Drinking Water Source Protection Report for the
Brown County Rural Water Association

The Brown County Rural Water Association is a community public water system that voluntarily completed their drinking water source assessment under the Wellhead Protection Program. The Susceptibility Analysis was completed by Ohio EPA.

Susceptibility Analysis for Brown County Rural Water Association (completed by Ohio EPA, 2003)

Delineation of the Wellhead Protection Area, Brown County Rural Water (completed by M.S. Beljin & Associates, 1998)

Potential Pollution Source Inventory, Brown County Rural Water (completed by M.S. Beljin & Associates, 1999)
ATTACHMENT A

Revised Susceptibility Analysis and Proposed Consumer Confidence Report Language for Brown County Rural Water Association

SUSCEPTIBILITY ANALYSIS:
A susceptibility analysis evaluates the likelihood that a public water system’s source water could become contaminated. The analysis is based on the sensitivity of the aquifer to contamination, the available water quality data for the water system, and the number and types of potential contaminant sources located within the protection area. More information on how Ohio EPA determines a water supply’s susceptibility to contamination can be found in Ohio EPA's Ground Water Susceptibility Analysis Process Manual. Copies of the manual are available by contacting Ohio EPA or visiting the following web site:
http://www.epa.state.oh.us/ddaqw/pdu/swap_guidance.html

Susceptibility Rating. The aquifer that supplies drinking water to Brown County Rural Water Association has a high susceptibility to contamination based on the aquifer’s sensitivity to contamination (explained in the following paragraph), and the numbers and types of potential contaminant sources within the protection area.

Aquifer Sensitivity. Brown County Rural Water Association’s wellfield draws water from the Ohio River buried valley aquifer system. Approximately 40 feet of sand, gravel and clay exists between the ground surface and the aquifer, providing limited protection from contaminants infiltrating from the ground surface to the aquifer. The depth to water in the buried valley aquifer is less than 40 feet below the ground surface. The topography is gently rolling, allowing for some of the precipitation to infiltrate into the aquifer instead of running off the ground surface. Brown County Rural Water Association receives approximately 40% of its groundwater recharge from the Ohio River and Straight Creek under normal pumping conditions (Beljin, 1998)\(^1\), which indicates a hydraulic connection between the Ohio River and the aquifer.

Water Quality. A review of Brown County Rural Water Association’s water quality record currently available in Ohio EPA’s drinking water compliance database and the Ambient Ground Water Monitoring database did not reveal any evidence of chemical contamination at levels of concern in the aquifer. However, samples of raw (untreated) water collected in 1999 and 2001 contained detectable levels of carbon tetrachloride in

its new wells on four occasions, with concentrations ranging from 2.6 - 15.0 μg/L. The maximum contaminant level for carbon tetrachloride is 5 μg/L. The source of the carbon tetrachloride has not been determined, but it is believed to be related to the installation of the wells. The last four quarterly consecutive sampling of the wells show that the carbon tetrachloride concentrations are below detection levels.

Please note that this water quality evaluation has some limitations:

4) The data evaluated are mostly from treated water samples, as Ohio EPA’s quality requirements are for the water being provided to the public, not the water before treatment. When available, raw (untreated) water sampling results are also evaluated.

5) Sampling results for coliform bacteria and naturally-occurring inorganics (other than arsenic) were not evaluated for this assessment, because they are not a reliable indicator of aquifer contamination. Positive coliform samples are also associated with operation and maintenance problems in the water system’s distribution network and may not indicate aquifer contamination.

Potential Contaminant Sources. There are fifteen potential contaminant sources within Brown County Rural Water Association’s protection area. The types of potential contaminant sources present include transportation routes (mainly, US Route 52), agriculture, septic systems and sanitary sewer lines, refueling stations, wastewater treatment systems, maintenance buildings, and the Ohio River. The serious floods that occur along the Ohio River, which have been particularly damaging in recent years, have inundated Ohio River wellfields and threatened the ground water quality.

Protective Strategies. Protective strategies are activities that help protect a drinking water source from becoming contaminated or further contaminated. Implementing these activities can provide a number of long-term benefits, including protecting the health of the consumers; preserving water resources for future generations; avoiding the expense of cleaning up a contaminated water supply or finding alternative sources of water; and preserving or enhancing the economic value of the area by securing an abundant supply of clean water.

Protective strategies that Brown County Rural Water Association may consider while developing its Drinking Water Source Protection Plan include:

- Educational Outreach: Informing people who live, work, or own property within your protection area about the benefits of drinking water protection is very important. Although some communities develop their own educational outreach resources, assistance is available at no cost from various agencies. Homeowners should also be made aware of the potential threat they can pose to the water supply. For more information on available brochures and educational
information please contact the Drinking Water Source Protection staff at (614) 644-2752, or visit our Web site at http://www.epa.state.oh.us/ddagw/pdu/swap_ps.html.

PROPOSED CONSUMER CONFIDENCE LANGUAGE:

Ohio EPA recently completed a study of Brown County Rural Water Association’s source of drinking water, to determine its susceptibility. According to this study, the aquifer (water-saturated zone) that supplies water to Brown County Rural Water Association has a high susceptibility to contamination. This determination is based on the following:

➢ presence of a relatively thin protective layer of clay overlying the aquifer,

➢ the shallow depth (less than 40 feet below ground surface) of the aquifer,

➢ and the presence of significant potential contaminant sources in the protection area, including periodic serious flooding of the Ohio River.

This susceptibility rating means that under currently existing conditions, the potential of the aquifer becoming contaminated is relatively high. This potential can be minimized by implementing appropriate protective measures. More information about the source water assessment or what consumers can do to help protect the aquifer is available by calling [insert your contact #].
DELINEATION OF
THE WELLHEAD PROTECTION AREA
BROWN COUNTY RURAL WATER
RIPLEY, OHIO

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September 1998
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1.0 Introduction

In this section the general background information regarding the wellhead protection program (WHP), the Brown County Rural Water Association (BCRWA) wellfield, and the approach to the wellhead protection area delineation are presented.

1.1 Background

Groundwater contamination is a serious problem facing the nation. Between 1971 and 1985, there were 52,181 reported cases of illness (mostly short-term digestive disorders) associated with groundwater contamination (USEPA, 1993). Also, more than 200 chemical contaminants have been identified in groundwater. The need to protect the susceptible water sources is apparent as these statistics suggest.

The 1986 Safe Drinking Water Act Amendments (SDWA) directed each state to develop a wellhead protection (WHP) program to protect public wells. A wellhead protection area (WHPA) is defined as (SDWA, Section 1428(a)):

"...the surface and subsurface area surrounding a water well or wellfield, supplying a public water system, through which contaminants are reasonably likely to move toward and reach such water well or wellfield."

Once the WHPA is delineated, the protection program can be completed to assist water resource managers in the control of water quality and the development of future supplies.

The Ohio EPA supplemented the federal regulations with legislation promoting regional development of WHP plans. In Ohio, approximately 75 percent of the 1,600 community public water systems rely on groundwater for all or a large portion of their water supply (OEPA, 1994). Although the Ohio General Assembly voted down mandatory WHP compliance, many of Ohio's 1,200 groundwater dependent communities are reconsidering their approach to groundwater management. The costs and complexities associated with previous remedial efforts make preventative measures offered by wellhead protection an attractive investment. A recent EPA report presented a cost-benefit analysis for seven communities with wellhead protection. It concluded that clean up of contaminated groundwater supplies may, on average, be thirty to forty
times more costly than preventing the contamination in the first place (USEPA, 1996). Among
the numerous advantages of wellhead protection, the main focus of the program is to ensure a
high-quality drinking water supply.

The seven components of a wellhead protection plan, as required by Ohio’s EPA (1984) are:

1. Delineate the wellhead protection area.
2. Identify and locate potential sources of contamination.
3. Identify appropriate protective strategies.
4. Assess the need for groundwater monitoring, and, if so, develop a monitoring plan.
5. Complete a contingency plan.
6. Develop a public involvement/education program.
7. Evaluate the need for new wells and take steps to secure and protect the future
wellfield from contamination.

Many municipalities have already formed planning teams to address potential contamination of
their drinking water. Community service organizations and public interest groups can conduct
citizen surveys to identify past/present contamination sources and land uses. Local government
agencies have the ability to implement the plan through control measures and manage its long-
term effectiveness. Government organizations can provide the team with historical data and
information concerning the geology and hydrology of the area. In addition, input from business
and other private entities will strengthen the approach to plan development. Engineers and
geologists from consulting companies or local universities offer the necessary technical expertise
to delineate the WHPA. Interaction between these members of local community will heighten
awareness of protecting groundwater while developing a long-term management approach.

1.2 Problem Description

The Brown County Rural Water is situated between Higginson and Ripley, Ohio, on the Ohio
River. Figure 1 is the regional map of the southern portion of Ohio along the US 52. The Brown
County Rural Water Association is located about 40 miles east of Cincinnati and a few miles west
of Ripley. The wellfields are located between the US 52 and the Ohio River. Figure 2 is a
portion of the U.S. Geological Survey topographic map of the Georgetown, Ohio quadrangle that
shows the location of the water treatment plant.
The Brown County Rural Water has decided to delineate the wellhead protection area (WHPA) using the preferred time of travel (TOT) criterion set forth by the EPA. The TOT criterion is a particle-tracking scheme that is used in the actual delineation of the WHPA. Using computed groundwater velocities from the flow model a set (or sets) of particles can be traced backward in time from the each wellhead until the user-defined TOT is reached (e.g., 1 or 5-year travel time). Connecting the endpoints of the particle pathlines delineates the capture zone for the particular time constraint, defining the WHPA.

Because the shape and size of a WHPA is sensitive to a variety of hydrogeologic factors, the assumptions used in the construction of the conceptual model are critical to interpretation of the WHPA. The most successful protection programs implement initial and boundary conditions that include a comprehensive understanding of groundwater movement from various sources under various stresses. Water quality analysis can supplement the wellhead delineation to give a more informative description of the pollution potential. Recognizing interactions between sources of surface, bedrock, and ambient groundwater that contribute to production water is achievable through a study of relative geochemistry. This combination of water quality analysis and wellhead delineation strengthens a protection program that is designed to ensure a safe, high-quality drinking water supply.

1.3 Objectives
The TOT criteria will be applied to determine the one-, three-, five-, and ten-year zones of contribution (ZOC) based on the current maximum pumping scenario. A volumetric budget will also be calculated to gain a better understanding of induced infiltration of surface water from the Ohio River. In the process of developing an aquifer flow model for the delineation of WHPA, the main goal is to evaluate the influence of the hydrogeologic parameters on the WHPA. After the model has been constructed and calibrated, a sensitivity analysis will be performed to evaluate the effect of parameter uncertainty on the delineated area.

In addition, a characterization the background geochemistry of the groundwater will be provided to confirm the effect of induced infiltration. This will include an assessment of the aquifer’s mixing potential, an analysis of temporal trends in water quality, and an investigation of spatial variation between water quality within the zone of influence (ZOI) and its surroundings.
The primary objectives of this study are:

1. *Assemble and evaluate data.* All data pertaining to the development and use of water resources from the Ohio River Aquifer for the Brown County Rural Water wellfields will be collected. This includes previous aquifer test data, baseflow hydrographs of the Ohio River, water level measurements, drillers logs, water quality data, and data of other hydrogeological investigations that will help build a conceptual model of the system.

2. *Develop a conceptual model.* This step is essentially the transformation of the real system into a mathematical model through a reasonable set of assumptions. "Reasonable" suggests that the geologic and hydrogeologic characteristics of the aquifer and its boundary conditions are preserved in the mathematical model such that it simulates the real system.

3. *Construct a numerical model.* A site-specific, three-dimensional (3D) aquifer flow model using the EPA approved, finite difference MODFLOW and MODPATH computer codes will be developed. MODFLOW solves the flow equation at discrete points in space and time using the block-centered, finite difference approach. Once a grid system is constructed, the boundary conditions assigned, and the aquifer properties specified, MODFLOW computes the hydraulic head at each of the nodes. MODPATH employs the head values generated by MODFLOW to compute groundwater velocities and using a particle-tracking technique delineates the time of travel (TOT).

4. *Calibrate the flow model.* Model calibration is the process where computed heads from the mathematical model are compared to observed heads from field tests to better estimate aquifer flow parameters. These parameters are then adjusted within applicable ranges so that the mathematical model calculates heads that nearly match the observed values with acceptable error.

5. *Delineate wellhead protection areas.* One component in wellhead protection planning is to determine the boundaries of the WHPA based on the modeling of what area contributes groundwater to a well within five-year period. In addition to a five-year criterion, the WHPA will be delineated for one-, three-, and ten-year TOT's.
6. **Perform a sensitivity analysis.** Once the model is calibrated, a sensitivity analysis will be used to determine the degree of influence any one parameter has on the model output. Evaluating the effect of input parameters on the delineation areas involves the comparison of area changes in the calculated WHPA with aquifer parameter changes. The model's volumetric budget was also used in the sensitivity analysis to evaluate induced infiltration.

7. **Evaluate groundwater geochemistry.** The background geochemistry of groundwater will be characterized to describe its spatial and temporal variability and to confirm the existence of induced infiltration.

### 1.4 Scope

In order to achieve the objectives outlined above, a series of tasks are required. They include:

- Review literature of previous studies and relevant data sources in a similar setting.
- Collect and evaluate existing data (data supplied by the OEPA, ODNR, USGS, ORSANCO, consultant reports, and other investigations of the region will be used to build the model).
- Collect and evaluate field data:
  - pump test data for evaluation of aquifer flow parameters.
  - water level measurements.
  - water quality sampling.
- Develop a database that will house relevant hydrogeologic data.
- Model groundwater flow.
- Delineate wellhead protection area (WHPA).
- Characterize groundwater geochemistry.
- Write report.
1.5 Report Organization

The remainder of this technical report is organized as follows:

- Section 2.0 provides a description of data sources used to develop the conceptual and numerical models. In addition, a subsection was dedicated to water quality data (surface water and groundwater).

- Section 3.0 presents the conceptual model through discussion of the site geology and hydrology. Model boundaries and aquifer parameters are described.

- Section 4.0 describes the groundwater flow model. The modeling procedure used in the study is described, as well as the results of various flow scenarios. The section also describes delineation of the wellhead protection area.

- Section 5.0 describes the groundwater and surface water geochemistry.

- Section 6.0 provides conclusions and recommendations, and

- Section 7.0 contains references.

The figures and tables are placed in two separate sections. All additional figures were divided into five appendices:

Appendix A: Well logs generated based on the drillers logs, aquifer test information, etc.
Appendix B: Aquifer test data reanalyzed for all production wells.
Appendix C: Groundwater quality parameters.
Appendix D: Piper and Stiff diagrams.
Appendix E: Ohio River flow, temperature, and water quality data.
2.0 Data Sources

Data for the study were obtained from existing literature and from the site-specific field investigation conducted during the period from January 1997 through March 1998.

2.1 Previous Studies

A literature search of previous geologic and hydrologic investigations of the Ohio River Aquifer focused on both the regional and local studies. These studies provided initial estimates of aquifer parameters, historical pumping rates, water levels, the Ohio River stage, geologic cross sections, and water quality.

The geology and water supply potential of southwestern Ohio is well documented in studies by Fenneman (1916) and Gepford (1970). Both references describe the influence of glaciation on the formation of the buried valley systems that exist in the region. The description of the drainage pattern and sediment deposition processes that characterize the current state of the Ohio River valley system is also provided in the mentioned references.

Several other reports have addressed the issue of groundwater quality in the area. A study at Heidelberg College (Baker et al., 1989) summarized nitrate concentrations in private wells for each Ohio county. A study by Burgess & Niple, Ltd. (1991) used available data to characterize the background quality of groundwater pertaining to aquifer type. Shy (1992) described the general geochemistry of aquifers in southwestern Ohio, provided basic statistics on major ion concentration levels, and correlated groundwater quality to aquifer recharge, mineralogy, and groundwater flow patterns.

Recently, several studies included simulation of groundwater flow in the Ohio River Aquifer (Lyverse et al., 1996; and Unthank, 1997). In 1984, the State of Kentucky began to require detailed permit applications for pumping of 10,000 gallons per day (gpd) or more. Lyverse and others (1996) developed a two-dimensional finite-element model as a tool for more effective management of the aquifer for the City of Louisville. The residents of Owensboro County depend on the Ohio River Aquifer as the primary source of drinking water. The USGS began an investigation in 1991 and, as a part of the study, they developed a groundwater model to evaluate management alternatives (Unthank, 1997).
2.2 Geologic Data

The rocks in Brown County range in age from the Cynthiana or Point Pleasant formation of the Trenton group to the West Union formation of the Niagara. The most exposed rocks are, however, of the Cincinnati group, Utica, Eden, Maysville, and Richmond formations (Figure 3: Regional Geology Map). The total thickness of the formations averages about 600 feet (Fanneman, 1906). The Cynthiana formation consists of limestone layers (up to 2 feet in thickness) separated by thin shale layers. Gray calcareous shale and thin layers of limestone represent the Utica formation. The outcrops of the formation can be found at the base of the hills along the Ohio River and along its tributaries. The Eden formation consists of blue calcareous shale with some limestone. The formation is the basal part of the hills along the Ohio River and the lower courses of tributaries (the White Oak and Straight Creeks).

The Brown County wellfield lies within the border of the Illinoian drift (Figure 3). The bedrock beneath the wellfield lies at an elevation of about 415 feet.

2.3 Hydrologic Data

A literature search of climatic, hydrologic, and hydrogeologic investigations was performed in the early stages of the investigation. In addition to the printed material, information was also obtained from various INTERNET databases.

2.3.1 Precipitation

Average monthly precipitation and average annual precipitation for Brown County, compiled from the National Weather Service (NWS), was collected for the period from 1931 to 1996 (Figures 6 and 7, respectively). Figure 8 shows monthly precipitation from 1982 through 1992.

2.3.2 Ohio River Data

Data related to the Ohio River are compiled and included in Appendix E. Figure E-1 shows streamflow measurements from 1985 through 1996. Because there are no continuous data available for the period, a composite set of data compiled from the ORSANCO database was created from three different locations: Cincinnati Station (January 1985 - September 1986), Maysville Station (October 1986 - June 1992), and Meldahl Dam Station (July 1992 - December 1986).
The water temperature in the Ohio River was compiled for the period January 1985 through December 1990 (Figure E-2). The Ohio River water quality data are shown in Figures E-3 through E-12. The data were compiled from the ORSANCO database.

2.4 Groundwater Data

The only regional type of groundwater study of Brown County is the Regional Ground-Water Resources Map of Brown County prepared by ODNR (1989). Most of the county is a poor source of groundwater as it falls into the ODNR category 'areas in which yields seldom exceed 3 gallons per minute (gpm)'. The Brown County Rural Water Association is located over a productive zone of permeable sand and gravel deposits adjacent to the Ohio River. The wellfields are located in the area where yields are greater than 100 gallons per minute and it was documented that the Ohio River Aquifer can yield as much as 700 gpm (ODNR, 1989).

2.4.1 Water Level Data

Groundwater levels were measured in five piezometers (P-1 through P-5) during the investigation. There were five rounds of measurements conducted in different seasons: spring 1997 (June), summer 1997 (July), fall 1997 (October), fall 1997 (November), and winter 1998 (February). The graph showing seasonal changes in groundwater levels in the five piezometers is depicted in Figure 17. The water level values are also tabulated and presented in Appendix B. The Ohio River stage data were compiled from the National Weather Service and used for comparison with the measured groundwater levels.

2.4.2 Groundwater Pumping

The Brown County Rural Water Association has two wellfields: an old wellfield consisting of seven wells (PW-1 through PW-7) and a new wellfield consisting of 6 wells (W-1 through W-6). The location of the wellfields is shown in Figure 18. Currently, only the old wellfield is being pumped. The wells are being pumped on a rotating schedule so that at any time only three to four wells are active. The average pumping rate per well is between 350 and 450 gpm. Historical records showing the actual pumping rates are available from the Brown County Rural Water (BCRW) treatment plant. The total pumping from the wellfield is approximately 1,700 gpm or 2.5 million gallons per day (mgd).
2.5 Water Quality

Surface water quality was obtained from the available databases (the Ohio EPA and ORSANCO databases). Water samples were obtained from production wells, the Ohio River, and a residential bedrock well. The samples were sent to a lab (Brookside Laboratories, New Knoxville, Ohio) for analysis of inorganic parameters. The sampling has been conducted four times to observe seasonal changes.

2.5.1 Surface Water

The water quality of the Ohio River was collected for the period from 1985 to 1996. The seasonal changes of the Ohio River water quality can be observed in the graphs presented in Appendix E. The following water quality parameters were analyzed: hardness, chloride, sulfate, phosphorus, nitrate, magnesium, iron, aluminum, manganese, and zinc. The parameters are shown in Figures E-3 through E-12, respectively. The surface water (the Ohio River) samples were also collected during the investigation.

2.5.2 Groundwater

Groundwater quality parameters were analyzed from the four sampling events of the production wells and the residential bedrock well (located a mile north of the wellfield). The following parameters were analyzed in the field: temperature, pH, and conductivity. The lab analysis included the following parameters: conductivity, pH, hardness, sodium, potassium, calcium, magnesium, chloride, bicarbonate, nitrate, iron, manganese, copper, silica, aluminum, and zinc. The results of the analysis are provided in Appendix C. The Piper and Stiff diagrams of the groundwater quality for each sampling event are given in Appendix D.
3.0 Conceptual Model

The Ohio River valley aquifer system lies in an alluvial valley filled with unconsolidated glacial outwash sand and gravel of the Pleistocene and Holocene Ages, overlain by silt and clay of Holocene Age. This alluvium forms a productive, however areally restricted aquifer that is hydraulically connected to the Ohio River. In this section, the hydrogeological setting of the Brown County Wellfield is described. In addition, the aquifer parameters important for wellhead protection area delineation are introduced.

3.1 Hydrogeologic Setting

The Ohio River valley aquifer system is a result of interglacial and preglacial stream channels. A physiographic, cross section description from the Ohio is as follows (Fenneman, 1916). The valley floor elevates in the range of 415 - 425 feet above sea level while spanning a distance in the range of 0.7 to 1.5 miles. The broad terrace reaches heights greater than 505 feet above mean sea level (msl). Figure 5 illustrates a typical hydrogeologic setting found in a buried valley aquifer system.

Coarse, unconsolidated, permeable sand and gravel with minimal occurrences of clay sediments typify the aquifer. Based on the drillers logs, six geologic cross sections were prepared (Figures 10 through 15). The location map of the cross sections is presented as Figure 9. Individual well logs referenced throughout this document are listed in Appendix A.

With respect to water production, the area along the Ohio River is particularly favorable because of induced stream infiltration by pumping (ODNR, 1989). Where recharge is available from the river, groundwater wells yielding as much as 700 gpm have been reported. Also, the unconfined nature of the aquifer suggests that the Brown County Rural Water Wellfield is being recharged from precipitation. Additional recharge of the aquifer is due to the fracture flow from the underlying bedrock and the valley walls.

The groundwater table elevation within the model area was estimated from the measured depth to the water and the surveyed “top-of-casing” of each piezometer. The measurements were made at least once a season in all of the wells in order to determine temporal fluctuations of the water table during the study period. Depth to water was measured between 25 and 29 feet, depending on the
surface elevation. The hydraulic head was estimated to vary spatially and temporarily between 475 and 480 feet above the mean sea level (msl). The natural direction of groundwater flow in the model area is from the valley walls towards the Ohio River. The direction of flow is, however, more complex when the production wells are turned on. The local flow pattern thus changes seasonally and it also depends on the configuration of the active wells, the pumping rates of the individual wells, and the Ohio River stage.

3.2 Model Area
The model domain or the groundwater model area must be clearly defined by its boundaries. Since the hydraulic conditions at the boundaries must be specified, it is always preferred, if possible, to select some natural boundaries (a significant surface water body or a geological boundary). The selected model area is usually a compromise between the area of interest and the area defined by some natural boundaries. The Brown County Rural Water WHPA model area coincides with the area bounded by geologic and hydrologic features. The model area is bounded on the north and south by the buried valley walls; on the west by the Whiteoak Creek; and on the east by the Straight Creek (Figures 2 and 18). The Ohio River lies within the model area and it is assumed that the aquifer is only partially penetrated by the river. The river and the creeks are separated from the aquifer by a thin layer of less permeable riverbed sediments.

3.3 Model Boundaries
The model area is bounded on the north and south by the bedrock walls which hydraulically can be simulated as "no-flow" boundaries (i.e., the flow in the bedrock is negligible compared to the flow in the alluvial aquifier). Some groundwater flow does occur from the valley walls into the model area and this was simulated by assigning additional recharge along the walls. The east and west boundaries are sufficiently far from the wellfields so they can be simulated as "constant head" boundaries (i.e., the hydraulic heads on the boundaries are not affected by the pumping of the wellfields). The top of the aquifer is defined by the water table. The top boundary is "free" to move up or down depending on the recharge, the pumping, and other hydraulic factors. The bottom of the model is defined by the boundary between the aquifer and the bedrock. The surface water bodies (the Ohio River and the creeks) were simulated as "head-dependent" boundaries (i.e., the direction and the rate of groundwater flow depends on the properties of the river/creek sediments, and the hydraulic head difference between the surface water and the groundwater.)
3.4 Model Parameters

The model parameters include hydraulic conductivity, recharge (from the precipitation), streambed conductance, recharge or discharge from the surface water.

3.4.1 Hydraulic Conductivity

The term hydraulic conductivity, $K$, is used to describe the rate at which water moves through the aquifer material. Spatially, $K$ can vary greatly at different depths and in different directions due to the manner in which deposition of material occurred. If the groundwater flow is mainly horizontal (two-dimensional), it is more convenient to use another parameter called transmissivity instead of hydraulic conductivity. Transmissivity, $T$, is the product of the average horizontal hydraulic conductivity of the aquifer and the average aquifer thickness. Defining correctly hydraulic conductivity (transmissivity) values is the key to understanding both groundwater flow velocities and the flow paths.

The hydraulic conductivity can be determined in the lab, based on the grain-size analysis, or in the field (e.g., aquifer tests, slug tests, tracer tests). The values obtained in the field are considered more reliable than the values obtained from the lab analysis. The aquifer tests were conducted on all BCRW production wells. The aquifer test data are plotted in Figures B-1 through B-20 (Appendix B). The results of the tests were summarized, along with the specific capacity data, in Figure 16. Most of the aquifer tests show that the transmissivity values are between 10,000 and 22,000 square feet per day (sq.ft./day). The specific capacity values range from 28 to 64 gallons per minute per foot of drawdown (gpm/ft).

The total saturated thickness of the aquifer is approximately 80 feet. The hydraulic conductivity was assumed to vary vertically as the sediments become courser with depth: the shallow zone hydraulic conductivity is from 50 to 75 feet per day (ft/d) and the deeper zone hydraulic conductivity is from 120 to 170 ft/d.

The vertical hydraulic conductivity is usually smaller than the horizontal hydraulic conductivity due to shape and orientation of the sediments. It was assumed that the vertical hydraulic conductivity values of the aquifer material at the BCRWA are 10 times smaller than the horizontal conductivity values.
3.4.2 Streambed Conductance

Because the locations of the production wells are relatively close to the Ohio River, some of the discharged water is derived from the river. The rate per unit area at which surface water infiltrates the streambed and enters the aquifer is principally dependent on three parameters: the permeability of the riverbed sediments, the riverbed thickness, and the difference in hydraulic head between the river stage and the groundwater level (hydraulic head). The streambed "conductance" is calculated using the streambed thickness, hydraulic conductivity, and the area perpendicular to the flow. The direction in which flow occurs across the streambed layer solely depends on the relative levels of the groundwater and the surface water. During low flow, mud and organic matter settle out and accumulate in the streambed layer, whereas periods of high flow scour this layer and increase the effective permeability of the sediment. However, the streambed of the Ohio River is predominantly sand, whereas, the stagnant waters of the two creeks (Whiteoak and Straight Creek) are chiefly comprised of much finer sediments. The hydraulic conductivity of the Ohio River and the creek sediments were assumed to be 10 and 1 feet per day (ft/day), respectively.

3.4.3 Recharge

An estimate of aquifer recharge via precipitation is necessary for modeling purposes as it represents another source of inflow to the wellfield. The significance of this parameter is evaluated using sensitivity analysis. The assumption was made that approximately one-third of all precipitation over the model area infiltrated into the subsurface. The remaining precipitation is either evaporated or converted to runoff. Initial recharge values in the development of the flow model are based on this assumption. Each active node in the uppermost model layer was assigned a recharge value of 9 inches per year (in/yr).

It is suspected that some amount of aquifer recharge is derived from leakage of the bedrock valley wall that forms the boundary to the model area. The presence of limestone in this formation suggests that bedrock seepage can be a relatively significant parameter. The presence of fractures can vary the seepage rate by several orders of magnitude. The recharge estimate from the valley wall is approximately 30 gallons per day per linear foot of the wall. The importance of the bedrock recharge to the overall groundwater budget is addressed in the sensitivity analysis. For the purpose of modeling, an additional areal recharge was added to the nodes located along the valley wall boundary of the model. The bedrock recharge was translated into a 360 inches per year areal recharge.
3.4.4 Porosity
Total porosity is defined as the ratio of all voids to the total volume of soil sample. Because the groundwater flow occurs only through interconnected pores, another parameter called "effective porosity" (the ratio of the volume of the interconnected pores to the total volume) is used instead. The effective porosity was assumed to be 0.2 or 20 percent.

3.4.5 Storativity
Storativity or the storage coefficient, $S$, is another parameter that impacts the distribution of hydraulic head in an aquifer under transient conditions. In the unconfined condition, this value can be viewed as a specific yield, $S_0$, which is the volume of water released from a volume of aquifer material drained corresponding to a decrease in hydraulic head. Initially, a well pumping from an aquifer will derive its water from the aquifer storage. Once depleted, the rate at which the well obtains its water is limited by the aquifer transmissivity. The values of the parameter were obtained in the field from the aquifer tests. However, this parameter was not used as the model input because only steady-state simulations were performed.


4.0 Groundwater Model

Once the conceptual model of a real system is constructed and the model parameters are estimated, a mathematical model needs to be developed using an approved computer code. MODFLOW and MODPATH are two well-accepted codes that were applied in this study. This section describes the modeling objectives, input parameters, model results, and the sensitivity analysis.

4.1 Modeling Objectives

The complex hydrogeological setting of the BCRWA wellfield requires the use of a numerical model. Once it was determined that a numerical model is necessary, the next step was to establish the objectives of the model. The groundwater modeling objectives are as follows:

- Integrate all the available data,
- Provide a predictive tool for evaluation of the groundwater flow,
- Evaluate induced infiltration; and
- Delineate one-, three-, five-, and ten-year WHPA.

The extensive fieldwork conducted over the study period, along with information obtained from previous studies, were analyzed and then translated into data input for the three-dimensional, finite difference, mathematical model. After calibration, the computer model was run to simulate current pumping scenarios, to quantify the amount of induced infiltration, and most importantly, to delineate the WHPA.

4.2 Modeling Procedure

Groundwater flow modeling activities at the BCRWA were performed as follows:

- Review of available data,
- Conceptual model development,
- Code selection,
- Numerical model development (Model design),
- Model calibration, and
- Predictive sensitivity analysis.

Groundwater modeling is an iterative process and some steps of the modeling procedure were revisited several times.
4.3 Grid Design

The area included in the groundwater flow model is 12,500 feet long and 5,500 feet wide, with the long side oriented in the east-west direction (Figure 19). The model grid consists of 250 columns and 110 rows that form uniform grid blocks (cells) of 50 by 50 feet. In order to better represent the change in aquifer material properties with depth, to model three-dimensional flow, and to take into account position of the well screens, the aquifer was divided into four layers. Thus, the total number of grid blocks in the model is 110,000. The top and bottom elevations of the layers is as follow:

<table>
<thead>
<tr>
<th>Model Layer</th>
<th>Top Elev. (ft)</th>
<th>Bottom Elev. (ft)</th>
<th>Thickness (ft)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Layer 1</td>
<td>485</td>
<td>465</td>
<td>20</td>
</tr>
<tr>
<td>Layer 2</td>
<td>465</td>
<td>455</td>
<td>10</td>
</tr>
<tr>
<td>Layer 3</td>
<td>455</td>
<td>435</td>
<td>20</td>
</tr>
<tr>
<td>Layer 4</td>
<td>435</td>
<td>405</td>
<td>30</td>
</tr>
</tbody>
</table>

4.4 Boundary Conditions

The model area consists of active cells (representing the aquifer and the surface water bodies) and inactive cells (representing the bedrock). The northern and southern boundaries of the "active" model area are represented as no-flow boundaries where the bedrock is in contact with the Ohio River Aquifer. The model boundary cells that fall either within the Straight Creek or the Ohio River were simulated as the constant head nodes. The section of the northern boundary within the Straight Creek has head values varying from 488 to 487 feet. The eastern and western boundary cells that coincide with the Ohio River nodes were assigned a constant head of 484 and 486 feet, respectively. These boundaries are distant far enough from the treatment plant such that no effects of pumping could be felt. The flow from the valley walls was simulated using additional recharge to the active model cells adjacent to the wall.

The Ohio River and the creeks were simulated by using the MODFLOW "river package". The river and creek elevation was assumed to be 485 feet (the pool elevation). The same elevation for the river and the creeks was used because the water in the creeks was stagnant during the investigation. The bottom of the river was assumed to be on the average 460 feet. However, the bottom of the river is not critical in the model computation as long as the river and the aquifer are hydraulically connected.
4.5 Model Parameters

There are eight model parameters that must be specified as input for the numerical computer model: (1) net recharge, (2) aquifer bottom elevation, (3) riverbed thickness, (4) riverbed vertical hydraulic conductivity, (5) river elevation (stage), (6) river bottom elevation, (7) aquifer hydraulic conductivity, and (8) effective porosity.

4.5.1 Hydraulic Conductivity

The greatest amount of uncertainty lies in the variability of hydraulic conductivity (K) within the model area. Consequently, calibration of this parameter was central to model development. The aquifer tests provided estimates of hydraulic conductivity (Appendix B). Because of the lack of geologic information, it was assumed that calibrated hydraulic conductivity values are equivalent in horizontal directions (K_h = K_v). The presence of sand and gravel stratification identified in well logs were used to support the assumption that vertical hydraulic conductivity (K_v) was an order of magnitude less than the horizontal estimate.

<table>
<thead>
<tr>
<th>Model Layer</th>
<th>K_h (ft/d)</th>
<th>K_v (ft/d)</th>
<th>K_w (ft/d)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Layer 1</td>
<td>50</td>
<td>50</td>
<td>5</td>
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<td>Layer 2</td>
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</tr>
<tr>
<td>Layer 4</td>
<td>170</td>
<td>170</td>
<td>17</td>
</tr>
</tbody>
</table>

4.5.2 Areal Recharge

The calibrated areal recharge for the model is 9 inches per year (in/yr). The site receives an average annual precipitation of approximately 43 inches (Figure 7) that is converted to evaporation, infiltration, or runoff. It was estimated that approximately 20 percent of this rainfall was assigned to all active nodes in the top layer of the model as recharge. Because the model is influenced by river recharge, the amount of areal recharge applied is relatively insignificant. An additional recharge was added to active nodes that abut the valley walls to account for potential seepage. Walton and Scudder (1960) estimated that in Fairborn, Ohio, about 30 gallons per day per linear foot (gpd/ft) of wall leaks into the valley-train aquifer. The active nodes against the walls have a calibrated recharge of 360 in/yr.
4.5.3 Riverbed Conductance

Because BCRWA wellfield is located close to the Ohio River, it is important that all input parameters associated with the river nodes in the model are properly assigned. Because of technical difficulties, the hydraulic conductivity and the thickness of the streambed layer were not measured during the investigation. Instead, a riverbed conductance value of 2,590 square feet per day (sq.ft/day), obtained from the literature and from the previous field investigations (Maucario, 1997), was assigned to all river nodes. The Whiteoak Creek and the Straight Creek riverbed sediments were assumed to be finer than the Ohio River sediments (the waters of the creeks are more stagnant). Because the hydraulic conductivity of the creek sediments was assumed to be lower than the hydraulic conductivity of the Ohio River sediments, a riverbed conductance value of 26 sq.ft/day was assigned to the cells that are located within the boundaries of the creeks.

4.5.4 Effective Porosity

The groundwater velocity is directly proportional to the hydraulic conductivity and the hydraulic gradient, and inversely proportional to the effective porosity. While the hydraulic gradients are computed by the model, based on the computed hydraulic heads, the hydraulic conductivity and the effective porosity must be specified by the user. Because the range of values that the porosity can take is rather limited, this parameter is rarely determined in the field. A literature value of 0.2 was used for all model layers. The importance of the parameter on the model results, particularly to the overall WHPA, was investigated using sensitivity analysis (Section 4.7.2).

4.6 Model Calibration

Calibration of a flow model is a time-consuming, trial and error process that involves adjustment of input parameters until the head distribution computed by the model closely matches the groundwater levels measured in the field. On average, the BCRWA production wells are assumed to pump 1,700 gpm. The field measurements of the hydraulic heads in the piezometers served as the basis for calibration of the steady state model. The initial input parameters for the steady state calibration were based on careful interpretation of data obtained from field tests and previous investigations. Calibration was ultimately accepted through a series of model runs using revised parameter values that produced output that agreed reasonably with the real system observations.
A calibration target is a point in space and time where the groundwater level (head) has been measured. All hydraulic heads measured in the study served as calibration targets for the flow model. They provide a means of assessing calibration quality because an error term, called a residual, is computed for each target location. The residual is defined as the difference between observed and computed water levels for a given location at a point in time. Negative residuals indicate that the calculated head (model) is too high and positive residuals indicate the calculated head is too low. A quick evaluation of model calibration can be determined from the residual mean statistic, which is computed by dividing the sum of residuals by the number of residuals (one for each target head). Because both positive and negative residuals are used in the calculation, this value should be close to zero for a good calibration.

Initial estimates of input parameters were revised within a reasonable range for each input parameter through a series of model runs until calibration met the user's criteria. The criteria are based on two principal calibration statistics: (1) the residual mean, and (2) the ratio of the residual standard deviation to the overall range in head across the model gradient. With a limited number of target locations, a residual mean of $\pm 0.5$ feet was predetermined as acceptable calibration. Also defined by the user prior to model simulation, the second criterion required the ratio of the residual standard deviation to the range in overall head be less than 10 percent. Once both criteria were satisfied, the model was considered calibrated.

4.7 Model Results

The calibrated flow model developed for the BCRWA was used in the prediction of pumping scenarios, in the evaluation of induced infiltration, and ultimately in the delineation of the WHPA. The predictions were based on steady state simulations.

4.7.1 Wellhead Protection Area (WHPA)

Figures 20, 21, and 22 show wellhead protection areas delineated using one-, three-, and ten-year time of travel, respectively. The model results presented in Figure 20, for one-year travel time, show two distinct, non-overlapping WHPAs: the old wellfield WHPA that covers the area between US 52 and the Ohio River and the new wellfield WHPA that extends south of US 52, less than 1,000 feet from the center of the wellfield.
Figure 21 shows that when the three-year time of travel criterion is used, there is a single WHPA for both new and old wellfield. The natural boundaries, i.e., the Ohio River, the Straight Creek, and the bedrock, are also limits of the WHPA extension. As illustrated in Figure 22, the ten-year WHPA has extended westward only. This is not surprising since the induced infiltration plays an important role in the overall water budget (Section 4.7.3).

The five-year time-of-travel is required by the Ohio EPA for delineation of WHPA. Figure 36 shows the WHPA, which will be used for the predictive sensitivity analysis (Section 4.7.2) and for the water budget analysis (Section 4.7.3).

4.7.2 Sensitivity Analysis
Six parameters were evaluated in the sensitivity analysis: (1) areal recharge, (2) horizontal hydraulic conductivity, (3) vertical hydraulic conductivity, (4) bedrock seepage, (5) riverbed conductance, and (6) effective porosity. Computed hydraulic head differentials between the calibrated steady state model and "sensitivity" model runs were evaluated. The hydraulic conductivity of the streambed and the hydraulic conductivity of the aquifer material are the most sensitive input parameters to the model results. One parameter not analyzed was the river stage. Throughout the period of study, river stage fluctuations influenced the regional groundwater levels. Because of the relatively high values of hydraulic conductivity in both the riverbed sediments and the aquifer itself, it is accepted that if the river rises, the water table will follow, vice versa. The river stage is inherently important to the model in setting constant head values at aquifer nodes housing this boundary condition.

Figures 24 through 33 illustrates effects of the changes in the input parameter values on the WHPA (all simulations were based on a five-year time of travel).

4.7.3 Water Budget
A groundwater model must have its total inflow equal to the total outflow in order to keep the water budget balanced. Because a numerical model is an approximation of a real system, there is always some difference between the total inflow and the outflow expressed as "% discrepancy". A numerical model is acceptable as long as the water budget error is less than 0.1 percent. The BCRWA model has "% discrepancy" less than 0.01 percent (Table 1).
Figure 34 shows inflow water budget for the whole model area. According to the modeling results, the most important source of groundwater recharge (45 percent) is the leakage from the Ohio River and the creeks. The other two sources of groundwater recharge are infiltration from precipitation (27 percent) and the groundwater flowing into the model area through the constant head boundaries (28 percent). It is important to stress that infiltration from precipitation includes recharge from the bedrock.

Figure 35 shows discharge components of the model outflow. The production wells are the most important in removing groundwater from the system (44 percent). The second most important component of the outflow budget is the discharge of groundwater to the Ohio River and the creeks. The surface water bodies normally act as discharge zones for groundwater. However, the hydraulic gradients can be reversed due to the pumping and the groundwater flow is reversed from the streams to the aquifer.

The sensitivity of the input parameters on the water budget is presented in Table 1. There were 29 flow scenarios used to evaluate the water budget for different input parameters. The same table lists all the changes in the input parameters.
6.0 Conclusions and Recommendations

During the study period (January 1997 through June 1998), all monitoring wells and production wells within the wellfield were sampled along with a residential well. Based on the data collected and the data obtained from the literature, a groundwater model was developed. The main objective of the model was to delineate wellhead protection area for the BCRWA wellfields. However, the model is a tool that can be used to investigate other management options (e.g., the optimal configuration of the pumping wells, the effects of the wellfield expansion, and others).

6.1 Conclusions

The following conclusions were developed during the study of the BCRWA wellfields:

- The transmissive sand and gravel encountered in BCRWA wellfield provide Brown County with capabilities of meeting future demands, providing the treatment plant is upgraded to handle the full capacity of the production wells already in place.

- The three- and five-year WHPAs are similar in size because BCRWA is surrounded by natural boundaries. The ten-year WHAP is also limited on three sides; the WHPA can only extend to the west.

- BCRWA receives approximately 40 percent of its groundwater recharge from the Ohio River and the Straight Creek under normal pumping conditions. The effect of the induced infiltration from the Ohio River was also evident in the analysis of the water quality.

- Production water at BCRWA is chiefly a mix of three different water types: (1) ambient groundwater, (2) surface water, and (3) bedrock water. Each type has a representative water quality that can influence the raw water pumped at the plant. The chemistry of the water sampled within the wellfield suggests that the seepage from the bedrock wall is negligible and the contribution to the overall flow is principally derived from the buried valley.

- The groundwater from the BCRWA wells is moderately hard. However, the hardness is removed before the water is put in the distribution system and the water is of very good quality.
6.2 Recommendations

- The BCRWA should complete other steps of the wellhead protection program (as described in Section 1.1). The next step is the Identification of Potential Pollution Sources within the delineated WHPA.

- The BCRWA should consider regulatory management strategies in order to prevent contamination of the wellfield.

- The BCRWA should investigate the potential for purchasing more land within the ten-year WHPA.

- The current monitoring network consists mostly of piezometers and it is inadequate for the monitoring of the groundwater quality. There is a need for several monitoring wells to serve as a warning system for potential migration of contaminants from the neighboring farmlands and from the Ohio River.

- The WHPA groundwater model should be upgraded in the future, as the more data become available. The modeling should be used to assist in designing any expansion of the current treatment system.

- The water quality sampling initiated during the study should be continued in order to improve our understanding of the water quality variability.

- The role of the Ohio River on the quantity and quality of the production water has been recognized in the study. However, to better quantify the induced infiltration from the river a field investigation is necessary (including seepage measurements, monitoring wells between the old wellfield and the Ohio River).
7.0 References


ODNR. 1976. Southwest Ohio Water Plan. Ohio Department of Natural Resources, Columbus, Ohio.


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Areas in which yields of 30 to 60 gallons per minute can be developed

Areas in which yields of 10 to 30 gallons per minute can be developed

Areas in which yields of 5 to 10 gallons per minute can be developed

Areas in which yields of 1 to 5 gallons per minute can be developed

Figure 5. Regional ground-water resources map of Brown County
Average Monthly Precipitation Near Brown County
Rural Water Association

(Years 1931 - 1996)
Monthly Precipitation at Maysville, Kentucky

(Years 1982 to 1992)
BROWN COUNTY RURAL WATER ASSOCIATION
WELLHEAD PROTECTION PROJECT
RIPLEY, OH
GROUNDBASE AND SUBSURFACE MODELING INVESTIGATION
HYDROLINK
9416 SHADY OAK COURT
CINCINNATI, OH 45231

INTERPRETED CROSS SECTION E-E'
CUT THROUGH NEW AND OLD WELLFIELDS

NOTES:
1. ELEVATION REFERENCED TO MEAN SEA LEVEL (MSL)
2. WATER LEVELS BASED UPON WELL COMPLETION

LEGEND
- TOPSOIL
- WELL GRADIENT SAND
- CLAY
- CLAY HARD PAN
- GRAY SAND
- GRAVEL
- CLAYEY GRAVEL
- CLAYEY SAND
- SILTY SAND
- BEDROCK
- STATIC WATER LEVEL
- WELL SCREEN
BROWN COUNTY RURAL WATER ASSOCIATION
WELLHEAD PROTECTION PROJECT
RIPLEY, OH
GROUNDWATER AND SUBSURFACE MODELING INVESTIGATION
HYDROLINK
9416 SHADY OAK COURT
CINCINNATI, OH  45231

INTERPRETED CROSS SECTION F-F'
CUT THROUGH NEW AND OLD WELLFIELDS

NOTES:
1. ELEVATION REFERENCED TO MEAN SEA LEVEL (MSL)
2. WATER LEVELS MEASURED UPON WELL COMPLETION
   HIGHLY TRANSMISSIVE
   MODERATELY TRANSMISSIVE
   LESS TRANSMISSIVE
   LEAST TRANSMISSIVE

LEGEND

TOPSOIL
WELL GRADED SAND
CLAY
CLAY HARDPAN
GRANULATED SAND
CLAYEY GRAVEL
CLAYEY SAND
BASAL SAND
BASAL WATER LEVEL
WELL SCREEN

© (Your Name) 2023 Draft 2 - Use Exclusively 10/14/97
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<th>kzlow</th>
<th>khalflow</th>
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<th>rec50dec</th>
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- **WHPA0**: Wellhead Protection Area Water Budget
- **kzhigh**: Increase Kz in all layers one order of magnitude
- **kzlow**: Decrease Kz in all layers one order of magnitude
- **khalflow**: Reduce Kx, Ky, and Kz in all layers by half
- **rec50inc**: Increase areal recharge by 50%
- **rec50dec**: Decrease areal recharge by 50%
- **wall2inc**: Increase bedrock seepage by 100%
- **walleq0**: Decrease bedrock seepage by 100%
- **crconup1**: Increase conductance in river and creeks one order of magnitude
- **crconup2**: Increase conductance in river and creeks two orders of magnitude
Sensitivity Analysis (Page 2 of 3)

<table>
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<th>Parameter</th>
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<th>3kzinc</th>
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<td>44.2%</td>
<td>44.2%</td>
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<td>37.6%</td>
<td>43.5%</td>
<td>43.5%</td>
<td>39.7%</td>
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</table>

- **ohio2inc**: Increase conductance in river and creeks twice as much
- **ohio2dec**: Decrease conductance in river and creeks half as much
- **poros4**: Porosity changed to 0.4
- **poros15**: Porosity changed to 0.15
- **whpalay3**: Wellhead Protection Area Water Budget for particles originating in 3rd layer
- **3kzinc**: Increase Kz in all layers one order of magnitude (Particles starting in 3rd layer)
- **3kzdec**: Decrease Kz in all layers one order of magnitude (Particles starting in 3rd layer)
- **kzlw50**: Reduce Kx, Ky, and Kz in all layers by half (Particles starting in 3rd layer)
- **3kinc**: Increase Kx, Ky, and Kz in layers 3 and 4 by 50% (Particles starting in 3rd layer)
- **3rechinc**: Increase areal recharge by 50% (Particles starting in 3rd layer)
### Sensitivity Analysis (Page 3 of 3)

<table>
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<tr>
<th></th>
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<td>43.1%</td>
<td>43.1%</td>
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- **3rechdec**: Decrease areal recharge by 50% (Particles starting in 3rd layer)
- **3wallinc**: Increase bedrock seepage by 100% (Particles starting in 3rd layer)
- **3walldec**: Decrease bedrock seepage by 100% (Particles starting in 3rd layer)
- **3crc260**: Increase conductance in river and creeks one order of magnitude (Particles starting in 3rd layer)
- **3crc2600**: Increase conductance in river and creeks two orders of magnitude (Particles starting in 3rd layer)
- **3crc5000**: Increase conductance in river and creeks twice as much (Particles starting in 3rd layer)
- **3crc1250**: Decrease conductance in river and creeks half as much (Particles starting in 3rd layer)
- **3por4**: Porosity changed to 0.4 (Particles starting in 3rd layer)
- **3por15**: Porosity changed to 0.15 (Particles starting in 3rd layer)
FIELD MEASUREMENTS

Date Sampled: 1/28/97

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### BROWN COUNTY LAB

6/11/97 (running PW-1, PW-3, PW-4; 1300 gpm total)**

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**PW-1 300gpm
**PW-3 500gpm
**PW-4 500 gpm

### BROWN COUNTY FIELD

6/11/97 (running PW-1, PW-3, PW-4; 1300 gpm total)**

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**PW-1 300gpm
**PW-3 500gpm
**PW-4 500 gpm
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<th>PW-5</th>
<th>PW-6</th>
<th>PW-7</th>
<th>Ohio River</th>
<th>Bedrock</th>
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### BROWN COUNTY LAB

**7/17/97**

PW-1, PW-3, PW-4, PW-5 running/ 1845 gpm total (PW-2 & PW-7 out of commission)

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<th>PW-3</th>
<th>PW-4</th>
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<th>PW-6</th>
<th>PW-7</th>
<th>Ohio River</th>
<th>Bedrock</th>
<th>W-1</th>
<th>W-2</th>
<th>W-3</th>
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### BROWN COUNTY FIELD

**7/17/97**

PW-1, PW-3, PW-4, PW-5 running/ 1845 gpm total (PW-2 & PW-7 out of commission)

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<th>PW-6</th>
<th>PW-7</th>
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<th>Bedrock</th>
<th>W-1</th>
<th>W-2</th>
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### WATER LEVELS

**7/17/97**

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<th>P-3</th>
<th>P-4</th>
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P-4 - can't unlock
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<th>PW-7</th>
<th>Ohio River</th>
<th>Bedrock</th>
<th>W-1</th>
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<td>0.91</td>
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WATER LEVELS

Date Measured: 10/17/97  W-1 @ 410 gpm and PW-1 @ 300 gpm (Pumping - 710 gpm total)

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<tr>
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<th>P-2</th>
<th>P-3</th>
<th>P-4</th>
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<tr>
<td>Depth to Water (feet)</td>
<td>28.04</td>
<td>26.56</td>
<td>27.08</td>
<td>n/a</td>
</tr>
<tr>
<td>Time</td>
<td>afternoon</td>
<td>afternoon</td>
<td>afternoon</td>
<td>n/a</td>
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<td>Casing Elevation (ft. above MSL)</td>
<td>507.2</td>
<td>506</td>
<td>508.2</td>
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<tr>
<td>Water Level (feet)</td>
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<td>481.12</td>
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P-4 - can't unlock
### FIELD MEASUREMENTS

11/10/97 (running PW-1, PW-4, PW-6, and W-2 since 9 am)**

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<th>PW-3</th>
<th>PW-4</th>
<th>PW-5</th>
<th>PW-6</th>
<th>PW-7</th>
<th>Ohio River</th>
<th>Bedrock</th>
<th>W-1</th>
<th>W-2</th>
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<tbody>
<tr>
<td><strong>pH</strong></td>
<td>n/a</td>
<td>n/a</td>
<td>n/a</td>
<td>n/a</td>
<td>n/a</td>
<td>n/a</td>
<td>n/a</td>
<td>n/a</td>
<td>n/a</td>
<td>n/a</td>
<td>n/a</td>
</tr>
<tr>
<td><strong>Hardness</strong></td>
<td>n/a</td>
<td>n/a</td>
<td>n/a</td>
<td>n/a</td>
<td>n/a</td>
<td>n/a</td>
<td>n/a</td>
<td>n/a</td>
<td>n/a</td>
<td>n/a</td>
<td>n/a</td>
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<tr>
<td><strong>Alkalinity</strong></td>
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<td>n/a</td>
<td>n/a</td>
<td>n/a</td>
<td>n/a</td>
<td>n/a</td>
<td>n/a</td>
<td>n/a</td>
<td>n/a</td>
<td>n/a</td>
<td>n/a</td>
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<tr>
<td><strong>Temp (Celsius)</strong></td>
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<td>13</td>
<td>11</td>
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<td>n/a</td>
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<td>n/a</td>
<td>n/a</td>
<td>n/a</td>
<td>n/a</td>
<td>n/a</td>
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Notes: PW-2 is out of commission; and PW-5 has a problem with switch.

### WATER LEVELS

11/10/97 (running PW-1, PW-4, PW-6, and W-2 since 9 am)**

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<th>P-1</th>
<th>P-2</th>
<th>P-3</th>
<th>P-4</th>
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<tbody>
<tr>
<td><strong>Depth to Water (feet)</strong></td>
<td>28.12</td>
<td>26.95</td>
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<td><strong>Time</strong></td>
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<td>3:45</td>
<td>3:45</td>
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<td>507.2</td>
<td>506</td>
<td>508.2</td>
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<td><strong>Water Level (feet)</strong></td>
<td>479.08</td>
<td>479.05</td>
<td>478.86</td>
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**BROOKSIDE LAB**

Date Sampled: 11/10/97

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<th>PW-1</th>
<th>PW-2</th>
<th>PW-3</th>
<th>PW-4</th>
<th>PW-5</th>
<th>PW-6</th>
<th>PW-7</th>
<th>Ohio River</th>
<th>Bedrock</th>
<th>W-1</th>
<th>W-2</th>
<th>W-3</th>
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</thead>
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<td>470</td>
<td>523</td>
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FIELD MEASUREMENTS

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<th>Bedrock</th>
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Notes: W-3 is being worked on. W-4, W-5, and W-6 online soon.

WATER LEVELS

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Notes: P-5 just found. This 2" diameter piezometer is located 20 ft. from PW-4.
### BROOKSIDE LAB

**Date Sampled:** 2/10/08

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<th>PW-6</th>
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<th>Ohio River</th>
<th>Bedrock</th>
<th>W-1</th>
<th>W-2</th>
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<td>470</td>
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**SETUP 1:**  South edge of access road through old wellfield directly north of PW-5

**NOTES:**
1. Measurements accurate to tenths only!
2. Casing bolt closest to setup surveyed.

**Known Elevations:**
- **PW-4 (GROUND)**
- **505.8 FT (BM Elevation)**
- **W-1, W-2, & W-3 (GROUND)**
- **528.0 FT (approx.)**

<table>
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<tr>
<th>FROM</th>
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**SETUP 2:** Center line of access road through new wellfield between W-2 and W-5.

**SETUP 3:** ~ 50 feet north of W-4 directly between W-4 and W-5.

**NOTES:**
1. Measurements accurate to tenths only!
2. Casing bolt closest to setup surveyed.

**Known Elevations:**
- **PW-4 (GROUND)**
- **505.8 FT (BM Elevation)**
- **(W-1, W-2, & W-3) GROUND**
- **528.0 FT (approx.)**

<table>
<thead>
<tr>
<th>FROM</th>
<th>TO</th>
<th>VERT (FEET)</th>
<th>ELEVATION (FT. ABOVE MSL)</th>
<th>REMARKS</th>
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Date: 2/10/98

Weather Conditions: ~ 37 degrees, Overcast, snow on ground

SETUP 4: ~ equidistant from PW-4 & PW-6 between the two online.

NOTES: (1) Measurements accurate to tenths only!

Known Elevations: PW-4 (GROUND) 505.8 FT (BM Elevation)

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<th>TO</th>
<th>VERT (FEET)</th>
<th>ELEVATION (FT. ABOVE MSL)</th>
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APPENDIX A
APPENDIX A: Well Logs

Figure A-1. Log of Boring for PW-1
Figure A-2. Log of Boring for PW-2
Figure A-3. Log of Boring for PW-3
Figure A-4. Log of Boring for PW-4
Figure A-5. Log of Boring for PW-5
Figure A-6. Log of Boring for PW-6
Figure A-7. Log of Boring for PW-7
Figure A-8. Log of Boring for W-1
Figure A-9. Log of Boring for W-2
Figure A-10. Log of Boring for W-3
Figure A-11. Log of Boring for W-4
Figure A-12. Log of Boring for W-5
Figure A-13. Log of Boring for W-6
Figure A-14. Log of Boring for P-2
Figure A-15. Log of Boring for P-4
Figure A-16. Log of Boring for 8-inch Test Well
Figure A-17. Log of Boring for Sturm
Figure A-18. Log of Boring for Osborn
Figure A-19. Log of Boring for US Army
**LOG OF BORING FOR PW-1**

**Well Log**

**Well: PW-1**  
Elev.: 504 ft.

<table>
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**Graphic and USGS Information**

**Description**

- Clay
- Sand and gravel

**Well Construction Information**

**WELL CONSTRUCTION**

- Date Compl.: 3/85
- Hole Diameter: 4 in.

**WELL CASING**

- Material: Steel
- Diameter: 12 in.
- Length: 57 ft. 6 in.

**WELL SCREEN**

- Material: S.S. Wirewound
- Diameter: 14 in.
- Length: 15 ft.
- Depth: 71 ft.

**PUMP INFORMATION**

- Type: Submersible turbine
- Capacity: 425 GPM
- Depth of Setting: 53 ft. (pilless adaptor)

**INITIAL PUMP TEST**

- Test Rate: 701 GPM
- Duration: 24 hrs.
- Drawdown: 17 ft. 4 in.
- Static Water Level: 245 ft.
- Quality: Clear

**GRAVEL PACK**

- Construction: 24 in. x 12 in.

**NOTES**
## LOG OF BORING FOR PW-2

**Date Drilled:** 11/20/64  
**ODNR Report No.:** 611604  
**Boring Location:** Old Wellfield south of P-2  
**Well Elevation:** 505 ft above MSL (est.)  
**Total Depth:** 72 ft.

### Well Log

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</table>

**Well:** PW-2  
**Elev.:** 505 ft.

### Graphic Log

- **Grout?**
- **Seal?**
- **Sand Pack**
- **Screen**

### Description

- **Clay**
- **Coarse gravel with sand**
- **Sand and gravel med. to fine.**

### Well Construction Information

- **Type:** Submersible turbine  
- **Capacity:** 425 GPM  
- **Depth of Suction:** 48 ft. (pitless adaptor)

### Initial Pump Test

- **Test Rate:** 730 GPM  
- **Duration:** 17 hrs.  
- **Drawdown:** 11 ft. 4 in.  
- **Static Water Level:** 25 ft.  
- **Quality:** Clear  
- **Construction:** 24 in. x 12 in.
**LOG OF BORING FOR PW-3**

**Brown County Rural Water Association**

**Site Assessment**

**Wellhead Protection Program**

**Higginsport-Ripley, OH**

**Date Drilled:** 11/22/84

**ODNR Report No.:** 616005

**Boring Location:** Old Wellfield north of PW-5

**Company Rep.:** Edward S. Schleack

**Note Elevation:** 504 ft. above MSL (est.)

**Drilling Firm:** Moody's of Dayton, Inc.

**Total Depth:** 70.5 ft.

---

**Well: PW-3**

**Elev.:** 504 ft.

---

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**DESCRIPTION**

**Clay**

**Sand and gravel**

---

**WELL CONSTRUCTION**

**Date Compl.:** 3/85

**Hole Diameter:** 24 in.

**WELL CASING**

**Material:** Stl. Steel

**Diameter:** 12 in. I.D.

**Length:** 51 ft. 6 in.

**WELL SCREEN**

**Material:** Stainless Steel

**Diameter:** 12 in. I.D.

**Length:** 20 ft.

**Slot Size:** 0.050 in.

**Depth:** 70.5 ft.

**PUMP INFORMATION**

**Type:** Submersible turbine

**Capacity:** 425 GPM

**Depth of Setting:** 48 ft. (pilless adaptor)

**INITIAL PUMP TEST**

**Test Rate:** 721 GPM

**Duration:** 18 hrs.

**Drawdown:** 13 ft. 5 in.

**Static Water Level:** 23.5 ft.

**Clasty:** Clear

**GRAVEL PACK**

**Construction:** 24 in. x 12 in.

---

**NOTES**
HYDROLINK
9416 SHADY OAK COURT
CINCINNATI, OH 45231

LOG OF BORING FOR PW-4

Brown County Rural Water Association
Site Assessment
Wellhead Protection Program

Higginsport-Ripley, OH

Well Log

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Well: PW-4
Elev.: 505.8 ft.

SIEVE ANALYSIS CUTTINGS

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<td>Soft brown clay</td>
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<td>Medium sand and few big rocks</td>
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<tr>
<td>Medium sand</td>
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<td>Hard brown clay and big rocks</td>
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WELL CONSTRUCTION

Date Compl.: 11/17/89
Hole Diameter: 24 in.

WELL CASING

Diameter: 12 in.
Length: 60 ft.

WELL SCREEN

Diameter: 12 in. I.D.
Length: 20 ft.
Depth: 63 ft.

PUMP INFORMATION

Type: Submersible turbine
Capacity: 350 GPM
Depth of Setting: 55 ft. (p'less adaptor)

INITIAL PUMP TEST

Test Rate: 329 - 448 GPM
Duration: 24 hrs.
Drawdown: 16 ft. 5 in.
Static Water Level: 24.75 ft.
Transmissivity: 127274 GPD/ft.
LOG OF BORING FOR PW-5

Well Log

**Well:** PW-5
**Elev.:** 505.5 ft.

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**SIEVE ANALYSIS CUTTINGS**

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**DESCRIPTION**

- **Top soil**
  - Brown clay
- **Soft brown clay**
  - Coarse sand with some big rocks
- **Coarse sand and gravel**
- **Coarse sand and few rocks**
- **Coarse sand and gravel**
- **Fine sand**

**WELL CONSTRUCTION**

- **Date Compl.:** 11/17/88
- **Hole Diameter:** 24 in.
- **WELL CASING**
  - Diameter: 12 in.
  - Length: 60 ft.
- **WELL SCREEN**
  - Diameter: 12 in. I.D.
  - Length: 62 ft.
- **PUMP INFORMATION**
  - Type: Submersible Turbine
  - Capacity: 350 GPM
  - Depth of Setting: 55 ft. (pumpless adapter)
- **INITIAL PUMP TEST**
  - Test Rate: 602 GPM
  - Duration: 24 hrs.
  - Drawdown: 13 ft. 6.5 in.
  - Static Water Level: 24.5 ft.
  - Transmissivity: 17443 GPD/ft.

**NOTES**

94-26-1999  C:WTECH465IBROWNCO/GEOWell
LOG OF BORING FOR PW-6

Well: PW-6
Elev.: 506 ft.

Depth in feet | Surf. Elev. 506
---|---
0 | 
5 | 
10 | 
15 | 
20 | 
25 | 
30 | 
35 | 
40 | 
45 | 
50 | 
55 | 
60 | 
65 | 
70 | 
75 | 
80 | 
85 | 
90 | 
95 | 
100 | 

Well Log

SIEVE ANALYSIS CUTTINGS

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DESCRIPTION

Brown silty clay
Brown fine sandy sand/trace gravel
Fine to medium sandy sand with trace gravel
Brown fine to medium sand/some coarse sand & gravel/trace silt
Fine to coarse brown sandy sand with coal layer
Brown fine sand/some medium sand/trace gravel
Brown fine to medium sand/some coarse sand & gravel loose
Brown - same as above with cobbles

Well Construction Information

WELL CONSTRUCTION
Date Compl.: 1/27/93
Hole Diameter: 24 in.
WELL CASING
Material: Steel
Diameter: 12 in.
Length: 61 ft. 9 in.
WELL SCREEN
Material: Cook Stainless Steel
Type: Wire Wrapped
Diameter: 12.75 in.
Length: 20 ft.
Joint: Threaded
Depth: 66 ft.
Slot Size: 0.030 in.
PUMP INFORMATION
Type: Submersible turbine
Capacity: 420 GPM
Depth of Setting: 42 ft.
INITIAL PUMP TEST
Test Rate: 550 GPM
Duration: 24 hrs.
Drawdown: 13 ft. 5 in.
Static Water Level: 26 ft.
Quality: Clear
GRAVEL PACK
Material: Silica (10 yds.)
Installation: Trimmed

NOTES

01-26-1998 C:IMTECH46BROWINC0GE0swell8bor
Well: PW-7
Elev.: 506 ft.

**Topsoil**
Brown silty clay

**Fine brown silty sand with clay**

**Fine to brown silty sand with gravel**

**Fine to medium gray sand with some coarse gravel.**

**Fine to medium brown silty sand**

**Fine to medium brown sand with gravel**

**Med. dense brown sand**

**Fine to med. brown sand with coarse gravel, dense cobbles and crushed limestone.**

**WELL CONSTRUCTION**
Date Compl.: 2/29/3
Hole Diameter: 24 in.

**WELL CASING**
Material: Steel
Diameter: 12 in.
Length: 91 ft. 9 in.

**WELL SCREEN**
Material: Cold Stainless Steel
Type: Wire Wrapped
Diameter: 12.75 in.
Length: 20 ft.
Jointed: Welded
Depth: 79 ft.
Slot Size: 0.030 in.

**PUMP INFORMATION**
Type: Submersible turbine
Capacity: 420 GPM
Depth of Sifting: 42 ft.

**INITIAL PUMP TEST**
Test Rate: 550 GPM
Duration: 24 hrs.
Drawdown: 10 ft. 4 in.
Static Water Level: 20.5 ft.
Quality: Clear

**GRAVEL PACK**
Material: Sieve (10 yds.)
Installation: Trimline

**NOTES**

**GRAPHIC**

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**LOG OF BORING FOR W-1**

**Brown County Rural Water Association**  
**Wellhead Protection Program**  
**Higginsport-Ripley, OH**

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**Graphic USGS**

**Well Construction Information**

- **DATE COMPL:** 5/20/98
- **GND ELEV:** 529.0 ft. above MSL
- **HOLE DIAMETER:** 24 in.
- **DIAMETER:** 12 in.
- **LENGTH:** 75 ft.
- **CEILING ELEVATION:** 529.0 ft. above MSL
- **JOINTS:** Welded
- **DIAMETER:** 12 in.
- **LENGTH:** 20 ft.
- **DEPTH:** 25 ft.
- **TYPE:** SS Wire Wrap
- **SLOT SIZE:** 0.040 in.
- **SUBMERSIBLE TURBINE**
- **CAPACITY:** 403 GPM
- **PUMP SET AT:** 68 ft.

**Initial Pump Test**

- **TEST RATE:** 803 GPM
- **DURATION:** 24 hrs.
- **DRAWDOWN:** 14 ft. 1 in.
- **STABILITY LEVEL:** 41 ft. 2 in.

**Gravel Pack**

- **MATERIAL:** Quartz #5
- **METHOD OF INSTALLATION:** Treemie

**GROUT**

- **MATERIAL:** Concrete
- **METHOD OF INSTALLATION:** Pour

**Notes**
HYDROLINK
9416 SHADY OAK COURT
CINCINNATI, OH 45231

LOG OF BORING FOR W-2

Date Drilled: 5/21/96
Hole Diameter: 24 in.
Company Rep.: Edward S. Schemack
Drilling Firm: Layne-Ohio
ODNR Report No.: 767296
Boring Location: New Wellfield east of W-3
Hole Elevation: 529.4 ft. above MSL
Total Depth: 106 ft.

Well: W-2
Elev.: 529.4 ft.

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Well Log

**GRAPHIC**

- Grout
- Seal
- Sand Pack
- Screen

**USCS**

- Top soil
- Brown silty clay (moist)
- CL
- Soft brown clay with coarse sand
- SC
- Coarse dark brown sand
- SW
- Fine to medium brown sand
- SW
- Fine brown sand clayey at 87'
- SC
- Fine to med. sand trace gravel
- SW
- Fine to med. sand & gravel
- GP
- F-M brown sand with rock & silty sand at bottom
- SW CL
- Hardpan

**DESCRIPTION**

WELL CONSTRUCTION
- Date Compl.: 5/28/96
- Ground Elevation: 529.4 ft. above MSL
- Hole Diameter: 24 in.

WELL CASING
- Diameter: 12 in.
- Length: 80 ft.
- Joints: Welded
- Casting Elevation: 531.6 ft. above MSL

WELL SCREEN
- Diameter: 12 in.
- Length: 16 ft.
- Depth: 96 ft.
- Type: SS Wire Wrap
- Slot Size: 0.040 in.

PUMP INFORMATION
- Type: Submersible turbine
- Capacity: 400 GPM
- Pump Set at: 68 ft.

INITIAL PUMP TEST
- Test Rate: 603 GPM
- Duration: 24 hrs.
- Drawdown: 13 ft. 4 in.
- Static Water Level: 41 ft.

GRAVEL PACK
- Material: Quartz #5
- Method of Installation: Trench

GROUT
- Material: Concrete
- Method of Installation: Pour

**NOTES**
**HYDROLINK**
9416 SHADYOAK COURT
CINCINNATI, OH 45231

**LOG OF BORING FOR W-4**

*Brown County Rural Water Association*
*Site Assessment*
*Wellhead Protection Program*
*Higginsport-Ripley, OH*

**Date Drilled:** 11/5/97  
**O&NP Report No.:** 797294
**Hole Diameter:** 24 in.  
**Boring Location:** New Wellfield east of W5
**Company Rep.:** Edward S. Schleack  
**Hole Elevation:** 536.7 ft. above MSL
**Drilling Firm:** Layne-Ohio  
**Total Depth:** 114 ft.

---

**Well Log**

**Well: W-4**
**Elev.: 536.7 ft.**

<table>
<thead>
<tr>
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<th>536.7</th>
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**GRAPHIC**

- Grout?
- Seal?
- Sand Pack
- Screen

**DESCRIPTION**

- **Topsoil**
- **CL** Brown silty clay
- **GP** Brown sand and large gravel
- **SW** Fine to medium brown sand
- **SVW** Brown fine sand
- **SP** Fine to medium sand with some gravel
- **SVW** Brown fine sand

**Well Construction Information**

- **WELL CONSTRUCTION**
  - Date Compl.: 12/24/97
  - Hole Diameter: 24 in.
  - Ground Elevation: 536.7 ft. above MSL

- **WELL CASING**
  - Diameter: 12 in.
  - Length: 80 ft.
  - Joints: Welded
  - Casing Elevation: 538.5 ft. above MSL

- **WELL SCREEN**
  - Diameter: 12 in.
  - Length: 20 ft.
  - Depth: 103 ft.
  - Type: SS Wire Wrap
  - Slot Size: 0.040 in.

- **PUMP INFORMATION**
  - Type: Submersible Turbine
  - Capacity: 400 GPM
  - Pump S/ft.: 75 ft.

- **INITIAL PUMP TEST**
  - Test Rate: 63 GPM
  - Duration: 24 hrs.
  - Drawdown: 19 ft.
  - Static Water Level: 52.5 ft.

- **GRAVEL PACK**
  - Material: Quartz #5
  - Method of Installation: Trench

- **GROUT**
  - Material: Concrete
  - Method of Installation: Pour

**NOTES**
## HYDROLINK
9416 SHADY OAK COURT
CINCINNATI, OH 45231

### LOG OF BORING FOR W-5

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**Well Log**

- **Well:** W-5
- **Elev.:** 535 ft.

**Well Construction Information**

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<td>Date Compl.</td>
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<td>Hole Diameter</td>
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<td>Ground Elevation</td>
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<td><strong>WELL CASING</strong></td>
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<td>Diameter</td>
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<td></td>
<td>Length</td>
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<td>Duration</td>
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<td>Drawdown</td>
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<td>Static Water Level</td>
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<td><strong>GRAVEL PACK</strong></td>
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<td>Material</td>
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<td>Method of Installation</td>
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<td><strong>GROUT</strong></td>
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<tr>
<td></td>
<td>Material</td>
</tr>
<tr>
<td></td>
<td>Method of Installation</td>
</tr>
<tr>
<td></td>
<td><strong>NOTES</strong></td>
</tr>
</tbody>
</table>

- **Topsoil**
- **Brown silty clay moist**
- **Brown clay**
- **Gravel**
- **Fine to medium brown sand**
- **Fine brown sand with gravel**
- **Fine brown sand**
- **Sand Pack**
- **Screen**
- **Sand and gravel**
- **Fine brown sand**
LOG OF BORING FOR W-6

(date: 10/21/97)

Brown County Rural Water Association
Site Assessment
Wellhead Protection Program
Higginsport-Ripley, OH
Well Log

<table>
<thead>
<tr>
<th>Depth in FEET</th>
<th>Surt. Elev.</th>
<th>USCS</th>
<th>DESCRIPTION</th>
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</thead>
<tbody>
<tr>
<td>0</td>
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<td>CL</td>
<td>Topsoil</td>
<td>WELL CONSTRUCTION</td>
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<tr>
<td>5</td>
<td>535</td>
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<td>Brown clay with silt</td>
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<td>GC</td>
<td>Silty sand</td>
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<td>GP</td>
<td>Brown clay and gravel</td>
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<td>Coarse brown sand and gravel</td>
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<td>40</td>
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<td>Fine to coarse brown sand</td>
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<td>GP</td>
<td>Coarse brown sand with gravel</td>
<td>Slot Size: 0.040 in.</td>
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<tr>
<td>80</td>
<td>455</td>
<td></td>
<td>Fine brown sand with some gravel</td>
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</tr>
<tr>
<td>90</td>
<td>445</td>
<td>SP</td>
<td></td>
<td></td>
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NOTES

MATERIAL: Quartz #5
METHOD OF INSTALLATION: Trench
GROUT: Concrete
METHOD OF INSTALLATION: Pour
<table>
<thead>
<tr>
<th>Depth in ft</th>
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<th>Well Construction Information</th>
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<td>Hole Diameter: 8 in.</td>
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<td>15</td>
<td>489</td>
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<td>20</td>
<td>484</td>
<td>Material: Steel</td>
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<td>25</td>
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<td>Diameter: 6 in.</td>
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<td>474</td>
<td>Length: 63 ft. 6 in.</td>
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<td>WELL SCREEN</td>
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<td>Material: S.S. Wire Wrap</td>
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<td>Diameter: 8 in.</td>
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<td>454</td>
<td>Length: 3 ft.</td>
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<td>Depth: 65 ft.</td>
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<td>WATER LEVEL DATA</td>
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<td>Depth to Water: 27 ft. 3.2 in.</td>
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</table>

**DESCRIPTION**

- **Brown clay**
- **Grey clay**
- **Coarse brown gravel with fine sand**
- **Brown sand with trace of medium to fine gravel**
- **Gray med. to fine sand with gravel and large rock**

**GRAPHIC**

- **USCS**
- **Description**

**Well Data**

- **Date Drilled:** 8/7/84
- **Hole Diameter:** 8 in.
- **Company Rep.:** Edward S. Schneck
- **Drilling Firm:** Moody's of Dayton, Inc.
- **Boring Location:** Old Wellfield north of PW-2
- **Hole Elevation:** 504 ft. above MSL (est.)
- **Total Depth:** 65 ft.
## Well Log

**Well:** P-4  
**Elev.:** 505.8 ft.

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<th>Well Construction Information</th>
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### Well Construction

**Date Compl.:** 12/29/92  
**Hole Diameter:** 8 in.  
**WELL CASINGS**  
**Wall Thickness:** 0.322 in.  
**Diameter:** 8 in.  
**Length:** 59 ft.  
**WELL SCREEN**  
**Material:** Stainless Steel  
**Type:** Wire Wrapped  
**Diameter:** 7.5 in.  
**Length:** 3 ft.  
**Joints:** Welded  
**Static Water Level:** 24 ft.

### Description

- **Top Soil:** Brown clayey sand
- **CL:** Clay
- **SW:** Sand heavy
- **Sand and gravel**
- **Sand some gravel**
- **GP:** Gravel and sand
- **SP:** Fine sand lumps of coal
- **GW:** Large gravel
**LOG OF BORING FOR 8-INCH TEST WELL**

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<td>Diameter: 8 in.</td>
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**Well Log**

- **Well:** 8" Test Well
- **Elev.:** 505.5 ft.

**Description**

- **Topsoil:** Brown clay with silt
- **Silty sand:**
- **Sand:**
- **Sand with gravel:**
- **Gravel with sand:**
- **Sand and gravel:**
- **Bedrock:**

**Notes:**

- Initial Pump Test:
  - Test Rate: 250 GPM
  - Duration: 8 hrs.
  - Drawdown: 7 ft.
  - Static Water Level: 25 ft.

**Gravel Pack**

- Material: Silica (Farraty No. 4)

**GROUT**

This log is for a 8-inch test well located at 9416 Shadyoak Court, Cincinnati, OH 45231, conducted by the Brown County Rural Water Association. The date drilled is July 1983, and the borehole is located near Property - Old Wellfield. The total depth is 84 ft. Above MSL (est.), and the hole elevation is 505.5 ft. The borehole is protected by a sand pack and screen, with the topsoil containing brown clay with silt. The well construction includes a 8 in. diameter casing, with a length of 84 ft. The well screen is 79 ft. deep, with a type of SS Wire Wrap. The test results indicate a test rate of 250 GPM with a drawdown of 7 ft. and a static water level of 25 ft. The gravel pack material is silica (Farraty No. 4).
**LOG OF BORING FOR STURM**

**Date Drilled:** 7/9/57  
**ODNR Report No.:** 179761

**Hole Diameter:** 6 in.  
**Boring Location:** Int. of Free Soil - Rte. 52

**Company Rep.:** H. L. Wilson  
**Hole Elevation:** 536 ft. above MSL (est.)

**Drilling Firm:** O. L. Wilson & Son  
**Total Depth:** 97 ft.

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**Well Log**

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<tr>
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</table>

**DESCRIPTION**

- **Clayey sand**
- **Clayey gravel**
- **Sand**

**Well Construction Information**

- **Date Compl.:** 7/9/57
- **Hole Diameter:** 6 in.
- **WELL CASING**
  - **Diameter:** 5 5/8 in.
  - **Length:** 93 ft.
- **WELL SCREEN**
  - **Type:** RB Tube
  - **Length:** 4 ft.
  - **Depth:** 57 ft.
- **PUMP INFORMATION**
  - **Type:** Jet
  - **Capacity:** 240 GPH
  - **Depth of Sumping:** 65 ft.
  - **INITIAL PUMP TEST**
    - **Test Rate:** 10 GPM
    - **Duration:** 3 hrs.
    - **Drawdown:** 3 ft.
    - **Static Water Level:** 68 ft.

**NOTES**
# LOG OF BORING FOR OSBORN

**Brown County Rural Water Association**  
**Site Assessment**  
**Wellhead Protection Program**  
**Higginsport-Ripley, OH**

**Well Log**

<table>
<thead>
<tr>
<th>Depth in feet</th>
<th>Surt. Elev.</th>
<th>GRAPHIC</th>
<th>USCS</th>
<th>DESCRIPTION</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
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<td>SC</td>
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<td>Brown sandstone</td>
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<td></td>
<td></td>
<td>Blue shale rock and limestone</td>
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<tr>
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<td>545</td>
<td>LS</td>
<td></td>
<td>Limestone and shale rock</td>
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<td>40</td>
<td>525</td>
<td></td>
<td></td>
<td>Shale rock</td>
</tr>
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</tr>
<tr>
<td>120</td>
<td>455</td>
<td></td>
<td></td>
<td></td>
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</tbody>
</table>

**Well Construction Information**

- **Date Drilled:** 12/22/93  
- **Hole Diameter:** 12 in.  
- **Boring Location:** 7112 Straight Creek Rd.  
- **Hole Elevation:** 570 ft. above MSL (est.)  
- **Total Depth:** 113 ft.

**WELL CONSTRUCTION**

- **Date Compl.:** 12/22/93  
- **Hole Diameter:** 12 in.

**WELL CASING**

- **Diameter:** 5 5/8 in.  
- **Length:** 39 ft.

**WELL SCREEN**

- **Type of Screen:** None

**PUMP INFORMATION**

- **Type:** Submersible turbine  
- **Capacity:** 10 GPM  
- **Pump Set at:** 107 ft.

**INITIAL PUMP TEST**

- **Test Rate:** 3.5 GPM  
- **Duration:** 1.5 hrs.  
- **Drawdown:** 112 ft.  
- **Static Water Level:** 38 ft.

**NOTES**

---

01-26-1998  
C:\MTECH\86\BROWNCORE\rtwellrock
LOG OF BORING FOR US ARMY

HYDROLINK
9416 SHADY OAK COURT
CINCINNATI, OH 45291

Brown County Rural Water Association
Site Assessment
Wellhead Protection Program
Higginson-Ripley, OH

Date Drilled: 10/26/85
Hole Diameter: 6 in.
Company Rep.: Stanley G. Ruby
Drilling Firm: Stanley G. Ruby

ODNR Report No.: 335485
Boring Location: Ohio River - White Oak Cr.
Hole Elevation: 500 ft. above MSL (est.)
Total Depth: 74 ft.

Well Log

<table>
<thead>
<tr>
<th>Depth (feet)</th>
<th>Surf. Elev. (ft)</th>
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</thead>
<tbody>
<tr>
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</tr>
<tr>
<td>95</td>
<td>405</td>
</tr>
<tr>
<td>100</td>
<td></td>
</tr>
</tbody>
</table>

Well: US ARMY
Elev.: 500 ft.

Clayey sand

Seal?

SC

Sand Pack?

Screen

DESCRIPTION

WELL CONSTRUCTION
Date Compl.: 10/26/85
Hole Diameter: 6 in.

WELL CASING
 Diameter: 6 in.
Length: 54 ft.

WELL SCREEN
Type: # 14-RB-WW
Length: 20 ft.
Depth: 62 ft.

PUMP INFORMATION
Type: Hand Pump
Depth of Setting: 62 ft.

INITIAL PUMP TEST
Test Rate: 40 GPM
Duration: 24 hrs.
Drawdown: 6 ft.
Static Water Level: 8 ft.
Quality: Clear

NOTES
APPENDIX B
APPENDIX B: Aquifer Tests

Figure B-1. Production Well PW-1
Figure B-2. Production Well PW-2
Figure B-3. Production Well PW-3
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Figure B-5. Production Well PW-4
Figure B-6. Production Well PW-5
Figure B-7. Production Well PW-6
Figure B-8. Production Well PW-7
Figure B-9. Production Well W-1
Figure B-10. Observation Well W-2 for W-1 Pump test
Figure B-11. Production Well W-2
Figure B-12. Observation Well W-3 for W-2 Pump test
Figure B-13. Production Well W-3
Figure B-14. Observation Well W-1 for W-3 Pump test
Figure B-15. Production Well W-4
Figure B-16. Observation Well W-6 for W-4 Pump test
Figure B-17. Production Well W-5
Figure B-18. Observation Well W-4 for W-5 Pump test
Figure B-19. Production Well W-6
Figure B-20. Observation Well W-5 for W-6 Pump test
Production Well PW-1

Transmissivity: 11647 sq ft/d
Storage Coefficient: 6.594e-004

Data Used: ○
Data Ignored: ×
Production Well PW-2

- Transmissivity: 22838 sq ft/d
- Storage Coefficient: 2.067e-06

Data Used vs. Data Ignored
Observation Well PW-1 for PW-3 Pump Test

Transmissivity: 46609 sq ft/d
Storage Coefficient: 6.263e-003

- Data Used
- Data Ignored
Production Well PW-4

Drawdown (feet)

Time (minutes)

Transmissivity 13650 sq ft/d
Storage Coefficient 2.694e-009

Data Used
Data Ignored
Production Well PW-6

- Transmissivity: 23827 sq ft/d
- Storage Coefficient: 1.120e-09

Please note that the data used in this graph is marked with 'x' and data ignored is marked with a circle.

Drawdown (feet) vs. Time (minutes)
Production Well PW-7

**Graph:**
- **Y-axis:** Drawdown (feet)
- **X-axis:** Time (minutes)

**Legend:**
- X: Data Used
- : Data Ignored

**Table:**
- **Transmissivity:** 23223 sq ft/d
- **Storage Coefficient:** 4.228e-008

**Graph Details:**
- Graph shows a trend line and data points indicating drawdown over time.
- The trend line suggests a linear relationship between drawdown and time.
Production Well W-1

Transmissivity: 10350 sq ft/d
Storage Coefficient: 8.453e-03

Data Used: ×
Data Ignored: ○
Observation Well W-2 for W-1 Pump Test

Transmissivity: 13370 sq ft/d
Storage Coefficient: 2.251e-001

Data Used ▲ Data Ignored
Production Well W-2

HydroLink

- Transmissivity: 9928 sq ft/d
- Storage Coefficient: 1.086e-06

Data Used: X
Data Ignored: O
Observation Well W-3 for W-2 Pump Test

**HydroLink**

- Transmissivity: 19541 sq ft/d
- Storage Coefficient: 6.685e-02

Data:
- X: Data Used
- ○: Data Ignored

**Axes:**
- Drawdown (feet) on the Y-axis
- Time (minutes) on the X-axis
Observation Well W-1 for W-3 Pump Test

- Transmissivity: 14652 sq ft/d
- Storage Coefficient: 4.551e-002

Data Used
Data Ignored
Production Well W-4

Transmissivity: 57946 sq ft/d
Storage Coefficient: 4.656e-047

Data Used
Data Ignored

Drawdown (feet)

Time (minutes)
Observation Well W-6 for W-4 Pumptest

Hydrotest
Transmissivity 10039 sq ft/d
Storage Coefficient 2.980e-002

X Data Used
X Data Ignored

Drawdown (feet)

Time (minutes)
Production Well W-5

Transmissivity: 10971 sq ft/d
Storage Coefficient: 6.706e-05

Data Used: X
Data Ignored: O
Observation Well W-4 for W-5 Pump test

HydroLink

- Transmissivity: 15547 sq ft/d
- Storage Coefficient: 3.483e-02

Data Used

Data Ignored
Production Well W-6

- Transmissivity: 37486 sq ft/d
- Storage Coefficient: 1.374e-034

HydroLine

Data Used: ○ Data Ignored
Observation Well W-5 for W-6 Pump Test

Transmissivity: 40502 sq ft/d
Storage Coefficient: 2.641e-06

Data Used: X
Data Ignored: ○
APPENDIX C
APPENDIX C: Groundwater Quality Parameters

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Figure C-14. Iron
Figure C-15. Manganese
Figure C-16. Copper
Figure C-17. Silica
Figure C-18. Aluminum
Figure C-19. Zinc
TDS vs. Conductivity

\[ y = 0.63x + 7.91 \]

\[ R^2 = 0.99 \]
Magnesium

![Bar chart showing magnesium levels across different locations and seasons.](chart_image)
Copper Concentration on 07/17/97

The graph shows the copper concentration in various locations on July 17, 1997. The x-axis represents different locations, and the y-axis shows the copper concentration in parts per million (ppm). The data points suggest a higher concentration at location PW-1 compared to others.
Aluminum

SMCL = 0.2 ppm

Bedrock  W-3  W-2  W-1  PW-4  PW-3  PW-1  PW-6  PW-2  PW-5  PW-7  Ohio River
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BROWN COUNTY
RURAL WATER ASSOCIATION
WELLHEAD PROTECTION PROJECT
RIPLEY, OH
GROUNDWATER AND SUBSURFACE MODELING INVESTIGATION
HYDROLINK
9416 SHADYOAK COURT
CINCINNATI, OH 45231

PIPER DIAGRAM FOR JULY 17, 1997 SAMPLING

PW-1 - SAMPLE FROM OLD WELLFIELD WELL 1
PW-3 - SAMPLE FROM OLD WELLFIELD WELL 3
PW-4 - SAMPLE FROM OLD WELLFIELD WELL 4
PW-5 - SAMPLE FROM OLD WELLFIELD WELL 5
PW-6 - SAMPLE FROM OLD WELLFIELD WELL 6
BEDROCK - SAMPLE FROM BEDROCK NEAR WELLFIELD
OHIO RIVER - SAMPLE FROM OHIO RIVER
BROWN COUNTY
RURAL WATER ASSOCIATION
WELLHEAD PROTECTION PROJECT
RIPLEY, OH
GROUNDWATER AND SUBSURFACE MODELING
INVESTIGATION
HYDROLINK
9416 SHADYDALE COURT
CINCINNATI, OH 45231

PIPER DIAGRAM FOR NOVEMBER 10, 1997 SAMPLING

PW-1 - SAMPLE FROM OLD WELLFIELD WELL 1
PW-3 - SAMPLE FROM OLD WELLFIELD WELL 3
PW-4 - SAMPLE FROM OLD WELLFIELD WELL 4
PW-5 - SAMPLE FROM OLD WELLFIELD WELL 6
PW-7 - SAMPLE FROM OLD WELLFIELD WELL 7
W1  - SAMPLE FROM NEW WELLFIELD WELL 1
W2  - SAMPLE FROM NEW WELLFIELD WELL 2
W3  - SAMPLE FROM NEW WELLFIELD WELL 3
OHIO RIVER - SAMPLE FROM OHIO RIVER

Dr:Geochm\Pipe\NOW7299.DOC LAST EDITED 12/18/97
BROWN COUNTY
RURAL WATER ASSOCIATION
WELLHEAD PROTECTION PROJECT
RIPLEY, OH
GROUNDBWATER AND SUBSURFACE MODELING INVESTIGATION
HYDROLINK
6416 SHADY OAK COURT
CINCINNATI, OH 45231

STIFF DIAGRAM FOR JUNE 12, 1997 SAMPLING

OHIO RIVER - SAMPLE FROM OHIO RIVER
PW-1 - SAMPLE FROM OLD WELLFIELD WELL 1
PW-2 - SAMPLE FROM OLD WELLFIELD WELL 2
PW-3 - SAMPLE FROM OLD WELLFIELD WELL 3
PW-4 - SAMPLE FROM OLD WELLFIELD WELL 4
PW-5 - SAMPLE FROM OLD WELLFIELD WELL 5
PW-6 - SAMPLE FROM OLD WELLFIELD WELL 6

Ca  Na+K  Mg  Fe  SO4  NO3  Cl
Ca  Na+K  Mg  Fe  SO4  NO3  Cl
Ca  Na+K  Mg  Fe  SO4  NO3  Cl
Ca  Na+K  Mg  Fe  SO4  NO3  Cl
Ca  Na+K  Mg  Fe  SO4  NO3  Cl
BROWN COUNTY
RURAL WATER ASSOCIATION
WELLHEAD PROTECTION PROJECT
RIPELY, OH
GROUNDWATER AND SUBSURFACE MODELING INVESTIGATION
HYDROLINK
9416 SHADYDAK COURT
CINCINNATI, OH 45231

STIFF DIAGRAM FOR JULY 17, 1997 SAMPLING

W1  -  SAMPLE FROM NEW WELLFIELD WELL 1
W2  -  SAMPLE FROM NEW WELLFIELD WELL 2
W3  -  SAMPLE FROM NEW WELLFIELD WELL 3
BEDROCK  -  SAMPLE FROM BEDROCK NEAR WELLFIELD
STIFF DIAGRAM FOR NOVEMBER 10, 1997 SAMPLING

BROWN COUNTY
RURAL WATER ASSOCIATION

WELLHEAD PROTECTION PROJECT
RIPLEY, OH

GROUNDWATER AND SUBSURFACE MODELING INVESTIGATION
HYDROLINK
9416 SHADYDAK COURT
CINCINNATI, OH 45231

PW-1 - SAMPLE FROM OLD WELLFIELD WELL 1
PW-3 - SAMPLE FROM OLD WELLFIELD WELL 3
PW-4 - SAMPLE FROM OLD WELLFIELD WELL 4
PW-6 - SAMPLE FROM OLD WELLFIELD WELL 6
PW-7 - SAMPLE FROM OLD WELLFIELD WELL 7
W1 - SAMPLE FROM NEW WELLFIELD WELL 1
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Figure E-12. Zinc in Ohio River at Meldahl Dam, Brown Co. Rural Water
Streamflow of Ohio River Near Brown Co. Rural Water

January 1985 - September 1986
October 1986 - June 1992
July 1992 - December 1986

Cincinnati Station
Maysville Station
Meldahl Dam Station
Temperature of Ohio River Near Brown Co. Rural Water
Hardness in Ohio River at Meldahl Dam

- Hardness (ppm)
Chloride in Ohio River at Meldahl Dam
Sulfate in Ohio River at Meldahl Dam, Brown Co. Rural Water
Nitrate-Nitrite as N in Ohio River at Meldahl Dam
Magnesium in Ohio River at Meldahl Dam

[Bar chart showing magnesium levels in ppm for various months from Jan-85 to Sep-96]
Iron in Ohio River at Meldahl Dam
Manganese in Ohio River at Meldahl Dam
Zinc in Ohio River at Meldahl Dam
POTENTIAL POLLUTION SOURCE INVENTORY
THE WELLHEAD PROTECTION PROGRAM
Brown County Rural Water
Ripley, Ohio

Prepared for:

Eugene Worthington
Brown County Rural Water Association
3834 US52
Ripley, Ohio 45167

Prepared by:

M.S. Beljin & Associates
9416 Shadyoak Court
Cincinnati, Ohio 45231

May 25, 1999
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Table 1. Potential Pollution Source Inventory
List of Acronyms

- amsl: Above Mean Sea Level
- b: Aquifer Saturated Thickness
- cfs: Cubic feet per second
- EPA: Environmental Protection Agency
- gpm: Gallons per minute
- gpd: Gallons per day
- ug/L: Micrograms per Liter
- K: Hydraulic Conductivity
- MCL: Maximum Contaminant Level
- NOAA: National Oceanic and Atmospheric Administration
- NWS: National Weather Service
- ODNR: Ohio Department of Natural Resources
- ODC: Ohio Department of Commerce
- OEPA: Ohio Environmental Protection Agency
- PPSI: Potential Pollution Source Inventory
- SDWA: Safe Drinking Water Act
- TOT: Time of Travel
- T: Transmissivity
- UIC: Underground Injection Control
- UST: Underground Storage Tank
- USEPA: United States Environmental Protection Agency
- USGS: United States Geological Survey
- VOCs: Volatile Organic Contaminants
- WHP: Wellhead Protection
- WHPA: Wellhead Protection Area
- ZOC: Zone of Contribution
- ZOI: Zone of Influence
1.0 Introduction

In this section the general background information regarding the wellhead protection program (WHP), the Brown County Rural Water Association (BCRWA) wellfield, the wellhead protection area delineation, and the approach to the potential pollution source inventory (PPSI) are presented.

1.1 Background

It is estimated that Ohio uses approximately one billion gallons of groundwater every day. Approximately 700,000 rural households depend on private wells for drinking water and about 85 percent of the State’s 1,480 community water system rely on groundwater for all or part of their water supply (OEPA, 1997). In addition, industry uses 350 million gallons per day, and agriculture uses about 10 million gallons per day for irrigation. The importance of managing groundwater resources was also recognized by the legislators on the national and the state level.

The 1986 Safe Drinking Water Act Amendments (SDWA) directed each state to develop a wellhead protection (WHP) program to protect public wells. A wellhead protection area (WHPA) is defined as (SDWA, Section 1428(e)):

"...the surface and subsurface area surrounding a water well or wellfield, supplying a public water system, through which contaminants are reasonably likely to move toward and reach such water well or wellfield."

The Ohio EPA (OEPA) supplemented the federal regulations with legislation promoting regional development of WHP plans. In May 1992, Ohio’s Wellhead Protection Program was approved by the USEPA. Although the Ohio General Assembly voted down mandatory WHP compliance, many of Ohio’s groundwater dependent communities are considering their approach to groundwater management. The costs and complexities associated with groundwater remediation make preventative measures offered by wellhead protection an attractive investment. A recent EPA report presented a cost-benefit analysis and concluded that cleanup of contaminated groundwater supplies may, on average, be thirty to forty times more costly than preventing the contamination in the first place (USEPA, 1996). Wellhead protection planning can help manage the risks associated with activities in or near wellfields and prevent degradation of groundwater resources.
The seven components of a wellhead protection plan are (OEPA, 1984):

1 - Delineate the wellhead protection area.
2 - Identify and locate potential sources of contamination.
3 - Identify appropriate protective strategies.
4 - Assess the need for groundwater monitoring, and, if so, develop a monitoring plan.
5 - Complete a contingency plan.
6 - Develop a public involvement/education program.
7 - Evaluate the need for new wells and take steps to secure and protect the future wellfield from contamination.

Ohio's Wellhead Protection Program requires that each public water system submit a Wellhead Protection Plan to Ohio EPA for a review. The Brown County Rural Water Association has already completed Step 1, Delineation of the Wellhead Protection Area (M.S. Beljin & Associates, 1998). This study focuses on Step 2, Potential Pollution Sources Inventory (PPSI).

1.2 Problem Description

The Brown County Rural Water Association (BCRWA) is situated between Higginsport and Ripley, Ohio, on the Ohio River. Figure 1 is the regional map of the southern portion of Ohio along the US 52. BCRWA is located about 40 miles east of Cincinnati and a few miles west of Ripley. The wellfields are located between US 52 and the Ohio River. Figure 2 is a portion of the U.S. Geological Survey topographic map of the Georgetown, Ohio quadrangle that shows the location of the water treatment plant.

Production water at BCRWA is chiefly a mix of three different water types: (1) ambient groundwater, (2) surface water (from the Ohio River), and (3) bedrock water. Each type has a representative water quality that can influence the raw water pumped at the plant. Realizing the contribution of each source-water type supports identification of the relative risk from potential pollutant sources.

In October 1997, it was discovered that the groundwater quality at the BCRWA's new wellfield has been affected by the man-made contaminant, carbon tetrachloride, at levels above the EPA’s drinking water standards. After measuring detectable levels of VOCs in two other wells in their
new wellfield, BCRWA has been faced with the costly cleanup of a portion of their drinking water supply. This occurrence coupled with the recent completion of both the delineation of the WHPA (M.S. Beljin & Associates, 1998a) and the hydrogeologic investigation of the carbon tetrachloride contamination (M.S. Beljin & Associates, 1998b), created an immediate interest in pursuing the next step of wellhead protection for future security of their portion of the Ohio River Aquifer System.

BCRWA has delineated the wellhead protection area (WHPA) using the preferred time of travel (TOT) criterion set forth by the EPA. The TOT criterion is a particle-tracking scheme that is used in the actual delineation of the WHPA. Calculated advective velocities from the flow model can be traced backward in time through the migration of particles until the user-defined TOT is reached (i.e., 5-year simulation). Connecting the endpoints of these streamlines delineates the capture zone for the particular time constraint, defining the WHPA (Figure 3). Potential pollution source identification will concentrate principally on this area and its immediate surroundings.

1.3 Objectives
The main objective of the Potential Pollution Source Inventory (PPSI) is "to identify any past, present, and proposed activities and land uses in and around the wellfield protection area that may pose a threat to ground water supplying the public water wells or wellfields" (OEPA, 1997).

Identifying potential pollution sources and educating local officials and community about those threats helps to gain support for the Wellhead Protection Plan. The information collected during a PPSI is important for development of an effective groundwater management plan.

1.4 Scope
In order to achieve the objectives outlined above, a series of tasks are required. They include:

- Review literature of previous studies and relevant data sources.
- Conduct visual surveys.
- Conduct personal interviews.
- Develop an inventory database of potential pollution sources.
- Prepare a map and table showing recorded PPSI data.
- Write report.
1.5 Report Organization

The remainder of this technical report is organized as follows:

- Section 2.0 is a description of data sources and methodology used in the report.
- Section 3.0 describes the potential sources of groundwater pollution.
- Section 4.0 provides conclusions and recommendations, and
- Section 5.0 contains references.
- Appendix: Photos.
2.0 Data Sources and Methodology

In this section the sources of information and the methodology used in identifying potential pollution sources are documented. The area surveyed includes the delineated WHPA and the immediate vicinity.

2.1 Database Search

Over twenty electronic and project databases have been searched for information regarding potential pollution sources at the regulated sites near the Brown County Rural Water Association (BCRWA). The following databases have been reviewed:

- Ohio EPA’s Office of Federal Facilities Oversight (OFFO);
- Ohio EPA’s Division of Emergency and Remedial Response (DERR);
- Ohio EPA’s Division of Solid and Infectious Waste Management (DSIWM);
- Ohio EPA's Division of Hazardous Waste Management (DHWM);
- Ohio EPA's Division of Surface Water (DSW);
- Ohio EPA's Division Drinking and Groundwater (DDGW);
- ODNR Division of Oil and Gas;
- ODNR Division of Geological Survey;
- ODNR Division of Reclamation;
- ODNR Division of Water;
- ODOC, Bureau of Underground Storage Tank Regulations (BUSTR)
- CERCLIS Superfund System;
- Federal Facility Information System (FFIS);
- PCB Activity Data System (PADS);
- Resource Conservation and Recovery Information System (RCRIS);
- Safe Drinking Water Information System (SDWIS);
- State Environmental Programs (STATE);
- Underground Injection Control (UIC);
- Enforcement Docket System (DOCKET);
- Permit Compliance System (PCS); and
- Toxics Release Inventory System (TRIS).
Ohio EPA's Office of Federal Facilities Oversight (OFFO) maintains a searchable database on the Internet that contains information on the environmental cleanup of federal facilities in Ohio. There are no sites located within Brown County.

Ohio EPA's Division of Emergency and Remedial Response (DERR) Master Sites List (MSL) and database includes three sites in Brown County: (1) Aberdeen Wellfield (850 US 52, Aberdeen), (2) Village of Ripley Wellfield (229 Water Works Road, Ripley), and (3) Rumpke Brown County Landfill (aka Bradford) (4348 Sunshine Road, Georgetown, Georgetown). These sites are all located outside the WHPA and are only of minor concern because of the distance from the wellfield.

Ohio EPA's Division of Solid and Infectious Waste Management (DSIWM) 1998 Facilities List contains only one site within Brown County, Rumpke Brown County Sanitary Landfill (north of Georgetown, Ohio). Although the site is active, it is located nearly 10 miles from the Ohio River far from the wellfield and the WHPA. The DSIWM also maintains a database of registered composting facilities. There are five composting facilities in the county, all of which are located outside of a 10-mile radius of the BCRWA.

Ohio EPA's Division of Hazardous Waste Management (DHWM) database contains the RCRA Notifiers List (a list of all RCRA Subtitle C waste handlers in Ohio). Of approximately 25 hazardous waste registered handlers in Brown County, none are located within the WHPA or within a five-mile radius of the Brown County Rural Water Association. The DHWM is the agency that permits Transportation, Storage, and Disposal (TSD) facilities. Currently, there are no TSD facilities in Brown County.

The OEPA's DSW provides a database that includes point source and nonpoint source information along with water quality for the watershed in question. The BCRWA is located in Watershed Group 47 (Lower Scioto River – Eagle & Straight Creeks). Point source information for the county is also searchable in the USEPA's PCS database.

The Ohio Department of Commerce (ODC) maintains a database on underground storage tanks under the Bureau of Underground Storage Tank Removal (BUSTR). Upon reviewing files, no underground storage tanks were found within the WHPA or immediate vicinity.
The USEPA's CERCLIS Superfund System contains information on all aspects of hazardous waste sites including an inventory of sites, planned and actual site activities, and financial information. The lone CERCLIS facility is the Rumpke Brown County Sanitary Landfill located north of Georgetown, Ohio, over 10 miles from the BCRWA.

The USEPA's PADS database contains generator, storer, transporter and permitted disposers under the Toxic Substances Control Act (TSCA). No such facilities exist in Brown County.

The USEPA's RCRIS is a database that tracts events and activities related to facilities which generate, transport, and treat, store or dispose of hazardous waste. It also provides information regarding notifications, permits, compliance, and corrective action activities required under the Resource Conservation and Recovery Act (RCRA). There are 19 facilities in Brown County, Ohio. A five-mile radius around the BCRWA is free of any such facilities.

The USEPA's SDWIS databases contain information about public water systems and their violations of EPA's regulations for safe drinking water. These statutes and accompanying regulations establish maximum contaminant levels (MCLs), treatment techniques, and monitoring and reporting requirements to ensure that water provided to customers is safe for human consumption. No facilities were returned in a search of these databases.

The STATE database is a federal database that shows if a particular facility is regulated by a state environmental program which may monitor air quality, waste water, drinking water, storage tanks, permits, and emergency response. No such facilities were displayed for a query of Brown County.

The USEPA's UIC program works with State and local governments to regulate injection wells in order to prevent them from contaminating drinking water resources. Currently, there are no such facilities in Brown County.

The USEPA's DOCKET database tracks civil judicial cases against environmental polluters. There are no such cases brought against any facility within a 10-mile radius of BCRWA at this time.
The USEPA's PCS database contains data on National Pollutant Discharge Elimination System (NPDES) permit holding facilities. PCS tracks permit, compliance, and enforcement states of NPDES facilities. According to the PCS database, there are 14 NPDES permitted facilities within Brown County. The Village of Ripley and the Village of Aberdeen, which are located upgradient of the BCRWA, both are permitted to discharge certain contaminated wastes to the Ohio River. Five miles east of Aberdeen is the Dayton Power & Light Company, which also discharges various contaminated wastes. All three contributors are in currently in compliance with their permits.

The USEPA's SSTs database tracks the registration of all pesticide-producing establishments and tracks annually the types and amounts of pesticides, active ingredients, and devices that are produced, sold, or distributed in each year. Pesticide application is a common practice in Brown County. There are three such facilities in Brown County, Ohio, two of which are located just north of the BCRWA in Georgetown.

The TRIS is a federal database that contains information from facilities on the amounts of over 300 listed toxic chemicals that the facilities release directly to the air, water, land, or that are transported off-site. A search of this database returned five facilities within Brown County: (1) Cincinnati Milacron, Mt. Orab, Ohio; (2) Mac Tools, Georgetown, Ohio; (3) Pepsi-Cola Bottling Company, Ripley, Ohio; (4) Trinity Industries, Mt. Orab, Ohio; and (5) U.S. Shoe Corporation, Ripley, Ohio. According to the database, U.S. Shoe transports 666 lbs/yr of acetone and 1100 lbs/yr of toluene along US 52 to Environmental Enterprises in Cincinnati. No toxic chemicals were reported as being released to the land surface, to the underground, or to the surface water.

2.2 Historical Aspect of Land Use

The Brown County provided two sources of information, one regarding past, present and future land and a zoning ordinance document. In addition to the current land use zoning, these documents provide information regarding flood zones as well as future land use patterns within the WHPA. With respect to wellfield management, BCRWA has eliminated industrial land uses within the WHPA in their future land use plans.
2.3 Visual Survey

The main objective of the Potential Pollution Source Inventory (PPSI) is "to identify any past, present, and proposed activities and land uses in and around the wellfield protection area that may pose a threat to ground water supplying the public water wells or wellfields" (OEPA, 1997).

As part of PPSI, a visual survey was conducted from January through March 1999. The visual survey included driving and walking around the WHPA and the surrounding area. Visual surveys are used to confirm the locations of previously identified potential pollution sources and to observe any new potential pollution sources and land uses. The located sources were placed on a basemap. During the visual survey, photographs were taken of the sites identified as potential pollution sources. The map and the photographs are presented in the appendix. A visual survey was also conducted along the banks of the Ohio River.

2.4 Mail Survey

Another method for obtaining potential pollution sources is a mail survey. The survey provides information on the type of facility, the period of operation, the presence of storage tanks, the types of chemicals used, and any type of releases that occurred at the site. However, because the wellfield is isolated from any residential areas, mail survey was not conducted.

2.5 Site Visits and Personal Interviews

In the early 1990s, Ms. Mary Ann Lucas of BCRWA conducted a door-to-door survey of 36 residential homes located between the Whitewater Creek and the Straight Creek (personal comm., Lucas, 1999). This survey was conducted in the response to the OEPA wellhead protection program. Ms. Lucas was unable to identify any significant potential pollutant sources in the area.

In addition, the personnel of the BCRWA were interviewed. Del Pullins, the general manager of BCRWA, recalled a fuel tank that was transported with the distribution section of BCRWA in 1994 from Georgetown to the current facilities on Route 52. The underground fuel tank in Georgetown served as a surface-mounted tank that is currently in use today at the service garage north of Route 52. In 1996, the move of the tank was addressed with the OEPA, and at that time no problems were noted or concerns addressed regarding the move. Brian Heaton, the BCRWA facility maintenance, suggested that the surface water collection system for Route 52 is a potential pollutant source. In an attempt to deal with the runoff problem, the Ohio Department of
Transportation (ODOT) approved a design for a storm water sewer network that would carry runoff to the wellfield. According to Mr. Heaton, an insufficient grade along Route 52 prompted BCRWA to redirect the runoff onto their property. Ken Shearwood, the plant superintendent, indicated that the company's sanitary sewer network is tied into a leach field just north of Route 52 across from the main office building.

2.6 Other Sources of Information

The other sources of information were past newspaper articles in the Cincinnati Enquirer and trips to the Ripley Library. Residents of Ripley were also informally interviewed.
3.0 Potential Pollution Source Inventory

This chapter describes past and present potential pollution sources within and adjacent to the BCRWA's WHPA that may pose a threat to groundwater.

3.1 Previous Studies

In 1996, BCRWA hired Layne-Ohio, Inc., Columbus, Ohio, to drill and install six additional production wells. These wells are located northwest of the existing wellfield (Figure 3). After the wells were completed, water samples were tested for organic and inorganic constituents. The analytical results of the September 3, 1996 sample from W-1 showed that all volatile organic compounds (VOCs) were below detection limits. The October 8, 1996 sample from W-2 showed low level concentrations of carbon tetrachloride (1.6 ug/L) and chloroform (1.3 ug/L). The September 5, 1996 sample from W-3 showed a low-level concentration of carbon tetrachloride (1.2 ug/L) and no chloroform. These three production wells were added to the rotation of the wells in the old wellfield. New wells W-5 and W-6 were sampled upon completion on October 21, 1997. The analytical results showed that both wells contained carbon tetrachloride, 4.0 ug/L (W-5) and 7.7 ug/L (W-6). The results of the November 6, 1997 sample from W-4 showed no detectable VOCs.

The maximum concentration level (MCL) for carbon tetrachloride is 5 ug/L. Because the laboratory analyses of the water samples from the new wellfield showed one exceedance of the MCL for carbon tetrachloride, the wells were resampled several times in 1998. Production wells W-1, W-3, and W-4 sampled in 1998 showed no detectable contaminants in any of the sampling events. Well W-2 showed low level concentrations of carbon tetrachloride (less than the MCL); and wells W-5 and W-6 showed carbon tetrachloride concentrations that exceeded the MCL of 5 ug/L. After confirming the presence of carbon tetrachloride, BCRWA decided to coordinate a site investigation with the Ohio Environmental Protection Agency (OEPA).

The field investigation was conducted using the state-of-art technology. Water and soil samples were obtained from boreholes drilled using the GeoProbe™ technique. The samples were analyzed at the site in a mobile laboratory. Activities related to the preparation of the field lab were performed on July 20, 1998, and the actual site investigation was conducted on July 21, 22, and 23, 1998.
After evaluation of the results, it was clear that only "shallow" samples showed some contamination. From that point on, it was decided to take water samples only from the shallow aquifer zone. Figure 5 summarizes the results of the chemical analyses of carbon tetrachloride (CCl₄) at the site. Production wells W-1 and W-4 have never shown carbon tetrachloride concentration levels above detection limits (0.5 ug/L). Well W-3 has been sampled five times; only the first sample, taken just after completion, showed any contamination (1.2 ug/L). The MCL for carbon tetrachloride (CCl₄) is 5 ug/L.

Well W-5 shows carbon tetrachloride concentrations that range from 4.0 - 31.8 ug/L. During the site investigation, the concentration levels decreased from 31.8 ug/L measured on July 21, 1998 to 14.6 ug/L measured on July 23, 1998. The concentration in Well W-6 also decreased during the site investigation. The concentration levels decreased from 7.2 ug/L measured on July 21, 1998 to 3.1 ug/L measured on July 23, 1998. These fluctuations could possibly be explained by purging of the wells during the investigation period.

Based on the preliminary analysis of the potential sources of the groundwater contamination, one potential source also considered was the neighbor's farm, just northwest of the site (Figure 6). One domestic well, screened at approximately the same depth as the new production wells, was identified on the farm. A water sample was collected from the well on June 12, 1998 along with samples from the six production wells in the new wellfield. The water sample collected from the domestic well had no detectable concentration of carbon tetrachloride or any other organic constituents.

Six soil samples were also taken at the three different locations and they were found to be free of any organic contaminants.

Based on the literature research and the field investigation conducted by M.S. Beljin & Associates and the OEPA, the following conclusions were made (M.S. Beljin & Assoc., 1998a,b):

- No contaminants were found in the sample collected off site (from a domestic well).
- No contaminants were found in the soil samples.
The only contaminant of concern (COC) at the site is carbon tetrachloride.

There are two distinct carbon tetrachloride plumes at the site: in the vicinity of wells W-5 ("W-5 Plume") and W-6 ("W-6 Plume").

The maximum measured concentration is 64.1 ug/L (GP-12), located 30 feet downgradient of well W-5, within W-5 Plume. The second plume, W-6 Plume, is relatively smaller in size and with lower carbon tetrachloride concentration than W-5 Plume. The plume is also of less concern because the last carbon tetrachloride concentration of the water sample from W-6 was 3.1 ug/L, less than the MCL (5.0 ug/L).

The approximate length of the W-5 plume is less than 100 feet; the approximate length of the W-6 Plume is less than 50 feet.

No pollutant source was identified as a result of the site investigation. However, it was noted by members of BCRWA that there was an uncontrolled spill of hydraulic fluids from the drilling rig in operations near wells W-5 and W-6 in October 1997. This potential pollution source was discussed at a meeting of BCRWA, M.S. Beljin & Associates, and the OEPA on February 5, 1999. At the meeting, Rich Bendula and Dan Cloyd of the OEPA mentioned the discovery of carbon tetrachloride at another site where the drilling processes are suspected sources of the contamination.

### 3.2 Land Use

Historically, the majority of land within BCRWA's WHPA has been used for rural farming of cash crops like tobacco and grain. While operating out of Georgetown, Ohio, BCRWA purchased its first piece of land within their current WHPA on October 29, 1983 (personal comm., Worthington, 1998). This 56.4-acre split of the Neu property comprised the area occupied by the old wellfield. On March 6, 1984, BCRWA added a 1.75-acre plot of land that was used to house the old chlorination building, which is no longer in use (Figure ??). In July 1990, BCRWA continued their acquisition plan to secure the land surrounding their wells by adding two more pieces of the Neu property totaling 33 acres that were used for farming, grazing, and mining of sand (personal comm., Worthington, 1998). Apparently, sand was excavated from a pit located along U.S. 52 (Figure ??) and sold to Dravo, Inc. (personal comm., Worthington, 1998). The open pit sand mine was immediately filled and leveled to conform to the land-use supported by
BCRWA (personal comm., Heaton, 1999). A couple years later, BCRWA became interested in constructing a new treatment plant along the Ohio River and purchased nearly 20 acres of farmland from Gwendolyn Cochrane for the proposed project on October 19, 1992. On October 27, 1993, BCRWA acquired the Doug Andrews farm, which makes up the eastern most portion of their property today. These 93.75 acres of farmland extend north and south of U.S. 52 bordering both Straight Creek and the Ohio River. Miscellaneous plots of farmland not owned by BCRWA are scattered throughout the WHPA (PHOTOS 12, 18 and 19, pages A-6 and A10). BCRWA is currently in negotiations with these landowners to buy the surrounding land within the WHPA in order to protect their water resources.

Fertilizer application and fumigation processes are noted as potential pollution sources within these old farmland areas. It is recognized that septic systems accompany the scattered residences within the WHPA, which are potential sources as well. Although any land use can present certain pollution risk, BCRWA’s WHPA has been isolated from the most undesirable land uses such as industrial or mobile home parks.

Wetlands occupy much of the WHPA (Figure 3; PHOTO 16, page A-8) which are ideal from a land-use management perspective for wellhead protection. In recent years, BCRWA has been purchasing property adjacent to their operation and upgrading their land uses to conform to the surroundings.

The most recent land acquisition included the property just east of the treatment plant (Figure 3; PHOTO 13, page A-8). BCRWA hired a drilling contractor to immediately plug and properly abandon the domestic water well located on the property using the OEPA protocol.

Much of the WHPA is paved with asphalt roadways and parking lots, which not only receive salts for deicing purposes but they also permit transportation of potential contaminants. Although there have not been any reported spills within the WHPA, the potential does exist under its current land use.

### 3.3 Potential Pollution Sources

Potential pollution sources were categorized based on the Ohio EPA guidance document (OEPA, 1997). It should be re-emphasized that the listed sources are only potential pollution sources and
they may or may not cause groundwater contamination. A visual survey of these potential sources was conducted to assess the current condition and risk potential of the operation. Photographs and the accompanying text presented below document the findings. Potential pollution sources are designated by a key number (Key #) that corresponds to its listing in Table 1.

3.3.1 Residential Sources
Within the BCRWA's WHPA and its vicinity there are scattered residential houses. The households were not surveyed for any particular hazardous chemicals, but it is expected that the households have a number of chemicals that may be potential sources of groundwater contamination.

Common Household Maintenance
The household maintenance products can be divided into three categories:

1. household products (drain cleaners, disinfectants, metal polishes, stain removers, etc.);
2. paints (varnishes, stains, dyes, wood preservatives, etc.); and
3. mechanical repairs (brake fluids, kerosene, automotive wastes, metal degreasers, etc.).

The Sturm farm residence (PHOTOS 18 through 21, Key #2 and 3, pages A-10 and A-11), which is adjacent to the western side of the BCRWA property, once ran a bait shop business in the abandoned building next to the house. Old farm equipment, two refrigerators, a gasoline tank, an air conditioner, a helium tank and a water tank were some of the potential sources observed from the BCRWA property on April 13, 1998. At the time of this report, there is speculation that Sturm will sell the property for residential development (Worthington, personal comm., 1999). BCRWA is interested in obtaining the land for wellhead protection.

3.3.2 Institutional Sources
Several institutional sources exist within the WHPA related to the operations of BCRWA. A visual survey was conducted to assess the current condition and risk potential of BCRWA's operations. Photographs and the accompanying text presented below document the findings.

Maintenance Building
North of U.S. Route 52, BCRWA operates a maintenance building for the company's vehicles (PHOTOS 6 and 9, Key #4, pages A-3 and A-5). As with any garage, the building serves as a solvent storage area and a repair shop. Potential contaminants include hydraulic oils, greases, and other solvents associated with mechanical operations. At the time of the inspection, there were no
observed spills and it was apparent that operations were controlled responsibly. A refueling station (PHOTO 7, Key #5, page A-4) also sits on the north side of the maintenance building. The above-ground storage tank is properly protected with guardrails to minimize an accidental release (PHOTO 7, Key #5, page A-4). It is recommended that the operations at the maintenance building be monitored and inspected on a systematic basis to ensure protection of BCRWA’s water resources.

**BCRWA Press Building**

The BCRWA press building is located south of the water treatment plant and houses two vehicles used for the land application of lime and maintenance of the BCRWA property (PHOTO 13, Key #6, page A-7). This press building is not used to the extent of the maintenance building on the north side of U.S. Route 52 and should not be viewed as a high-risk potential pollution source. It is recommended that the existing protection measures by BCRWA include routine inspections.

**Access Roads and U.S. 52**

Some of the WHPA is paved with asphalt roadways and parking lots which permit access to the BCRWA’s facilities (PHOTOS 2, 5, 8, 14, 15, and 22, Keys #1 and 7, pages A-1, A-4, A-7, A-8, A-10, and A-12). ODOT maintains U.S. Route 52, which runs through the WHPA. ODOT applies salts for deicing purposes and potentially herbicides to control vegetative growth around these areas. Both U.S. Route 52 and the access roads on BCRWA property also serve as transportation routes for potential contaminants into the WHPA. Application of herbicides and deicing products are to be discouraged. It is also recommended that travelers and transporters along U.S. Route 52 are notified when they enter/leave the WHPA. Installation of a guardrail along U.S. Route 52 should be considered, which would minimize potential releases to BCRWA’s wellfield.

The storm water collection system along U.S. Route 52 is also a potential pollution source. As currently designed, runoff along U.S. Route 52 in front of BCRWA property is channeled and discharged from an outlet pipe into the new wellfield (PHOTOS 23 and 24, Key #8, page A-13). Any spill along the highway would pipe the contamination towards BCRWA’s wells. There is no documentation that a spill has ever occurred along this portion of U.S. Route 52. However, it is recommended that BCRWA develop a contingency plan in the event of such a release.
Land Application of Lime

BCRWA has a practice of using available land for the application of lime sludge (PHOTO 9, Key #9, page A-5). The lime sludge generated in the water treatment process at BCRWA is principally a source of calcium and magnesium, which do not pose a significant health risk if leached. Given the current land application, continued operation is acceptable with respect to WHP.

BCRWA Wastewater Disposal System

The sanitary sewer system at BCRWA is comprised of grinders at both the treatment plant and the administrative building, pressurized sewer lines, a septic holding tank, and leach lines. The leach field that handles all of BCRWA’s sewage is located north of U.S. Route 52, across from the BCRWA entrance (PHOTO 4, Key #10, page A-2). Septic fields are known to leach constituents like nitrate and phosphorus. It should be noted that any waste waters or contaminants flushed have the potential to reach the groundwater beneath the leach field. It is therefore recommended that BCRWA implement a warning system to control the discharge of potential contaminants.

Miscellaneous Sources

Stockpiles of uncovered waterlines, fittings, and utility covers can be seen in PHOTO 8 (Key #11, page A-4). Also, there is a building that houses a generator that is located in the new wellfield (PHOTO 15, Key #12, page A-8). This structure is designed with a secure double-walled dike system to prevent the movement of possible spills. The old chlorination building across from the BCRWA entrance is not used and there is a plan to remove the building (PHOTO 3, Key #13, page A-2). These sources are low-risk but could be incorporated with the proposed inspection program of BCRWA PPS facilities.

3.3.3 Commercial Sources

This section details the activities of commercial operations that lie within the WHPA.

The Ohio River

The Ohio River is used for barge transportation of commercial goods (PHOTO 11, Key #14, page A-6). During the delineation phase of wellhead protection, it was recognized that the old wellfield at BCRWA induces surface water infiltration from the Ohio River. Therefore, any contaminant releases to the Ohio River have the potential to affect the raw water quality at BCRWA. Periodically in the past, releases have been reported. It is recommended that BCRWA contact
relevant authorities and request notification of any spill events. It is also suggested that BCRWA develop a contingency plan when contamination does occur, which may include a temporary shut down of wells pumping from the old wellfield, near the river.

3.3.4 Industrial Processes
The industrial processes known to occur within the WHPA are limited to the institutional sources controlled by BCRWA, detailed in section 3.3.2.

3.3.5 Miscellaneous Sources
Miscellaneous sources of potential contamination are presented in this section.

Abandoned or Open Wells
Although there is no knowledge of any abandoned or open water wells, it is listed as a potential pollution source because domestic wells are conduits for direct communication with the aquifer. Any contaminants inadvertently dumped into these “holes” would quickly reach BCRWA’s water resources. It is recommended that as BCRWA continues to purchase surrounding land that they properly plug and abandon any existing wells in accordance with state requirements.

It is also suggested that the trimmie pipes located next to each production well in the new wellfield be provided with locks.

3.4 Summary
The complete list of all potential pollution sources is summarized in Table 1. The table also contains a relative ranking of potential pollution source (PPS) impact on the groundwater (column PPS Impact in Table 1). There is no standard procedure for ranking the potential pollution sources. In this study, the following criteria were used in assessing the impact: hydrogeologic setting beneath the facility, location from the wells (distance and direction), the chemical characteristics, physical integrity of the storage facilities, the quantity of chemicals, and operational characteristics (frequency and manner of chemical application). Based on these characteristics, all potential pollution sources were characterized into three categories: high, medium, and low.
4.0 Conclusions and Recommendations

The survey and analysis of the potential pollution sources has lead to several conclusions and a list of recommendations. It is important to recognize that the list of activities and potential sources that could lead to groundwater contamination can never be complete. Old pollution sources and past unreported contaminant releases could be a problem for the BCRWA wellfields. Educating the public of the importance of the groundwater resource for the future of the region is the best pollution prevention measure.

4.1 Conclusions

After completing the inventory of potential pollution sources (PPS) within wellhead protection area (WHPA) and in the vicinity of WHPA, the following conclusions were made:

- There are 15 potential pollution sources within the WHPA. Some of the listed sources are not presently active (e.g., the old chlorination building).

- Out of fifteen (15) PPSs six (6) ranked as potentially "high impact" sources, all within the WHPA. The Ohio River itself is a potential pollution source as the river water can be affected by any other pollution sources upgradient from the wellfields. Some of the "high impact" sources belong to BCRWA (e.g., the maintenance building) and the source control should be easily implemented.

- There are 2 "medium impact" sources and 7 "low impact" sources within the WHPA. Most of the "low impact" sources are not likely to ever become pollution sources of groundwater resources. The land use around the wellfields is overall appropriate. BCRWA's future land use plan eliminates industrial zoning from within the WHPA, which is compatible to the program.
4.2 Recommendations

Because Brown County is relatively undeveloped, BCRWA is in a unique position to prevent contamination of groundwater resources from any future development in the area. The following recommendations were made:

- BCRWA should continue to acquire lands for WHP.

- It is recommended that BCRWA correct the problems regarding trunnic pipes in the new wellfield immediately by providing them with locks.

- It is recommended that the operations at the maintenance building be monitored and inspected on a systematic basis to ensure protection of BCRWA's water resources.

- Installation of a guardrail along U.S. Route 52 should be considered, which would minimize potential risk of spills to BCRWA's wellfield. Because the storm sewer discharges within the new wellfield, it is recommended that BCRWA develop a contingency plan in the event of such a spill.

- It is recommended that BCRWA implement an early warning system to control the discharge of potential contaminants near high-risk pollution sources. This could include the installation of monitoring wells (this will be addressed in the next phase of WHP). Sources that are low-risk could be incorporated with the proposed inspection program of BCRWA PPS facilities.

- It is recommended that BCRWA be in contact with relevant authorities and request notification of any spill events on the Ohio River. It is also suggested that BCRWA develops a contingency plan when contamination does occur, which may include a temporary shut down of wells pumping from the old wellfield, near the river (this will also be addressed in the next phase of WHP).

- As BCRWA continues to purchase surrounding land, they should properly plug and abandon any existing wells in accordance with state requirements.
• BCRWA should post signs at the borders of the WHPA to notify drivers that they are entering/leaving a pollution sensitive area.

• Upon approval of the Potential Pollution Source Inventory (PPSI), BCRWA should pursue the next step of the WHP Program.
5.0 References


Figures
Figure 1. Location Map of Brown County Rural Water Association.
Figure 2. Site Location Map
Figure 5. Brown County Rural Water Association Site Investigation
Carbon Tetrachloride Concentrations (ug/l)

- Domestic Well: < 0.5 6/12/98
- W-6: < 0.5 7/22/98
- GP-4: < 0.5 7/22/98
- W-3: 27.4 7/22/98
- GP-5: > 35.5 7/23/98
- W-2: 1.68 12/03/98, 1.81 10/28/98, 3.8 7/23/98, 0.6 7/21/98, 4.56 6/12/98, 1.03 4/15/98, 1.6 10/2/96
- GP-7: < 0.5 7/23/98
- GP-8: < 0.5 7/23/98
- GP-9: 2.2 7/23/98
- GP-10: < 0.5 7/23/98
- W-4: < 0.5 7/22/98
- GP-11: < 0.5 7/23/98
- GP-12: < 0.5 7/23/98
- W-1: < 0.5 9/3/96
- W-1: < 0.5 12/03/98
- W-2: < 0.5 10/28/98
- W-2: < 0.5 7/23/98
- W-2: < 0.5 6/12/98
- W-2: < 0.5 4/15/98
Figure 6. BCRWA Wellhead Protection Program
Potential Pollution Source Inventory

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Denotes WhPA (10-Year TDT)
Numbers Represent PHOTO Numbers in Appendix A.

Map Prepared by M.S. DELJIN & ASSOCIATES
Tables
<table>
<thead>
<tr>
<th>Key #</th>
<th>Facility Name</th>
<th>Address</th>
<th>Land Use</th>
<th>Type of Activity</th>
<th>Pollutant Source</th>
<th>Location</th>
<th>Source of Info</th>
<th>PPS Impact</th>
<th>Comments</th>
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</thead>
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<tr>
<td>1</td>
<td>Ohio Department of Transportation</td>
<td>U.S. Route 52</td>
<td>Transportation</td>
<td>Transportation for Cargo Trucks</td>
<td>Debris, Herbicides, &amp; Spills</td>
<td>Within WHPA</td>
<td>Site Visit</td>
<td>High</td>
<td>No spills have been reported.</td>
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<td>U.S. Route 52</td>
<td>Agricultural</td>
<td>Farming</td>
<td>Fertilizers and Fumigants</td>
<td>Within WHPA</td>
<td>Site Visit</td>
<td>Medium</td>
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<td>3</td>
<td>Sturn Residence/Old Bell Shop</td>
<td>U.S. Route 52</td>
<td>Residential/Commercial</td>
<td>Septic System, Refueling Tank, Refrigerators</td>
<td>Nitrates (Septic), BTEX, and Refrigerants</td>
<td>Within WHPA</td>
<td>Site Visit</td>
<td>High</td>
<td>No spills have been reported.</td>
</tr>
<tr>
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<td>BCRWA</td>
<td>U.S. Route 52</td>
<td>Institutional/Industrial</td>
<td>Garage/Maintenance Building</td>
<td>Hydraulic oils, BTEX, Solvents</td>
<td>Within WHPA</td>
<td>Site Visit</td>
<td>High</td>
<td>Above-ground storage tank.</td>
</tr>
<tr>
<td>5</td>
<td>BCRWA</td>
<td>U.S. Route 52</td>
<td>Institutional/Industrial</td>
<td>Refueling Station</td>
<td>BTEX Compounds</td>
<td>Within WHPA</td>
<td>Site Visit</td>
<td>Medium</td>
<td>Principally used for vehicle storage.</td>
</tr>
<tr>
<td>6</td>
<td>BCRWA</td>
<td>U.S. Route 52</td>
<td>Institutional/Industrial</td>
<td>Press Building</td>
<td>Hydrocarbons, Solvents</td>
<td>Within WHPA</td>
<td>Site Visit</td>
<td>Low</td>
<td></td>
</tr>
<tr>
<td>7</td>
<td>BCRWA</td>
<td>U.S. Route 52</td>
<td>Institutional/Transportation</td>
<td>Access Roads Transferring to the Wetlands</td>
<td>Debris, Herbicides, &amp; Spills</td>
<td>Within WHPA</td>
<td>Site Visit</td>
<td>Low</td>
<td>No spills have been reported.</td>
</tr>
<tr>
<td>8</td>
<td>BCRWA</td>
<td>U.S. Route 52</td>
<td>Institutional/Industrial</td>
<td>U.S. Route 52 Storm Sewer System</td>
<td>Runoff Containing Metals and Solvents</td>
<td>Within WHPA</td>
<td>Site Visit</td>
<td>High</td>
<td></td>
</tr>
<tr>
<td>9</td>
<td>BCRWA</td>
<td>U.S. Route 52</td>
<td>Institutional/Industrial</td>
<td>Land Application and Impoundments of Lins</td>
<td>Metals (Calcium and Magnesium)</td>
<td>Within WHPA</td>
<td>Site Visit</td>
<td>Low</td>
<td>Spread/Excavated and filled with lime.</td>
</tr>
<tr>
<td>10</td>
<td>BCRWA</td>
<td>U.S. Route 52</td>
<td>Institutional/Industrial</td>
<td>Wastewater Disposal System</td>
<td>Nitrates (Septic), Wastewater Effluent</td>
<td>Within WHPA</td>
<td>Site Visit</td>
<td>High</td>
<td>Handles all BCRWA wastewater.</td>
</tr>
<tr>
<td>11</td>
<td>BCRWA</td>
<td>U.S. Route 52</td>
<td>Institutional/Industrial</td>
<td>Stockpiles - Waterline, Utility Cut Covers, Fittings</td>
<td>Metals</td>
<td>Within WHPA</td>
<td>Site Visit</td>
<td>Low</td>
<td></td>
</tr>
<tr>
<td>12</td>
<td>BCRWA</td>
<td>U.S. Route 52</td>
<td>Institutional/Industrial</td>
<td>Generator Building</td>
<td>Lubricating oil, Degreasers, Solvents</td>
<td>Within WHPA</td>
<td>Site Visit</td>
<td>Low</td>
<td>Double-walled containment system.</td>
</tr>
<tr>
<td>13</td>
<td>BCRWA</td>
<td>U.S. Route 52</td>
<td>Institutional/Industrial</td>
<td>Old Cheeseflakes Building</td>
<td>Not in Use</td>
<td>Within WHPA</td>
<td>Site Visit</td>
<td>N/A</td>
<td>Used as storage. It will be removed.</td>
</tr>
<tr>
<td>14</td>
<td>Ohio River</td>
<td>—</td>
<td>Transportation/Recreation</td>
<td>Wastewater Discharge/Spills/Runoff</td>
<td>Metals, VOCs, Pesticides, etc.</td>
<td>Within WHPA</td>
<td>Site Visit</td>
<td>High</td>
<td>All potential newpoint contamination.</td>
</tr>
<tr>
<td>15</td>
<td>BCRWA</td>
<td>U.S. Route 52</td>
<td>Institutional</td>
<td>Uncovered Trench, Pipes/Wells/Peazometers</td>
<td>Unlinked</td>
<td>Within WHPA</td>
<td>Site Visit</td>
<td>Low</td>
<td></td>
</tr>
</tbody>
</table>
Appendix

PHOTOS
PHOTO 1. Entrance to the Brown County Rural Water Association Treatment Plant.

PHOTO 2. U.S. Route 52
PHOTO 3. The Old Chlorination Building.

PHOTO 4. BCRWA Wastewater Disposal System.
PHOTO 5. Location of the Old, Open-Pit Sand Mine on the Former Neu Property.

PHOTO 6. BCRWA Maintenance Building and Garage.
PHOTO 7. Above-Ground Fuel Tank.

PHOTO 8. Waterline Stockpile Area.
PHOTO 9. Land Application of Lime (Foreground) and Maintenance Building (Background).

PHOTO 10. Maintenance Road.
PHOTO 11. The Ohio River.

PHOTO 13. BCRWA Press Building.

PHOTO 14. BCRWA Water Treatment Plant.
PHOTO 15. Generator Building and Air Sparging System at Well W-5.

PHOTO 16. Wetlands - South of the New Wellfield at BCRWA.
PHOTO 17. Land Application Trench for Well W-5 Purge Water.

PHOTO 19. Sturm Farm (Spring 1999).

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PHOTO 24. Profile of Storm Water Outlet Pipe Near the New Wellfield.