968	960	27.18	2.19
3/28/1968	570	16.14	1.96
3/29/1968	455	12.88	1.90
3/30/1968	382	10.82	1.85
3/31/1968	354	10.02	1.83
Average	288.61	8.17	1.79

Location	USGS 03267900 - Mad River at St. Paris Pike at Eagle City, Ohio - Latitude 39°57'51", Longitude 83°49'54" NAD27		
Drainage area (sq. mi.)	310		
Gage datum	904.66 feet above sea level NGVD29		
Date	Discharge Measurements flow (ft^3/s)	Discharge Measurements flow (m^3/s)	Back calculated gage height (m)
4/1/1968	506	14.33	1.93
4/2/1968	392	11.10	1.86
4/3/1968	354	10.02	1.83
4/4/1968	510	14.44	1.93
4/5/1968	472	13.37	1.91
4/6/1968	371	10.51	1.84
4/7/1968	343	9.71	1.83
4/8/1968	318	9.00	1.81
4/9/1968	290	8.21	1.79
4/10/1968	276	7.82	1.79
4/11/1968	266	7.53	1.78
4/12/1968	256	7.25	1.77
4/13/1968	239	6.77	1.76
4/14/1968	259	7.33	1.78
4/15/1968	284	8.04	1.79
4/16/1968	252	7.14	1.77
4/17/1968	248	7.02	1.77
4/18/1968	252	7.14	1.77
4/19/1968	239	6.77	1.76
4/20/1968	239	6.77	1.76
4/21/1968	233	6.60	1.76
4/22/1968	227	6.43	1.76
4/23/1968	239	6.77	1.76
4/24/1968	248	7.02	1.77
4/25/1968	245	6.94	1.77
4/26/1968	242	6.85	1.77
4/27/1968	230	6.51	1.76
4/28/1968	221	6.26	1.75
4/29/1968	218	6.17	1.75
4/30/1968	218	6.17	1.75
Average	289.57	8.20	1.79

Location	USGS 03267900 - Mad River at St. Paris Pike at Eagle City, Ohio - Latitude 39°57'51", Longitude 83°49'54" NAD27		
Drainage area (sq. mi.)	310		
Gage datum	904.66 feet above sea level NGVD29		
Date	Discharge Measurements flow (ft^3/s)	Discharge Measurements flow (m^3/s)	Back calculated gage height (m)
5/1/1968	218	6.17	1.75
5/2/1968	218	6.17	1.75
5/3/1968	218	6.17	1.75
5/4/1968	218	6.17	1.75
5/5/1968	212	6.00	1.75
5/6/1968	201	5.69	1.74
5/7/1968	204	5.78	1.74
5/8/1968	204	5.78	1.74
5/9/1968	204	5.78	1.74
5/10/1968	204	5.78	1.74
5/11/1968	233	6.60	1.76
5/12/1968	399	11.30	1.86
5/13/1968	301	8.52	1.80
5/14/1968	259	7.33	1.78
5/15/1968	287	8.13	1.79
5/16/1968	354	10.02	1.83
5/17/1968	294	8.33	1.80
5/18/1968	270	7.65	1.78
5/19/1968	252	7.14	1.77
5/20/1968	245	6.94	1.77
5/21/1968	236	6.68	1.76
5/22/1968	227	6.43	1.76
5/23/1968	736	20.84	2.06
5/24/1968	2090	59.18	2.80
5/25/1968	834	23.62	2.12
5/26/1968	1180	33.41	2.32
5/27/1968	3780	107.04	3.55
5/28/1968	1560	44.17	2.53
5/29/1968	935	26.48	2.18
5/30/1968	734	20.78	2.06
5/31/1968	622	17.61	2.00
Average	578.35	16.38	1.95

Location	USGS 03267900 - Mad River at St. Paris Pike at Eagle City, Ohio - Latitude 39°57'51", Longitude 83°49'54" NAD27		
Drainage area (sq. mi.)	310		
Gage datum	904.66 feet above sea level NGVD29		
Date	Discharge Measurements flow (ft^3/s)	Discharge Measurements flow (m^3/s)	Back calculated gage height (m)
6/1/1968	562	15.91	1.96
6/2/1968	618	17.50	1.99
6/3/1968	538	15.23	1.95
6/4/1968	486	13.76	1.91
6/5/1968	450	12.74	1.89
6/6/1968	422	11.95	1.88
6/7/1968	390	11.04	1.86
6/8/1968	370	10.48	1.84
6/9/1968	360	10.19	1.84
6/10/1968	350	9.91	1.83
6/11/1968	340	9.63	1.83
6/12/1968	330	9.34	1.82
6/13/1968	310	8.78	1.81
6/14/1968	300	8.50	1.80
6/15/1968	286	8.10	1.79
6/16/1968	360	10.19	1.84
6/17/1968	330	9.34	1.82
6/18/1968	310	8.78	1.81
6/19/1968	300	8.50	1.80
6/20/1968	290	8.21	1.79
6/21/1968	280	7.93	1.79
6/22/1968	272	7.70	1.78
6/23/1968	270	7.65	1.78
6/24/1968	280	7.93	1.79
6/25/1968	300	8.50	1.80
6/26/1968	310	8.78	1.81
6/27/1968	300	8.50	1.80
6/28/1968	286	8.10	1.79
6/29/1968	270	7.65	1.78
6/30/1968	260	7.36	1.78
Average	351.00	9.94	1.83

Location	USGS 03267900 - Mad River at St. Paris Pike at Eagle City, Ohio - Latitude 39°57'51", Longitude 83°49'54" NAD27		
Drainage area (sq. mi.)	310		
Gage datum	904.66 feet above sea level NGVD29		
Date	Discharge Measurements flow (ft^3/s)	Discharge Measurements flow (m^3/s)	Back calculated gage height (m)
7/1/1968	250	7.08	1.77
7/2/1968	240	6.80	1.76
7/3/1968	230	6.51	1.76
7/4/1968	220	6.23	1.75
7/5/1968	210	5.95	1.75
7/6/1968	210	5.95	1.75
7/7/1968	200	5.66	1.74
7/8/1968	200	5.66	1.74
7/9/1968	190	5.38	1.73
7/10/1968	190	5.38	1.73
7/11/1968	184	5.21	1.73
7/12/1968	180	5.10	1.73
7/13/1968	181	5.13	1.73
7/14/1968	200	5.66	1.74
7/15/1968	220	6.23	1.75
7/16/1968	210	5.95	1.75
7/17/1968	200	5.66	1.74
7/18/1968	190	5.38	1.73
7/19/1968	200	5.66	1.74
7/20/1968	198	5.61	1.74
7/21/1968	190	5.38	1.73
7/22/1968	180	5.10	1.73
7/23/1968	180	5.10	1.73
7/24/1968	181	5.13	1.73
7/25/1968	466	13.20	1.90
7/26/1968	293	8.30	1.80
7/27/1968	244	6.91	1.77
7/28/1968	346	9.80	1.83
7/29/1968	240	6.80	1.76
7/30/1968	212	6.00	1.75
7/31/1968	202	5.72	1.74
Average	220.55	6.25	1.75

Location	USGS 03267900 - Mad River at St. Paris Pike at Eagle City, Ohio - Latitude 39°57'51", Longitude 83°49'54" NAD27		
Drainage area (sq. mi.)	310		
Gage datum	904.66 feet above sea level NGVD29		
Date	Discharge Measurements flow (ft^3/s)	Discharge Measurements flow (m^3/s)	Back calculated gage height (m)
8/1/1968	482	13.65	1.91
8/2/1968	276	7.82	1.79
8/3/1968	237	6.71	1.76
8/4/1968	498	14.10	1.92
8/5/1968	390	11.04	1.86
8/6/1968	272	7.70	1.78
8/7/1968	339	9.60	1.83
8/8/1968	442	12.52	1.89
8/9/1968	390	11.04	1.86
8/10/1968	307	8.69	1.81
8/11/1968	268	7.59	1.78
8/12/1968	244	6.91	1.77
8/13/1968	237	6.71	1.76
8/14/1968	226	6.40	1.76
8/15/1968	220	6.23	1.75
8/16/1968	248	7.02	1.77
8/17/1968	230	6.51	1.76
8/18/1968	226	6.40	1.76
8/19/1968	220	6.23	1.75
8/20/1968	212	6.00	1.75
8/21/1968	202	5.72	1.74
8/22/1968	195	5.52	1.74
8/23/1968	188	5.32	1.73
8/24/1968	181	5.13	1.73
8/25/1968	178	5.04	1.73
8/26/1968	174	4.93	1.72
8/27/1968	170	4.81	1.72
8/28/1968	167	4.73	1.72
8/29/1968	160	4.53	1.71
8/30/1968	157	4.45	1.71
8/31/1968	150	4.25	1.71
Average	254.39	7.20	1.77

Location	USGS 03267900 - Mad River at St. Paris Pike at Eagle City, Ohio - Latitude 39°57'51", Longitude 83°49'54" NAD27		
Drainage area (sq. mi.)	310		
Gage datum	904.66 feet above sea level NGVD29		
Date	Discharge Measurements flow (ft^3/s)	Discharge Measurements flow (m^3/s)	Back calculated gage height (m)
9/1/1968	150	4.25	1.71
9/2/1968	160	4.53	1.71
9/3/1968	150	4.25	1.71
9/4/1968	150	4.25	1.71
9/5/1968	157	4.45	1.71
9/6/1968	170	4.81	1.72
9/7/1968	151	4.28	1.71
9/8/1968	148	4.19	1.71
9/9/1968	145	4.11	1.70
9/10/1968	145	4.11	1.70
9/11/1968	154	4.36	1.71
9/12/1968	154	4.36	1.71
9/13/1968	151	4.28	1.71
9/14/1968	145	4.11	1.70
9/15/1968	142	4.02	1.70
9/16/1968	142	4.02	1.70
9/17/1968	164	4.64	1.72
9/18/1968	167	4.73	1.72
9/19/1968	167	4.73	1.72
9/20/1968	154	4.36	1.71
9/21/1968	145	4.11	1.70
9/22/1968	139	3.94	1.70
9/23/1968	154	4.36	1.71
9/24/1968	148	4.19	1.71
9/25/1968	151	4.28	1.71
9/26/1968	148	4.19	1.71
9/27/1968	148	4.19	1.71
9/28/1968	145	4.11	1.70
9/29/1968	139	3.94	1.70
9/30/1968	142	4.02	1.70
Average	150.83	4.27	1.71

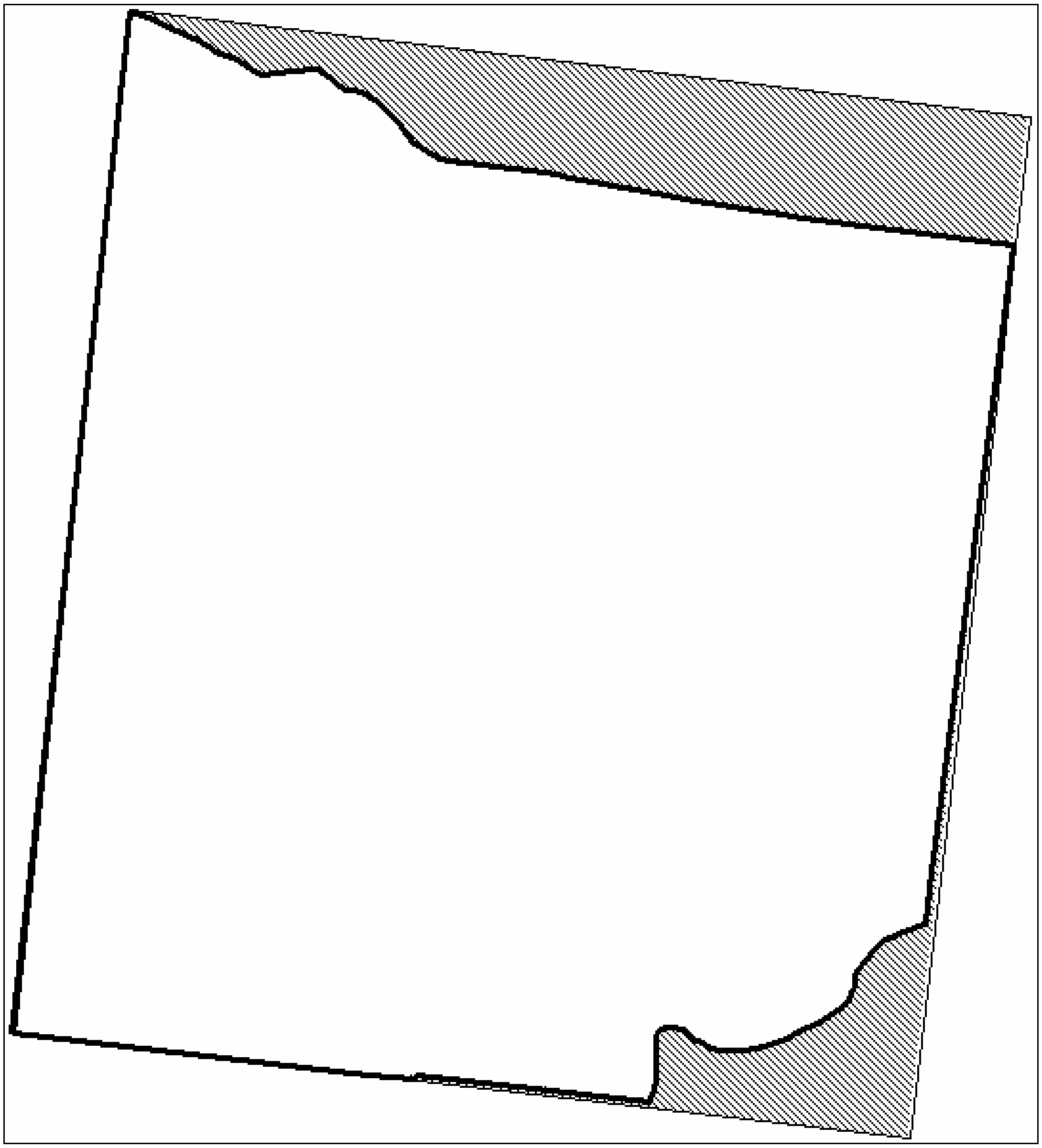
Location	USGS 03267900 - Mad River at St. Paris Pike at Eagle City, Ohio - Latitude 39°57'51", Longitude 83°49'54" NAD27		
Drainage area (sq. mi.)	310		
Gage datum	904.66 feet above sea level NGVD29		
Date	Discharge Measurements flow (ft^3/s)	Discharge Measurements flow (m^3/s)	Back calculated gage height (m)
10/1/1968	145	4.11	1.70
10/2/1968	142	4.02	1.70
10/3/1968	151	4.28	1.71
10/4/1968	139	3.94	1.70
10/5/1968	136	3.85	1.70
10/6/1968	136	3.85	1.70
10/7/1968	139	3.94	1.70
10/8/1968	142	4.02	1.70
10/9/1968	139	3.94	1.70
10/10/1968	142	4.02	1.70
10/11/1968	139	3.94	1.70
10/12/1968	133	3.77	1.70
10/13/1968	130	3.68	1.70
10/14/1968	130	3.68	1.70
10/15/1968	130	3.68	1.70
10/16/1968	136	3.85	1.70
10/17/1968	139	3.94	1.70
10/18/1968	139	3.94	1.70
10/19/1968	133	3.77	1.70
10/20/1968	130	3.68	1.70
10/21/1968	133	3.77	1.70
10/22/1968	139	3.94	1.70
10/23/1968	139	3.94	1.70
10/24/1968	139	3.94	1.70
10/25/1968	139	3.94	1.70
10/26/1968	136	3.85	1.70
10/27/1968	130	3.68	1.70
10/28/1968	130	3.68	1.70
10/29/1968	133	3.77	1.70
10/30/1968	133	3.77	1.70
10/31/1968	136	3.85	1.70
Average	136.68	3.87	1.70

Location	USGS 03267900 - Mad River at St. Paris Pike at Eagle City, Ohio - Latitude 39°57'51", Longitude 83°49'54" NAD27		
Drainage area (sq. mi.)	310		
Gage datum	904.66 feet above sea level NGVD29		
Date	Discharge Measurements flow (ft^3/s)	Discharge Measurements flow (m^3/s)	Back calculated gage height (m)
11/1/1968	136	3.85	1.70
11/2/1968	133	3.77	1.70
11/3/1968	130	3.68	1.70
11/4/1968	130	3.68	1.70
11/5/1968	139	3.94	1.70
11/6/1968	145	4.11	1.70
11/7/1968	160	4.53	1.71
11/8/1968	154	4.36	1.71
11/9/1968	151	4.28	1.71
11/10/1968	148	4.19	1.71
11/11/1968	145	4.11	1.70
11/12/1968	145	4.11	1.70
11/13/1968	145	4.11	1.70
11/14/1968	145	4.11	1.70
11/15/1968	151	4.28	1.71
11/16/1968	334	9.46	1.82
11/17/1968	276	7.82	1.79
11/18/1968	258	7.31	1.78
11/19/1968	237	6.71	1.76
11/20/1968	212	6.00	1.75
11/21/1968	195	5.52	1.74
11/22/1968	184	5.21	1.73
11/23/1968	178	5.04	1.73
11/24/1968	220	6.23	1.75
11/25/1968	234	6.63	1.76
11/26/1968	206	5.83	1.74
11/27/1968	192	5.44	1.73
11/28/1968	304	8.61	1.80
11/29/1968	386	10.93	1.85
11/30/1968	262	7.42	1.78
Average	194.50	5.51	1.74

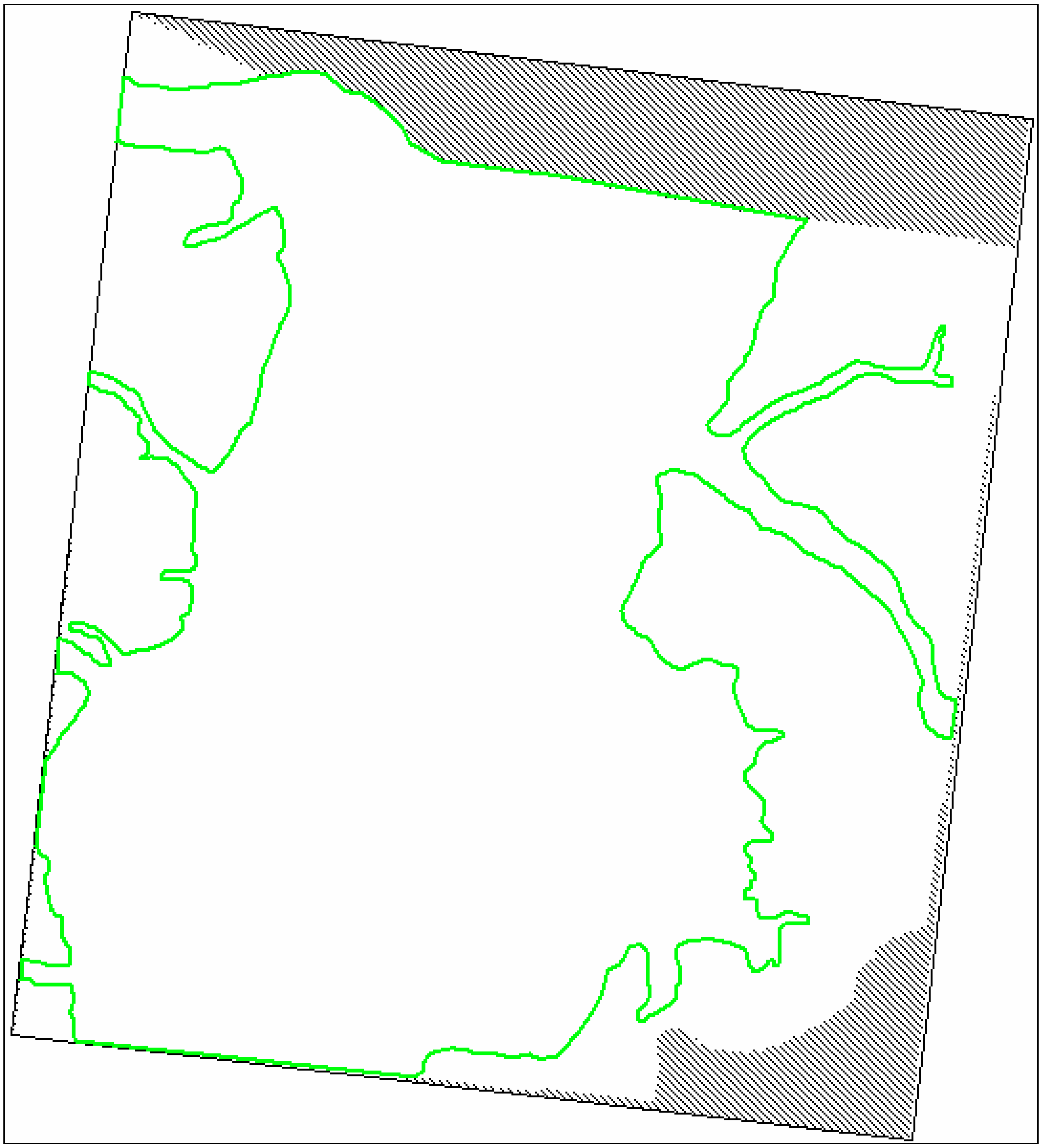
Location	USGS 03267900 - Mad River at St. Paris Pike at Eagle City, Ohio - Latitude 39°57'51", Longitude 83°49'54" NAD27		
Drainage area (sq. mi.)	310		
Gage datum	904.66 feet above sea level NGVD29		
Date	Discharge Measurements flow (ft^3/s)	Discharge Measurements flow (m^3/s)	Back calculated gage height (m)
12/1/1968	244	6.91	1.77
12/2/1968	296	8.38	1.80
12/3/1968	276	7.82	1.79
12/4/1968	638	18.07	2.01
12/5/1968	450	12.74	1.89
12/6/1968	318	9.00	1.81
12/7/1968	272	7.70	1.78
12/8/1968	244	6.91	1.77
12/9/1968	226	6.40	1.76
12/10/1968	216	6.12	1.75
12/11/1968	212	6.00	1.75
12/12/1968	212	6.00	1.75
12/13/1968	223	6.31	1.75
12/14/1968	223	6.31	1.75
12/15/1968	209	5.92	1.74
12/16/1968	202	5.72	1.74
12/17/1968	206	5.83	1.74
12/18/1968	209	5.92	1.74
12/19/1968	251	7.11	1.77
12/20/1968	272	7.70	1.78
12/21/1968	230	6.51	1.76
12/22/1968	293	8.30	1.80
12/23/1968	442	12.52	1.89
12/24/1968	282	7.99	1.79
12/25/1968	251	7.11	1.77
12/26/1968	240	6.80	1.76
12/27/1968	606	17.16	1.99
12/28/1968	1640	46.44	2.57
12/29/1968	686	19.43	2.03
12/30/1968	466	13.20	1.90
12/31/1968	386	10.93	1.85
Average	352.29	9.98	1.83

APPENDIX M

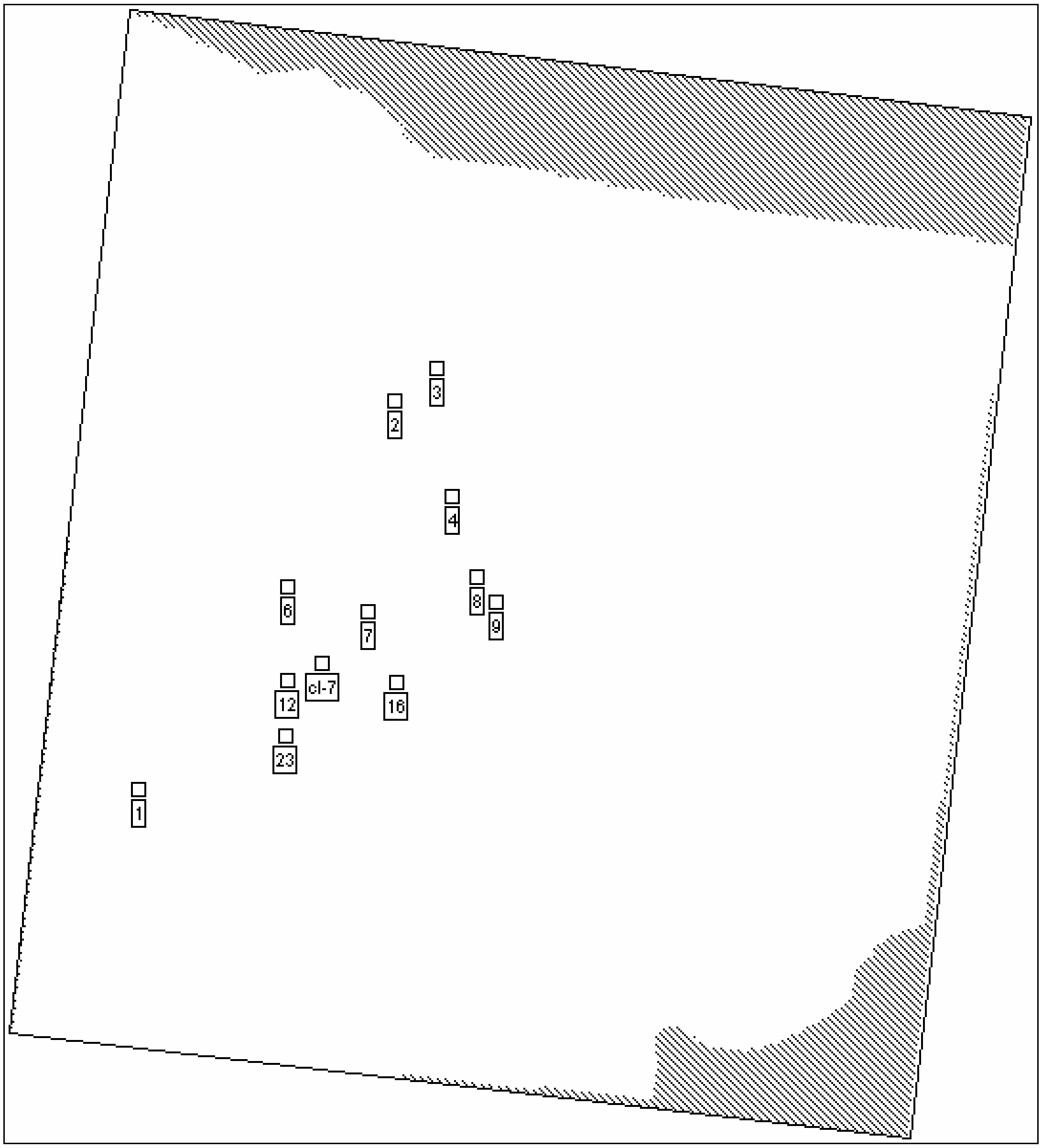
SWTP MODEL TRANSIENT INPUT PARAMETERS



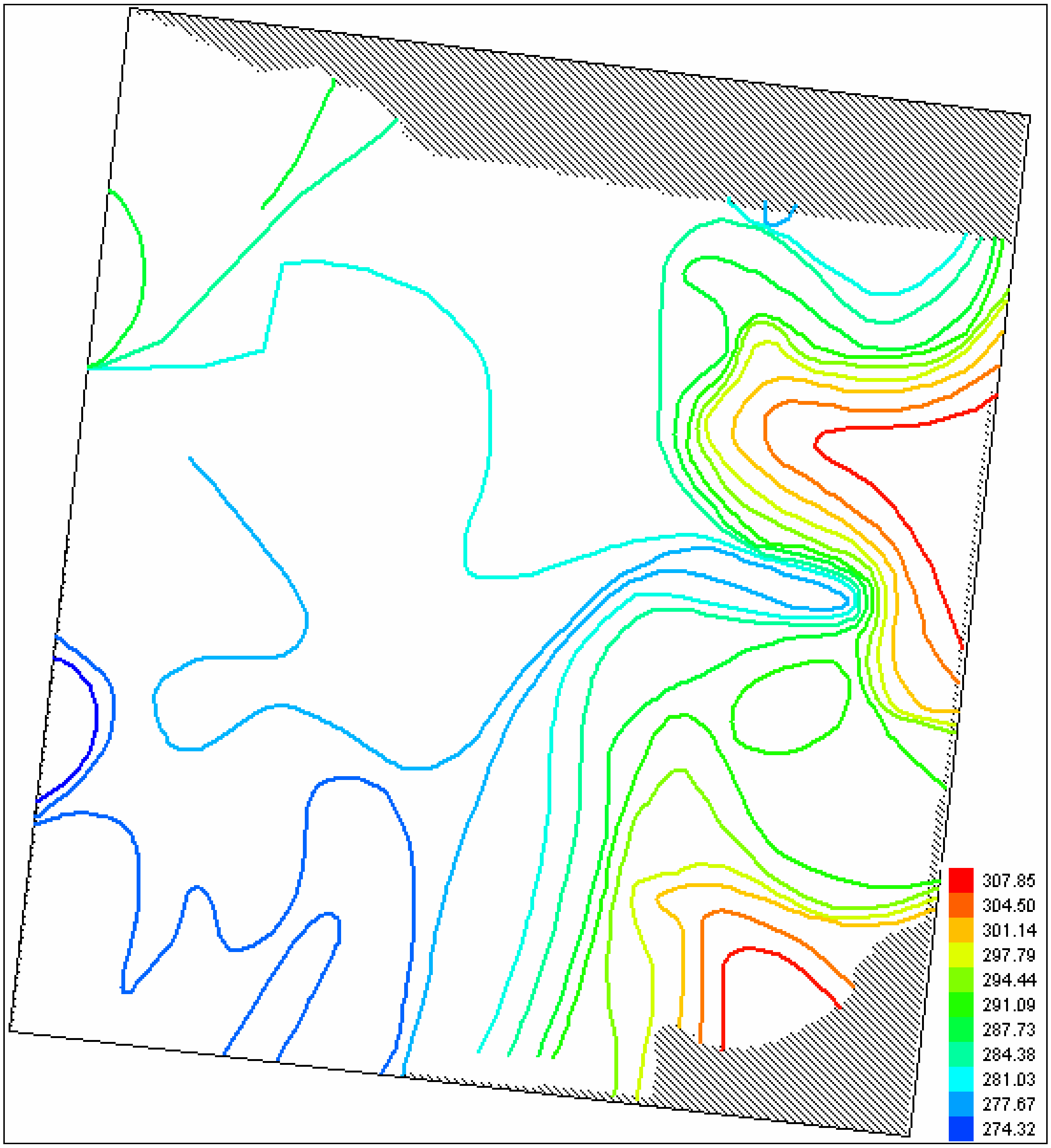
SWTP Domain Outline and Gridded Area



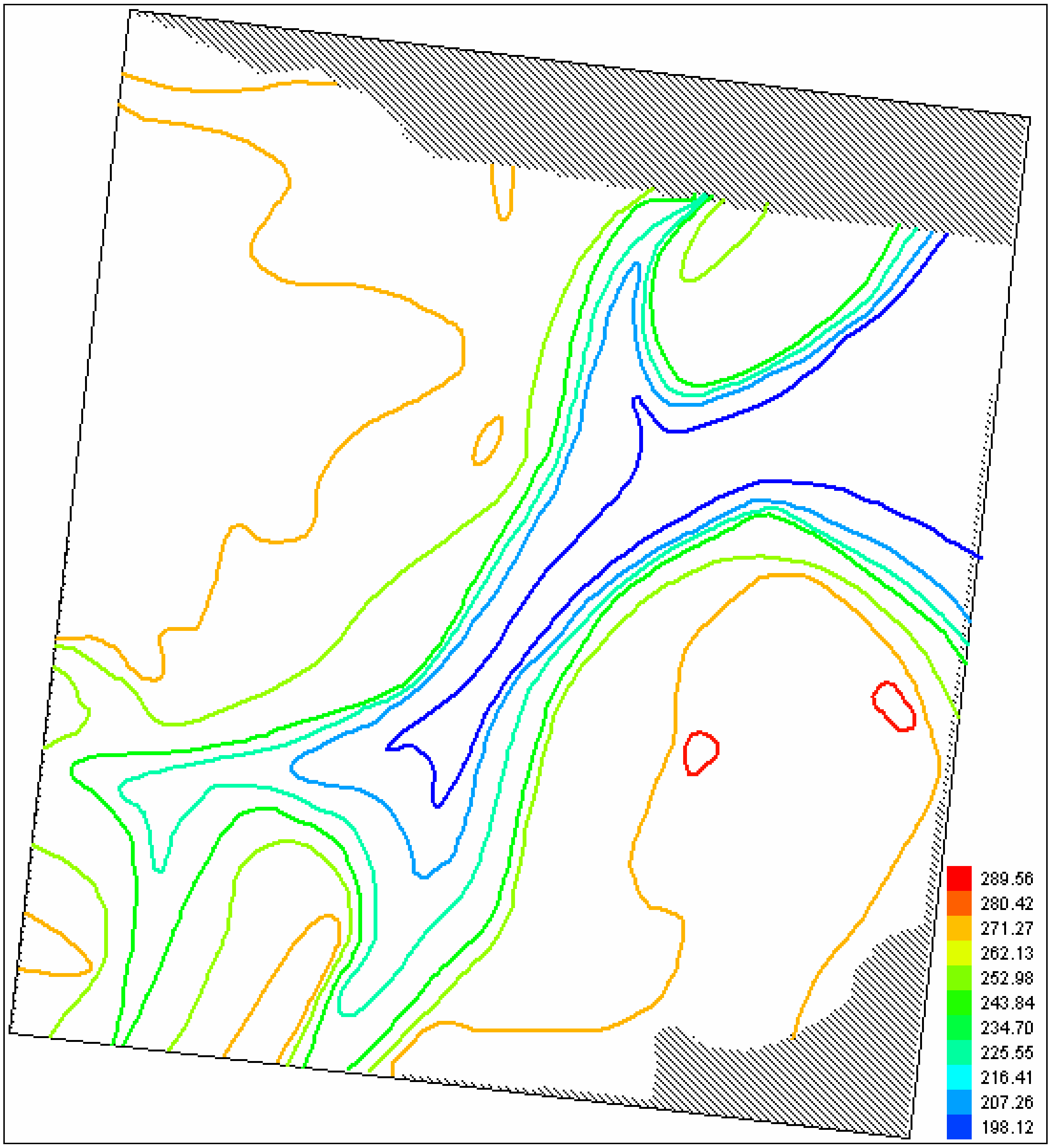
Recharge and Hydraulic Conductivity Area



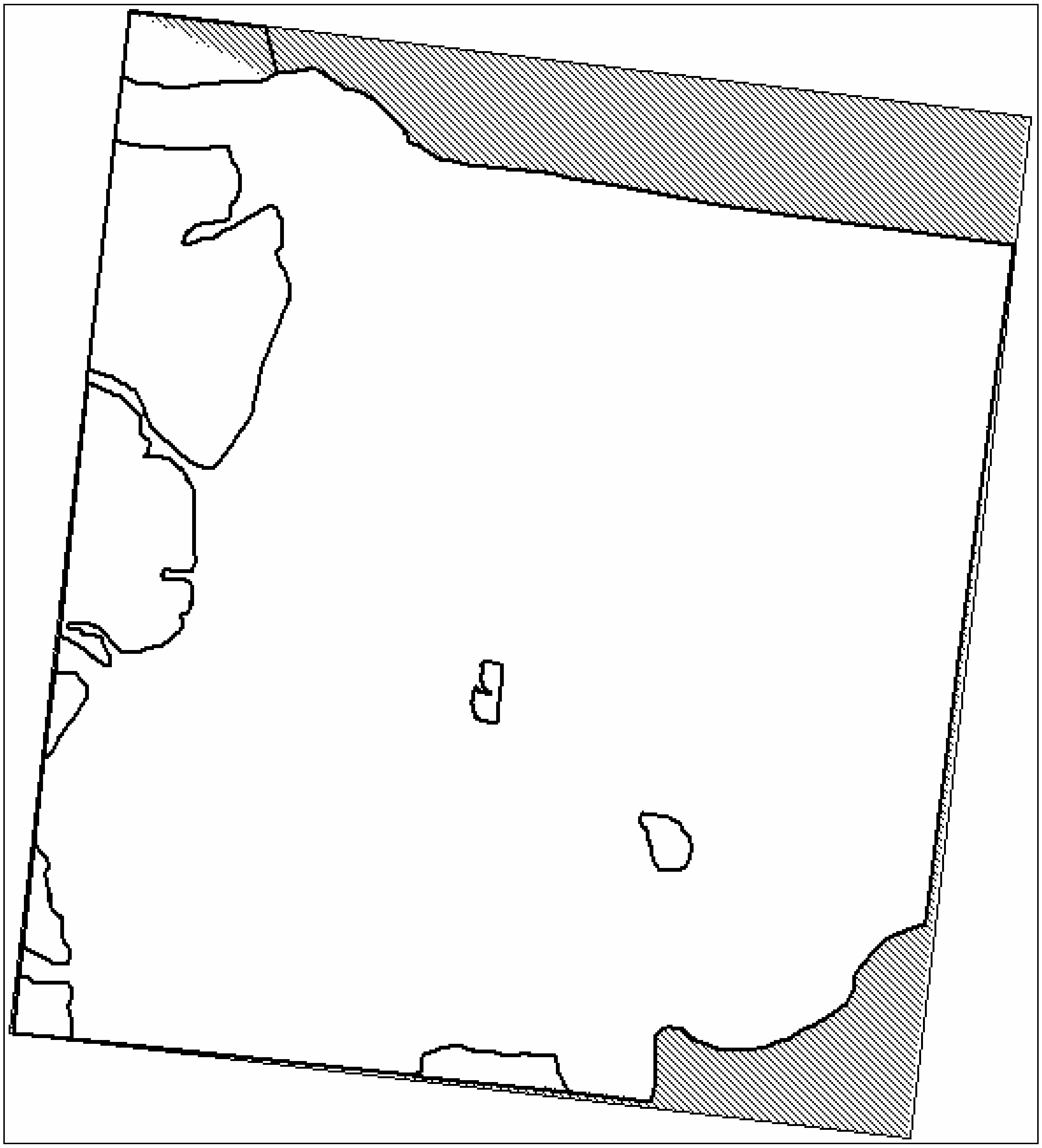
Sandpoints



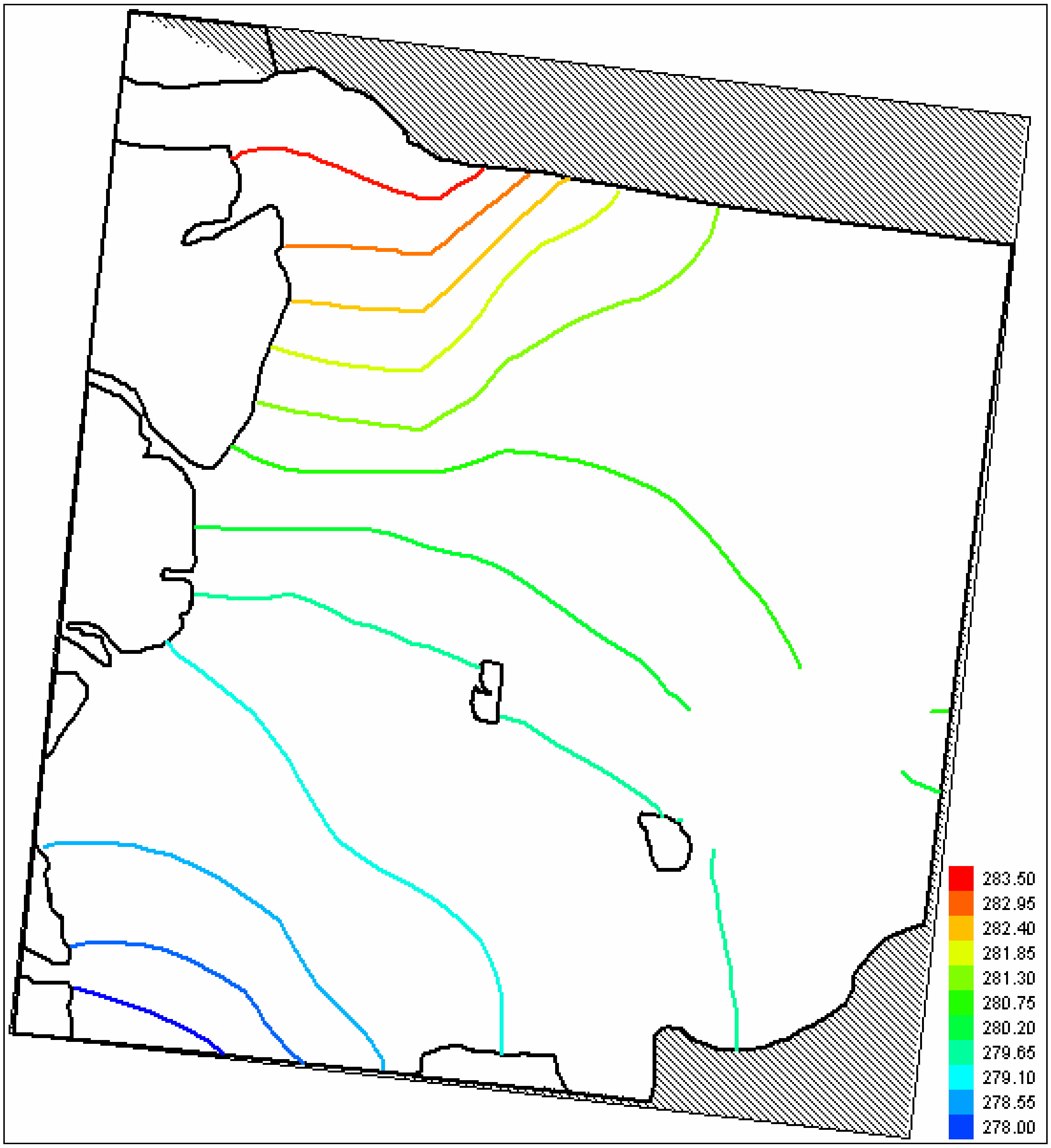
Top Elevation in Meters



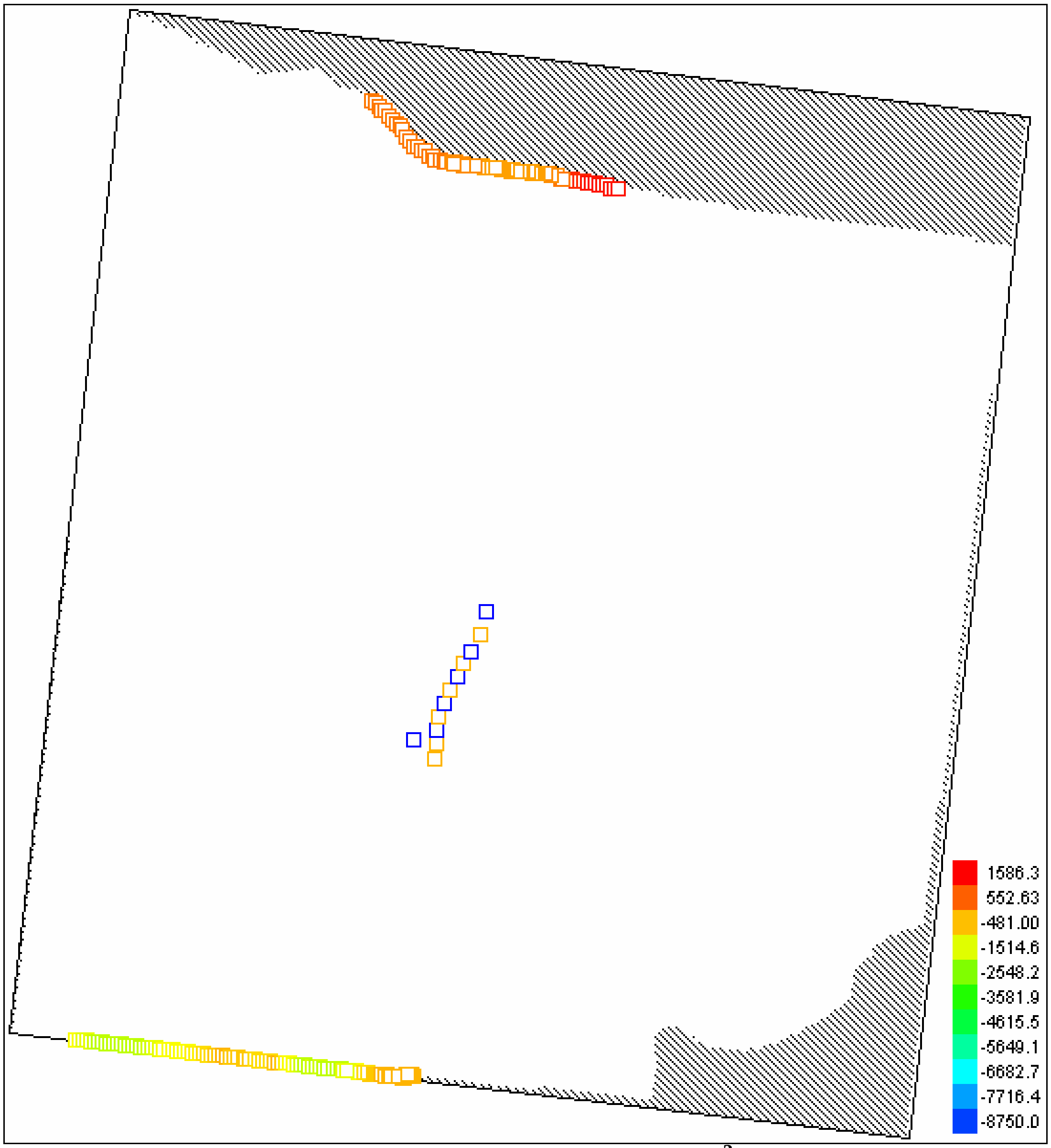
Bottom Elevation in Meters



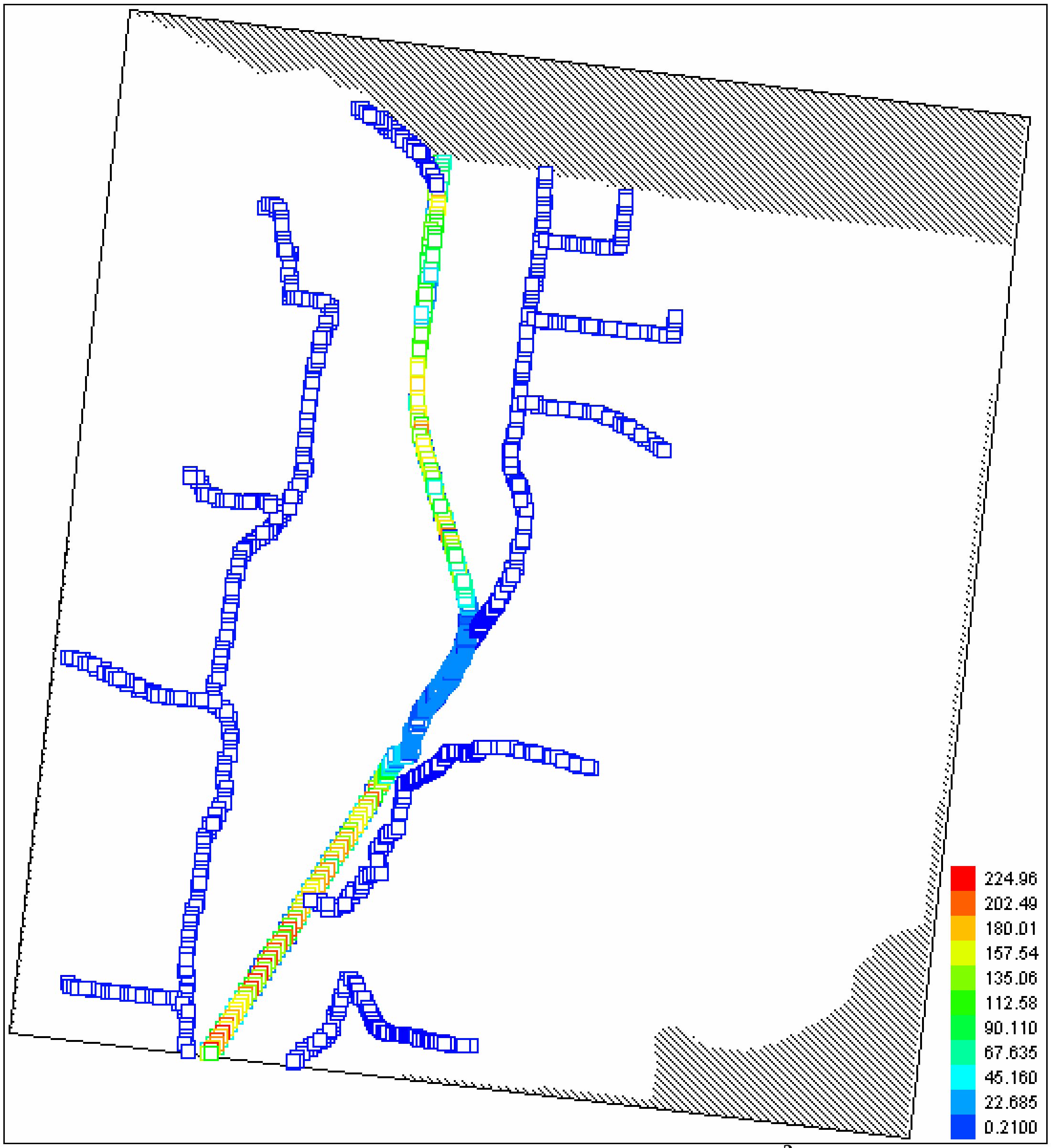
Added Inactive Areas



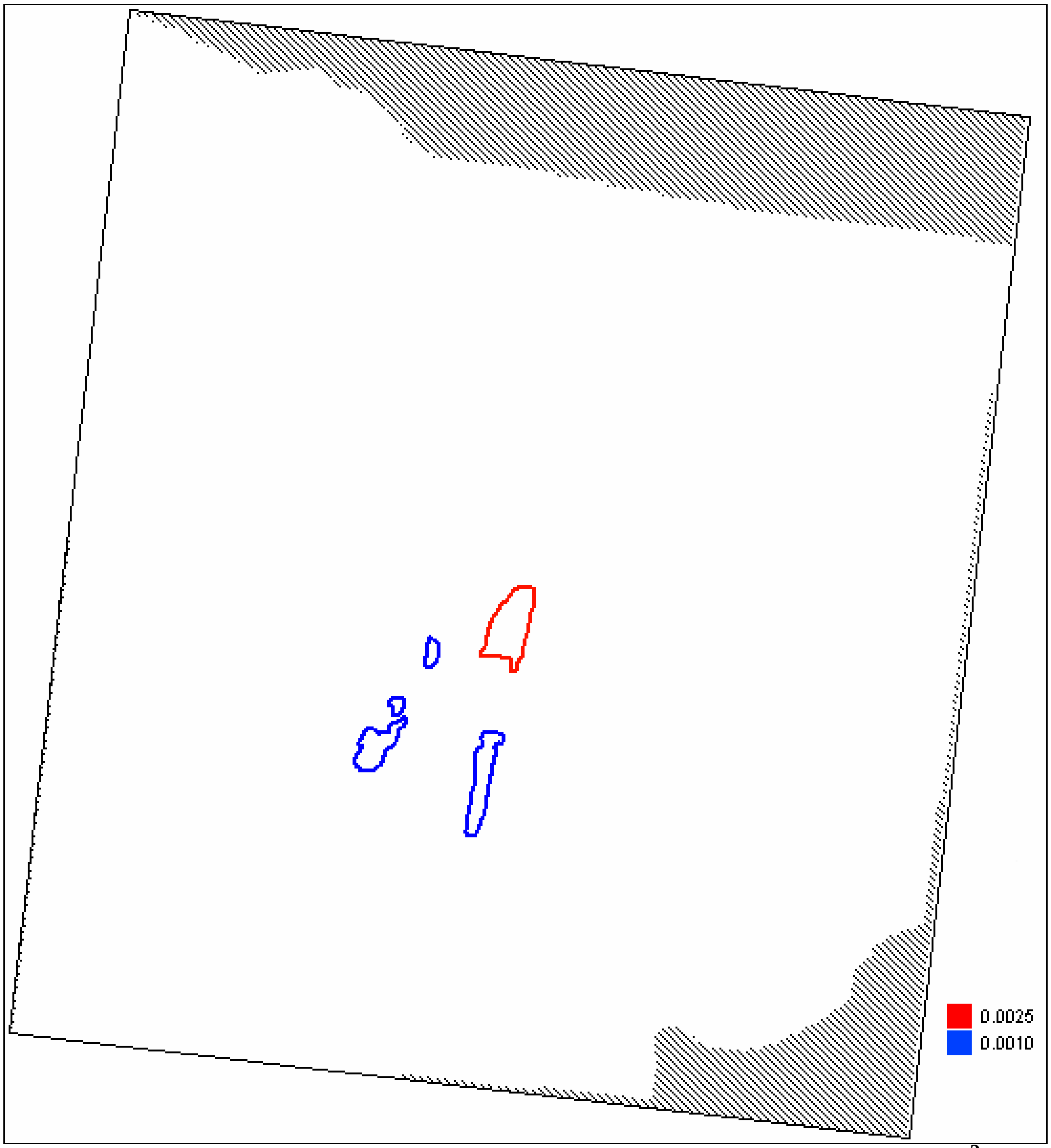
Initial Head Contours for Final Model in Meters



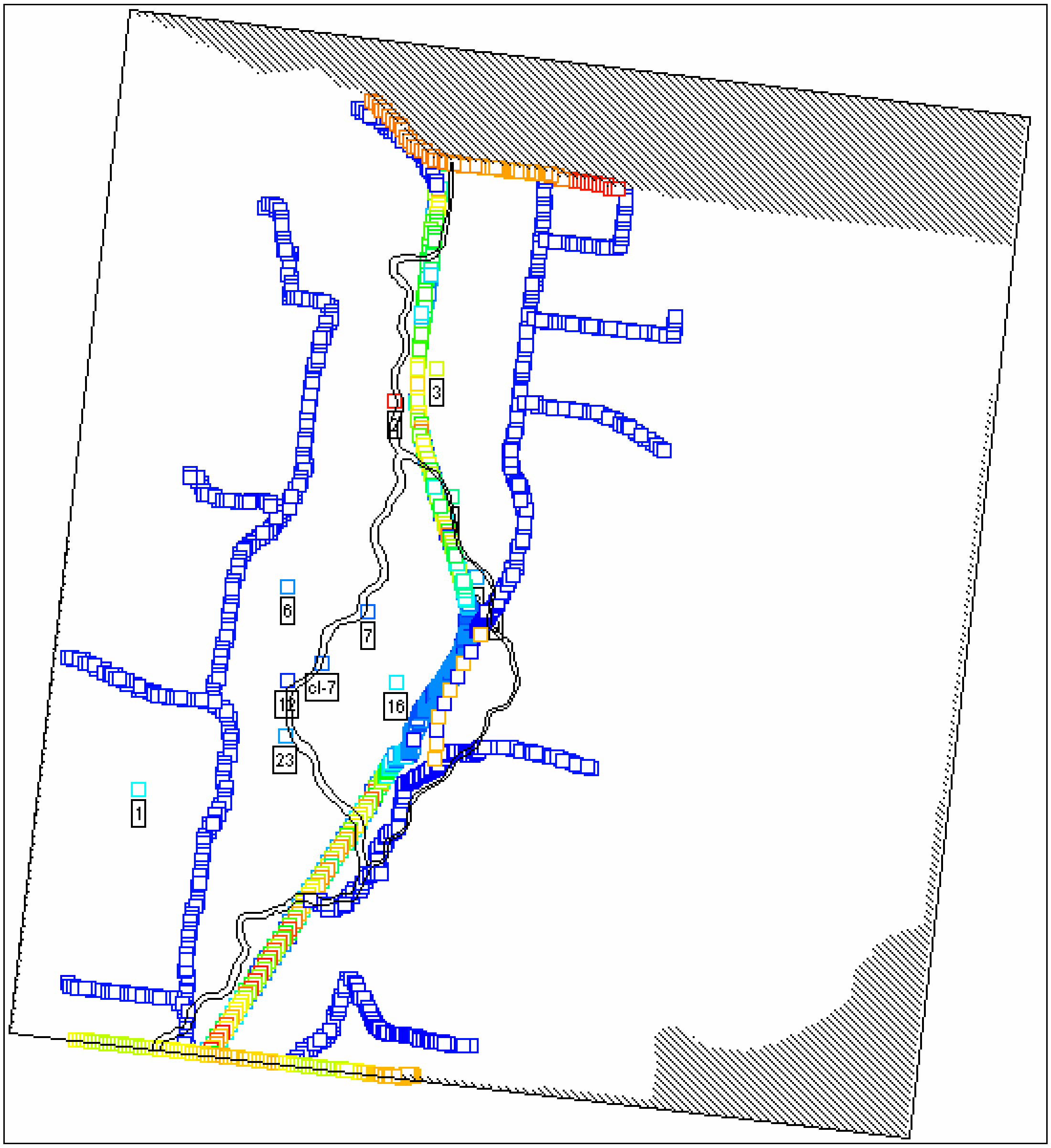
Well Locations and Stresses in m^3/d



Point River Layers and Conductance in m^2/d



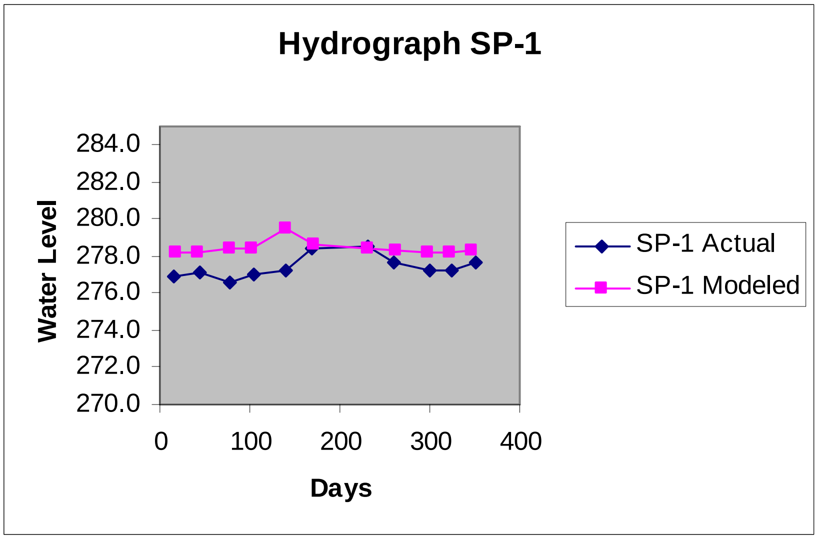
Lake (Area General Head Boundary) Locations and Conductance in m^2/d

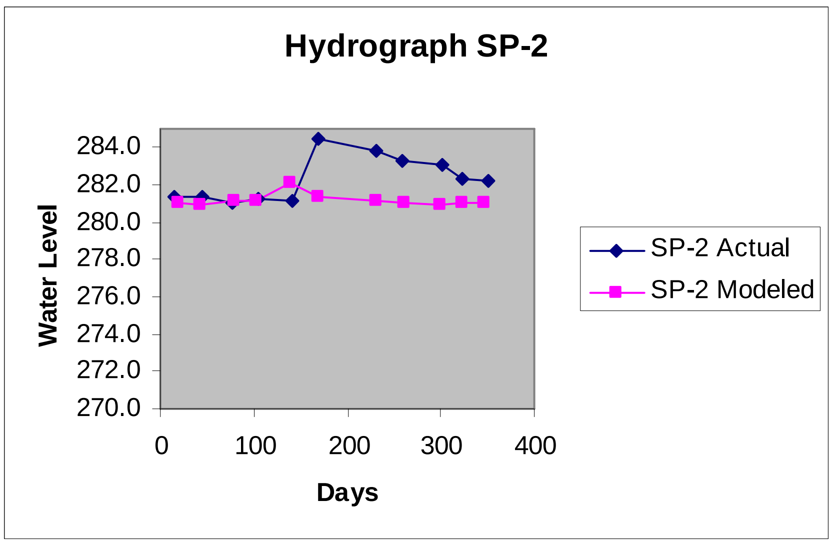


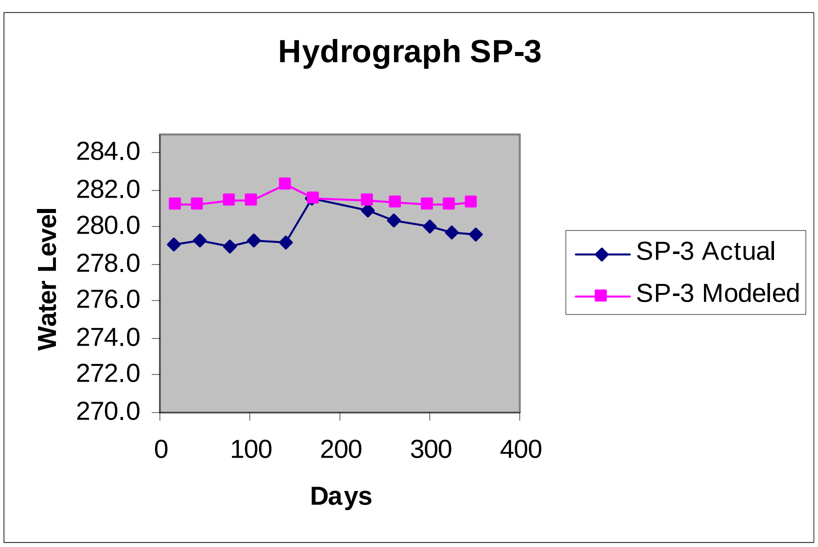
Original Course of the Mad River in Relation to Site Features

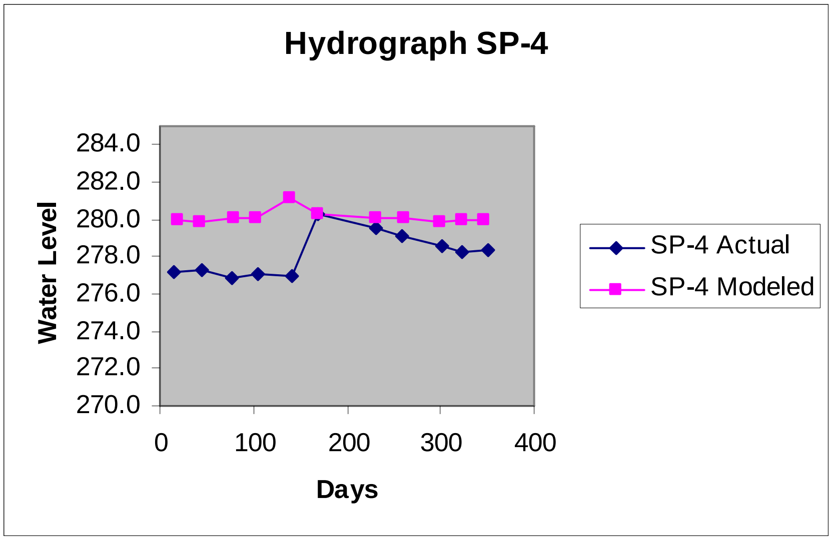
APPENDIX N

SWTP MODEL CALIBRATION HYDROGRAPHS

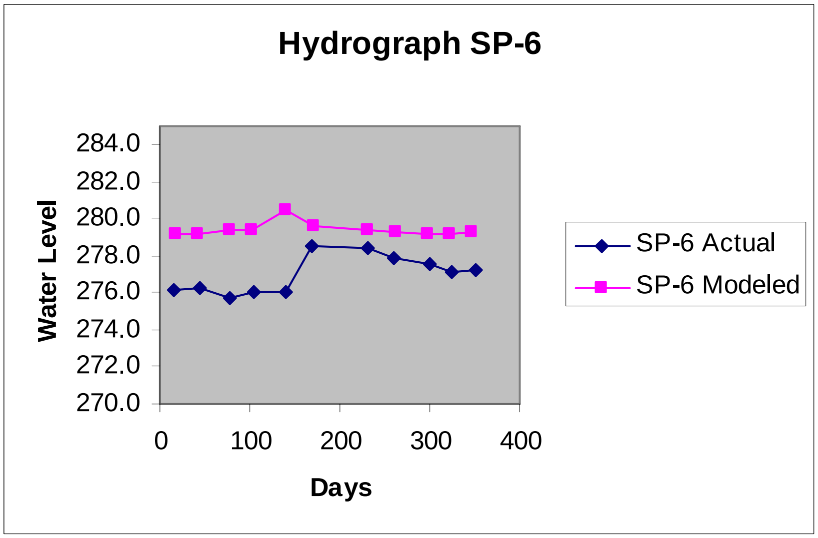

Hydrograph SP-1
Water Level
284.0
282.0
280.0
278.0
276.0
274.0
272.0
270.0
0
100
200
300
400
Days
SP-1 Actual
SP-1 Modeled


Hydrograph SP-2
Water Level
284.0
282.0
280.0
278.0
276.0
274.0
272.0
270.0
0
100
200
300
400
Days
SP-2 Actual
SP-2 Modeled

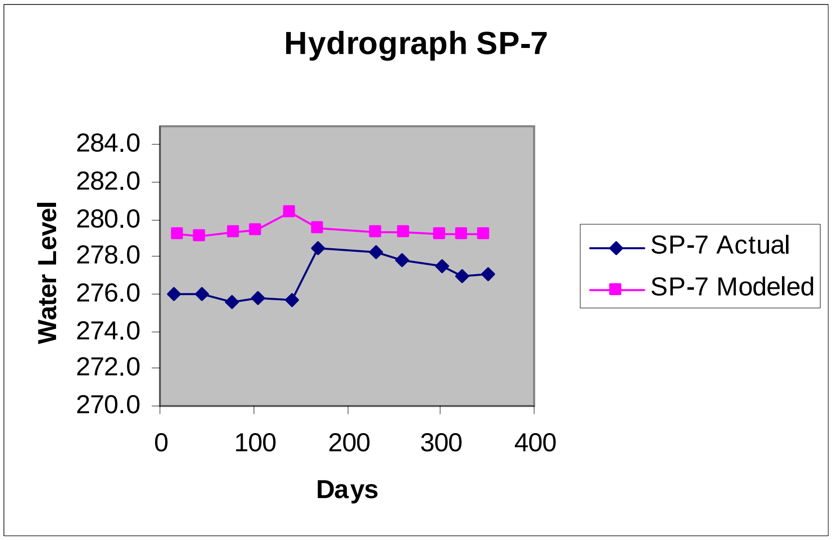

Hydrograph SP-3
Water Level
284.0
282.0
280.0
278.0
276.0
274.0
272.0
270.0
0
100
200
300
400
Days
SP-3 Actual
SP-3 Modeled



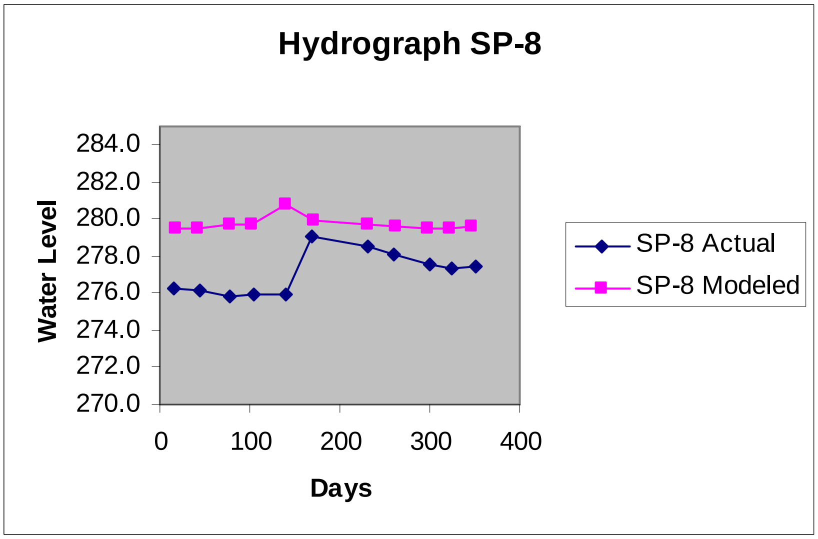
Hydrograph SP-4
Water Level
284.0
282.0
280.0
278.0
276.0
274.0
272.0
270.0
0
100
200
300
400
Days
SP-4 Actual
SP-4 Modeled

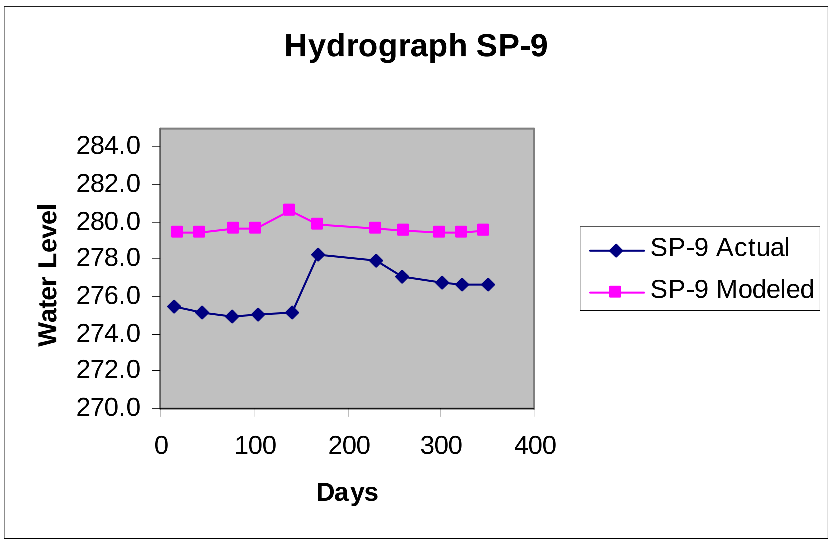


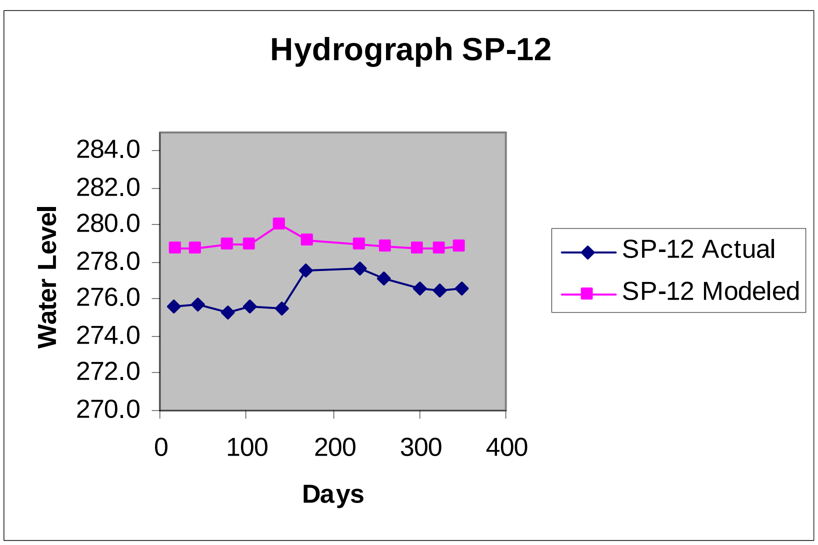
Hydrograph SP-6
Water Level
284.0
282.0
280.0
278.0
276.0
274.0
272.0
270.0
0
100
200
300
400
Days
SP-6 Actual
SP-6 Modeled

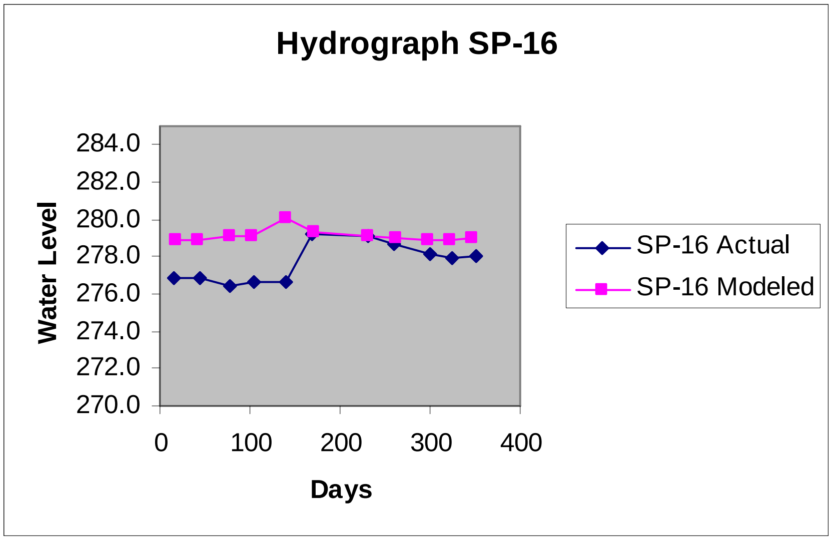


Hydrograph SP-7
Water Level
284.0
282.0
280.0
278.0
276.0
274.0
272.0
270.0
0
100
200
300
400
Days
SP-7 Actual
SP-7 Modeled

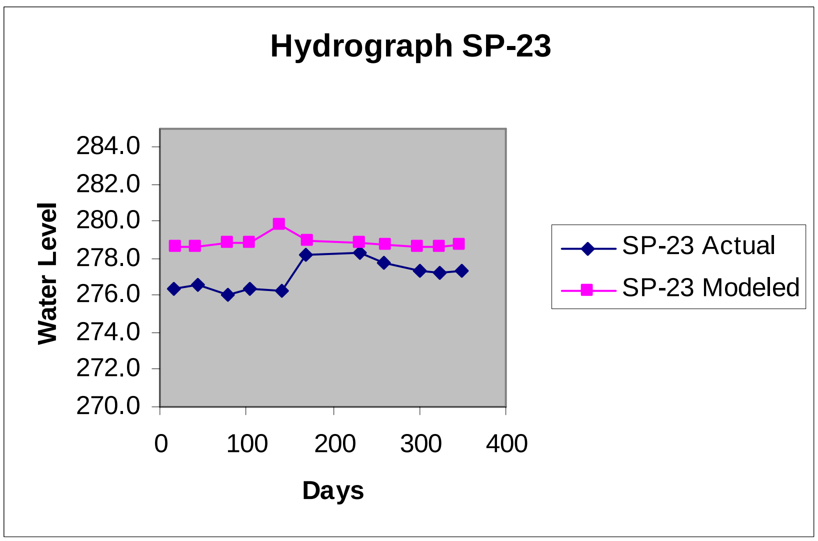

Hydrograph SP-8
Water Level
284.0
282.0
280.0
278.0
276.0
274.0
272.0
270.0
0
100
200
300
400
Days
SP-8 Actual
SP-8 Modeled


Hydrograph SP-9
Water Level
284.0
282.0
280.0
278.0
276.0
274.0
272.0
270.0
0
100
200
300
400
Days
SP-9 Actual
SP-9 Modeled

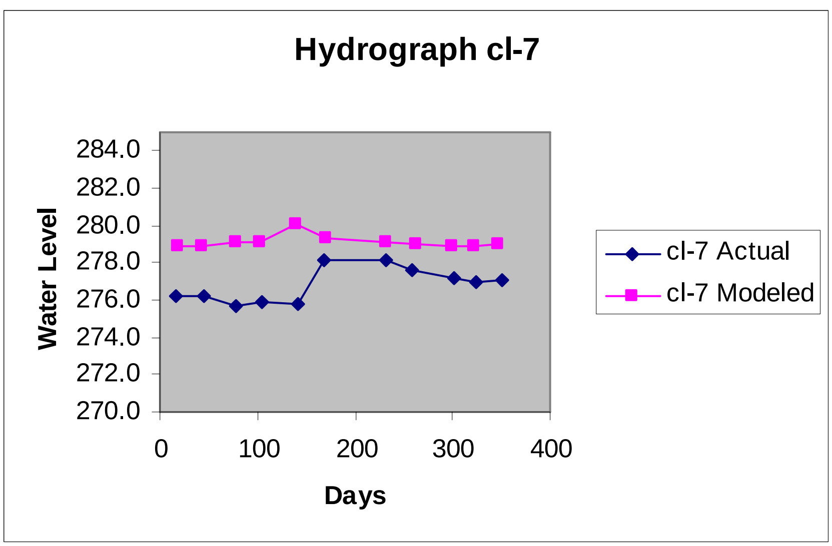

Hydrograph SP-12
Water Level
284.0
282.0
280.0
278.0
276.0
274.0
272.0
270.0
0
100
200
300
400
Days
SP-12 Actual
SP-12 Modeled



Hydrograph SP-16
Water Level
284.0
282.0
280.0
278.0
276.0
274.0
272.0
270.0
0
100
200
300
400
Days
SP-16 Actual
SP-16 Modeled



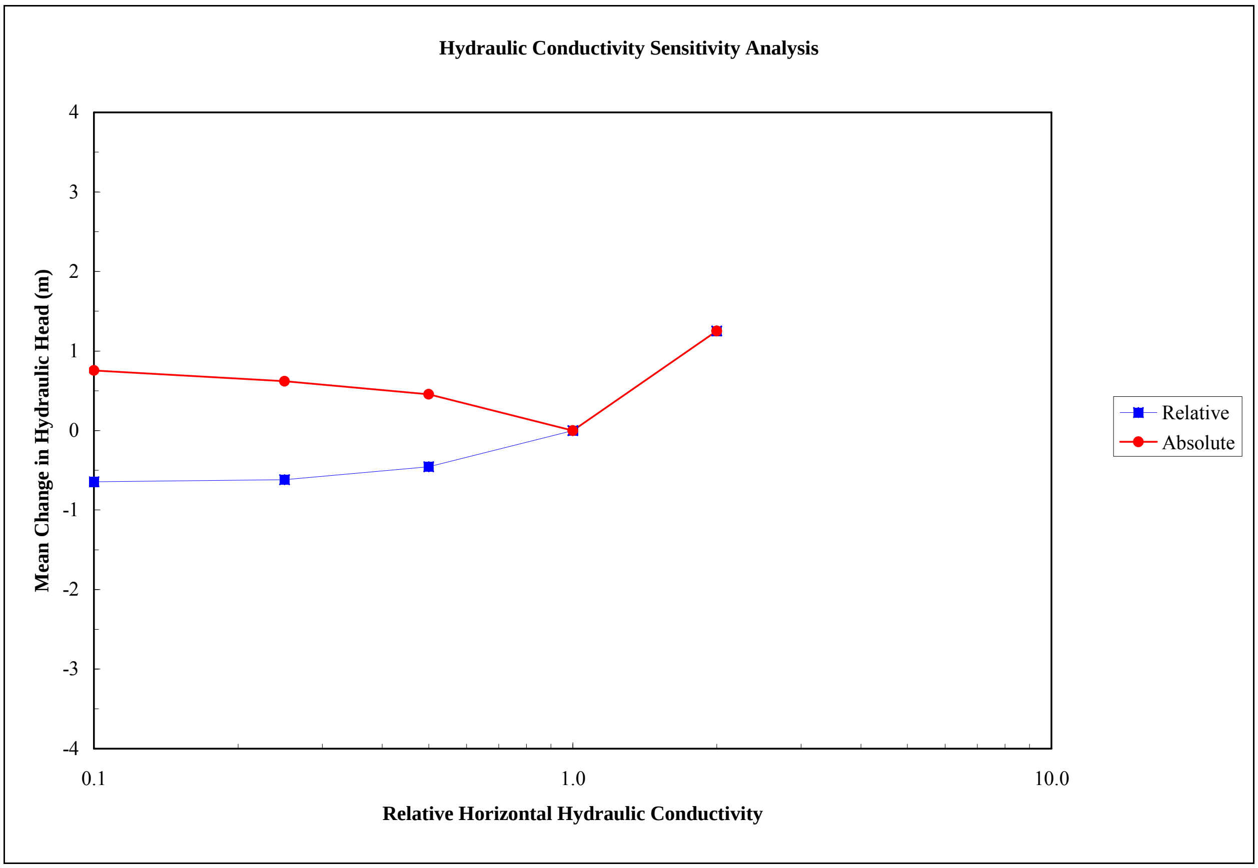
Hydrograph SP-23
Water Level
284.0
282.0
280.0
278.0
276.0
274.0
272.0
270.0
0
100
200
300
400
Days
SP-23 Actual
SP-23 Modeled

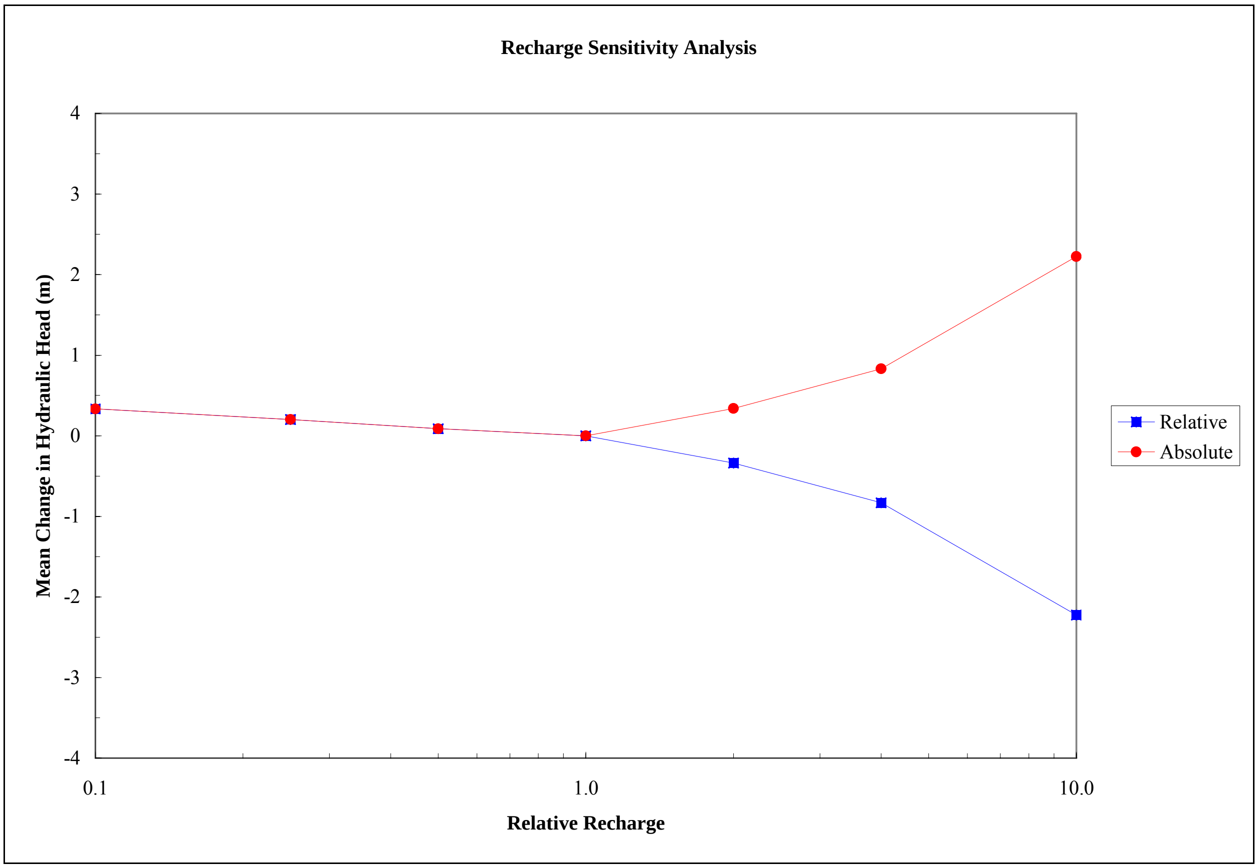


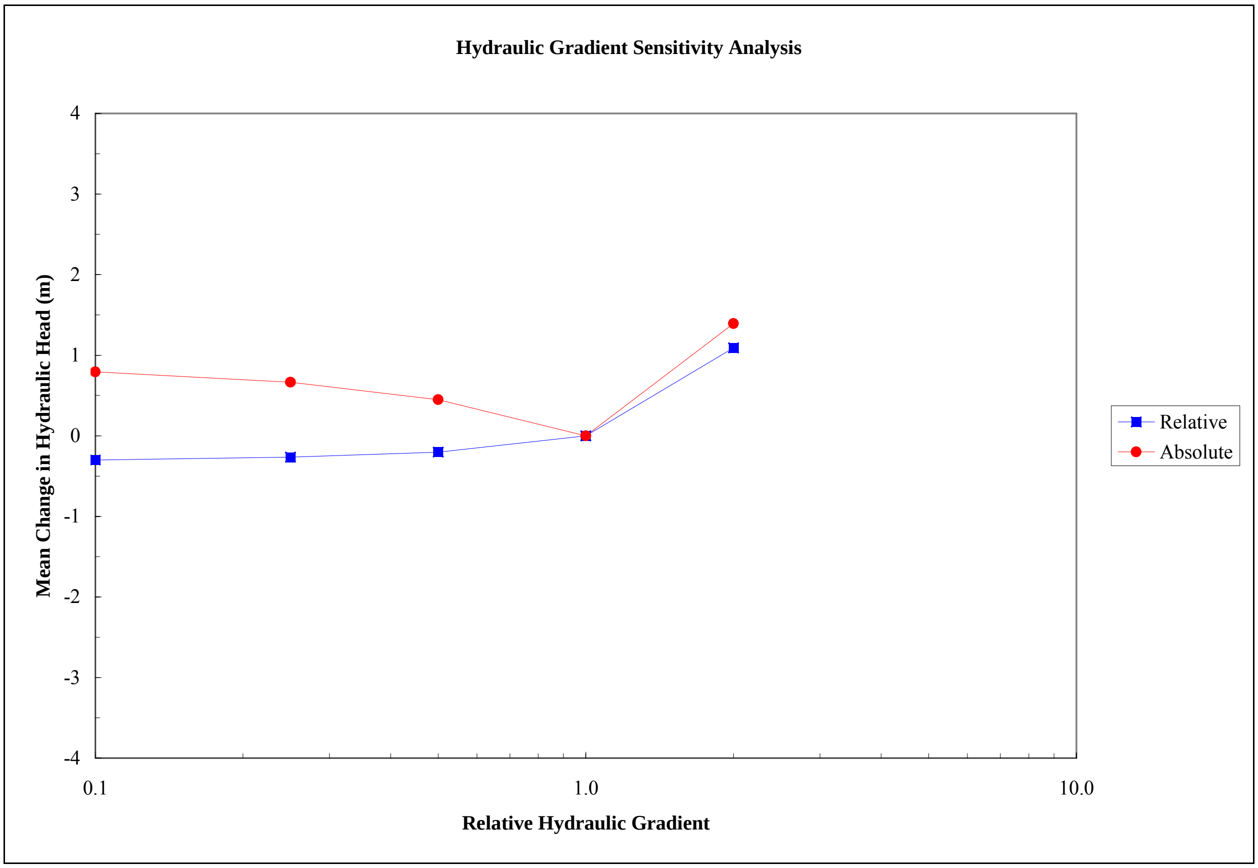
Hydrograph cl-7
Water Level
284.0
282.0
280.0
278.0
276.0
274.0
272.0
270.0
0
100
200
300
400
Days
cl-7 Actual
cl-7 Modeled

APPENDIX O

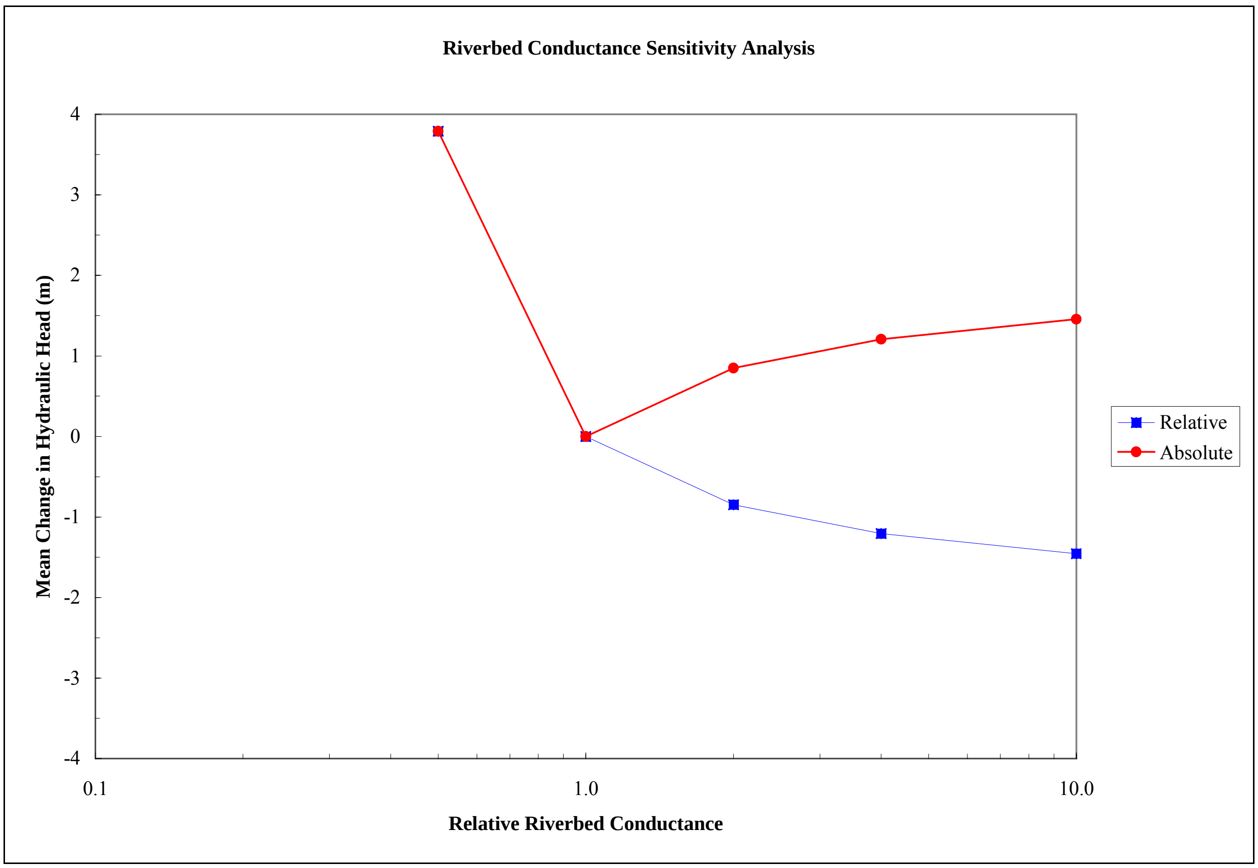
SWTP TRANSIENT MODEL SENSITIVITY GRAPHS


Hydraulic Conductivity Sensitivity Analysis
Mean Change in Hydraulic Head (m)
4
3
2
1
0
-1
-2
-3
-4
0.1
1.0
10.0
Relative Horizontal Hydraulic Conductivity
Relative
Absolute


Recharge Sensitivity Analysis
Mean Change in Hydraulic Head (m)
4
3
2
1
0
-1
-2
-3
-4
0.1
1.0
10.0
Relative Recharge
Relative
Absolute



Hydraulic Gradient Sensitivity Analysis
Mean Change in Hydraulic Head (m)
4
3
2
1
0
-1
-2
-3
-4
0.1
1.0
10.0
Relative Hydraulic Gradient
Relative
Absolute


Riverbed Conductance Sensitivity Analysis
4
3
2
1
0
-1
-2
-3
-4
Mean Change in Hydraulic Head (m)
0.1
1.0
10.0
Relative Riverbed Conductance
Relative
Absolute