State College Borough Water Authority
State College, Pennsylvania

Source Water Protection Report

January 2007

N.A. Water Systems

STATE COLLEGE BOROUGH WATER AUTHORITY
STATE COLLEGE, PENNSYLVANIA

SOURCE WATER PROTECTION REPORT

JANUARY 2007

PREPARED BY:
DAVID A. YOXTHEIMER, P.G.

APPROVED BY:
ROBERT W. ANDERSON, C.P.G.

56002680

N.A. Water Systems

120 Radnor Road
State College, Pennsylvania 16801
tel 814 231 2170· fax 814 231 2174

Source Water Protection Report
Table of Contents

Page No.

Source Water Protection Report
Table of Contents

Page No.

Source Water Protection Report
Table of Contents

Acknowledgements

Max Gill and the great staff and board of directors at State College Borough Water Authority for their proactive commitment toward protection of the region's water resources. PaDEP for providing the Source Water Protection Grant to help fund this project. Bill Syrett of PSU's meteorological department for providing data. Spring Creek Watershed Community's Water Resource Monitoring Project personnel for use of their water level monitoring data for this project. Bob Crum and his staff at Centre Regional Planning Agency for the terrific summaries of land use and zoning of each wellfield. Acknowledgement is also due to Dr. Charles W. Downer, Research Hydraulic Engineer and lead developer of GSSHA, for his valuable advice and assistance with the model development effort.

List of Tables

List of Figures

List of Appendices (on CD)

State College Borough Water Authority
Source Water Protection Report
Section 1
Introduction

1.1 Purpose and Objectives

The purpose of this Source Water Protection Program for the State College Borough Water Authority (SCBWA) is to protect all of its drinking water sources to ensure the highest quality and most reliable water supply for its consumers. The SCBWA's Source Water Protection Program consists of both a Wellhead Protection Program for SCBWA Wellfields 2, 4, 5, 6, and 7, and a Watershed Protection Program for Wellfields 1 and 3 and the Shingletown Reservoir. The objectives of these programs are to characterize the contributing (recharge) area of each source, identify potential contaminant sources, and minimize or manage activities within those contribution areas that have the potential to degrade source water quality using best management practices. In addition, the characterization of the contributing area of each source and the conceptual and computer models will be valuable planning tools for assessing future land-use impacts to the region's invaluable water resources. The ultimate objective of these efforts is to provide long-term protection of the area's drinking water resources.

1.2 Background Information

It is expected that significant growth and development will continue to occur in the State College area with resultant land-use change and increased potential for water quality degradation. The wellhead and watershed protection programs contained herein are necessary to ensure that proper management techniques are utilized for long-term protection of the area's valuable water resources. The University Area Joint Authority's (UAJA) Beneficial Reuse Project is one example of a project that requires extensive understanding of the Slab Cabin Run watershed and source contribution areas to protect the area's water resources. The Slab Cabin Run watershed protection program characterizes the watershed so that the effects of significant projects, such as the Beneficial Reuse Project, can be assessed for water quality impacts, while the wellhead protection program assesses potential impacts to each SCBWA wellfield. In combination, the watershed and wellhead protection programs detailed in this report will provide the SCBWA with a comprehensive means to ensure the long-term protection of the area's water resources. The SCBWA Source Water Protection Program total cost was approximately $500,000 and was funded by a PaDEP Source Water Protection Grant totaling $250,000 with the SCBWA and UAJA providing the remaining funding.

1.2.1 Hydrogeologic Setting

The SCBWA Wellfields and Shingletown Reservoir are situated in Nittany Valley, in the Valley and Ridge physiographic province. Nittany Valley is underlain by folded and faulted carbonate bedrock bounded by Tussey Ridge to the southeast and Bald Eagle Ridge to the northwest. Waters entering the aquifer ultimately drain to Spring Creek and leave the basin through Milesburg Gap in Bald Eagle Ridge. The carbonate bedrock in Nittany Valley is characterized as karst terrain. Most of the water in the aquifer is stored and transmitted through dissolution openings representing an average one to two percent of the aquifer's volume, based on estimates of field specific yield by Giddings (1974). The dissolution openings exist due to the migration of slightly acidic waters through bedrock fractures. Carbon dioxide in groundwater forms a weak acid that dissolves calcite, which is a component of limestone and dolomite rock. Acidic groundwater moving through fractures and other spaces within the rock gradually alters small openings, creating large passages and networks of interconnected conduits. Most flow and passage enlargement takes place at or just below the water table, the level below where the ground is saturated with water. The dissolving of bedrock is characterized by both small features (e.g., fractures and fissures) and large features (e.g., caves, sinkholes, and underground streams). Typically the limestone is very dense and mostly impermeable, except where solution processes have enlarged the bedrock fractures. This explains why a well's yield at one location may be quite high (in excess of 1,000 gallons per minute), while another well's yield may be quite low (less than 5 gallons per minute).

The aquifers in Nittany Valley are anisotropic and heterogeneous, in that groundwater flows preferentially in certain directions due to geologic structure. Several factors combine to make the Nittany Valley Aquifer heterogeneous in the way it stores and transmits groundwater. Carbonate rocks having differing chemical compositions and geographic settings have different susceptibilities to dissolution resulting in different hydraulic characteristics. Bedding plane partings separate rock layers that parallel the valley, and can be inclined at various angles. The bedding plane partings are preferential dissolution features and therefore can become widened by solution processes and provide enhanced groundwater flow paths. In addition, nearly vertical zones of fracture concentration (visible as fracture traces on aerial photography) can provide avenues for significant groundwater flow. In some locations, faults have juxtaposed rock layers with different hydraulic properties and so created impediments of varying significance to flow. The same faults can have associated fracture zones that channel groundwater flow parallel to the faults.

The headwaters of Slab Cabin Run form in Tussey Mountain and enter Nittany Valley in the gap above Pine Grove Mills where flow continues northeast through Nittany Valley until Slab Cabin Run joins Spring Creek in Houserville. The study area of the upper Slab Cabin Run drainage basin is approximately 27 square miles. Several mountain tributaries (sinking and/or ephemeral) and numerous springs feed into Slab Cabin Run, which has a dynamic flow regime consisting of both losing and gaining stretches of flow. SCBWA Wellfields 1 and 3 are located in the upper Slab Cabin Run Basin as shown in Figure 1. Shingletown Reservoir is located in Shingletown Gap of Tussey Mountain, also shown in Figure 1. The reservoir is fed by Roaring Run, a tributary of Slab Cabin Run, which is fed by mountain springs and recharge that originates from the sandstones that form the ridges and the colluvium that blankets the mountain slopes. Roaring Run's flow decreases significantly during dry times of the year and typically sinks into Nittany Valley's carbonate bedrock floor as it exits Shingletown Gap. The SCBWA's other five wellfields (Wellfields 2, 4, 5, 6, and 7) are located within the Spring Creek watershed.

1.2.2 Water System Description

The SCBWA has a combined water supply system consisting of seven wellfields (Wellfields 1 though 7) and one reservoir (Shingletown Reservoir). Figure 1 is a regional map showing wellfield locations and Table 1 lists each of the wellfields, well construction information, their respective estimated sustainable yield, and the geologic formation tapped by each. The combined estimated yield of all wellfields is over 45 million gallons per day (MGD), however the SCBWA system is limited to a groundwater withdrawal of 9.1 MGD by the Susquehanna River Basin Commission (USFilter, 2002). The system's typical average daily demand is between 5 to 6 MGD. The SCBWA serves approximately 66,024 customers via 27,421 connections with a distribution area including all or parts of Benner Township, Borough of State College, College Township, Ferguson Township, Harris Township and Patton Township.

The Shingletown Reservoir is fed by Roaring Run and provides water (approximately 1.3 MGD) to the SCBWA distribution system after treatment by filtration. Roaring Run's flow at the reservoir typically decreases during the summer months and the wellfields are then used to supplement water-use demands. Wellfields 1 and 3 (a.k.a. Thomas and Harter Wellfields, respectively) are piped to the filtration plant for treatment prior to entry into the distribution system. The filtration plant uses direct filtration and has a permitted capacity of 4.3 MGD. The remaining wells are treated via disinfection and pumped into the distribution system.

1.2.3 Land Use and Zoning

According to land use studies conducted for the Centre County Planning Office and Centre Regional Planning Agency, current land-use designations within the Spring Creek watershed consist of agriculture (36%), forest/water (37%) and residential (10%), with the remaining land classified as a mixture of industrial, public, recreation, transportation, utilities, and vacant. Centre Regional Planning Agency personnel worked in collaboration with SCBWA steering committee members to create summaries of each wellfield that discuss the existing land use, zoning, relationship to the Centre Region Comprehensive Plan, land preservation, stormwater regulations, sewage disposal, water supply, development, and future challenges. These summary reports are included as Appendix A.

As mentioned in the previous section, the UAJA's Beneficial Reuse Project proposes to recharge up to an estimated 1.5 MGD of water in the upper Slab Cabin Run watershed. The Beneficial Reuse Project has completed the planning, design, and treatment facility construction phases. The initial phase to convey Beneficial Reuse water to the Centre Hills Country Club for irrigation is currently under construction. The Beneficial Reuse Project has obvious benefits to the region and the environment, however any impacts it may have on the Slab Cabin Run watershed will need to be assessed prior to implementation. The Upper Slab Cabin Run watershed has been characterized during this study to allow an assessment of the effects of significant projects, such as the Beneficial Reuse Project, which is discussed later in this report.

Karst regions are particularly sensitive to land use activities because surface contaminants can flow easily through sinkholes and rapidly through the aquifer, thus impacting groundwater supplies. Stormwater runoff can carry petrochemicals, domestic and industrial chemicals, trash, fertilizers, pesticides, herbicides, animal decay products, as well as sewage effluent, therefore potentially providing a substantial risk of contamination to the groundwater supply. In high-growth communities like State College, construction activities can destabilize the delicate equilibrium between the surface and underground components of karst geology, causing altered drainage patterns and sinkhole collapse. The clearing and stabilization of land for buildings and roads is a particularly serious threat to groundwater, therefore minimizing land-use impacts to water quality is a critical component of any source water protection plan.

1.2.4 Previous Related Studies

Wellhead protection studies were completed by Nittany Geoscience, Inc., for each of the SCBWA wellfields and are summarized in reports submitted to SCBWA in May 1992. Wellhead protection areas were delineated using calculated fixed radius, hybrid simplified variable shapes with hydrogeological mapping, and combined numerical and analytical modeling techniques using a one-year time-of-travel to delineate wellhead protection areas. The recommended PaDEP wellhead protection area delineation techniques have evolved since these studies were completed, however to the extent possible, information from these previous studies has been utilized to update the wellhead protection areas and create watershed and wellhead protection programs. In addition, certain aspects of Slab Cabin Run and Upper

Spring Creek have been studied and presented in several Penn State graduate student theses, and the United States Geological Survey published a conceptual groundwater model report for the entire Spring Creek Basin in June 2005. The wellhead and watershed protection areas in this report were delineated using the best available geologic information combined with state-of-the-art computer modeling technology to provide the SCBWA and its customers great utility in the future as a planning tool.

State College Borough Water Authority
Source Water Protection Report
Section 2
Upper Slab Cabin Run Watershed Protection Study

The ultimate goal of developing this comprehensive Watershed Protection Program for SCBWA is to protect each of the water sources (Shingletown Reservoir and Wellfields 1 and 3) contained in upper Slab Cabin Run. This has been achieved through characterization of the contribution area of each source and long-term management practices for activities and land-use changes within the contribution areas of each source that have the potential to degrade source water quality. The methods used for characterization of the contributing area, the results, and the prescribed recommendations for protecting the drinking water resources of upper Slab Cabin Run are described in this section.

2.1 Literature and Data Review

A comprehensive literature and data review was conducted to prevent duplication of effort from previous studies. The review included all available SCBWA reports including drilling, aquifer testing, and wellhead protection studies. In addition a literature search was conducted through The Pennsylvania State University library system for relevant theses and reports as well as N.A. Water Systems' collection of local geologic studies.

Available meteorological data from The Pennsylvania State University Department of Meteorology were obtained from Mr. Bill Syrett for use in the watershed and groundwater modeling effort. In addition, stream level and groundwater level data were obtained from the Spring Creek Watershed Community's Water Resources Monitoring Project's water level and stream level database, and were used in the watershed model.

The Centre County Planning Office provided the 2001 aerial photo-based GIS mapping coverage of Centre County for use in the study. Supplementary GIS data were collected via Global Positioning System mapping of all production and monitoring wells. In addition, each of the eleven stream gauges on Slab Cabin Run were GPS surveyed.

Geologic base mapping for the study area was digitized into GIS mapping using Dr. Richard Parizek's (Penn State Professor of Geosciences) unpublished 1982 geologic maps for the area. Available soils mapping was obtained from Penn State's

Department of Soils Science. The soils mapping data set was in a GIS format and imported for use for this study.

Existing water level data sets were incorporated into the study as necessary. The water level mapping from Todd Gidding's Ph.D. dissertation (Giddings, 1968) as well as the Susquehanna River Basin Commission's (SRBC) October 1994 Spring Creek Watershed Map (Taylor, 1997) was used as needed. A water level database from 60 wells monitoring as part of an on-going water level monitoring program funded by SCBWA was also used as historic water level data. All data collected for this Watershed Protection Program were then compiled and formatted as necessary for use in this report. Data used in the report are provided in appropriate appendices and in GIS format.

2.2 Water Level Surveys

The water level elevations in a total of 30 observation wells within the upper Slab Cabin Run Basin were monitored on a quarterly basis from September 2002 through December 2005. Figure 2 shows the location of each of the monitoring wells with data summarized in Appendix B. Additional discussion on the results of water level monitoring is provided in this report in Section 2.7-Conceptual Model.

2.3 Stream Gauging

A total of 11 stream gauging locations were installed on upper Slab Cabin Run during September 2002 to measure stream flow to create a flow-rating curve at each location. A Teledyne Gurley flow meter was used to measure flow at each location during the period of September 2002 through November 2005. During each stream flow measurement a staff gauge level reading was also recorded. In addition, the elevation of each staff gauge was GPS-surveyed so the stream level elevation could be used in relation to the measured flow on the stream-rating curve. Figure 2 shows the location of each stream gauge while Appendix C contains the stream flow rating curves for each stream gauge location. Additional discussion on the results of stream flow monitoring is provided in this report in Section 2.7-Conceptual Model.

2.4 Aquifer Testing

Pumping test data for SCBWA Wells 11 (Wellfield 1) and 25 (Wellfield 3) were collected in April 2003. Water levels were monitored in available observation wells during each test. The aquifer tests were conducted so as to minimize disruption to normal wellfield operation. The overall objectives were to use the aquifer testing data for calculating aquifer hydraulic properties, estimating the well capture zones to assist in calibrating the groundwater model, and for determining potential groundwater withdrawal impacts on Slab Cabin Run. A brief summary of the results for each pumping test is presented below.

Wellfield 1 Aquifer Testing - Well 11

Well 11, contained in Wellfield 1, is the well most frequently used well in this wellfield, and therefore was chosen for aquifer testing purposes to determine the typical drawdown in the aquifer from its use. The aquifer test of Well 11 commenced on April 15, 2003, and was pumped at a rate of approximately 1,400 gpm to the filtration plant for 48 hours. Prior to aquifer testing a round of static water levels was collected in all available wells and water levels were monitored in nearby available private wells. Appendix D summarizes the data and includes water level charts for each well. Well 11 had 3.86 feet of drawdown after 48 hours of pumping at 1,400 gpm. Nearby SCBWA Wells 7 and 8 had drawdown of 1.93 and 1.91 feet, respectively. The range of water level drawdown in private wells ranged from 0.09 feet (Wilson) to 1.03 feet (Antle), with six of the nine wells showing 0.10 or less feet of drawdown, indicating the relatively localized effects that pumping Well 11 has on the aquifer. It should be noted that Well 25 was in operation during the testing at a rate of approximately 1,500 gpm. As will be discussed in later sections, there is evidence that Well 11 receives a portion of its flow from Slab Cabin Run, therefore Wellfield 1's recharge area includes a more expansive surface water recharge area than pumping test data alone would indicate.

Wellfield 3 Aquifer Testing-Well 25

Well 25, located in Wellfield 3, is the well most frequently used in this wellfield, and therefore was chosen for aquifer testing purposes to determine the typical drawdown in the aquifer. The aquifer test of Well 25 commenced on April 1, 2003, and was pumped at a rate of approximately 1,400 gpm to the filtration plant for 48 hours. Prior to aquifer testing a round of static water levels was collected in all available wells and water levels were monitored in nearby available private wells. Appendix D summarizes the data and includes water level charts for each well. Well 25 had 3.23 feet of drawdown after 48 hours of pumping at 1,400 gpm. Nearby SCBWA Test Wells 26 and 27 had drawdown of 0.85 and 0.69 feet, respectively, while Well 22 exhibited 0.34 feet of drawdown. The range of water level drawdown in private wells ranged from 0.14 feet (Kliendorfer) to 0.67 feet (Krout), while four of the nine private wells had negligible or slight increases in water levels, indicating the relatively localized effects that pumping Well 25 has on the aquifer. The flow in Roaring Run, which is approximately 100 feet east of Well 25, was measured upstream and down stream of Well 25 near the end of the pumping test to assess any potential recharge from streambed infiltration. Roaring Run's flow was consistently at 975 gpm upstream from Well 25 and ranged from 680-785 gpm downstream, indicating that approximately 200-300 gpm of water was infiltrating through the streambed and likely recharging Well 25. It should be noted that Well 7 was in operation during the testing at a rate of approximately 700 gpm. As will be discussed in later sections, there is evidence that Well 25 receives a portion of its flow from Slab Cabin Run, therefore Wellfield 3's recharge area also encompasses a more expansive surface recharge area than pumping test data would indicate.

2.5 Geophysical Surveying

Electrical resistivity surveying was conducted near Wellfields 1 and 3 to characterize the subsurface conditions such as depth to bedrock, presence of voids and fractures, and depth to water. Standard resistivity arrays were used, including Wenner, dipole-dipole and Schlumberger arrays. The subsurface information was then used as a means to estimate the variation of the depth to bedrock near each wellfield for groundwater modeling purposes. Appendix E contains the Wellfields 1 and 3 resistivity array model results. The resistivity model results for Wellfield 1 were unfortunately affected by the presence of subsurface water lines, and therefore are not able to be used for geologic interpretation.

The resistivity model results for Wellfield 3 indicate the types of expected features within a karst terrain exist, including vertical fracture zones, and widely-varying depths to bedrock. The modeled subsurface resistivity range was from less than 1 ohm-m to greater than 1000 ohm-m, which is not suprising given that resistivity values can range widely when measuring features such as water-filled fractures, saturated clays, and carbonate bedrock. The features with resisitvity values on the lower end of the scale (blue to green in color) are most likely saturated silts and clays, while the features with higher resistivity values (orange to red) are interpreted to be bedrock.

2.6 Fracture Trace Analysis

The nature of groundwater flow and well yields within Nittany Valley can be greatly influenced by the presence of fracture traces. Fracture traces are natural linear features consisting of topographic (including straight stream segments), vegetation, or soil-tonal alignments that are visible primarily on aerial photographs and are less than 1 mile in length. Fracture traces also may be revealed by valley alignment changes, gaps in ridges, gulley development, aligned sinkholes and swallets, localized springs, and diffuse seepage areas (Parizek and others, 1971; Wood, 1980). These natural photolinear features are interpreted to be caused by vertical to subvertical zones of fracture concentration within the bedrock. Fracture traces for this Source Water Protection Study were mapped using two sets of black and white aerial photography flown in 1937 and 1983. Two experienced scientists carefully mapped fracture traces independently on each photo set using a stereoscope in a radius of approximately one mile for each wellfield, and then compared the fracture trace mapping results. The fracture traces that were commonly mapped by both scientists were then retained for fracture trace mapping purposes. Figure 3 shows fracture traces mapped as part of this study within the upper Slab Cabin Run Basin. Average yields of wells drilled on fracture traces are statistically higher than those drilled off fracture traces (Lattman and Parizek, 1964, Parizek and Drew, 1966, Siddiqui, 1969). The wells in SCBWA Wellfield 1 pre-dated the advent of the fracture trace analysis method, nonetheless, these wells appear to have intercepted significant water-bearing fractures given their high yields (in excess of 1,000 gpm). The wells contained in SCBWA Wellfield 3 were sited on fracture trace intersection sites and are also high-yielding wells.

2.7 Dye Tracing

A dye trace study was conducted during November 2005 through May 2006 on upper Slab Cabin Run. The objectives of the dye trace study included:

1. Determining the influence of groundwater withdrawal on Slab Cabin Run,
2. Determining the major zones of contribution (recharge area) of Wellfields 1 and 3,
3. Determining the travel time of dye through the aquifer system from various points, and
4. Determining appropriate locations for introduction of Beneficial Reuse water into the watershed to minimize potential impacts to Wellfields 1 and 3.

The methods and results of the dye tracing study are presented in the following sections.

2.7.1 Methods

The Crawford Hydrology Laboratory at Western Kentucky University was utilized for analysis of samples collected from monitoring points for the various dyes used in the project. The first step in the dye tracing study was to determine if any background concentrations of fluorescent dyes exist. The presence of background concentrations of each type of dye to be used at each monitoring location was assessed by collection of samples from each monitoring point approximately 2 weeks before initiation of the dye trace study. Activated charcoal receptors were placed in the flow at each monitoring point for approximately one week to verify the absence or presence of background dye concentrations. The receptors were analyzed prior to initiation of the dye trace study so that the presence of any background concentrations of dye could be verified prior to the dye trace test and the testing protocol could be modified if necessary.

The dye trace study was conducted once the background fluorescence results were determined to be satisfactory. A different type of dye was injected at each location so multiple dyes could be detected at each monitoring point and traced back to the associated source. The locations listed below were used in this study for injection of the dyes noted as shown in Figure 4:

1. Slab Cabin Run at Pine Grove Mills-Sulphorhodamine B (SRB) dye.
2. Musser Gap tributary stream at Route 45-Fluorescein dye.
3. Roaring Run below Shingletown Reservoir-Tinopal CBS-X (optical brightener).

These points were selected based on the known hydrology of the stream, the potential for dye interaction with the wellfields and monitoring points, and accessibility. The dyes used in this study (sulphorhodamine B, fluorescein, tinopal CBS-X) are among the most commonly used tracers and are safe for human and aquatic consumption at the concentrations to be used for this study. Five pounds of each dye was dissolved into five gallons of water and was directly poured into sinking streams (Slab Cabin Run and Roaring Run), and direct injection into ephemeral streams (Musser Gap tributary) followed by sufficient flushing (approximately 1000 gallons) for introduction into the watershed. Extreme caution was used to avoid any cross contamination of dyes at the different sampling points while also making sure that personnel who add the dyes do not come in contact with any sampling equipment.

The locations and sampling interval for dye detection at each monitoring point is summarized below with time related to dye injection time. In addition a brief rationale for selection of each monitoring point is provided.

- Spring pool behind Watkins Dariette on Route 26/45 - Samples for sulphorhodamine B were collected every four hours for 24 hours and daily thereafter until dye concentration had dissipated. This location was selected to verify that the sinking portion of Slab Cabin Run in Pine Grove Mills does re-emerge here to ultimately provide most of Slab Cabin Run's flow.
- Slab Cabin Run near former Ferguson Township wastewater treatment plant - Samples for sulphorhodamine B were collected every four hours for 24 hours and daily thereafter until dye concentration had dissipated. This location was selected to verify that the sinking portion of Slab Cabin Run in Pine Grove Mills and behind Watkins Dariette does ultimately provide most of Slab Cabin Run's flow.
- Destiny Farm Spring (at junction of Routes 26 and 45) - Samples for sulphorhodamine B were collected every two days for eight days and weekly until the dye concentration had dissipated. This location was selected to determine if this spring emanates from where Slab Cabin Run sinks in Pine Grove Mills or is the groundwater discharge point for the portion of the groundwater basin that extends southwest, beyond Slab Cabin Run's surface drainage. If no dye was

detected then it could be assumed that this water is from the extended groundwater basin, which does also provide significant perennial flow to Slab Cabin Run.

- Slab Cabin Run at Scott Road - Samples for sulphorhodamine B were collected every four hours for 24 hours and daily thereafter until dye concentration had dissipated. This location was selected to simulate the addition of Beneficial Reuse water to Slab Cabin Run via a wetland, which is proposed to occur in this general vicinity. Once Sulphorhodamine B was detected from this location, the travel time to down stream receptors could be estimated.
- Well 11 in SCBWA Wellfield 1 (Thomas Wellfield) - Samples for sulphorhodamine B, fluorescein, and tinopal CBS-X were collected daily until dye was detected and daily thereafter until dye concentrations had dissipated. This location was selected to determine the travel time to Wellfield 1 from each of the dye injection points to better define the recharge area.
- Wellfield 25 in SCBWA Wellfield 3 (Harter Wellfield) - Samples for sulphorhodamine B, fluorescein, and tinopal CBS-X were collected daily until dye was detected and daily thereafter until dye concentrations had dissipated. This location was selected to determine the travel time to Wellfield 3 from each of the dye injection points to better define the recharge area.
- Slab Cabin Run across from the SCBWA Building - Samples for sulphorhodamine B, fluorescein, and tinopal CBS-X were collected daily until dye was detected and daily thereafter until dye concentrations had dissipated. This location was selected to determine the travel time from injection points to Slab Cabin Run in the vicinity of the wellfields.
- Slab Cabin Run at Atherton Street - Samples for sulphorhodamine B, fluorescein, and tinopal CBS-X were collected daily until dye was detected and daily thereafter until dye concentrations had dissipated. This location was selected to determine the travel time from injection points to Slab Cabin Run and if groundwater baseflow input occurs.

In addition, samples were collected after the first significant rainfall that occurred once the dye concentration had significantly dissipated to determine if there was a spike in concentrations due to flushing of the aquifer system from rain.

2.7.2 Dye Trace Study Results

Sulphorhodamine B

Sulphorhodamine B had the most widespread occurrence of detections in the study, which was expected since it had been added to the uppermost portion of Slab Cabin Run. Figure 5 shows the concentration of sulphorhodamine B at each of the stream receptor locations in Slab Cabin Run and Figure 6 shows the concentration of sulphorhodamine B in Wells 11 and 25. Appendix F contains all of the dye trace data analytical results. Based on dye analytical results the following arrival times and estimated travel rates are provided for each location:

- Watkins Dariette: 20 hour dye arrival over a subsurface distance of 2600 feet (0.6 mi/day or 130 ft/hr),
- Slab Cabin Run near former Ferguson Twp. wastewater treatment plant: 24 hour dye arrival through combined subsurface and surface flow distance of 4,375 feet (0.83 mi/day or 182 ft/hr),
- Scott Road: 48 hour dye arrival primarily through surface flow distance of 7,900 feet (0.75 mi/day or 164 ft/hr),
- Slab Cabin Run across from SCBWA Building: 5-day dye arrival primarily through surface flow distance of 21,500 feet (0.81 mi/day or 180 ft/hr).
- SCBWA Wells 11 and 25 each had sulphorhodamine B detections after 5 days, indicating that the dye migrated to these wells at a rate similar to its arrival at Slab Cabin Run across from SCBWA Building.

The presence of sulphorhodamine B in Well's 11 and 25 indicates that both wellfields are under the influence of surface water from Slab Cabin Run. Well 25's maximum sulphorhodamine B concentrations were significantly higher than Well 11's (82 ppb/day compared to 1 ppb/day), suggesting that Well 25 has an enhanced surface connection to Slab Cabin Run during lower stream stages. The sulphorhodamine B travel time to Wellfields 1 and 3 from the proposed Beneficial Reuse recharge area near Rt. 26/45 junction is approximately 3 days based on the dye trace study results at this low stream stage. In addition, the dye trace results indicate the rapidity with which surface contaminants such as fuel or chemical spills, fertilizers, road salts, etc., can move through the aquifer into the drinking water supply. The dye also moved though the system quite rapidly, flushing out to negligible levels within approximately four weeks.

Fluorescein

Fluorescein was added to the Slab Cabin Run watershed via flushing six gallons of the dye into the dry streambed of Musser Gap with approximately 1,100 gallons of water. This dye arrived in Wells 11 and 25 between days 20 and 28 at similar concentrations (0.76 ppb/day and 0.56 ppb/day), but was detected in Slab Cabin after 13 days at a concentration of 1 ppb/day. The approximate travel rate of fluorescein to Slab Cabin Run in the vicinity of the wellfields was 675 ft/day via a combination of subsurface and surface flow. Figure 7 shows the fluorescein concentrations for Wells 11 and 25 and Slab Cabin Run. It is suspected that the fluorescein emanated from a series of springs on the Windy Hill Farm property, which flow directly to Slab Cabin Run. It is also possible that a portion of the fluorescein remained underground and was then intercepted by Wells 11 and 25, which could explain the delayed detection in these wells along with their similar dye concentrations. The travel rate of the fluorescein to Wells 11 and 25 is approximately 315 ft/day, assuming that it took 28 days to reach these wells.

Tinopal CBS-X

Tinopal CBS-X (a.k.a. optical brightener) was added to Roaring Run just upstream from where this stream typically sinks, approximately 1,800 feet upstream (south) from where Roaring Run crosses under Route 45. Roaring Run flows adjacent to Wellfield 3, therefore it was suspected that this dye would show up in Well 25 relatively rapidly. Surprisingly, the tinopal CBS-X did not show up in Well 25 until 128 days after it had been added to the watershed, for a calculated travel rate of 33 ft/day. Tinopal CBS-X concentrations in Well 25 had dissipated to background concentrations after 142 days, therefore took approximately two weeks to move through the aquifer in the vicinity of Well 25. Blue Spring in Boalsburg had low concentrations (0.55-0.65 ppb/day) of tinopal CBS-X after 84 days, for an estimated travel rate of 108 ft/day. Figure 8 shows the tinopal CBS-X concentrations for Well 25 and Blue Spring. Based on the known direction of bedrock strike and the aquifer’s strike parallel anisotropy, it is feasible that the tinopal CBS-X could have moved along bedrock strike to reach Blue Spring. Tinopal CBS-X does appear to have a detection lag time compared to other dyes, which could be attributed to it’s affinity to adsorb to the aquifer matrix based on personal communication with Adam Coffman, Lab Manager, Crawford Hydrology Lab. Therefore, some of the dye arrival delay could be attributed to this, however the dye arrivals are still relatively slow as compared to the travel rates of the other dyes. One complicating factor is the potential background concentrations of tinopal CBS-X, because it is found in many laundry detergents and therefore could originate from the on-lot septic systems that exist in the Shingletown/Roaring Run area and in the residential area upgradient from Blue Spring.

2.8 Conceptual Model of Upper Slab Cabin Run

A conceptual model on the upper Slab Cabin Run’s surface and groundwater flow was created to help develop a numerical watershed model. The conceptual model was based on interpretation of surface topography, geology, previous hydrogeologic studies, stream flow, and a karst feature inventory of the study area.

This section presents a summary of hydrogeologic information on the upper Slab Cabin Run Basin (Basin) to allow estimates of the available groundwater resources to protect the Basin's very valuable water resources. Future land-use changes may have a significant impact on Slab Cabin Run's stream flow and public water supply wellfields within the Basin. This section of the study attempts to estimate the available groundwater resources and identify the critical recharge areas within the Basin to minimize the impacts that changing land uses may have on water resources. A hydrogeologic conceptual model is then presented that provides an overview of the Basin's hydrologic and geologic characteristics.

2.8.1 Watershed Characteristics

Study Area Description

The upper Slab Cabin Run Basin surface drainage is an area approximately 15.8 mi^2 (10,100 acres), with a groundwater divide extending an estimated additional 11.5 mi^2 (7,360 acres) to the southwest as shown in Figure 9. Slab Cabin Run discharges into Spring Creek as a major tributary near Houserville. Spring Creek then drains into Bald Eagle Creek in Milesburg, before ultimately draining to the Susquehanna River and then to the Chesapeake Bay. Land use within the Basin is a mixture of agricultural and residential land use in the valley with forested mountain slopes. SCBWA Wellfields 1 and 3 provide approximately 50% (3 million gallons per day) of the area's water supply, therefore, protection of these very valuable water resources is of great regional importance. An innovative wastewater reuse project (Beneficial Reuse Project) is proposed to introduce up to 3.0 MGD of highly-treated municipal wastewater to the Basin, and is discussed in more detail in Section 2.16 of this report.

Meteorological Characteristics

Average annual precipitation for the State College area over the period of 1941 to 1994 is approximately 38 inches (Taylor, 1997) including 15 inches of runoff (with 12 inches of base runoff), and 23 inches of evapotranspiration. Average monthly rainfall amounts are spread out somewhat evenly on an annual basis over this same time period with a range of 2.36 to 3.90 inches per month. Most groundwater recharge typically occurs during the late fall, winter snowmelt, and spring rains. Little or no groundwater recharge typically occurs during the summer months due to increased runoff from higher intensity thunderstorm-related rains, increased transpiration from plant uptake, and evaporation from higher land surface temperatures. The average annual air temperature is 49.4°F with a mean high temperature in July of 71.7° F and a mean low temperature in January of 26.5° F (Pennsylvania State Climatologist, 2003).

Geologic Setting

Upper Slab Cabin Run Basin is located in the Valley and Ridge Physiographic Province of the Appalachian Mountains. Tussey Mountain bounds the basin to the southeast with a surface drainage divide occurring with the Spruce Creek Basin to the west as shown in Figure 9. Tussey Mountain is a double-breasted ridge formed by the underlying Bald Eagle Sandstone and Tuscarora Orthoquartzite with the Juniata Sandstone forming an intermontaine valley. The northwest-facing mountain slope is underlain by the Reedsville Shale and the valley floor is primarily underlain by the carbonate bedrock of the Trenton and Beekmantown groups. Figure 3 shows the bedrock geology of the Basin as mapped by Parizek (1982).

The Basin is underlain by 6,000 to 8,000 ft of interbedded limestone, dolomite, and minor sandstone of Cambrian and Ordovician age as contained in the geologic description later in this section. These strata were folded into anticlines and synclines of the Nittany Anticlinorium during the Alleghenian Orogeny, providing a northeast/southwest strike (averaging about N60E) orientation to the bedrock. The Penns Valley Anticline extends through the northern portion of the Basin and plunges to the northeast. Bedrock dips steeply (approximately 60°) to the southeast beneath Tussey Ridge with dips moderating (ranging from approximately 25-45°) to the southeast in the carbonate bedrock valley on the south side of the axis of the anticline. Bedrock also dips moderately (approximately 25-45°) to the northwest on the north side of the Penn's Valley anticline.

The existence of carbonate bedrock in the Basin's valley is conducive to the formation of some karst features, including sinkholes, sinking streams, springs, and solutionally-enlarged bedding planes, joints, and fractures. No significant caves are mapped in the Basin; however buried caves may exist, especially along the base of Tussey Mountain where slightly acidic mountain runoff can dissolve the carbonate bedrock as it migrates into the valley. The focused mountain runoff into the valley has consequently formed a concentration of sinkholes in the carbonate bedrock along the foot of Tussey Mountain. A karst feature inventory of Slab Cabin Run was conducted and is shown in conjunction with the geologic map on Figure 3. Also shown on Figure 3 are sinkholes mapped by Mr. William Kochanov of the Pennsylvania

Geologic Survey, however it should be noted that the sinkholes were not field verified.

Based on the Soil Survey of Centre County (Braker, 1981) soils in the valley portion of the Basin consist primarily of residual soils that have been formed from the carbonate bedrock and therefore are primarily silty clays and clays of the Hagerstown-Opequon-Hublersburg Association with smaller areas consisting of the Morrison Association. The depth of soils in the valley is highly variable from 0 to upwards of 30 feet in thickness. Soils along Tussey Mountain consist primarily of residual and colluvial soils forming from the slope-forming shale and ridge-forming sandstone and consequently consist mostly of clayey to sandy loams of the Hazleton-Laidig-Andover Series.

The soils on top of the carbonate bedrock can be piped downward into the bedrock via bedrock fractures and ultimately form sinkholes. Epikarst is defined as the interface zone between soil and rock in karst landscapes and is characterized by small fractures, conduits and solution pockets that may or may not be filled with water. Water movement and storage in the epikarst zone appears to play an important role in the hydrologic regime of many karst aquifers. Epikarst features in the Basin likely play a significant role on the interaction between surface water and groundwater.

Hydrogeology

Groundwater flow in the Basin's heterogeneous carbonate bedrock is anisotropic, primarily controlled by preferential solution features, especially along the epikarst, bedding planes, thrust faults, and formation contacts that influence ground-water movement parallel to the bedrock's southwest-northeast strike. Groundwater flow across bedrock strike is generally along zones of fracture concentration (fracture traces), joints, and normal faults (Parizek and others, 1971).

Figure 3 shows fracture traces mapped as part of this study within the Basin. Average yields of wells drilled on fracture traces are statistically higher than those drilled off fracture traces (Lattman and Parizek, 1964, Parizek and Drew, 1966, Siddiqui, 1969). Parizek has described three principal types of permeability in the Nittany Valley carbonate aquifers, (1) primary or diffuse flow dominated, (2) fracture dominated, and (3) conduit dominated. The diffuse and the conduit permeabilities are the two extremes of the permeability conditions found in the valley carbonate rocks, while the fracture-dominated permeability is a degree of permeability in between the other two (Parizek and others, 1971). The permeability of the carbonate bedrock within upper Slab Cabin Run Basin is interpreted to be a combination of diffuse flow, fracture flow, and with some shallow conduit flow, where diffuse recharge is fed into fracture systems and ultimately into conduit features where present.

The streams enter the Basin from three water gaps in Tussey Mountain (Pine Grove Mills Gap, Musser Gap, and Shingletown Gap) and each provides focused groundwater recharge into the Basin as these tributaries tend to underdrain through the streambed as they cross over the carbonate valley floor. A summary of the water-bearing properties of each formation (adapted from Wood, 1980) within the Basin is provided below.

Tuscarora Formation

The Early Silurian age Tuscarora Formation consists of fine-grained to conglomeratic, white to gray orthoquartzite with common cross-bedding and ripple marks, and forms the highest and southern ridge of the double-breasted Tussey Mountain. The total thickness of this formation is approximately 550 feet. Few wells tap this formation, however well yields may be sufficient for domestic use (ranging from 1-10 gallons per minute) with good quality, soft water.

Juniata Formation

The Late Ordovician age Juniata Formation underlies the Tuscarora Formation and consists of fine-grained, red sandstone with some interbedded shale with common interbedding. This formation underlies the intermontaine valley between the double-breasted Tussey Mountain and drains much of the mountain precipitation toward the water gaps. The thickness of this formation is about 550 feet. The average well yield is about 25 gpm with a reported range of 16-80 gpm from nine wells. Water quality is typically good with soft water.

Bald Eagle Formation

The Late Ordovician age Bald Eagle Formation grades into the Juniata Formation and consists of coarse-grained, grayish to white sandstone with common cross-bedding. The thickness of this formation is approximately 700 to 800 feet. The three water gaps in Tussey Mountain within the study area are formed in the Bald Eagle Formation. The average well yield is about 20 gpm with a reported range of 0 to 60 gpm from nine wells. Water quality is typically good with soft water.

Reedsville Formation

The Late Ordovician age Reedsville Formation conformably underlies the Bald Eagle Formation and grades from brownish-gray sandstone in its upper section, to shale and into a dark-gray calcareous shale in the lower section (approximately 400 feet, sometimes known as the Antes Shale). The total thickness of this formation ranges from 900 to 1,400 feet. The average well yield is 40 gpm with a reported range of 10 to 180 gpm from 16 wells. Water quality is generally good with soft to moderately hard water.

Trenton Group

The Coburn, Salona and Nealmont Formations make up the Middle Ordovician age Trenton Group, which conformably underlies the Reedsville Formation.

The Middle Ordovician age Coburn Formation consists of black, thin-bedded, fossiliferous, argillaceous limestone and calcareous shale that weathers to medium light gray. The Coburn Formation is approximately 300 feet thick. The argillaceous nature of the Coburn Formation inhibits solution feature formation and therefore high yielding wells are rare in this formation.

The underlying, Middle Ordovician age Salona Formation is quite similar in appearance and lithology to the Coburn Formation except that it contains few fossils, weathers yellowish gray, and has fewer calcareous shale beds. The Salona Formation ranges from 180 to 300 feet thick. The argillaceous nature of the Salona Formation inhibits solution feature formation and therefore high yielding wells are rare in this formation.

The Middle Ordovician age Nealmont Formation consists of medium- to dark-gray, thin- to thick-bedded, argillaceous, fossiliferous, limestone. The Nealmont Formation thickness is approximately 70 feet with an unconformity at the contact with the underlying Benner Formation. The Nealmont Formation is the premier cave-forming formation in the region, suggesting that high yielding wells could be encountered in the Nealmont Formation. As mountain recharge flows off Tussey Mountain into the valley it likely begins to sink into the groundwater system via sinkholes in the Nealmont and underlying formations, including the Benner, Hatter, and Loysburg Formations. The reported range of well yields in the Trenton Group is 2 to 400 gpm with an average yield of 10 gpm. Water quality is usually good but hard.

The Middle Ordovician age Benner Formation unconformably underlies the Nealmont Formation and consists of light- to dark-gray, medium- to thick-bedded, fine- to coarse-grained limestone with some fossiliferous zones. The Benner Formation is approximately 150 feet thick. The

Benner Formation is cave-producing and would be expected to have high yielding wells, however few data are available (Rauch, 1972). The water quality for the Benner Formation is expected to be good but hard.

The Middle Ordovician age Snyder Formation conformably underlies the Benner Formation and consists of medium- to dark-gray, fine-grained, medium-bedded limestone that weathers to light gray. Bedding planes show ripple marks and mud cracks with interbeds of limestone pebbles. The thickness of the Snyder Formation is about 80 feet. Few data are available for the Snyder Formation, but well yields should be sufficient for domestic use, and water quality should generally be good but hard.

The Middle Ordovician age Hatter Formation conformably underlies the Snyder Formation and consists of medium- to dark-gray, medium- to thin-bedded limestone that weathers tan/gray and is dolomitic near the top. The lower beds have a worm-eaten appearance. The Hatter Formation is approximately 75 feet thick. The Hatter is cave-producing and would be expected to have high yielding wells; however, few data are available (Rauch, 1972). The water quality is expected to be good but hard.

The Middle Ordovician age Loysburg Formation unconformably underlies the Hatter Formation. The upper 60 feet of the formation (known as the Clover Member) consists of dark-gray, thin-bedded, fossiliferous limestone. The lower 0 to 400 feet (known as the Milroy Member) consists of thin, alternating, ribbon-like bands of very light-gray limestone and brownish-gray dolomite, and has also been referred to as the “tiger-striped member”. The total thickness of the Loysburg Formation is 50 to 450 feet. Some cave development does occur in the upper two-thirds of the Clover Member, and would be expected to have high yielding wells, however few data are available (Rauch, 1972). The water quality is expected to be good but hard.

Beekmantown Group

The Bellefonte, Axemann, Nittany, and Stonehenge formations make up the Early Ordovician age Beekmantown Group, which conformably underlies the Loysburg Formation.

The upper 200 feet of the Bellefonte Formation consists of light- to medium-gray, fine-grained dolomite that weathers to a yellowish or whitish gray with conchoidial fracturing. The lower 1,000 to 1,200 feet consists of medium- to dark-gray, thin-bedded, very fine- to medium-crystalline dolomite. The total thickness of the Bellefonte Formation is approximately 1,400 feet. Reported well yields from 16 wells ranged from 2 to 500 gpm with an average yield of approximately 20 gpm, with some wells that pump sand. The water quality is generally good but hard.

The Axemann Formation consists of dark-bluish gray, thin-bedded, microcrystalline limestone that weathers to light gray. Its thickness ranges from approximately 400 to 700 feet. Few well data from the Axemann Formation are available, however some large springs do issue from the Axemann, especially at the contact with the Bellefonte Formation in Nittany Valley near the eastern portion of Centre County. This contact has been considered as a drilling target for water supply projects due to the large springs that issue along it. The water quality is generally good but hard.

The Nittany Formation consists of alternating beds of light- to dark-gray dolomite with significant nodular and bedded chert in the lower section. The total thickness of the Nittany Formation is about 1,200 feet. The Nittany Formation is one of the most prolific aquifer units in the area with yields from 23 non-domestic wells ranging from 0 to 2,200 gpm with an average yield of 500 gpm. Sand pumping and borehole collapse can be a problem with wells in the Nittany Formation. Water quality is generally good but very hard (average hardness 205 mg/L).

The Stonehenge Formation consists of relatively pure, blue limestone with 0.5- to 6-foot interbeds of mottled or laminated dolomite and is moderately fossiliferous. The basal portion has a flaggy appearance with common conglomerates, and a reddish, thin-bedded, fossiliferous limestone conglomerate (Butts and Moore, 1936). The total thickness of the Stonehenge is 250-600 feet. The reported range of well yields is from 1 to 30 gpm. This formation is not mapped to occur in the near surface in the study area but is included since it underlies the Nittany Formation and occurs just north of the study area.

The Late Cambrian age Gatesburg Formation conformably underlies the Stonehenge Formation and consists of four members including the Mines Member, Upper Sandy Member, Ore Hill Member, and Lower Sandy Member. The Mines Member consists primarily of dark gray, coarse-grained dolomite with some light gray dolomite with a thickness of 150 to 230 feet. One available well in the Mines Member has a reported yield of 490 gpm, therefore indicating it has potential as a productive unit. The Upper Sandy Member is composed of dark, thin-bedded, silty dolomite; thin-bedded, finely crystalline dolomite with some shaley beds; and medium- to coarse-grained orthoquartzite. These beds have been cyclically deposited and range in thickness from 3 to 50 feet. The total thickness of the Upper Sandy Member is about 650 to 700 feet. The Upper Sandy Member is the most prolific aquifer in the region with well yields ranging from 7 to 8,000 gpm and a mean yield of 415 gpm. The orthoquartzite beds tend to weather into loose sand and may account for many of the water-bearing zones in this formation. Sand pumping and well collapse are common problems in this unit. This formation tends to form ridges due to its relatively high resistance and therefore has very deep water levels, often greater than 300 feet. The Ore Hill Member consists primarily of dark-gray, massive, coarsely-crystalline dolomite with a thickness of 130 to 310 feet. The Lower Sandy Member is very similar in lithology to the Upper Sandy Member, with fewer orthoquartzite beds. No well data are available for either the Ore Hill or Lower Sandy members. In general, water quality from all of the Gatesburg members should be of high quality but hard.

2.8.2 Groundwater Flow

Figure 9 is a water table map of the Basin as generated from a round of water level measurements taken on June 24, 2005, in 31 public and private wells within the basin. Each well had been previously surveyed with a high precision GPS unit with vertical resolution of approximately 0.2 feet, which should be sufficient for a regional water table mapping project such as this. As shown in Figure 9, the regional direction of groundwater flow in the valley is toward Slab Cabin Run, generally paralleling both bedrock strike and Slab Cabin Run in the center of the basin.

As shown in Figure 9, the projected direction of groundwater flow coming off the flanks of Tussey Mountain is downslope (north/northwest) and then turns toward the northeast, generally parallel to bedrock strike once groundwater reaches the valley's carbonate bedrock. Groundwater flow from the north side of Slab Cabin Run is south/southeast toward Slab Cabin Run. The direction of groundwater flow shown in Figure 9 is likely more tortuous along fracture paths when considered on microscale as compared to the relatively smooth flowpaths portrayed in the figure. The groundwater basin extends significantly to the southwest beyond the surface water basin, which can be attributed to the northeast-plunging bedrock causing groundwater under-drainage away from the Spruce Creek Basin and toward the Slab Cabin Run/Spring Creek Basin.

It should be noted that on June 24, 2005, Slab Cabin Run appears to be perched near Staff Gauge 1 in Pine Grove Mills and again at Staff Gauges 8, 9, 10 and 11 when comparing the stream gauge elevations to nearby well water level elevations. Slab Cabin Run's flow conditions during the June 24, 2005, measurements are considered to be average. Unfortunately, groundwater elevations were not available along the entire stretch of Slab Cabin Run, so it is difficult to assess if and where Slab Cabin Run becomes a gaining stream. It is worth noting that past stream gauge monitoring records indicate that Slab Cabin Run generally gains water as it flows downstream and loses some flow below Staff Gauge 8, which could be expected if it is perched. The perched condition indicates that groundwater baseflow is not occurring on this stretch of Slab Cabin Run since the stream bottom elevation is higher than the water table elevation. Significant groundwater flow is likely occurring beneath Slab Cabin Run as convergent flow is occurring based on water table mapping. Previous studies (Nittany Geoscience, 1991) indicate that Slab Cabin Run has both losing and gaining stretches.

2.8.3 Groundwater Recharge Mechanisms

Parizek (1984) described eight pathways for groundwater recharge in the Spring Creek Basin including:

- Infiltration of direct precipitation within residual and transported soils that blanket bedrock aquifers,
- Infiltration of direct precipitation in areas of exposed bedrock outcrops,
- Concentrated surface runoff from mountain slopes into sinkholes near the base of the ridges (e.g. Tussey Mountain),
- Diffuse surface runoff from the mountain slopes into soil-covered carbonate rock,
- Concentrated stormwater runoff into sinkholes within upland areas in the valley that are underlain by carbonate aquifers,
- Stormwater runoff from impervious areas where water may travel to sinkholes or diffusely seep into soils at the fringes of impervious areas,
- Water loss along perched, intermittent, or permanent streams, and
- Leakage from storm drains, water lines, on-lot sewage effluent disposal, and irrigation practices.

Each of these recharge mechanisms occur in the Basin to a certain degree, however the addition of mountain recharge into the valley and sinking streams appear to be the most dominant groundwater recharge mechanisms.

2.8.4 Factors Affecting Well Yields

Siddiqui (1969) and Parizek (1984) evaluated well yields in the Spring Creek Basin in comparison to six hydrogeologic factors: variations in bedrock lithology, bedrock dip, topographic setting, depth to water table, the wells' proximity to anticlinal or synclinal axes, and the location of the wells with respect to fracture traces or concentrations of fractures zones. The researchers evaluated productivity of the wells, defined as adjusted specific capacity per foot of static saturated thickness, as the measure of well yield.

Results showed that wells on or near fracture traces were more productive than wells not near fracture traces. The median productivity for wells near fracture traces was 0.079 gal/min/ft compared to a median productivity of 0.0014 gal/min/ft for wells not near fracture traces. Wells in sandy dolomites and coarse-grained dolomites, such as the Gatesburg Formation, were the best producers; the median productivity was 0.12 gal/min/ft for wells tapping the Upper Sandy Member of the Gatesburg Formation. Wells tapping the Nittany Dolomite had the second highest productivity (0.068 gal/min/ft) compared to wells from other limestone formations, the Bellefonte Dolomite, and shale bedrock aquifers. Parizek and Siddiqui made the following conclusions from their research:

- Wells installed in bedrock with significant secondary and primary intergranular porosity and permeability have the highest yields,
- Wells in valley bottoms were more productive than wells in valley slopes or uplands,
- Wells near anticlinal axes were more productive than wells near synclinal axes, and
- Wells installed into bedrock that dips less than 15° had higher yields than wells into bedrock with steeper dips.

2.8.5 Characteristics of Existing Public Water Supply Wellfields

Two major municipal wellfields, Wellfields 1 and 3, are operated by SCBWA in the Basin as shown in Figure 9. Wellfield 1 contains four wells and Wellfield 3 contains three wells. Each of the wells in Wellfield 1 have open intervals between 70-165 feet below grade and well yields range from 3,000 to over 7,000 gpm with a combined wellfield yield of approximately 12 million gallons per day (MGD) (USFilter, 2002). The three wells in Wellfield 3 have open intervals ranging from 50-300 feet below grade with yields ranging from 750 to over 5,000 gpm for a combined wellfield yield of 5.8 MGD (USFilter, 2002).

The combined permitted withdrawal from the entire upper Slab Cabin Run watershed is approximately 7.5 MGD. The high productivity of the SCBWA wells is attributed to large, solutionally-enhanced fracture zones and conduits encountered by each well which provide high volumes of recharge to each well. Wellfield 1 is along Slab Cabin Run, which has convergent groundwater flow occurring beneath the perched stream, which likely serves to provide significant recharge to this wellfield. Wellfield 3 is along Roaring Run, which typically sinks upgradient from this wellfield and therefore likely provides significant recharge to this wellfield. A well video conducted by USFilter in Well 11 revealed a large void near the bottom of this well estimated to extend outward approximately 10 feet in all directions from the center of the borehole, indicating the scale of the water-bearing features in the Basin.

Wellfields 1 and 3 have some hydraulic connection based on previous pumping test records, however drawdown is minimal between the wellfields (less than five feet) and typically only one well from each wellfield is pumped at any given time. Wellfield 3 does reportedly get turbid during periods of high rainfall, while Wellfield 1 has had bacteriological contamination, suggesting that each wellfield does have surface water connections. The surface water connections in these two wellfields are further supported by the dye trace study results presented earlier. In addition, as would be expected water levels rise rapidly in these wells after significant precipitation events, however the well water levels do not drop significantly (maximum of twenty feet) during drought periods compared with wells in the center of the valley due to the proximity to streams and convergent groundwater flow.

2.8.6 Stream Hydrology

The upper Slab Cabin Run Basin surface drainage is an area approximately 15.8 mi^2 (10,100 acres), with a groundwater divide extending an estimated additional 11.5 mi^2 (7,360 acres) to the southwest as shown in Figure 9 based on the June 24, 2005 water table map. Mountain gap tributaries emanating from the headwaters of Slab Cabin Run begin in Tussey Mountain where it flows out of the gap in Pine Grove Mills, with mountain gap tributaries emanating from Musser Gap and Shingletown gap significantly augmenting the streamflow. Each of these mountain gap tributaries sink into the subsurface much of the year as they enter the carbonate valley setting. The sinking surface runoff from Tussey Mountain provides much of the groundwater recharge for the Basin while some of the water re-emanates from numerous small springs on the valley floor of the basin. Slab Cabin Run has historically gone dry during drought periods and therefore portions of the Basin become under drained.

A total of 11 stream gauges have been installed along upper Slab Cabin Run from the mountain gap at Pine Grove Mills to the downstream end of the defined study area as shown on Figure 2. Figure 10 shows the measured streamflow of Upper Slab Cabin Run at each of these gauges under varying flow conditions. Stream flow was measured at each station with a Teledyne Gurley flow meter with flow measured at a depth of four-tenths of the stream depth from the stream bottom, where average stream flow velocity typically occurs. From November 2002 to April 2004 the flow at the downstream end of the Basin ranged from 7.3 to 37.3 cfs (3,260 to 16,740 gpm) as shown in Figure 11. From these data it is apparent that Slab Cabin Run is a gaining stream along much of its course. During several periods of measurement Slab Cabin Run does appear to lose flow between Staff Gauges 8 to 10, which is the section of the stream where SCBWA Wellfields 1 and 3 are located. Based on the November 2002 to April 2004 dataset, when flow is lost along this stretch the influent loss ranges from approximately 180 to 960 gpm. Slab Cabin Run flow data also show that this same stretch can be gaining with flow increases along this stretch ranging from 520 to 1830 gpm. During this period there is an average net loss of flow of approximately 195 gpm, while average combined groundwater withdrawal from SCBWA wellfields is approximately 2,000 gpm. It is evident that groundwater withdrawal may impact flow in Slab Cabin Run to a certain degree, however not all of the water recharging the wellfields is coming from Slab Cabin Run, and there is still a net gain of flow downstream. The rest of Slab Cabin Run is generally gaining, which is thought to occur mainly via combination of surface runoff, baseflow and through a series of small springs and seeps that occur between Tussey Mountain and the south side of Slab Cabin Run that flow primarily out of the Bellefonte Dolomite. In addition, significant additions of flow to Slab Cabin Run occur when the tributary streams are flowing out of Musser Gap and Shingletown Gap.

There are several explanations why Slab Cabin Run loses flow along its lower section, especially between Staff Gauges 8 and 10. The formation of swallets (sinkholes that open up in the streambed) in Slab Cabin Run have occurred historically in this area and have had the capacity to take some or all of the stream's flow. The swallets are repaired once detected to preserve stream flow and groundwater quality; however some loss of flow could still be occurring around the swallets if not perfectly sealed. This portion of Slab Cabin Run appears to be perched, especially during dry periods; therefore the potential for streambed infiltration exists, especially where the streambed sediment is coarser. In addition, groundwater withdrawal via public water supply wellfields will tend to increase the potential for streambed infiltration.

2.8.7 Upper Slab Cabin Run Water Budget

This section of the report estimates the amount of available groundwater within the Basin. The results of previous groundwater availability studies conducted by Taylor (1997) and R.E. Wright Associates (1992) for the Spring Creek Basin are utilized and compared to the results of the data collected for this upper Slab Cabin Run study.

Taylor (1997) determined that groundwater recharge (calculated as base-flow runoff) for the entire Spring Creek ground-water basin averaged 0.793 Mgal/d/mi^2. The recharge is calculated from the streamflow gaging station for Spring Creek at Milesburg, Pa., during 1968–94. The entire groundwater basin area was calculated as 165.6 mi^2 by Taylor (1997). The maximum base flow per unit area (recharge rate) was 1.157 Mgal/d/mi^2 and the minimum was 0.452 Mgal/d/mi^2 during that period. The median recharge rate is 0.802 Mgal/d/mi^2 during this period. R.E. Wright and Associates (1992) conducted a groundwater availability study for upper Spring Creek Basin and determined the average groundwater recharge value was 0.734 Mgal/d/mi^2, indicating that the calculated groundwater recharge rates from each study are in close agreement with one another. The data collected for this upper Slab Cabin Run study are insufficient to allow for accurate estimations of groundwater recharge since the data span a relatively short period of time and data were not collected on a daily or more frequent basis. This section of the report quantifies the available groundwater resources based on previous studies and then compares stream flow and groundwater withdrawal to the estimated groundwater availability.

As previously noted, the surface area of the upper Slab Cabin Run Basin is approximately 15.8 mi^2 with a groundwater divide extending an estimated additional 11.5 mi^2 to the southwest, therefore the entire groundwater basin is 27.3 mi^2. Using the slightly more conservative average groundwater recharge value of 0.734 $Mgal/d/mi^2$ calculated from the R. E. Wright study and multiplying it by the total areal extent of the groundwater basin, a total average groundwater recharge value of approximately 20 MGD is derived for the Basin. Based on historical monthly records of stream flow at Staff Gauge 11 from November 1991 through September 2005, the average flow at the downstream end of the Basin is 6.7 MGD, which incorporates significant drought periods with no flow in Slab Cabin Run. This 6.7 MGD of average flow at the downstream end of the Basin, incorporates both groundwater baseflow and surface runoff. Taylor (1997) estimated average baseflows of 85, 87, and 81 percent of total flow in Spring Creek at the Axemann, Milesburg, and Houserville stream gauges, respectively, while Giddings (1974) estimated that baseflow comprises 86 percent of stream flow for Spring Creek. Using the 86 percent baseflow value and 6.7 MGD of flow in Upper Slab Cabin Run under average conditions, then 5.7 MGD of the 6.7 MGD of flow in Slab Cabin Run consists of baseflow. The remaining 14.3 MGD of available groundwater is not providing baseflow to upper Slab Cabin Run since it is perched in locations, and therefore is interpreted to be withdrawn via public or private wells with the remaining groundwater flowing beneath upper Slab Cabin Run. Approximately 3 MGD of groundwater is intercepted by SCBWA wellfields, which is ultimately returned to Spring Creek via the outfall from the University Area Joint Authority's wastewater treatment plant. The remaining 11.3 MGD is left to provide baseflow downstream to lower Slab Cabin Run where it eventually intercepts the water table or ultimately provides baseflow to Spring Creek.

2.8.8 Conceptual Model of Upper Slab Cabin Run

As is evident from the previous sections of this report, Slab Cabin Run's hydrology is a dynamic system consisting of complex surface water and groundwater interaction as presented in this conceptual model of upper Slab Cabin Run. As previously noted, Slab Cabin Run begins in the intermontaine valley occurring between the double-breasted Tussey Mountain where surface runoff and mountain baseflow combine to form Slab Cabin Run's headwaters. Slab Cabin Run then emanates from

Tussey Mountain's confines via the water gap above Pine Grove Mills, which may exist due to fracture-related weaknesses in the otherwise resistant Bald Eagle Sandstone. As the stream flows out of the sandstone and across the Reedsville Shale, it continues to increase in flow down the mountain flank and out in the valley. As Slab Cabin Run reaches the valley setting it initially flows without significant loss over the shaley limestone of the Salona and Coburn formations which is overlain by residual and colluvial soils. Slab Cabin Run then sinks once it begins to cross the purer, sinkhole-prone limestone of the Nealmont Formation just below Pine Grove Mills as it enters the carbonate bedrock valley.

Slab Cabin Run is then mostly a dry streambed for approximately one-half mile until it re-emerges as a rise pool behind Watkins Dariette, located along Routes 26 and 45. Slab Cabin Run rises and then immediately sinks back into the subsurface via a sump adjacent to the rise pool, which suggests that shallow epikarst features control the stream's flow. During extreme precipitation events when the subsurface drainage system is overwhelmed, Slab Cabin Run will flow continuously over ground from the Pine Grove Mill's water gap to the rise pool and continue downstream to Spring Creek.

Slab Cabin Run again re-emerges approximately 1000 feet to the northeast as another rise pool behind the Limestone Inn, where it then typically flows continuously downstream across the Bellefonte Dolomite, except where it may dry up during drought periods.

A relatively large spring, estimated to flow at greater than 300 gpm, emanates northwest of the Junction of Routes 26 and 45 and joins Slab Cabin Run just before it flows under Route 26, thus providing a significant addition of flow to Slab Cabin Run. This spring appears to be recharged from the groundwater basin that extends southwest beyond the Slab Cabin Run surface basin based on the dye trace study results that showed no dye detections in this spring. As Slab Cabin Run flows toward the northeast across the Bellefonte Dolomite its flow increases via surface runoff, soil interflow, and several smaller springs that occur along Route 45, such as the springs at Windy Hill Farms. These springs flow out of the Bellefonte Dolomite and into Slab Cabin Run and are interpreted to originate from more diffuse mountain recharge that sinks as it flows off the mountain slope and from direct mountain recharge.

In addition to the springs that add flow to Slab Cabin Run, significant additions of flow occur from Musser Gap and Shingletown Gap when these tributaries are flowing, however they typically only flow after heavy rains or during spring snowmelt events. Otherwise, as previously noted, these mountain tributaries sink through their cobbly streambeds as they cross the carbonate bedrock, with stream flow typically disappearing across the Nealmont Formation. This sinking flow contributes significant groundwater recharge that does not appear to provide much, if any, stream baseflow under normal conditions when Slab Cabin Run is perched and not in hydraulic communication with the water table. As Slab Cabin Run continues to flow past the Musser Gap tributary, it would appear to be in a perched condition as evidenced by the sinking of the Musser Gap tributary. In addition, there is typically some loss of stream flow below the Musser Gap tributary and Staff Gauge 8, further indicating that Slab Cabin Run is perched and has flow infiltrating through the streambed. Stream flow typically rebounds near Staff Gauge 10, where the typically dry Roaring Run joins Slab Cabin Run, with flow continuing to increase to the downstream extent of the study area near Staff Gauge 11. As previously noted, under average conditions significant volumes of groundwater flow are recharged to the aquifer via sinking mountain runoff and tributaries and this flow apparently converges beneath Slab Cabin Run.

Figure 11 shows the overall conceptual model for the Upper Slab Cabin Run basin, with mountain recharge collecting in Tussey Mountain, this recharge flowing out and sinking into the valley’s carbonate bedrock, and thus providing significant groundwater recharge to the basin. Groundwater flow is generally convergent toward Slab Cabin Run, which is thought to be generally perched below its convergence with the Musser Gap tributary under normal conditions. The conceptual model shows a critical recharge zone occurring from the contact of the Reedsville Shale and the carbonate bedrock out toward Slab Cabin Run approximately 3,000 feet, where much of the mountain runoff sinks into the subsurface. This zone is especially prone to having land uses or surface activities affect the groundwater quality and therefore should be managed accordingly to protect water quality. The critical recharge zone is nearly coincident with the Tussey Ridge Overlay District ordinance adopted by Ferguson Township in 2004, which limits the amount of development that may occur on certain soil types coincident within this critical recharge area. Any proposed development within the Overlay District must be conducted with a significant amount of geotechnical work to demonstrate that the sites hydrologic conditions will not be significantly altered while also determining the site’s suitability for structures.

2.9 Watershed and Groundwater Flow Model

Two computer models were developed as components of the upper Slab Cabin Run watershed protection program. A groundwater flow model was developed in MODFLOW (the USGS modular ground-water model, Harbaugh, et al. 2000). This model also served as a component of the Wellhead Protection Program for SCBWA.

Its principal objectives are to predict groundwater flow pathways and capture zones of the SCBWA wells under a variety of recharge conditions. This model is further described in Section 3.1.5. This model was used in the Watershed Protection Program to examine perturbations of groundwater flow and well capture zones induced by recharge resulting from additions of water to the land surface.

A second computer model of the upper Slab Cabin Run watershed (watershed model) was developed to analyze and make predictions regarding surface water runoff and channel flow in the upper Slab Cabin Run watershed. As the interaction of surface and ground water is an important element of the watershed conceptual model, it was also recognized as a necessary element of the computer model. Gridded Surface Subsurface Hydrologic Analysis (GSSHA), written by Downer, et al., (2002) was selected for this work, as it is one of very few computer programs capable of simulating fully coupled surface and groundwater flow. Model development was done using the implementation of GSSHA in WMS (Watershed Modeling System, ver. 7.1, EMS-I, 2004).

The watershed model had many objectives, among them the capacity to predict the effects of land-use changes in the watershed and to ultimately serve as a planning tool. Furthermore, the model was intended to predict peak flow rates at various points of the watershed for differing storm events, and relate those flows to potential pollutant levels. GSSHA was developed for the US Army Corps of Engineers specifically to support this type of work; it was developed by the Watershed Systems Group within the Coastal and Hydraulics Laboratory of the Engineer Research and Development Center (Downer, et al., 2002). WMS provided a modeling system to support the development of input files and post processing of model output.

There are a number of empirically-based models that have been used to estimate storm water runoff and channel flows in watersheds where influence of water can be safely ignored once it has fully infiltrated the soil profile (i.e. a Hortonian watershed). The upper Slab Cabin Run watershed does not fit this simple model, as subsurface runoff, groundwater infiltration, and groundwater exfiltration are important processes. In contrast to empirically based models, GSSHA explicitly solves for the multitude of physical processes controlling surface runoff, infiltration, soil moisture retention, evaporation, transpiration, lateral subsurface flow, groundwater exfiltration, and channel hydrodynamics. To accomplish this, GSSHA requires a substantial burden of input data, including high frequency hydrometerological data (15-minute precipitation, hourly solar radiation, cloud cover, etc.), land cover attributes (vegetation, roughness, albedo, etc.), soil hydrologic characteristics (hydraulic conductivity, suction head, porosity, etc.), flow channel hydrologic characterisitics (gradient, shape, surface roughness, etc.), and groundwater parameters (boundary heads, horizontal hydraulic conductivity, unsaturated zone depth, etc.).

The upper Slab Cabin Run watershed (and the Spring Creek Watershed in general) is unusual in the degree to which direct measurements and laboratory analyses are available for many of the input parameters required by GSSHA. Nevertheless, the marshalling and preparation of input data was a much more extensive task for the watershed model than it was for the MODFLOW-based groundwater flow model. The modeling effort was also fortunate to have high frequency (15-minute) stream flow data (Spring Creek Watershed Community, 2004) to use for model calibration. Acknowledgement is due to the Water Resources Monitoring Project for making available these data from the stream gauges they monitor and maintain on Slab Cabin Run.

Acknowledgement is also due to Dr. Charles W. Downer, Research Hydraulic Engineer and lead developer of GSSHA, for his valuable advice and assistance with the model development effort. His assistance included numerous modifications and updates to portions of the GSSHA code being used by the watershed model to simulate surface water infiltration and interactions with groundwater. Despite the advantage of this assistance and the unusual degree of site-specific information, the effort to calibrate the model to historic stream flow measurements was unsuccessful. The inability to simulate historic stream flow measurements with adequate accuracy means that the model cannot be used to meet its set objectives.

The watershed model can be adjusted to simulate peak storm discharges under specific meteorological circumstances. However, in so doing the same model fails to simulate peak flows under different circumstances. When adjusted to match average flows, the model fails to match low or high flows. Furthermore, when adjusted to roughly match storm flow runoffs, the model significantly underestimates the duration and strength of post-peak recession curves. Several reasons have been identified for these deficiencies. The principal reason is that the model does not adequately account for the effects of groundwater infiltration and exfiltration on channel flow (even when piezometric heads are simulated with reasonable accuracy). Previous work indicated the likelihood of varying degrees of subsurface flow through karst conduits beneath Slab Cabin Run. What was not known was whether the magnitude of these flows was sufficient to overwhelm the limitations of the available data and computer modeling techniques. The dye tracing work conducted by this study indicates the significance of such flow with regard to mass transfers from the channel to the subsurface, and to pumped wells.

Subsurface conduit flow appears to be a dominant factor near Slab Cabin Run and places a significant fraction of the modeled surface channel flow in the subsurface, which would account for the incapacity of the model to be calibrated to measurements of the channel flow. One reason for this is that the visible flow represented by stage measurement represents an unknown fraction of the combined surface/subsurface flow, and that unknown fraction is probably highly variable with respect to time and location during the passage of a storm event. In contrast, the model simulates all of the channelized runoff as being in the surface channel. Even if the actual subsurface flow fraction could somehow be estimated, the model lacks the capacity to explicitly simulate flow in karst conduits (even if the hydrodynamic properties of such conduits were known).

The GSSHA model had several other important limitations in its application to the upper Slab Cabin Run watershed. One limitation is that the model's representation of groundwater flow is limited to two dimensions. This limitation was known, but accepted because there was not an alternative model having both the coupled flow capabilities of GSSHA and a three-dimensional groundwater flow module. However, the two-dimensional limitation made it difficult to accurately simulate time-dependent groundwater heads, given the surface relief and relatively deep groundwater flow paths in the watershed. The second limitation with respect to groundwater flow is that GSSHA does not accept time-dependent boundary conditions. This limitation was also problematic, because the boundaries of the upper Slab Cabin Run surface water basin do not correspond with groundwater flow boundaries. The intent of the two-model approach was to use the fully three-dimensional groundwater flow model to overcome some of the limitations of the groundwater flow module in the watershed model. However, this was forestalled by the finding of a significant conduit flow component. This, and the short time-step coupling of surface and groundwater flow in the GSSHA model made it impracticable to carry out the planned sharing of information between the watershed and groundwater models.

The apparent significance of shallow conduit flow and the difficulty of quantifying its time-dependent characteristics will remain as impediments to meeting the objectives set for the watershed model, even if additional effort were to be expended with some future model having expanded capabilities. It may be that a model based on GSSHA or something similar may find practical application with a more limited set of objectives, for example, as a local-scale screening or preliminary design tool in areas under consideration for land modification or surface water application. A description of the watershed model and its development are presented in Appendix G. This description documents the effort made in the model development.

Fortunately, this source water protection program was designed to be able to utilize data collected during the study to assess the relationship of surface water and groundwater flow in Slab Cabin Run. In particular the dye tracing program results provide a unique opportunity that allow determinations of the nature of the connection between surface water and groundwater to be made directly. In retrospect, the results of the dye tracing study would not likely be able to be closely replicated by any coupled groundwater and surface water model. The results of the dye trace study are used in lieu of a calibrated surface water model for the purpose of determining the source water protection areas for Wellfields 1 and 3.

2.10 Source Water Assessment

PaDEP conducted a source water protection area delineation as part their contaminant source inventory which is complemented by the work done in this study.

Figure 12 shows the modeled groundwater capture zone during typical wellfield use for Wellfields 1 and 3. The typical use capture zone in Figure 12 was delineated by running each well separately (i.e. one pumping well at a time) at the typical pumping rate for the wellfield. The individual capture zones were then superimposed and the total area was then delineated as the “typical use” capture zone to provide a conservative capture zone that encompasses the total potential capture zone given use of any well in a wellfield. Figure 13 shows the source water protection area for Wellfields 1 and 3 which encompasses the entire surface drainage basin of Upper Slab Cabin Run and the portion of the extended groundwater drainage that would be captured by pumping these wellfields. PaDEP’s contaminant source inventory includes several potential contaminant sources as identified on Figure 13. For purposes of this study Wellfields 1 and 3 are considered to be groundwater sources under the influence of surface water, since they have been characterized to be at least partially recharged from Slab Cabin Run. In addition, Shingletown Reservoir is a surface water source. PaDEP’s Source Water Assessment is included in Appendix H. The objectives of the assessment are to identify the pollutants in the contributing area, and then rank them in order of concern. The information compiled by PaDEP was then incorporated into this more detailed Source Water Protection Program report.

PaDEP uses the following three-zone classification system for watersheds that are larger than 100 square miles:

Zone A

A buffer area ¼ mile wide on either side of a stream extending upstream that encompasses a 5-hour time of travel.

Zone B

An area 2 miles wide area on either side of a stream extending upstream to cover a 25-hour time of travel.

Zone C

The remainder of the watershed.

On October 8, 1994, revisions to 25 Pa. Code Chapter 109.1 of DEP’s rules and regulations defined a three-tiered wellhead protection area approach as follows:

Zone I.

The protective zone immediately surrounding a well, spring or infiltration gallery which shall be a 100-to-400-foot radius depending on site-specific source and aquifer characteristics. For a new system or as an expansion of an existing system, the water supplier must own or substantially control, through a deed restriction or other methods acceptable to the Department, the Zone I wellhead protection area in order to prohibit activities within Zone I that may have a potential adverse impact on source quality or quantity.

Zone II.

The zone encompassing the portion of the aquifer through which water is diverted to a well or flows to a spring or infiltration gallery. Zone II shall be a 1/2-mile radius around the source unless a more detailed delineation is approved.

Zone III.

The zone beyond Zone II that contributes surface water and groundwater to Zones I and II.

The Zone I, II, and III wellhead protection areas have been delineated for SCBWA Wellfields 1 and 3, using PaDEP-approved methodologies. The SCBWA's Zone I wellhead protection areas for each wellfield were estimated based on graphs developed by PaDEP that factor in each well's lithology, open-interval length, and pumping rate. The groundwater model was used to determine the combined capture zones (equivalent to a Zone II wellhead protection area) for Wellfields 1 and 3 as shown in Figure 13. The Zone III wellhead protection area has been delineated for Wellfields 1 and 3 based on the modeled groundwater capture zone (Zone II) and surface water drainage toward Zone II. The Zone III assessment area encompasses the most extensive of the surface water or groundwater basins, which in this case is consistent with the Zone C classification. In addition, the dye trace study results were used to indicate the estimated recharge time of travel to Wellfields 1 and 3. The spatial extent of the combined wellhead protection areas for Wellfields 1 and 3 are 16.34 square miles for Zone II, and 21.5 square miles for Zone III.

The Shingletown Reservoir Source Water Protection Area was delineated using the entire watershed (Zone C) as shown on Figure 14, since the watershed is relatively small. The Shingletown Reservoir Zone C Source Water Protection Area encompasses an area of 2.30 square miles.

2.11 Contaminant Source Inventory

The contaminant source inventory was conducted by PaDEP in the Source Water Assessment and is included as Appendix H. Each pollutant typically associated with the land use type or activity was identified and mapped. The potential pollutants were individually run through a series of matrices to identify a Susceptibility Rating for each particular contaminant. A letter value of A (high) thru F (low) was thus assigned to each contaminant. The factors that determine the assigned value are time of travel, persistence, quantity, sensitivity of the water source and whether the contaminant is found at a registered or regulated facility. Two non-point potential sources of contamination (PSOCs), the major roads and the developed areas within the contributing area of the well fields received an “A” and “B” rank, respectively, and are the highest ranked PSOCs in PaDEP’s source water assessment report. The other six PSOCs were rated as C (auto repair shops, on-lot septic, sewer lines, agriculture, and gas stations) or D (drinking water treatment plant). Fortunately, no PSOCs were identified for the Shingletown Gap Reservoir. The ranked sources of potential groundwater contaminant sources are contained in the PaDEP Source Water Assessment contained in Appendix H and shown individually in Figure 13.

The 7.0-mile section of Slab Cabin Run that extends from the junction of Routes 26 and 45 to its confluence with Spring Creek near Houserville was classified as an “impaired” water body according to the United States Environmental Protection Agency’s 303(d) list in late 2002. The sources of the stream impairments included agricultural grazing, flow modifications, a golf course, and urban runoff. The reported impacts to Slab Cabin Run include siltation, flow variability, and thermal modification. As further discussed in Section 2.15 of this report, the SCBWA is fully committed to preserving the region’s water resources. The SCBWA has taken several steps toward improving Slab Cabin Run and its tributaries’ overall quality through riparian buffer installation, property acquisition, reduced reliance on Wellfields 1 and 3, and public education.

2.12 Contingency Planning

SCBWA has written a contingency plan/emergency response plan so that any spills or other source water-threatening incidents can be responded to in an effective and timely manner. This plan is included as Appendix I and details SCBWA’s approach to deal with a variety of situations to ensure the timely and effective protection of the water resources in such an event. The dye tracing study conducted as part of this study aided in the response planning in case of a surface spill to Slab Cabin Run. For instance a spill into Upper Slab Cabin Run above Pine Grove Mills could be most effectively captured in the rise pool behind Watkins Dariette. A second measure would be to shut off Wellfields 1 and 3 in case of a spill to prevent induced vertical migration into the aquifer from groundwater withdrawal, since there is a known surface connection to Slab Cabin Run. The dye tracing program also provided guidance on the rate of migration of contaminants from various points giving SCBWA personnel general timeframes of how long contaminants may take to reach Wellfields 1 and 3 as previously summarized.

2.13 New Source Planning

New source planning was undertaken as part of this program as well during the SCBWA's long-range planning process with their engineer, Gwin, Dobson & Foreman. Previous investigations have been conducted by Dr. Richard Parizek for the Centre Region Planning Commission in 1987 to determine the best areas for future groundwater development within the upper Spring Creek Basin. Based on the results of this study, ten areas were delineated as having potential for high capacity wellfields including: Barrens Region (Scotia), Circleville, Houserville-Lemont, Big Hollow-Spring Creek, Fillmore, Oak Hall-Boalsburg, Harter Wellfield-Shingletown, Pine Grove Mills, Tadpole-Fairbrook, and Centennial Region. Since this study several of these wellfields have been developed as recommended in the study (Circleville, Harter, Fillmore, Kocher). Two other groundwater development efforts (DeArmit and Ashcraft properties) were conducted outside of the ten target areas. The DeArmit Wellfield has a reported safe yield of 2-3 MGD, and the Ashcraft Wellfield has a reported safe yield of approximately 1 MGD. The issue of intra-basin transfer occurs when considering the use of wellfields that occur outside of the Spring Creek Watershed, such as the DeArmit Wellfield, which is located in the Spruce Creek watershed.

The Gatesburg Formation (especially near the Barrens region) remains as a largely underutilized aquifer system that provides excellent water quality, and the surrounding land use is protected as state gamelands. These factors make future groundwater development in the Barrens attractive, however additional considerations such as where the greatest water demand increase will occur should be considered. The disadvantages of groundwater development in the Barrens region include the high cost of drilling due to the deep water table, sand pumping problems, and the relatively great distance to the SCBWA service area. Therefore a detailed cost analysis should be conducted to determine the economic feasibility of drilling production wells in the Barrens region. It should be noted the Gatesburg Formation does occur in closer proximity to the SCBWA service area than the Barrens region, and these areas should be further considered as discussed below.

A second target formation is the Nittany Formation, which is currently tapped by Wellfields 1, 3, and 4, but still has available groundwater resources at sufficient distances from these wellfields. The advantages of the Nittany Formation are that it typically provides high quality water in sufficient quantity for municipal use, and occurs in close proximity to the SCBWA service area. A possible disadvantage of the Nittany Formation is the effect that nearby urbanization could have on water quality and groundwater recharge. Other areas should also be considered for future development, however factors such as urbanization, existing groundwater contamination problems, and future demand should be weighed in to the decision-making process. Figure 15 shows all potential target areas and existing wellfields.

Another consideration for increasing future groundwater capacity is through optimization of the existing wellfields and increasing the withdrawal permits to satisfy future demands. In April 2002, USFilter conducted a safe yield evaluation for all of the SCBWA wellfields and determined that a total of 48 MGD can be theoretically pumped from all of the wellfields without considering regulatory limits or changes in water quality (especially turbidity). The SCBWA is currently using approximately 5 to 6 MGD on average, therefore a large unused capacity exists, however the SCBWA is currently limited by the overall 9.1 MGD SRBC withdrawal permit. Increasing the current PaDEP and SRBC withdrawal permits would be possible, however the regulatory considerations discussed below must be taken into account.

PaDEP and SRBC both regulate the SCBWA groundwater withdrawals and therefore the feasibility, timing and other logistics for acquiring new or increased withdrawal permits must be considered. In general, the most important factors that need to be considered for increased permit withdrawals as a result of a new source or increases from existing sources include the following:

- Proposed groundwater withdrawal impacts to other groundwater users, streams, wetlands, etc.
- Timing and cost of obtaining new permits (2-3 years costing $3 million/MGD), and
- Intra-basin transfer from Spruce Creek to Spring Creek watershed.

These issues will need to be dealt with on a case-specific basis, however it is clear that many regulatory factors need to be considered prior to increasing the permitted withdrawals.

2.14 Public Education

A Source Water Protection Steering Committee was formed consisting of key stakeholders, and representatives appointed from the municipalities and townships in the Centre Region. A total of 12 steering committee members met on a quarterly or more frequent basis to facilitate effective implementation of this source water protection plan, as well as to foster public participation and education. The steering committee served for both the wellhead and watershed protection programs. The steering committee consisted of the following members:

- Dennis Hammeister-Supervisor, Harris Twp.
- Kevin Abbey-Planning Commission, Ferguson Twp.
- Greg Love-Zoning Officer, Halfmoon Twp.
- David Koll-Supervisor, College Twp.

- Bryce Boyer-Supervisor, Patton Twp.
- Mark Whitfield-Public Works Director, State College Borough
- Richard Mauser-Benner Twp.
- Ann Donovan-Centre County Conservation District
- Cory Miller-Executive Director, University Area Joint Authority
- Rob Cooper-Director of Engineering Services, Penn State
- Robert Crum-Planning Director, Centre Regional Planning Agency

Regular meetings were held to discuss the status of the program, provide guidance, and to ensure the program is being managed properly for long-term commitment. The initiatives fostered by SCBWA and its Source Water Protection Steering Committee are discussed in the next section.

The SCBWA has been actively seeking public education opportunities having already made several public presentations as detailed in Section 2.15 of this report. The SCBWA will advertise and provide public presentations of the findings of this study at public meetings (such as municipal supervisor or planning commission meetings) in each of the municipalities within its service area to foster source water protection public education. The public education presentations will occur within one year of final acceptance of this study and will include results and conclusions of the study as well as recommendations for public involvement. In addition, the SCBWA newsletter and website will be used as additional avenue to provide public education information to its customers.

2.15 Watershed Protection Area Management and Commitment

SCBWA has pursued a variety of effective watershed protection area management techniques to be proactively protective of the Slab Cabin Run watershed and its regionally vital water resources. Over the past 15 years SCBWA has, at a cost of $12 million, constructed three new wellfields to supply its' growing system and to reduce the dependence on the Thomas and Harter Wellfields. In order to better use these new wellfields, SCBWA has constructed several system interconnects so that water from the new wellfields can be distributed to areas formerly supplied by the Thomas and Harter Wells. SCBWA personnel monitor the flow in Slab Cabin Run and as the flow declines in the stream, SCBWA can increase production from wells located outside of the Slab Cabin Run watershed to reduce the impact on the stream. Another factor that will further limit the demand on the Thomas and Harter wells is the limited potential for growth in the zones supplied by these wells. The Thomas and Harter wells supply State College Borough and Harris Township. State College Borough is essentially fully developed and Harris Township is committed to limited growth (much of the Township lies outside of the Regional Growth Boundary). Based on these factors, and the SCBWA's significant efforts to improve water quality in the watershed with property purchases and riparian buffer development, it is expected that stream environment will continue to improve.

The additional initiatives outlined below were achieved by review of local zoning and ordinances including *The Stormwater Management Plan for The Spring Creek Watershed*. Development right transfers and land acquisition has also been explored by SCBWA to aid in the watershed protection program. Outreach to the local agricultural community has been done to raise awareness of federal and state programs that provide financial support for riparian buffer planting that will improve Slab Cabin Run's water quality. In addition, SCBWA has submitted position letters in regard to various proposed land use changes as they become aware of these projects, and will continue to assist the local municipalities with the myriad issues that can arise with development in the area. A listing of the successful public education and watershed protection initiatives undertaken by SCBWA is provided below.

1. Mr. Max Gill, SCBWA Executive Director, has made several source water protection presentations including a water resources Public Forum run by the Spring Creek Watershed Community which was sponsored in part by SCBWA. In addition, several presentations have been made to municipalities, planning commissions, and to the Centre County Realtors Association to discuss the importance of groundwater protection and results of this study.

2. The SCBWA continues to explore and pursue water resource protection initiatives, including riparian buffer installation, well construction ordinances, working with the agricultural community to reduce non-point pollution sources, and public education. Mr. Gill held several meetings with landowners and with representatives of the Centre County Conservation District regarding establishing stream bank buffers along Slab Cabin Run and Roaring Run, a tributary of Slab Cabin Run. These streams supply surface water and impact the groundwater in the Water Authority's Thomas and Harter Well Fields. To date, three property owners have established or have agreed to establish riparian buffers along these streams and to install stream bank fencing to reduce any agricultural impacts on the streams.

3. The SCBWA continues its efforts to preserve lands within the Slab Cabin Run watershed to preserve the water resources of Wellfields 1 and 3. The SCBWA worked closely with the ClearWater Conservancy and with local municipalities, to recently purchase 423 acres in Musser Gap, a key tributary of Slab Cabin Run. This property will then be conveyed to the Pennsylvania Department of Conservation and Natural Resources and become part of Rothrock State Forest. This would ensure continued protection of the regions' groundwater resources. The SCBWA has agreed to contribute up to $550,000 in matching funds to

support acquisition of this key parcel of property, which is known to provide recharge to SCBWA Wellfields 1 and 3 based on dye tracing study results. The SCBWA also purchased 59 acres along W. Whitehall Road to preserve the recharge areas for these wellfields.

4. Mr. Gill's early concern about the potential development of land near Musser Gap lead to submittal of a position paper to Ferguson Township's planning personnel about the potential impact to the area's vital groundwater resources from this development. This paper and the support of others helped foster the adoption of the Ridge Overlay District Ordinance, which ensures that any development within the carbonate bedrock along the toe of Tussey Ridge is done to minimize water quality impacts. This ordinance is a great achievement toward protection of critical recharge areas along the base of Tussey Ridge.
5. In cooperation with the SCBWA, the Centre Regional Planning Agency has recently finished summaries for each wellfield that include information on municipal location, land use, relationship to the regional comprehensive plan, and zoning to assist in this task and for public education. These summary reports will be publicly available as public education material and are included as Appendix A of this report.
6. A survey of local wellhead protection area and well construction ordinances was conducted to determine the status of any existing or proposed ordinances. Currently, the SCBWA is determining how best to implement a region-wide well construction ordinance to ensure that any wells drilled within the area meet minimum construction standards for aquifer protection.
7. SCBWA voluntarily connected Wellfield 1 to the SCBWA Filtration Plant to ensure delivery of only the highest-quality drinking water to its customers.
8. The SCBWA newsletter is circulated to all of its customers (65,000 people) and presents public education material including source water protection and conservation tips.
9. The SCBWA annually pledges financial contributions to the Spring Creek Watershed Community's Water Resources Monitoring Project, which collects water level and quality information within the Spring Creek Basin.
10. The SCBWA has worked closely with UAJA since the inception of the Beneficial Reuse Project, to ensure this important project advances while also protecting the area's water resources. Additional discussion on the Beneficial Reuse Project is provided in the next section.
11. The SCBWA continues to work with each of the local municipalities, governments, landowners, and stakeholders to foster source water protection initiatives in the

Spring Creek Watershed and will continue to commit energy toward source water protection goals.

As previously mentioned, the SCBWA will continue with public education initiatives by making source water protections presentations to municipal supervisors, planners, and the general public.

2.16 Beneficial Reuse Project Discussion

The UAJA's Beneficial Reuse project is an innovative wastewater reuse project that is proposed to introduce up to 3.0 MGD of highly-treated municipal wastewater to the Slab Cabin Run basin. This project is designed to protect Spring Creek from the wastewater's thermal impacts by treating the wastewater via microfiltration, reverse osmosis, and disinfection. The reclaimed water will then be pumped back to upper Slab Cabin Run basin to provide enhanced stream flow and groundwater recharge to the aquifer. As currently proposed, up to 1.5 MGD of treated wastewater will be recharged to the portion of Slab Cabin Run just downstream of Business Rte. 322 (Atherton St.). A portion of this 1.5 MGD will be utilized for irrigation at the Centre Hills Country Club as needed, with the balance used for stream flow enhancement via a constructed wetland proposed to be located northeast of the intersection of Branch Road and Atherton St., on the Kissinger property. Eventually as more than 1.5 MGD of reclaimed water becomes available, the final proposed phase will be to recharge the upper Slab Cabin Run watershed at a yet to be determined location. The current proposed locations are near where Slab Cabin Run passes by the Route 26/45 junction, just east of Pine Grove Mills.

The environmental benefits of a consistent supply of recharge water to Slab Cabin Run are obvious, however the potential impacts on the area's water resources from emerging contaminants such as endocrine disruptors and personal care products that can be found in treated wastewater are uncertain. Given the current state of uncertainty with emerging contaminants, the SCBWA's perspective on the Beneficial Reuse project is to proceed with the project, but with caution to prevent recharge of Wellfields 1 and 3 with Beneficial Reuse Water. The results of the upper Slab Cabin Run dye trace study indicated that Wellfields 1 and 3 do receive surface recharge from Slab Cabin Run rather rapidly. The dye trace study was partly designed to determine the potential travel times of recharge water from Slab Cabin Run to Wellfields 1 and 3. It was determined that dye added in the vicinity of the Slab Cabin Run/Route 26 confluence, a proposed area for Beneficial Reuse recharge via wetlands, were detected in SCBWA Wells 11 and 25 within three days. This discovery lead to a re-thinking of how Beneficial Reuse recharge might be applied in the Upper Slab Cabin Run Basin. The groundwater model was utilized to simulate two Beneficial Reuse scenarios, one with 1.5 MGD of recharge near the confluence of Slab Cabin Run and the junction Routes 26 and 45 (Scenario 1), and one with 1.5 MGD of recharge near the Route 26/Whitehall Road intersection (Scenario 2). Each of these model scenarios were run assuming that both Wellfields 1 and 3 were each pumped at typical rates. The groundwater particle tracking from both of these scenarios is shown in Figure 16. Scenario 1 shows that Wellfield 1 would ultimately receive recharge from addition of Beneficial Reuse water to this area, which is not suprising especially given what is now known about the nature of recharge to this wellfield from the dye tracing test. Scenario 2 shows that the recharge water would generally travel along strike and would ultimately provide baseflow to Slab Cabin Run below SCBWA Wellfields 1 and 3, therefore bypassing the wellfields. One key to conducting the Beneficial Reuse Project in Slab Cabin Run without recharging Wellfields 1 and 3 is to prevent overland runoff going into Slab Cabin Run, as it has been determined that water in Slab Cabin Run will eventually recharge these wellfields. The groundwater model shows that the Route 26/Whitehall Road recharge scenario could achieve the recharge without recharging Wellfields 1 and 3, however there is the possibility that some "short-circuiting" of groundwater flow could occur and Wellfields 1 and 3 could therefore receive Beneficial Reuse recharge. Additional site-specific studies would need to be conducted to verify if the Route 26/Whitehall Road modeled scenario is realistic, but it does provide some basis for siting a Beneficial Reuse recharge area in this portion of the Slab Cabin Run basin.

2.17 Slab Cabin Run Watershed Protection Program Discussion

The Slab Cabin Run Watershed Protection Program has been conducted to meet the needs of SCBWA to protect its valuable water resources within this basin. The groundwater level monitoring, stream flow monitoring collection, field surveys, dye tracing, data analysis, and groundwater modeling provides the basis for determining the nature of groundwater recharge within this complex hydrogeologic setting. A combination of mountain recharge and streamflow provide much of the recharge to the portion of the aquifer that recharges Wellfields 1 and 3, and the surface recharge for Shingletown Reservoir. The dye tracing study revealed the relatively rapid and interconnected nature of surface and subsurface flow in Slab Cabin Run and the ultimate recharge to Wellfields 1 and 3. The vulnerability of Wellfields 1 and 3 to surface contaminants exists as demonstrated by the presence of dye in these wellfields five days after injected into the watershed, traveling at a rate of up to nearly one mile per day. Therefore it is imperative that the SCBWA continue its management and commitment to watershed protection in Upper Slab Cabin Run to ensure the long-term protection of these very valuable water resources. SCBWA's management and board of directors have the knowledge, insight, resources, and initiative to continue the wise stewardship of the area's water resources and will continue to look for future opportunities to work with the local municipalities, landowners, and the agricultural community toward the goal of long-term water resource protection.

State College Borough Water Authority
Source Water Protection Report
Section 3
Wellhead Protection Study

The goal of developing this comprehensive Wellhead Protection Program for SCBWA is to protect each of the wellfields classified as groundwater sources, which includes Wellfields 2, 4, 5, 6, and 7. This has been achieved through characterization of the contribution area of each wellfield and long-term management practices for activities and land-use changes within the contribution areas of each wellfield that have the potential to degrade groundwater quality. Wellfields 2, 4, and 7 are contained in the Spruce Creek surface drainage, however are mostly within the Spring Creek groundwater basin. Regional groundwater mapping studies done by SRBC (Taylor, 1997) and Giddings (1974) show that some of the groundwater within the Spruce Creek headwaters actually drains toward Spring Creek. The extended Spring Creek groundwater basin is thought to be caused by the northeast-plunging bedrock, which drains groundwater toward the Spring Creek Basin. The Spring Creek/Spruce Creek groundwater divide is likely a transient feature that migrates seasonally in relation to aquifer levels. This study helps better define the dynamics of this groundwater divide as it relates to protection of the SCBWA's wellfields. Many of the same methodologies used for the upper Slab Cabin Run watershed protection program were utilized to characterize the portions of the aquifer recharging each wellfield, therefore a brief summary of the methodologies used for the wellhead protection study of each wellfield is presented followed by the results for each wellfield.

3.1 Wellhead Protection Study Methods

3.1.1 Data Acquisition

The data utilized for the SCBWA Wellhead Protection study were acquired from the same sources as for the Watershed Protection study including the literature review (Penn State and N.A. Water System's library), GIS data (Centre County Planning, geologic mapping (Parizek's 1982 unpublished mapping redigitized), soils mapping (PSU GIS mapping), meteorological data (PSU meteorology department), and water level data (Water Resources Monitoring Project and SCBWA). All data collected for this Wellhead Protection program were then compiled and formatted as necessary for use in this report. Data used in the report are provided in appropriate appendices and in GIS format as referenced.

3.1.2 Aquifer Testing

SCBWA Wellfields 5 and 6 had aquifer testing conducted as possible without disrupting routine wellfield operation as described in the respective sections for those wellfields. All available observation wells were monitored during each test to determine pumping impacts on the aquifer. The results of the aquifer testing are contained in the respective Results sections for each wellfield.

3.1.3 Geophysical Surveying

Electrical resistivity surveying was conducted around each wellfield to characterize the subsurface conditions such as depth to bedrock, presence of voids and fractures, and depth to water. Standard resistivity arrays were used, including Wenner, dipole-dipole and Schlumberger arrays. The subsurface information was then used as a means to estimate the variation of the depth to bedrock near each wellfield for groundwater modeling purposes. Appendix E contains the location of each resistivity array for each wellfield and the model results, while additional discussion is presented in the Results section for each wellfield.

3.1.4 Fracture Trace Analysis

As previously discussed, the nature of groundwater flow and well yields within Nittany Valley can be greatly influenced by the presence of fracture traces. A fracture trace analysis was conducted around each wellfield by two experienced scientists independently. The fracture traces that were commonly mapped by both scientists were then retained for fracture trace mapping purposes. Fracture traces mapped for each wellfield are shown on each wellfield's geologic map as referenced. The wells contained in SCBWA Wellfields 2, 4, 5, 6, and 7 were mapped on fracture traces, which at least in part accounts for the higher than average yield of wells found in those wellfields.

3.1.5 Groundwater Flow Model

A groundwater flow model was created to delineate each of the SCBWA wellfield's recharge areas and Zone II wellhead protection areas. The model domain includes all of the SCBWA wellfields and the source areas of the groundwater captured by those wellfields. In addition, the model boundaries were selected to coincide with natural groundwater flow divides wherever feasible. Therefore, the model encompasses the Spring Creek groundwater basin, which includes the Spring Creek watershed and upper portions of the Spruce Creek watershed. Figure 1 shows the regional source water protection areas with other scenarios presented and discussed in later sections of this report.

The flow model was developed in MODFLOW 2000 in the Groundwater Modeling System (GMS version 5.1, EMS-I). MODFLOW is an industry standard groundwater modeling program developed and maintained by the US Geological Survey (Harbaugh, et al., 2000). GMS (Environmental Modeling Research Laboratory, 2004) is a modeling environment that facilitates pre- and post-processing of model input and output. MODPATH (Pollock, 1994), a particle tracking post-processor for MODFLOW, was used to map zones of groundwater capture by water supply wells.

Previous delineations of wellhead protection areas for the SCBWA wellfields (Nittany Geoscience, 1992) included areas delineated by two-dimensional particle tracking. Those delineations differ from those provided here by omitting the influence of the vertical dimension and by having been based on piezometric heads (well water levels) tied to a specific time frame and recharge condition. Conditions that might alter well capture zones, such as drought or modifications of pumping at other well fields, could not be accounted for by the previous method. The groundwater model developed for this study includes all the SCBWA and Pennsylvania State University (PSU) wellfields and provides for a regional perspective on the area's groundwater conditions under various scenarios, including fluctuations in rainfall such as drought. In addition the impact of regional land use changes, such as increased development and impervious surface, can be simulated to assist in land use planning initiatives. The groundwater model is also fully three-dimensional and so can account for the influence on capture zones of features such as the depths of the open intervals of water supply wells.

Appendix J provides a detailed description of the model and its calibration to the comprehensive water level survey of October 1994 (Taylor, 1997). Output from the regional steady-state groundwater model, and specifically wellhead protection area delineations under a range of recharge conditions, are presented and discussed in later sections of this report. It should be noted that the influence of fracture traces on the shape of the SCBWA wellfield capture zones was tested by comparing the groundwater model's output in a scenario where a discrete fracture crosses through a wellfield versus the model output for a wellfield without any discrete fracture traces. The presence of the fracture trace was simulated as running perpendicular (approximately southeast to northwest) to the region's northeasterly groundwater flow direction. This northwest/southeast fracture trace orientation was selected to maximize any effect the fracture may have on the well's capture zone. In brief, there was no significant effect on the delineated capture zone's shape with the inclusion of the fracture trace in the groundwater model.

3.1.6 Source Water Assessment

PaDEP conducted a source water protection area delineation as part their contaminant source inventory for each wellfield. PaDEP's Source Water Assessment is included in Appendix H. The objectives of the assessment are to identify the pollutants in the contributing area, and then rank them in order of concern. This information is then incorporated into the more detailed Source Water Protection Program report.

On October 8, 1994, revisions to 25 Pa. Code Chapter 109.1 of DEP's rules and regulations defined a three-tiered wellhead protection area approach as follows:

Zone I.

The protective zone immediately surrounding a well, spring or infiltration gallery which shall be a 100-to-400-foot radius depending on site-specific source and aquifer characteristics. For a new system or as an expansion of an existing system, the water supplier must own or substantially control, through a deed restriction or other methods acceptable to the Department, the Zone I wellhead protection area in order to prohibit activities within Zone I that may have a potential adverse impact on source quality or quantity.

Zone II.

The zone encompassing the portion of the aquifer through which water is diverted to a well or flows to a spring or infiltration gallery. Zone II shall be a 1/2-mile radius around the source unless a more detailed delineation is approved.

Zone III.

The zone beyond Zone II that contributes surface water and groundwater to Zones I and II.

The Zone I, II, and III wellhead protection areas have been delineated for SCBWA Wellfields 2, 4, 5, 6, and 7, using PaDEP-approved methodologies. The SCBWA's Zone I wellhead protection areas for each wellfield were estimated based on graphs developed by PaDEP that factor in each well's lithology, open-interval length, and pumping rate. The groundwater model was used to delineate each wellfield's Zone II wellhead protection area for each of the SCBWA wellfields under maximum permitted pumping conditions. Using the maximum permitted pumping rate scenario to estimate the Zone II wellhead protection area provides a conservative wellhead protection area estimate since each wellfield is typically pumped at a fraction of the permitted rates. The Zone III wellhead protection area for each wellfield was estimated by delineating the surface drainage that would flow toward the Zone I and II wellhead protection areas for each wellfield.

3.1.6 Contaminant Source Inventory

The contaminant source inventory was conducted by PaDEP in the Source Water Assessment and is included as Appendix H. Each pollutant typically associated with the land use type or activity was identified, mapped, and ranked a letter value of A (high) thru F (low) as previously discussed. The results of the contaminant source inventory are summarized in the Results section for each respective wellfield.

3.1.7 Contingency Planning

SCBWA has written a contingency plan/emergency response plan so that any spills or other source water-threatening incidents can be responded to in an effective and timely manner. This plan is included as Appendix I and details SCBWA's approach to deal with a variety of situations to ensure the timely and effective protection of the water resources in such an event.

3.1.8 New Source Planning

New source planning was undertaken as part of this program as well during the SCBWA's long-range planning process with their engineer, Gwin, Dobson & Foreman. The results of this effort were presented in Section 2.13 New Source Planning.

3.1.9 Public Education

The public education aspect of the SCBWA Wellhead Protection Program was conducted jointly with the Watershed Protection Program including the Steering Committee and other public education initiatives and is discussed in Section 2.14 Public Education.

3.1.10 Wellhead Protection Area Management and Commitment

The SCBWA has pursued a variety of effective wellhead protection area management techniques to be proactively protective of the area's invaluable wellfields. The initiatives outlined below were achieved by review of local zoning and ordinances including *The Stormwater Management Plan for The Spring Creek Watershed*. Land acquisition has also been explored by SCBWA to aid in the wellhead protection program. A listing of the successful public education and wellhead protection initiatives undertaken by SCBWA beyond those listed for the Watershed Protection Program is provided below and in each wellfield's Results section.

1. Creation of groundwater contaminant survey forms for local industries that may exist within delineated Wellhead Protection Areas.
2. Purchase of 24 acres immediately surrounding the Alexander Wellfield to provide a buffer around the wells from planned commercial development.

3. Proactive quarterly groundwater monitoring of SCBWA test wells in the Ashcraft Wellfield and Buffalo Run to determine if the I-99 acid-rock drainage is migrating to the Gatesburg Aquifer.
4. Worked with Ferguson Township Public Works personnel to minimize road salt application in the vicinity of Wellfield 5 to prevent adverse impacts to groundwater quality.

3.2 Wellfield 2 (Gray's Woods Wellfield) Wellhead Protection Study Results

3.2.1 Background Information

Wellfield 2 consists of Wells 17, 18, and 19 as shown on Figure 1 with more detailed maps included as Figures 17 and 18. Wellfield 2 is located in Halfmoon Township where land use in the immediate area around the wellfield is largely forested, with a mixture of agriculture and residential land use in the surrounding area. SCBWA owns the 21.6 acres encompassing the wellfield area, and there will be a 200-foot parkland buffer to the north and east. Zoning in the area is a mixture of agricultural (A-1) where agricultural land uses and single-family dwellings are allowed, and Planned Community (PC), where development may occur but requires that 40 percent of a tract to be preserved as open space. In addition the PC zoning prohibits certain land uses within wellhead protection areas and requires a 150-foot buffer around well sites. Land use and the geologic setting in the area are generally conducive to protection of the area's groundwater resources, with a deep water table, thick soil cover, and lack of significant industrial activity. Some conditional land uses that could impact groundwater resources in the area include mining, however no mines are known to be proposed or operating in the area. Agricultural land uses could be non-point sources of groundwater contamination, however the thick soil cover and deep water table likely minimize these potential impacts. The forecasted growth for this area is 1500-2000 new dwelling units in the next 30 years. An environmentally sound and economically feasible wastewater treatment alternative may also be a future challenge for this area since it is outside of the regional growth boundary and not serviced by public sewer. The Centre Regional Planning Agency's summary in Appendix A provides additional detailed discussion on the current and future land use in the area.

3.2.2 Hydrogeologic Setting

Wellfield 2 consists of Wells 17, 18, and 19 as shown on Figure 1 with more detailed maps included as Figures 17 and 18. Wellfield 2 is located in the Barrens Region on the northwest side of Nittany Valley, in the Valley and Ridge physiographic province. Test wells intersect deep (100 to 300 feet), well-drained, sandy soils underlain by quartzose carbonate rocks, which are characteristic of the Barrens Region. The wellfield is in the Spring Creek groundwater basin and the Spruce Creek (surface) drainage basin (Wood, 1980).

The geologic map of the region shows that the test drilling of Wellfield 2 probably penetrated rocks of the Ore Hill and Lower Sandy members of the Gatesburg Formation. These are the lower units of what has been referred to as the Gatesburg Aquifer (Parizek, 1980). Rocks encountered in the test drilling of Wellfield 2 are consistent with published descriptions of these rock units. The Ore Hill Member consists predominantly of dark-gray, medium- to coarsely-crystalline dolomite with minor interbeds of shale and siltstone and is approximately 250 to 300 feet in thickness (Parizek, 1987; Wood, 1980; Hunter, 1977). The Lower Sandy Member is predominantly orthoquartzite and dolomite with interbeds of shaley and sandy dolomites and has a thickness of approximately 400 to 500 feet (Parizek, 1987; Wood, 1980; Hunter, 1977).

Wellfield 2 is on the southeast-dipping limb of the Buffalo Run Anticline where the Birmingham Thrust Fault, which surfaces approximately 3000 feet northwest of the wellfield, superposes the Cambrian-age rock layers intersected by the wellfield over relatively younger and more steeply inclined Cambrian and Ordovician strata. Parizek (1980) assumed that the Birmingham Thrust Fault is a barrier to groundwater flow in a northwest-southeast direction. Significant capacity for groundwater storage and transmission is probably provided by solution voids along joints and surfaces separating rock layers. This transmissive capacity would tend to promote flow in the northeast-southwest direction of the rock layers (flow under static conditions is to the northeast, according to Wood, 1980). The Gatesburg Aquifer extends over 10 miles in this direction (Parizek, 1980). Test drilling confirmed Parizek's (1980) estimate that significant quantities of groundwater could be tapped from the aquifer to depths of at least 600 feet. Weathering of the Gatesburg Formation has resulted in a significant thickness (100 to 300 feet) of sandy well-drained residual soils overlying the Barrens region. This deeply-developed permeability is in part responsible for the relatively deep water table (150 to 350 feet) (Parizek, 1987). Surface water flow in the area directly adjacent to the wellfield is minimal owing to the high infiltration capacities of the sandy soils and deep water table. Therefore, most precipitation not lost to evapotranspiration provides recharge to the Gatesburg Aquifer. When precipitation rates exceed infiltration, surface water flow drains to tributaries of Beaver Branch located south of the site.

Two electrical resistivity geophysical survey transects were conducted in the vicinity of Wellfield 2 to assist in the subsurface characterization of the wellfield as contained in Appendix E. The depth to bedrock is typically greater than 100 feet in this area and the resistivity models do not appear to show the depth to bedrock at the modeled depths of either 32.2 meters (106 feet) or 52.9 meters (173 feet). The resistivity models reinforce the significantly deep soil cover in the Gatesburg Formation.

3.2.3 Wellhead Protection Area Delineation

Table 2 summarizes the Zone I, II, and III wellhead protection areas for Wellfield 2. The Zone 1 wellhead protection area radii for each well are: Well 17-400 feet, Well 18-100 feet, Well 19-400 feet. Figures 17 and 18 show the delineated capture zones under normal and maximum-permitted pumping rates, respectively, based on the groundwater model results. Each map includes geology, fracture traces in the vicinity of the wells, mapped sinkholes, and potential sources of contamination identified in PaDEP's source water assessment. Two model scenarios were run to delineate the capture zones, one scenario under typical pumping conditions and one scenario using the maximum permitted pumping rate for each well simultaneously. Under both scenarios the Wellfield 2 capture zone extends through the Gatesburg Formation and toward Bald Eagle Ridge, with the maximum permitted pumping scenario showing more hydraulic capture toward the southwest. The capture zone for Wellfield 2 under the maximum-permitted pumping rates, shown in Figure 18, represents the Zone II wellhead protection area for Wellfield 2 and has an area of 6.39 square miles. The Zone III wellhead protection area for Wellfield 2 is that area that would ultimately contribute both surface water and groundwater to Zone II and is also shown on Figure 18 with a total area of 8.38 square miles.

3.2.4 Potential Sources of Contamination

Fortunately there are no registered potential point sources of contamination in the Wellfield 2 wellhead protection area based on the extent of the capture zone and the PaDEP environmental site database. As previously discussed the land use in this area is a combination of forest (State Gamelands 176), agricultural and residential. The PaDEP source water assessment contained in Appendix H notes the following activities that may be potential sources of contamination for Wellfield 2 in decreasing order of rank with associated contaminants of concern: transportation corridors (road salt, MTBE), residential/light commercial (various), agricultural activities (nitrate), on-lot waste disposal (nitrate), and drinking water treatment plants (chlorine). In general, the deep water table and thick soil mantle provide a high level of groundwater protection for Wellfield 2, however potential future growth in this area may increase the likelihood for groundwater quality impacts due to on-lot septic system disposal and increased traffic.

3.3 Wellfield 4 (Nixon Wellfield) Wellhead Protection Study Results

3.3.1 Background Information

Wellfield 4 consists of Wells 41, 43, and 53 as shown on Figure 1 with more detailed maps included as Figures 19 and 20. Wellfield 4 is located in Ferguson Township, approximately 3 miles southwest of State College, where land use in the immediate area around the wellfield is mostly pasture, with a mixture of mostly agriculture and woodland with some residential land use in the surrounding area. Zoning in the area is predominantly rural agricultural (RA) which allows only one residential dwelling unit per 50 acres, which is very restrictive with respect to development and is conducive to protecting groundwater resources from development pressures. The Centre Regional Planning Agency's summary in Appendix A provides additional detailed discussion on the current and future land use in the area.

3.3.2 Hydrogeologic Setting

Wellfield 4 is on gently rolling topography in a northeast-trending valley situated between Gatesburg Ridge to the northwest and a less prominent ridge to the southeast. Gatesburg Ridge rises to 300 feet above the 1,180 feet above mean sea level (amsl) elevation of the wellfield at a distance of approximately 5000 feet northeast. Ephemeral drainage runs through the wellfield to the southwest where it joins the Beaver Branch, whose waters ultimately enter Spruce Creek and the Juniata River. However, the ambient groundwater table is sloped so that under natural conditions groundwater locally flows from the southeast toward the northwest, ultimately turning northeast to drain to the Spring Creek drainage basin and the West Branch of the Susquehanna River. Therefore, the wellfield lies on a strip of land between two major drainage divides (separated by about 5 miles near the wellfield) in which surface water and groundwater flow in generally opposed directions.

The Nixon Wellfield produces from a carbonate bedrock aquifer that is bounded by Tussey Ridge to the southeast and Bald Eagle Ridge to the northwest. Most of the water in the aquifer is stored and transmitted through dissolution openings representing an average 1 to 2 percent of the aquifer's volume (based on estimates of field specific yield by Giddings, 1974). The openings were created by the passage of slightly acidic waters through fractures. Some rock formations, such as the Nittany Dolomite that is penetrated by Well 43 in the Nixon Wellfield, also possess a diffuse intergranular storage space (porosity) that is similar in volume to the dissolution openings.

Five electrical resistivity geophysical survey transects were conducted in the vicinity of Wellfield 4 to assist in the subsurface characterization of the wellfield as contained in Appendix E. The depth to bedrock is shown to range from 16-20 meters (approximately 50-65 feet), which is consistent with drilling logs in this wellfield and with the Nittany Dolomite

3.3.3 Wellhead Protection Area Delineation

Table 2 summarizes the Zone I, II, and III wellhead protection areas for Wellfield 4. The Zone 1 wellhead protection area radii for each of the wells is 400 feet, which assumes that the 2,700 gpm rate permitted by SRBC is evenly distributed amongst the wells. Figures 19 and 20 show the delineated capture zones under normal and maximum-permitted pumping rates, respectively, based on the groundwater model results. Each map includes geology, fracture traces in the vicinity of the wells, mapped sinkholes, and potential sources of contamination identified in PaDEP's source water assessment. Two models were conducted to delineate the capture zones, one scenario under typical pumping conditions and one scenario using the maximum permitted pumping rate for each well simultaneously. Under both scenarios the Wellfield 4 capture zone extends along bedrock strike through the Nittany, Stonehenge, and Gatesburg formations, with the maximum permitted pumping scenario showing more hydraulic capture toward the southwest, generally along bedrock strike. The capture zone for Wellfield 4 under the maximum-permitted pumping rates shown in Figure 20 represents the Zone II wellhead protection area for Wellfield 4 and has an area of 3.42 square miles. The Zone III wellhead protection area for Wellfield 4 is that area that would ultimately contribute both surface water and groundwater to Zone II and is also shown on Figure 20 with a total area of 27.36 square miles, which significantly increases the wellhead protection area due to the large tracts of land that have surface drainage toward the wellfield's capture zone.

3.3.4 Potential Sources of Contamination

Fortunately there are no registered potential point sources of contamination in the Wellfield 4 wellhead protection area based on the extent of the capture zone and the PaDEP environmental site database. As previously discussed the land use in this area is a combination of agriculture and forest with some residential. The PaDEP source water assessment contained in Appendix H notes the following activities that may be potential sources of contamination for Wellfield 4 in decreasing order of rank with associated contaminants of concern: transportation corridors (road salt, MTBE), residential/light commercial (various), agricultural activities (nitrate), on-lot waste disposal (nitrate), pipelines/sewers (nitrate) and drinking water treatment plants (chlorine). In general, the current zoning (RA) and lack of significant forecasted growth provides a high level of groundwater protection for Wellfield 4. Agricultural land uses could be non-point sources of groundwater contamination and the area is not served by public sewer, therefore the combination of agricultural land uses and on-lot septic systems could also be potential sources of contamination, specifically nitrates and coliform bacteria. In addition, there are some mapped sinkholes within approximately one mile of the wellfield in the Zone II wellhead protection area, which combined with a large drainage area toward the wellfield could direct non-point contaminants into the aquifer.

3.4 Wellfield 5 (Chestnut Ridge) Wellhead Protection Study Results

3.4.1 Background Information

Wellfield 5 (Circleville Wellfield) consists of Wells 55 and 57 as shown on Figure 1 with more detailed maps included as Figures 21 and 22. Wellfield 5 is located in Ferguson Township, where land use in the immediate area around the wellfield is primarily residential with some light commercial activity. Wellfield 5's location near relatively dense residential development, adjacent to a busy intersection, in an area particularly susceptible to sinkhole formation, makes it one of the more susceptible wellfields to the adverse impacts that development pressures and transportation corridors can have on groundwater. The Centre Regional Planning Agency's summary in Appendix A provides additional detailed discussion on the current and future land use in the area.

3.4.2 Hydrogeologic Setting

Wellfield 5 is located on the southeast limb of the Gatesburg Anticline where the rock dips 10 to 25 degrees towards the southeast. No structural complexities have been mapped directly in the area, however tear and thrust faults have been mapped one - half to one mile south-southeast of the study area. Both wells penetrate the Gatesburg Formation with Well 55 intercepting the Upper Sandy Member and Well 57 intercepting the Mines and Upper Sandy members. The Upper Sandy Member consists of orthoquartzite, dolomite cemented sandstone, pure dolomite, shaley dolomite, and sandy dolomite. The Mines Member primarily consists of coarse-grained dolomite and oolitic chert (Hunter, 1977). The contact between these members is transitional and can be determined by the lack of chert and an increase in the amount of sandstone in the Upper Sandy Member. Parizek (1987) reports a range of yields of less than 10 to greater than 1000 gpm from wells penetrating these formations. The depth to water in the area ranges from 150 to 200 feet. As previously noted, the area is prone to sinkhole formation and several large sinkholes used for stormwater basins are adjacent to the wellfield and previous soil collapses have been repaired to prevent rapid infiltration of surface water into the groundwater system.

Four electrical resistivity geophysical survey transects were conducted in the vicinity of Wellfield 5 to assist in the subsurface characterization of the wellfield as contained in Appendix E. The depth to bedrock is shown to be greater than 20 meters (approximately 65 feet), which is consistent with drilling logs in this wellfield. Resistivity models from transects 36 and 62 show high conductivity zones that may be representative of clay or water-filled voids near the bedrock interface as well as pinnacled bedrock surfaces, which are common in this area.

A pumping test was conducted on Well 57 from July 21-23, 2003, to determine the impacts on the aquifer from pumping this well at its typical pumping rate of 340-350 gpm. Water levels were monitored in SCBWA Well 55 during the testing and the water level in this well actually rose approximately 0.5 feet during the test, while the water level drawdown in Well 57 was approximately 20 feet. Appendix D summarizes the data and includes water level charts for each well.

3.4.3 Wellhead Protection Area Delineation

Table 2 summarizes the Zone I, II, and III wellhead protection areas for Wellfield 5. The Zone 1 wellhead protection area radii for Well 55 is 135 feet and for Well 57 is 140 feet. Figures 21 and 22 show the delineated capture zones under normal and maximum-permitted pumping rates, respectively, based on the groundwater model results. Each map includes geology, fracture traces in the vicinity of the wells, mapped sinkholes, and potential sources of contamination identified in PaDEP's source water assessment. Two models were conducted to delineate the capture zones, one scenario under typical pumping conditions and one scenario using the maximum permitted pumping rate for each well simultaneously. Under both scenarios the Wellfield 5 capture zone extends along bedrock strike through the Nittany, Stonehenge, and Gatesburg Formations. The capture zone for Wellfield 5 under the maximum-permitted pumping rates shown in Figure 22 represents the Zone II wellhead protection area for Wellfield 5 and has an area of 2.93 square miles. The Zone III wellhead protection area for Wellfield 5 is that area that would ultimately contribute both surface water and groundwater to Zone II and is also shown on Figure 22 with a total area of 13.12 square miles.

3.4.4 Potential Sources of Contamination

Fortunately there are no registered potential point sources of contamination in the Wellfield 5 wellhead protection area based on the extent of the capture zone and the PaDEP environmental site database. As previously discussed the land use in this area is primarily residential and therefore the resultant pressure from increased development is of concern for Wellfield 5. The PaDEP source water assessment contained in Appendix H notes the following activities that may be potential sources of contamination for Wellfield 5 in decreasing order of rank with associated contaminants of concern: transportation corridors (road salt, MTBE), residential/light commercial (various), agricultural activities (nitrate), pipelines/sewers (nitrate), on-lot waste disposal (nitrate), drinking water treatment plants (chlorine), and printer and blueprint shops (xylenes). In general, the land use in the area surrounding Wellfield 5 could have impacts on water quality, especially transporation corridors, given the proximity of the wellfield to a busy intersection and nearby sinkholes. Elevated chloride levels have been detected in Well 57, and the SCBWA has worked with Ferguson Township personnel to minimize the use of road salt in the nearby vicinity of this wellfield.

3.5 Wellfield 6 (Alexander) Wellhead Protection Study Results

3.5.1 Background Information

Wellfield 6 (Alexander Wellfield) consists of Wells 62, 63, 64, and 65 as shown on Figure 1 with more detailed maps included as Figures 23 and 24. Wellfield 6 is located in Benner Township very near the Patton Township border. Land use in the immediate area around the wellfield is primarily agricultural, with the University Park Airport directly south, several light industrial operations (Fullington Bus and Airport Commerce Park) to the west and east, and single family home neighborhoods further to the east. The land in Benner Township is zoned Campus Industrial in the immediate area around the wellfield, which allows agriculture, light commercial and industrial facilities, but prohibits industrial use that would use chemicals that may degrade water quality. The remaining portion of the wellfield area in Benner Township is zoned as low-density residential. The adjacent Patton Township is zoned as Agricultural (A-1) where residential development may occur but requires 50% of each tract to be preserved as open space. The Patton Township area is also zoned as Planned Airport District (PAD), which allows mixed uses, however requires 40% to be preserved as open space and prohibits land uses that would store chemicals that could adversely impact groundwater, such as road salt, petroleum products and other hazardous materials. Wellfield 6's location near commercial and industrial operations would normally make the wellfield particularly susceptible to contamination, however additional protection is afforded by the thick soil cover and relatively deep water table (>200 feet). The Centre Regional Planning Agency's summary in Appendix A provides additional detailed discussion on the current and future land use in the area.

3.5.2 Hydrogeologic Setting

Wellfield 6 is located in the Nittany Valley of the Valley and Ridge physiographic province on the north edge of the Gatesburg Ridge. This wellfield is located on the northwest limb of the Gatesburg Anticline where the strata dip 10 to 20 degrees toward the northwest. No on-site structural geologic complexities exist, although the Birmingham thrust fault has been mapped one-half to one mile north-northwest of the study area. Wellfield 6 penetrates the Upper Sandy Member of the Gatesburg Formation. The Upper Sandy Member consists of orthoquartzite, dolomite-cemented sandstone, pure dolomite, shaley dolomite, and sandy dolomite (Hunter, 1977). Parizek (1987) reports a range of yields of less than 10 to greater than 1000 gpm from wells penetrating this formation. Buffalo Run, a tributary of Spring Creek, is the nearest stream draining the area. However, the area is predominantly underdrained by the relatively permeable, unconsolidated and semi-consolidated residuum of the Gatesburg Formation, and the adjacent carbonate formations.

Three electrical resistivity geophysical survey transects were conducted in the vicinity of Wellfield 6 to assist in the subsurface characterization of the wellfield as contained in Appendix E. The depth to bedrock is shown to be apprixmately 20 meters (approximately 65 feet), which is consistent with drilling logs in this wellfield and the known geology of the area. In addition, the bedrock surface appears to be pinnacled in some areas with near vertical zones of low resistivity (e.g. center of Transect 48), which are consistent with vertical fracturing.

A pumping test was conducted on Well 64 from July 28-30, 2003, to determine the impacts on the aquifer from pumping this well at its typical pumping rate of 310-340 gpm. Water levels were monitored in two accessible SCBWA wells in Wellfield 6 and four nearby available private wells. Appendix D summarizes the data and includes water level charts for each well. Drawdown in all monitored wells decreased from approximately 0.2 to 0.5 feet during the testing period, with the exception of the Alexander residential well, which had approximately 3 feet of drawdown, but may have been related to use of this well. The results of this test indicate the relatively low impact that use of Well 64 has on the surrounding wells, due in large part to the high productivity and relatively low demand on this well.

3.5.3 Wellhead Protection Area Delineation

Table 2 summarizes the Zone I, II, and III wellhead protection areas for Wellfield 6. The Zone 1 wellhead protection area radii for each well is as follows: Well 62- 295 feet, Well 63-175 feet, Well 64-330 feet, and Well 65-175 feet. Figures 23 and 24 show the delineated capture zones under normal and maximum-permitted pumping rates, respectively, based on the groundwater model results. Each map includes geology, fracture traces in the vicinity of the wells, mapped sinkholes, and potential sources of contamination identified in PaDEP's source water assessment. Two models were conducted to delineate the capture zones, one scenario under typical pumping conditions and one scenario using the maximum permitted pumping rate for each well simultaneously. Under both scenarios the Wellfield 6 capture zone extends southwest along bedrock strike primarily through the Gatesburg Formation. The capture zone for Wellfield 6 under the maximum-permitted pumping rates shown in Figure 24 represents the Zone II wellhead protection area for Wellfield 6 and has an area of 13.39 square miles. The Zone III wellhead protection area for Wellfield 6 is that area that would ultimately contribute both surface water and groundwater to Zone II and is shown on Figure 24 with a total area of 20.05 square miles.

3.5.4 Potential Sources of Contamination

There are several registered potential point sources of contamination in and near the Wellfield 6 wellhead protection area based on the extent of the capture zone and the PaDEP environmental site database. The sites include several Resource Conservation Recovery Act (RCRA) Small Quantity Generators (Lowe's, State of the

Art) and leaking underground storage tanks (Patton Twp., and Ameron), however fortunately these facilities utilities are quite distant (> 5 miles) from the wellfield and do not pose a significant or immediate threat to the groundwater source of Wellfield 6. The Fullington Bus facility is adjacent to the wellfield and has above ground fuel storage tanks with secondary containment that should not pose a hazard to the wellfield as long as there is not a surface release during fueling operations. In addition, the University Park Airport is near Wellfield 6 to the southeast and although outside of the delineated capture zone, could be a source of jet fuel and deicing agents. The PaDEP source water assessment contained in Appendix H notes the following activities that may be potential sources of contamination for Wellfield 6 in decreasing order of rank with associated contaminants of concern: transportation corridors (road salt, MTBE), residential/light commercial (various), PSU wastewater spray fields (nitrates), University Park Airport (MTBE), pipelines/sewers (nitrate), agricultural activities (nitrate), landfills and dumps (various), drinking water treatment plants (chlorine), on-lot waste disposal (nitrate), gas stations (MTBE), vehicle repair shops (MTBE), and RCRA facilities (various). Wellfield 6's location near commercial and industrial operations, and several mapped sinkholes, would normally make the wellfield particularly susceptible to contamination, however additional protection is afforded by the thick soil cover and relatively deep water table (>200 feet), thereby minimizing these potential risks.

3.6 Wellfield 7 (Kocher) Wellhead Protection Study Results

3.6.1 Background Information

Wellfield 7 (Kocher) consists of Wells 71, 73, 78, and 79 as shown on Figure 1 with more detailed maps included as Figures 25 and 26. Wellfield 7 is located in Ferguson Township where land use in the immediate area around the wellfield is primarily agricultural, with forest to the north and single family home neighborhoods to the west. Zoning in the area is predominantly rural agricultural (RA) which allows only one residential dwelling unit per 50 acres, which is very restrictive with respect to development and is conducive to protecting groundwater resources from development pressures. The remaining area is zoned as rural residential or single family residential. The Centre Regional Planning Agency's summary in Appendix A provides additional detailed discussion on the current and future land use in the area.

3.6.2 Hydrogeologic Setting

Wellfield 7 is situated within Nittany Valley, in the Valley and Ridge physiographic province. The wellfield is within the Tadpole-Fairbrook region, identified by Parizek (1987) as a potential high yield wellfield. Of the ten potential high-yield wellfields identified by Parizek (1987), the Tadpole-Fairbrook region was the only region to receive a "very high" overall ranking, with an estimated yield potential of four to eight million gallons per day (Parizek, 1987). Wellfield 7 is located within the Spruce Creek surface-water drainage basin. The Spring Creek groundwater-drainage divide, a transient feature, extends into the Spruce Creek surface-water drainage basin. Wellfield 7 is situated on this transient boundary. The nearest surface-water stream, Tadpole Run, is located approximately 2000 feet southwest of the wellfield and flows northward toward Beaver Branch, a tributary of Spruce Creek.

The geologic map of the region as well as detailed logging of drill cuttings, indicates that the Wellfield 7 wells penetrate rocks of the Stonehenge Limestone and the Mines Dolomite Member of the Gatesburg Formation. The Stonehenge Limestone is predominantly limestone with some dolomitic limestone, and it has a thickness of approximately 300 to 500 feet (Hunter, 1977). The Mines Dolomite Member is predominantly dolomite with abundant oolitic chert, and it has a thickness of approximately 260 feet (Hunter, 1977).

The wellfield is on the southeast-dipping limb of the Pennsylvania Furnace anticline. Mapped bedding in the vicinity of Wellfield 7 dips 27-43 degrees to the southeast. Major structural features mapped in the vicinity include two thrust faults and numerous cross faults (Hunter, 1977). Another prominent feature is the Port Matilda-McAlevys Fort lineament, which cuts through the Pennsylvania Furnace anticline just southwest of the wellfield (Tadpole Run flows northward along this lineament). Parizek (1987) points out that the Port Matilda-McAlevys Fort lineament results in an increased overall permeability and storativity in the region. The combined effects of these structural features result in an abundance of available groundwater in the vicinity. In general, depth to water in the region surrounding Wellfield 7 is shallow, typically less than 100 feet depending upon topographic setting and seasonal fluctuation. In Wellfield 7 the depth to water ranges from 50 to 100 feet.

Three electrical resistivity geophysical survey transects were conducted in the vicinity of Wellfield 7 to assist in the subsurface characterization of the wellfield as contained in Appendix E. The depth to bedrock is shown to be apprixmately 20 meters (approximately 65 feet), which is consistent with drilling logs in this wellfield and the known geology of the area. In addition, the bedrock surface appears to be pinnacled in some areas with near vertical zones of low resistivity (e.g. near center of Transects 52 and 53, and left side of Transect 54), which are consistent with vertical fracturing.

3.6.3 Wellhead Protection Area Delineation

Table 2 summarizes the Zone I, II, and III wellhead protection areas for Wellfield 7. The Zone 1 wellhead protection area radii for Wells 71, 73, and 78 is 400 feet, and for Well 79 is 140 feet. Figures 25 and 26 show the delineated capture zones under normal and maximum-permitted pumping rates, respectively, based on the groundwater model results. Each map includes geology, fracture traces in the vicinity of the wells, mapped sinkholes, and potential sources of contamination identified in PaDEP's source water assessment. Two models were conducted to delineate the capture zones, one scenario under typical pumping conditions and one scenario using the maximum-permitted pumping rate for each well simultaneously. Under both scenarios the Wellfield 7 capture zone extends along bedrock strike through the Gatesburg Formation and then extends southward into the Nittany and Axemann formations, with the maximum pumping scenario showing hydraulic reach toward Tussey Ridge. The capture zone for Wellfield 7 under the maximum-permitted pumping rates shown in Figure 25 represents the Zone II wellhead protection area for Wellfield 7 and has an area of 6.65 square miles. The Zone III wellhead protection area for Wellfield 7 is that area that would ultimately contribute both surface water and groundwater to Zone II and is also shown on Figure 25 with a total area of 12.62 square miles.

3.6.4 Potential Sources of Contamination

Fortunately there are no registered potential point sources of contamination in the Wellfield 7 wellhead protection area based on the extent of the capture zone and the PaDEP environmental site database. As previously discussed the land use in this area is a combination of agriculture and forest with some residential. The PaDEP source water assessment contained in Appendix H notes the following activities that may be potential sources of contamination for Wellfield 7 in decreasing order of rank with associated contaminants of concern: transportation corridors (road salt, MTBE), residential/light commercial (various), agricultural activities (nitrate), and on-lot waste disposal (nitrate). In general, the current zoning and lack of significant forecasted growth provides a high level of groundwater protection for Wellfield 7. Agricultural land uses could be non-point sources of groundwater contamination and the area is not served by public sewer, therefore the combination of agricultural land uses and on-lot septic systems could also be potential sources of contamination, specifically nitrates and coliform bacteria. In addition, there are some mapped sinkholes within approximately one mile of the wellfield in the Zone II wellhead protection area, which combined with agricultural runoff could direct non-point contaminants into the aquifer.

3.7 Wellhead Protection Program Discussion

The SCBWA Wellhead Protection Program has been conducted to meet the needs of the SCBWA to protect its valuable wellfields. The groundwater level monitoring, field surveys, data analysis, and groundwater modeling provides the basis for determining the nature of groundwater recharge within this complex hydrogeologic setting. The wellhead protection areas delineated in this study show that each wellfield's capture zone is overwhelmingly related to bedrock strike along which groundwater preferentially flows. In most cases the wellfield capture zones are relatively narrow compared to their length, which ranged from approximately 2 to 10 miles. The wellhead protection areas also extend across various types of land uses and municipal boundaries, which adds to the challenge of source water protection management. As previously mentioned, the SCBWA has the resources and wherewithal to be proactive in its long-term source water protection efforts, which include public education, involvement with local government and development issues.

REFERENCES

Braker, W.L., 1981, Soil survey of Centre County, Pennsylvania: U.S. Department of Agriculture, Soil Conservation Service, 162 p.

Butts, C., and Moore, E.S., 1936, Geology and mineral resources of the Bellefonte

Quadrangle, Pa.: U.S. Geological Survey Bulletin 855, 111 p.

Ciolkosz, E.J., April 2000, Pennsylvania State Soil Characterization Laboratory, Database System Documentation, Agronomy Series Number 145, Agronomy Dept, Pennsylvania State University, 19 p.

Downer, C.W., and F.L. Ogden, 2002, GSSHA – Users Manual, US Army Engineering Research and Development Center, Vicksburg, Miss.

Environmental Modeling Research Laboratory, 2004, Groundwater Modeling System – Tutorial, Vol. 1, Brigham Young University,

Environmental Modeling Research Laboratory, 2004, Watershed Modeling System – version 7.1, Brigham Young University,

Fulton, J.W., Koerkle, E.H., McAuley, S.D., Hoffman, S.A., and L.F. Zarr, June 2005, Hydrologic Setting and Conceptual Hydrologic Model of the Spring Creek Basin, Centre County, Pennsylvania, USGS, Scientific Investigations Report 2005-5091, 83p.

Giddings, M.T., 1974, Hydrologic budget of Spring Creek Drainage Basin, Pennsylvania: University Park, Pa., The Pennsylvania State University, Ph.D. dissertation, 76 p., 2 pls. 13 figs.

Harbaugh, A.W., Banta, E.R., Hill, M.C., and M.G. McDonald, 2000, MODFLOW-2000, the US Geological Survey Modular Ground-Water Model-User Guide to Modularization Concepts and Ground-Water Flow Process, USGS Open File Report, 00-92.

Lattman, L.H., and Parizek, R.R., 1964, Relationship between fracture traces and the occurrence of ground water in carbonate rocks: Journal of Hydrology, v. 2, p. 73-91.

Nittany Geoscience, January 1992, Determination of Wellhead Protection Areas for the State College Water Authority Nixon Well Field, Feguson Township, Pa.

Nittany Geoscience, 1991, Evaluation of the Influence of Groundwater Withdrawal from Harter and Thomas Wellfields on Slab Cabin Run, State College, Pennsylvania: 17 p.

Parizek, R.R., and T.H. Filley, 1982, Centre Region Aquifer Study, Part 1, Abstract and Maps from Definitions of Aquifers and Confining Beds within the Centre Region, Centre County, Pennsylvania, Centre Regional Planning Commission.

Parizek, R.R., 1978, Ground-water pollution potential from land use adjacent to the Harter Well Field, Borough of State College Water Authority, Consulting Hydrogeologist, 23 p.

Parizek, R.R., and Drew, L.J., 1966, Random drilling for water in carbonate rocks: Proceedings of a symposium and short course on computers and operations research in mineral industries, Mineral Industries Experiment Station, Vol. 3, (Special Publication 2-65), The Pennsylvania State University, University Park, Pa., p. 1-22.

Parizek, R.R., White, W.B., and Langmuir, Donald, 1971, Hydrogeology and Geochemistry of Folded and faulted carbonate rocks of the central Appalachian type and related land use problems: Pennsylvania State University Circular 82.

Parizek, R.R., 1984, Pollution potential of aquifers within the Centre Region, Centre County, Pennsylvania – Working element 2: State College, PA, report submitted to the Centre Regional Planning Commission, 71 p.

Pennsylvania State Climatologist, 2003, accessed June 24, 2003, at http://pasc.met.psu.edu/PA_Climatologist/fod/index.html

Pollock, D.W., 1994, User's Guide for MODPATH/MODPATH-PLOT, Version 3: A particle tracking post-processing package for MODFLOW, the US Geological Survey Ground-Water Flow Model, USGS, Open File Report 94-464.

Rauch, H.W., 1972, The effects of lithology and other hydrogeologic factors on the development of solution porosity in the middle Ordovician carbonates of central Pennsylvania: University Park, Pa., The Pennsylvania State University, M.S. thesis, 530 p.

R.E. Wright Associates, 1992, Groundwater Management and Development Plan, Upper Spring Creek Basin.

Siddiqui, S.H., 1969, Hydrogeologic factors influencing well yields and aquifer hydraulic properties of folded and faulted carbonate rocks in central Pennsylvania: University Park, Pa., The Pennsylvania State University, Ph.D. dissertation, 502 p.

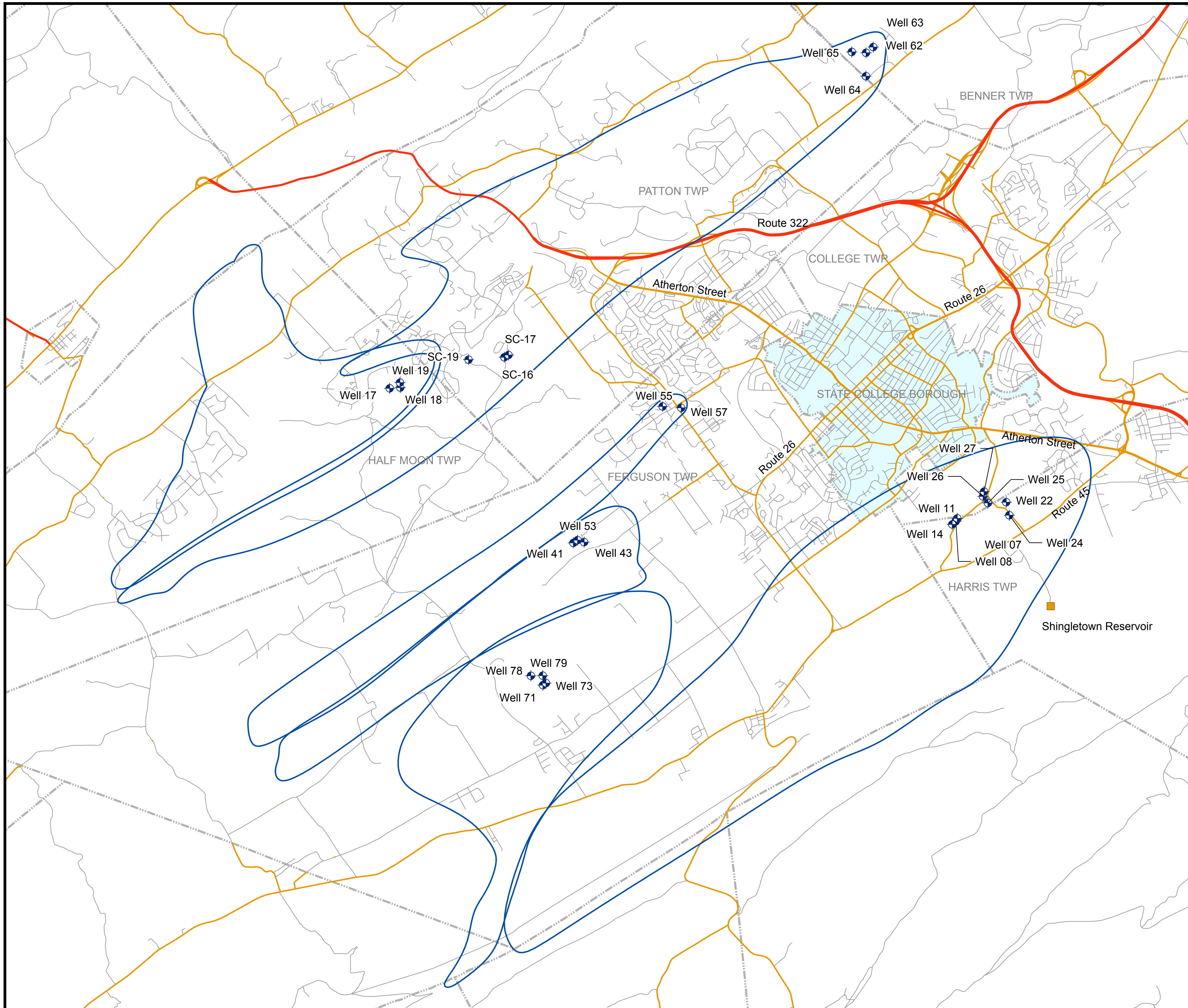
Spring Creek Watershed Community, 2004, 2004 State of Water Resources Report, Water Resources Monitoring Project, 31p.

Taylor, L.E., 1997, Water budget for the Spring Creek Basin: Harrisburg, Pa., Susquehanna River Basin Commission Publication 184, 19 p.

USFilter, 2002, Safe Well Yield Evaluation, SCBWA, 28 p.

Wood, C.R., 1980, Groundwater Resources of Centre County: Pennsylvania Geological Survey, 4th ser., Water Resource Report 48, 60 p.

FIGURES



N
W E
S

LEGEND

Drinking Water Source

- SCBWA Well
- Reservoir
- Highway
- State Road
- Local Road
- Municipality Boundary
- Zone II Wellhead Protection Area

Notes:

1. Map displayed in the Pennsylvania State Plane North Coordinate System, US Survey Feet, North American Datum of 1983 (NAD83).
2. Road data and municipality boundaries derived from shapefiles created by the Pennsylvania Department of Transportation, Harrisburg, PA, 2006.
3. Wells locations obtained from high-accuracy GPS surveys conducted by N.A. Water Systems in March and April of 2004.

0 3,000 6,000 12,000
Feet

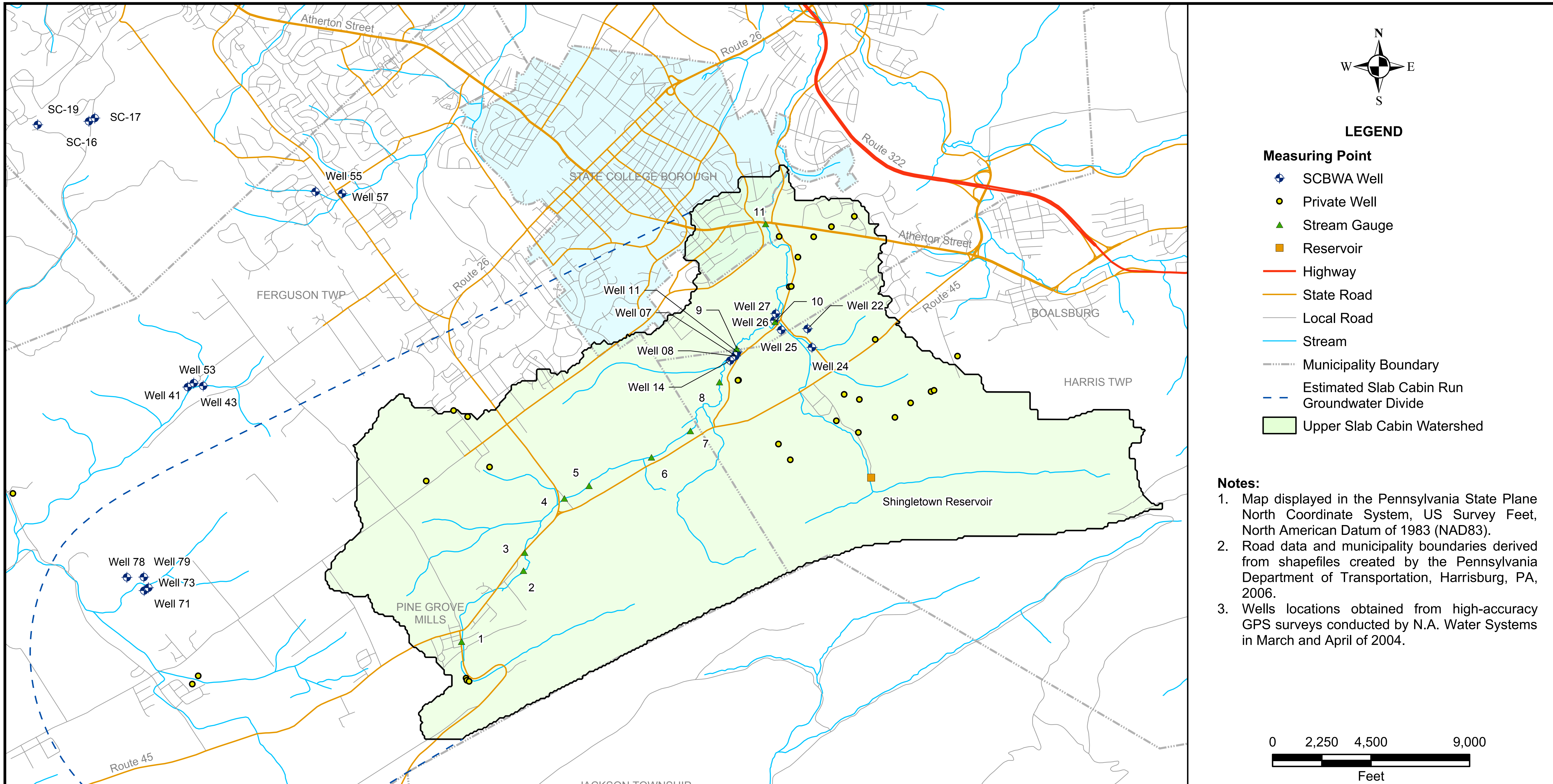
FIGURE 1

Map of the State College Borough Water Authority's Drinking Water Sources Showing Delineated Zone II Wellhead Protection Areas for Each Wellfield

State College Borough Water Authority,
State College, Pennsylvania

N.A. Water Systems

Z:\databases\scwa\gisdata\arcmap_doc\2006\56002690-002.mxd; February 8, 2007



Notes:

1. Map displayed in the Pennsylvania State Plane North Coordinate System, US Survey Feet, North American Datum of 1983 (NAD83).
2. Road data and municipality boundaries derived from shapefiles created by the Pennsylvania Department of Transportation, Harrisburg, PA, 2006.
3. Wells locations obtained from high-accuracy GPS surveys conducted by N.A. Water Systems in March and April of 2004.

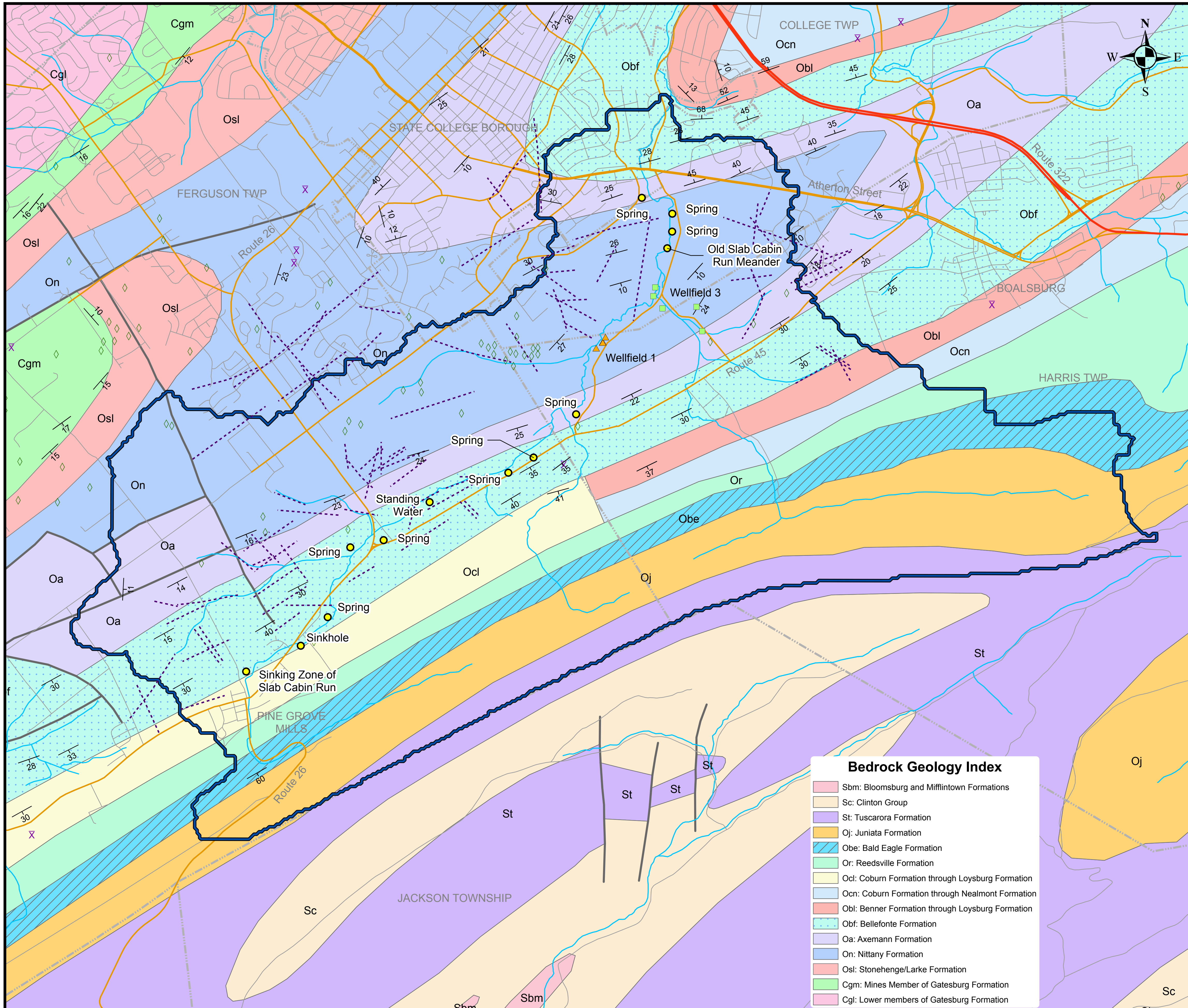
FIGURE 2

Upper Slab Cabin Run Study Area Showing SCBWA Wells, Observation Wells, and Stream Gauges

State College Borough Water Authority, State College, Pennsylvania

N.A. Water Systems

Z:\databases\scwa\gisdata\arcmap_doc\2006\56002690-003.mxd; September 26, 2006



LEGEND

- Highway
- State Road
- Local Road
- Municipality Boundary
- Upper Slab Cabin Watershed
- Stream
- 2003 Slab Cabin Karst Survey Feature

Bedding Strike and Dip

- Normal
- Overturned

USGS Karst Feature

- Sinkhole
- Surface Mine
- Fault Lines
- Fracture Trace

SCBWA Well

- Wellfield 1 Well
- Wellfield 3 Well

Notes:

1. Map displayed in the Pennsylvania State Plane North Coordinate System, US Survey Feet, North American Datum of 1983 (NAD83).
2. Road data and municipality boundaries derived from shapefiles created by the Pennsylvania Department of Transportation, Harrisburg, PA, 2006.
3. Geology derived from Pennsylvania Bureau of Topographic and Geologic Survey, Department of Conservation and Natural Resources, Bedrock Geology of Pennsylvania shapefile, 2001.
4. Karst survey completed on March 27, 2003 by N.A. Water Systems.
5. Sinkhole mapping derived from W. Kochanov of Pennsylvania Geologic Survey.

0 1,750 3,500 7,000
Feet

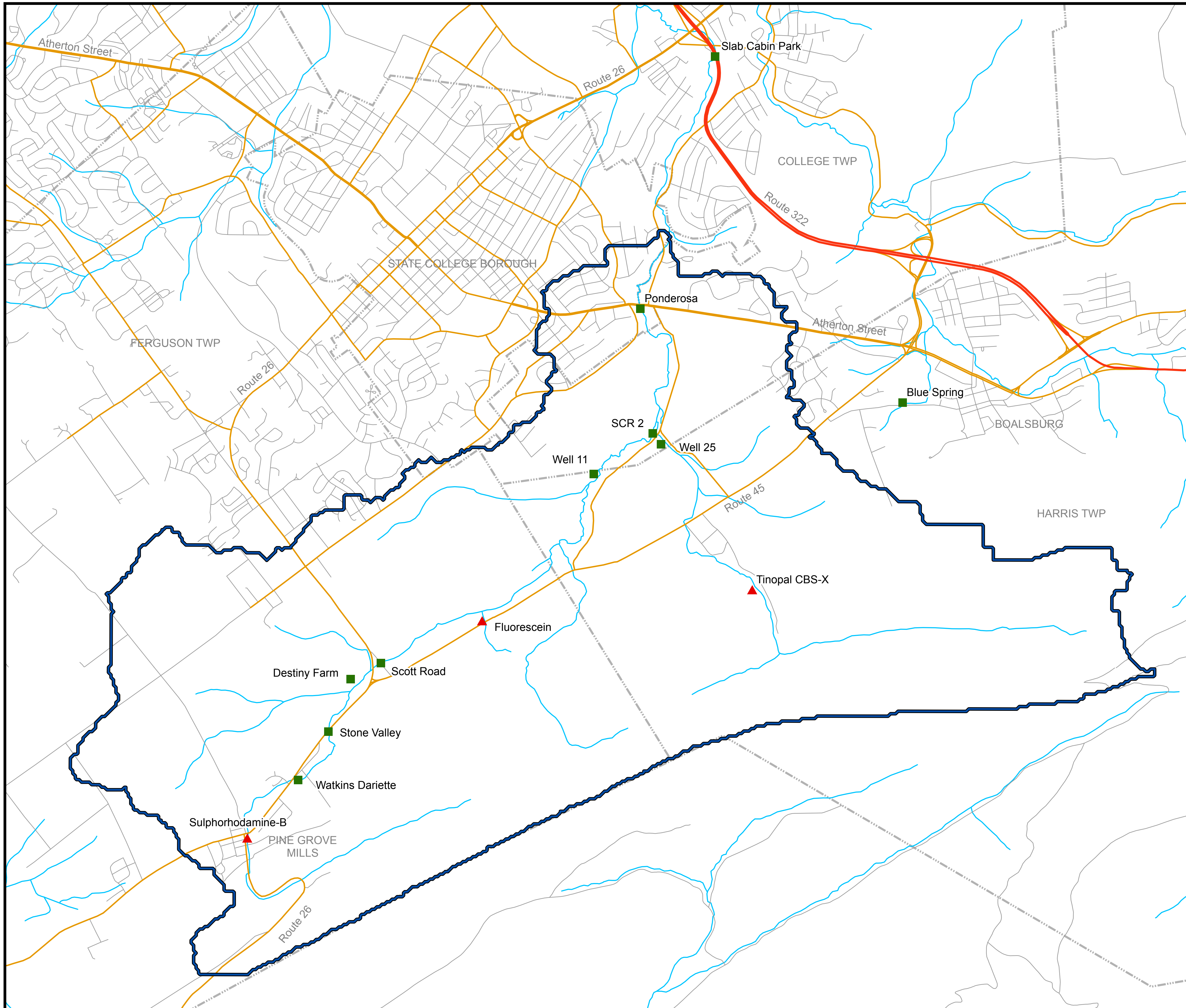
FIGURE 3

Geologic Map of the Upper Slab Cabin Run Basin Showing Fracture Traces, Karst Features, Sinkholes, and Bedrock Outcrop Mapping

State College Borough Water Authority,
State College, Pennsylvania

N.A. Water Systems

Z:\databases\scwa\gisdata\arcmap_doc\2006\56002690-006.mxd; January 19, 2007



N W E S

LEGEND

Dye Test Location

- Injection
- Receptor
- Upper Slab Cabin Watershed
- Highway
- State Road
- Local Road
- Municipality Boundary
- Stream

Notes:

1. Map displayed in the Pennsylvania State Plane North Coordinate System, US Survey Feet, North American Datum of 1983 (NAD83).
2. Road data and municipality boundaries derived from shapefiles created by the Pennsylvania Department of Transportation, Harrisburg, PA, 2006.

0 1,750 3,500 7,000
Feet

FIGURE 4

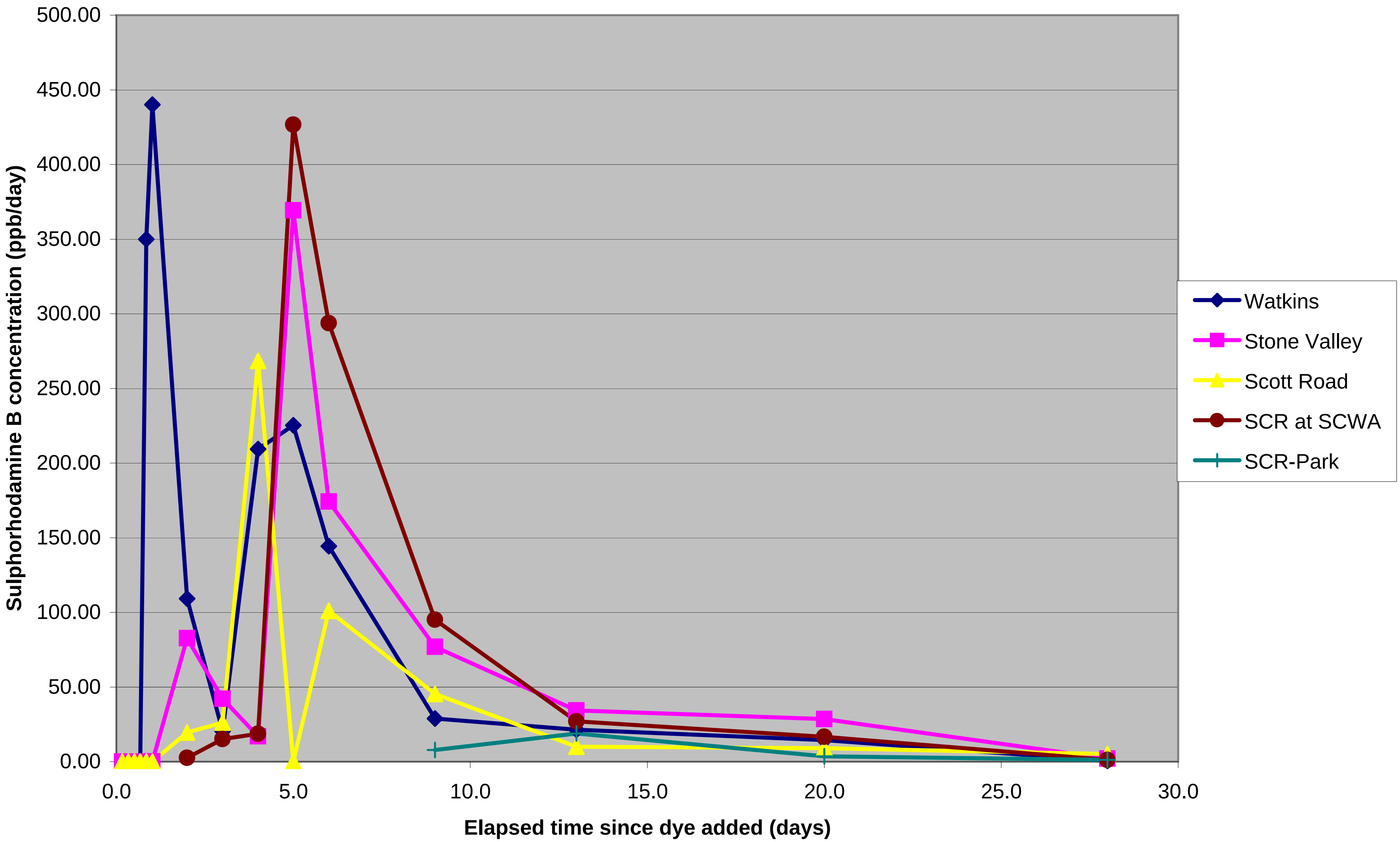
Dye Trace Study Injection and Monitoring Points

State College Borough Water Authority, State College, Pennsylvania

N.A. Water Systems

Z:\databases\scwa\gisdata\arcmap_doc\2006\56002690-007.mxd; January 23, 2007

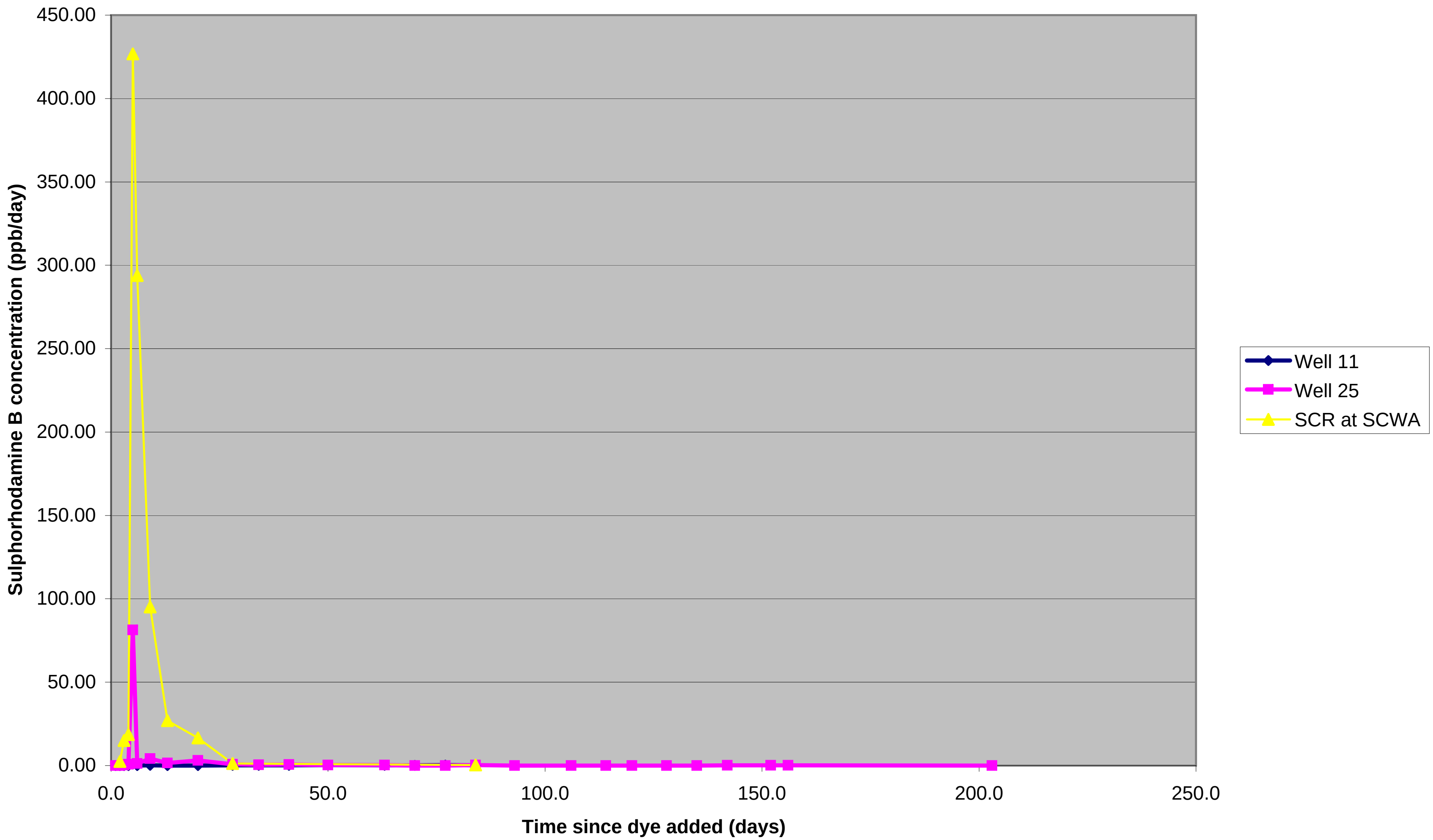
Figure 5
Slab Cabin Run Sulphorhodamine B Dye Trace Results



sjw-067

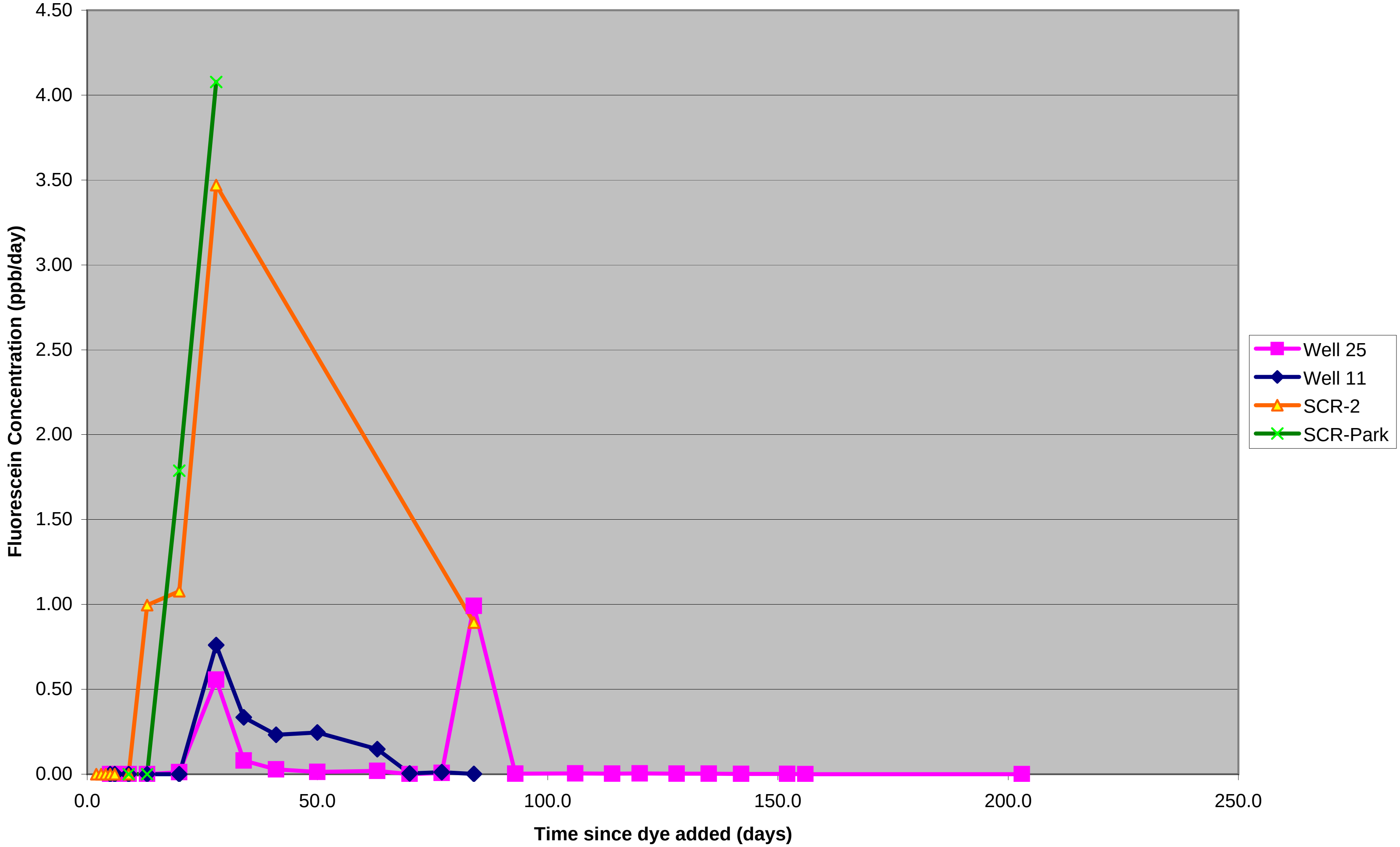
N.A. Water Systems

Figure 6
Sulphorhodamine B Concentration in Wells



N.A. Water Systems

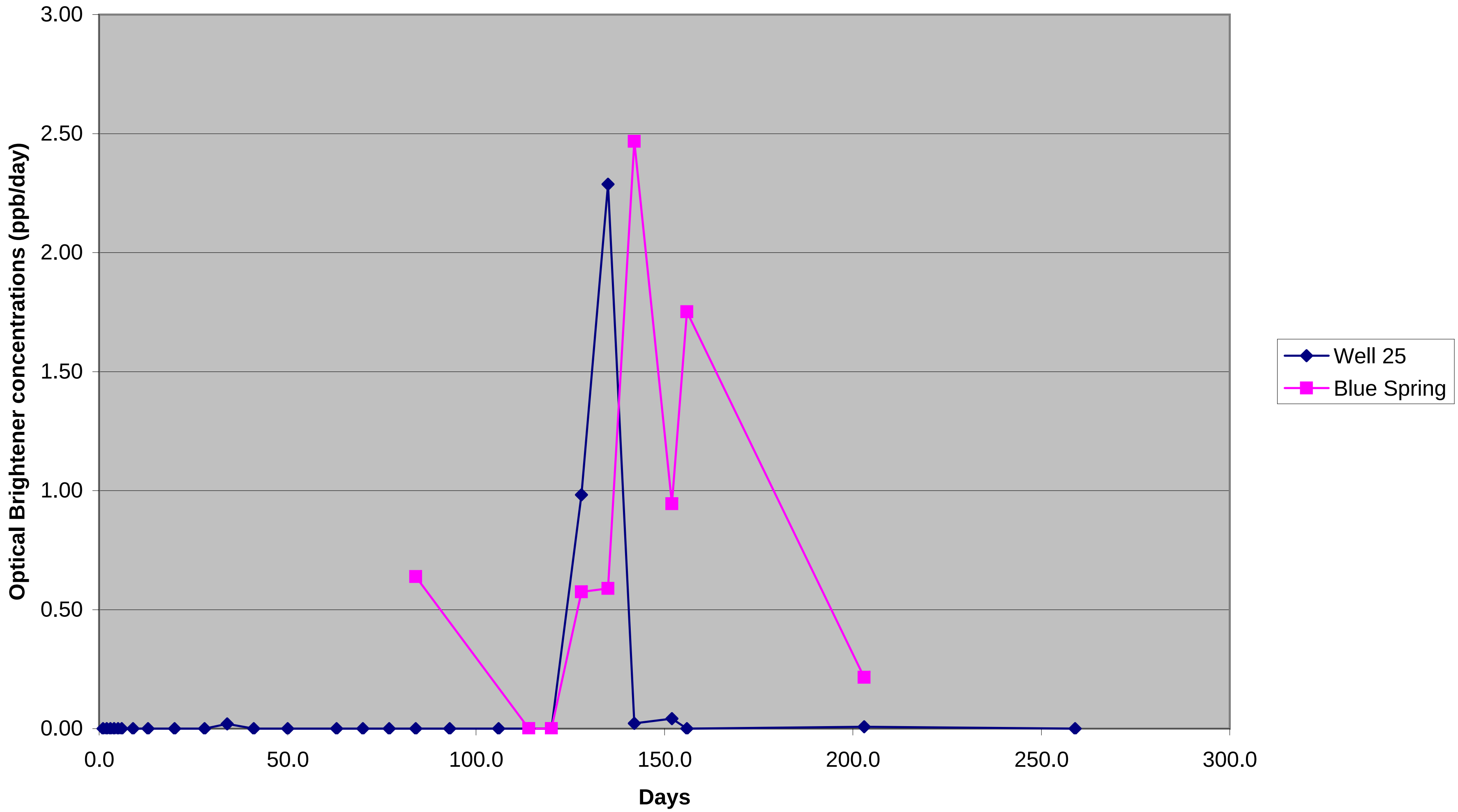
Figure 7
Fluorescein Concentration in Slab Cabin Run and Wells



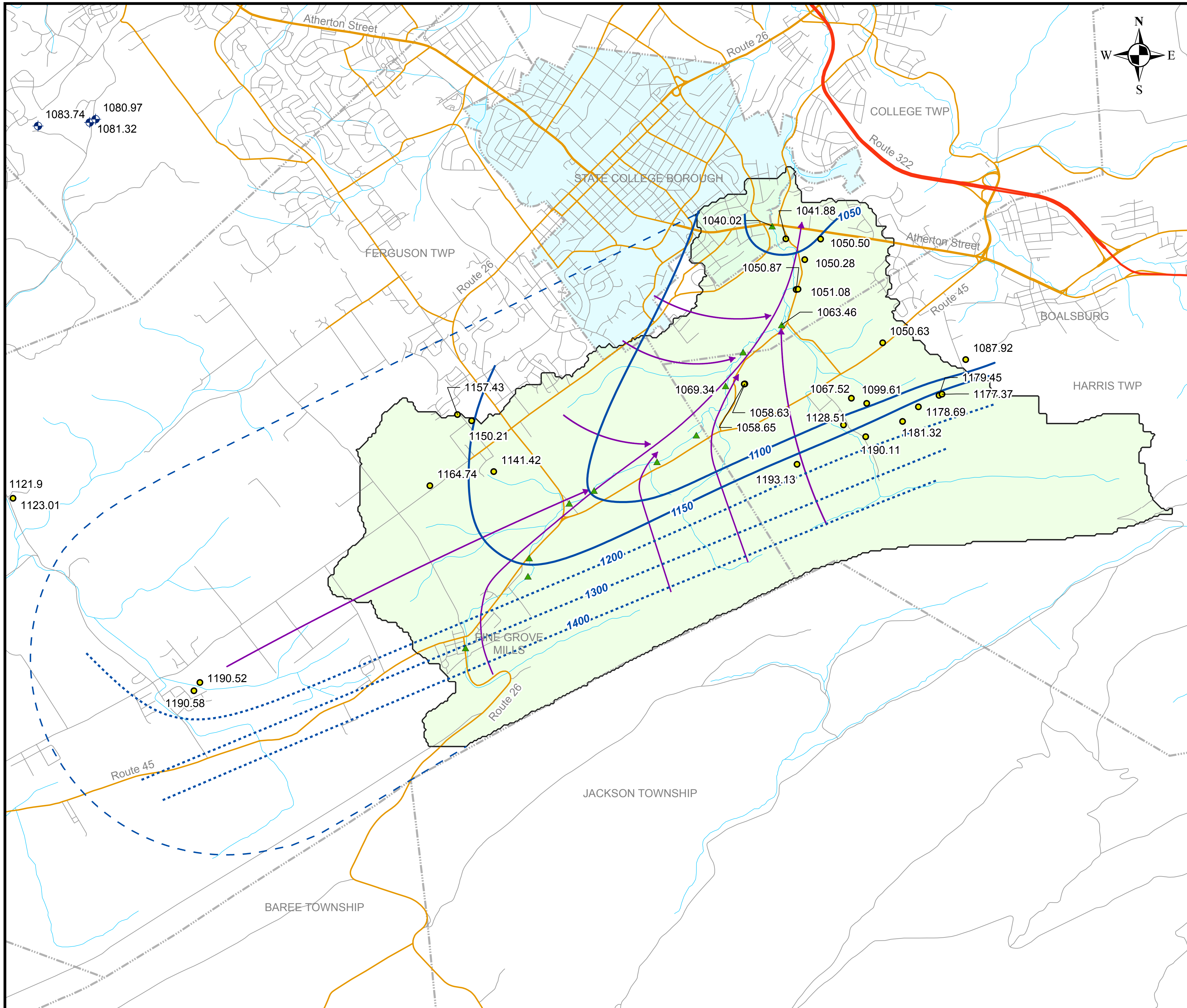
sjw-067

N.A. Water Systems

Figure 8
Optical Brightener in Well 25 and Blue Spring



N.A. Water Systems



LEGEND

- Highway
- State Road
- Local Road

Measuring Point

- SCBWA Well
- Private Well
- Stream Gauge
- Reservoir
- Stream
- Municipality Boundary
- Estimated Slab Cabin Run Groundwater Divide
- Upper Slab Cabin Watershed
- Groundwater Flow Direction
- Groundwater Elevation Contour
- Estimated Groundwater Contour

Notes:

1. Map displayed in the Pennsylvania State Plane North Coordinate System, US Survey Feet, North American Datum of 1983 (NAD83).
2. Road data and municipality boundaries derived from shapefiles created by the Pennsylvania Department of Transportation, Harrisburg, PA, 2006.
3. Wells locations obtained from high-accuracy GPS surveys conducted by N.A. Water Systems in March and April of 2004.
4. Groundwater elevations for wells measured on June 24, 2005. Groundwater elevations at stream gauges measured on November 16, 2004.
5. Groundwater elevations expressed in feet with respect to the North American Vertical Datum of 1988 (NAVD88).

0 2,250 4,500 9,000

Feet

FIGURE 9

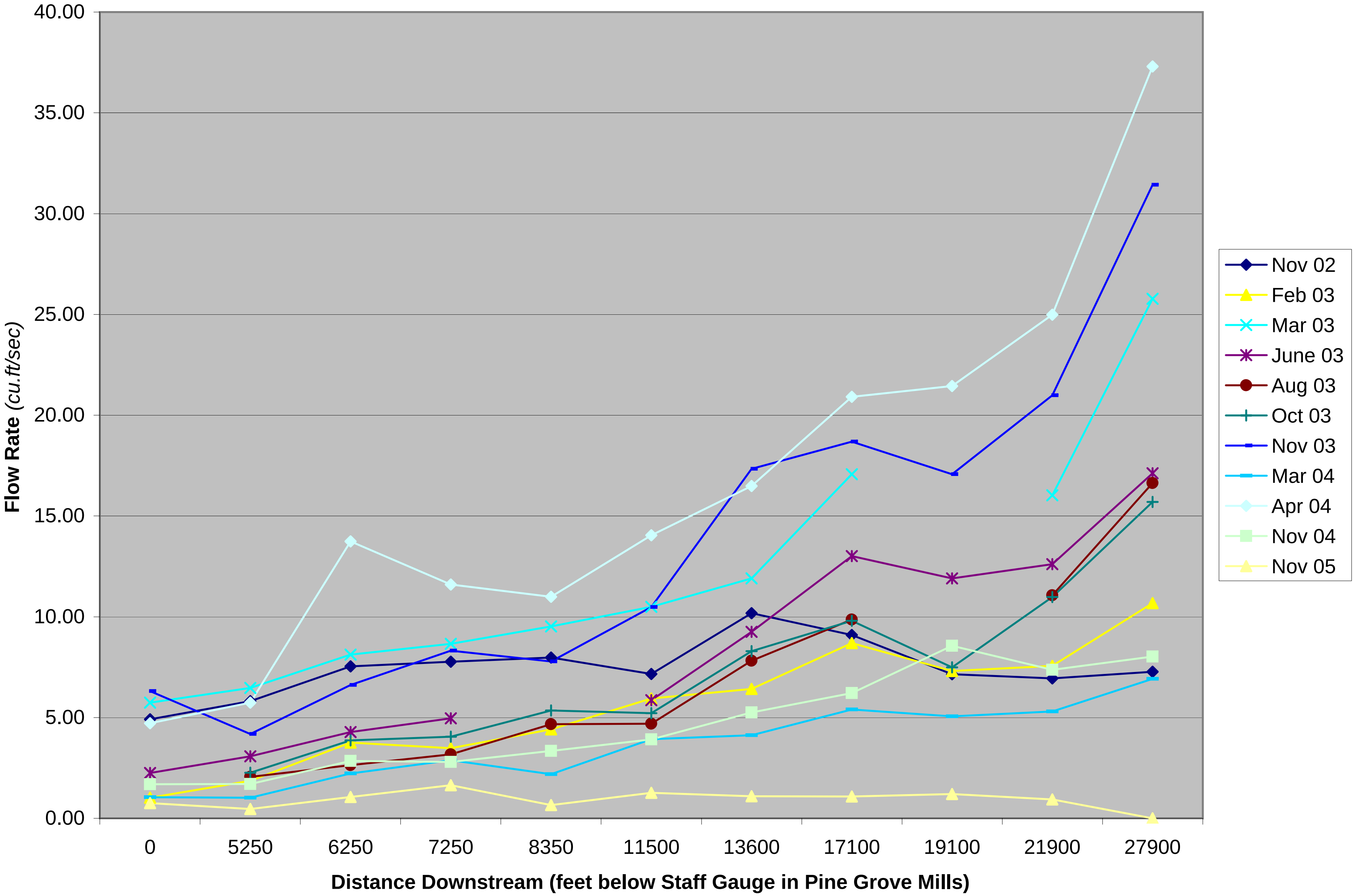
Water Table Elevation Map Showing Production Wells, Private Wells, and Staff Gauge Locations

State College Borough Water Authority,
State College, Pennsylvania

N.A. Water Systems

Z:\databases\scwa\gisdata\arcmap_doc\2006\56002690-005.mxd; February 9, 2007

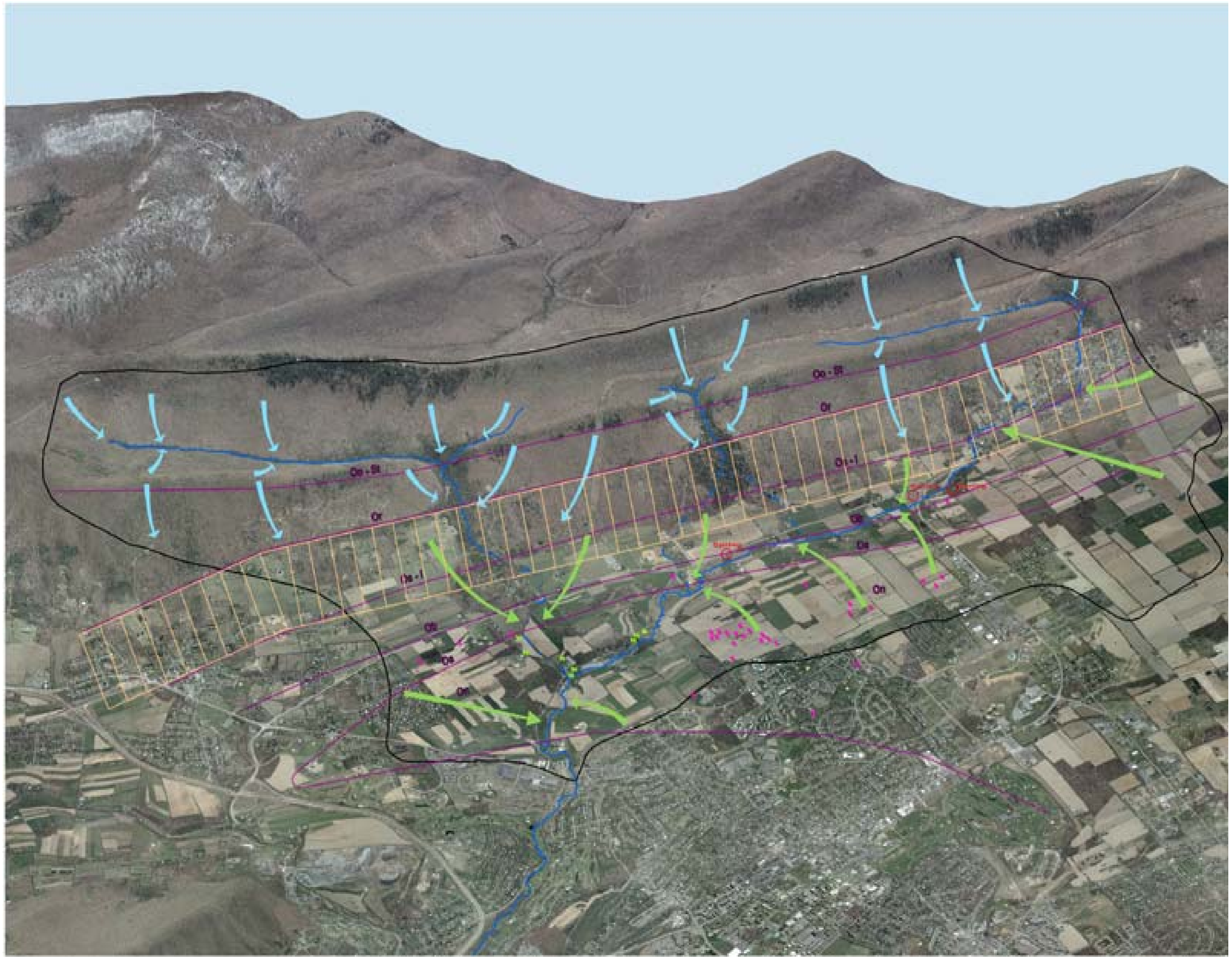
Figure 10
Upper Slab Cabin Run's Flow Rates versus Distance Downstream



sjw-067

N.A. Water Systems

N.A. Water Systems



Upper Slab Cabin Run

Conceptual Watershed Model

- Project area
- Streams
- Ephemeral Streams
- Sinkholes
- Wells
- Springs
- Surface Flow Direction
- Groundwater Flow Direction
- Geologic Contact
- Sinking Surface Water Zone

Geologic Formations

Oo - St
Oswego through Tuscarora Formations

Or
Reedsville Formation

Os - I
Salona through Loysburg Formation

Ob
Bellefonte Formation

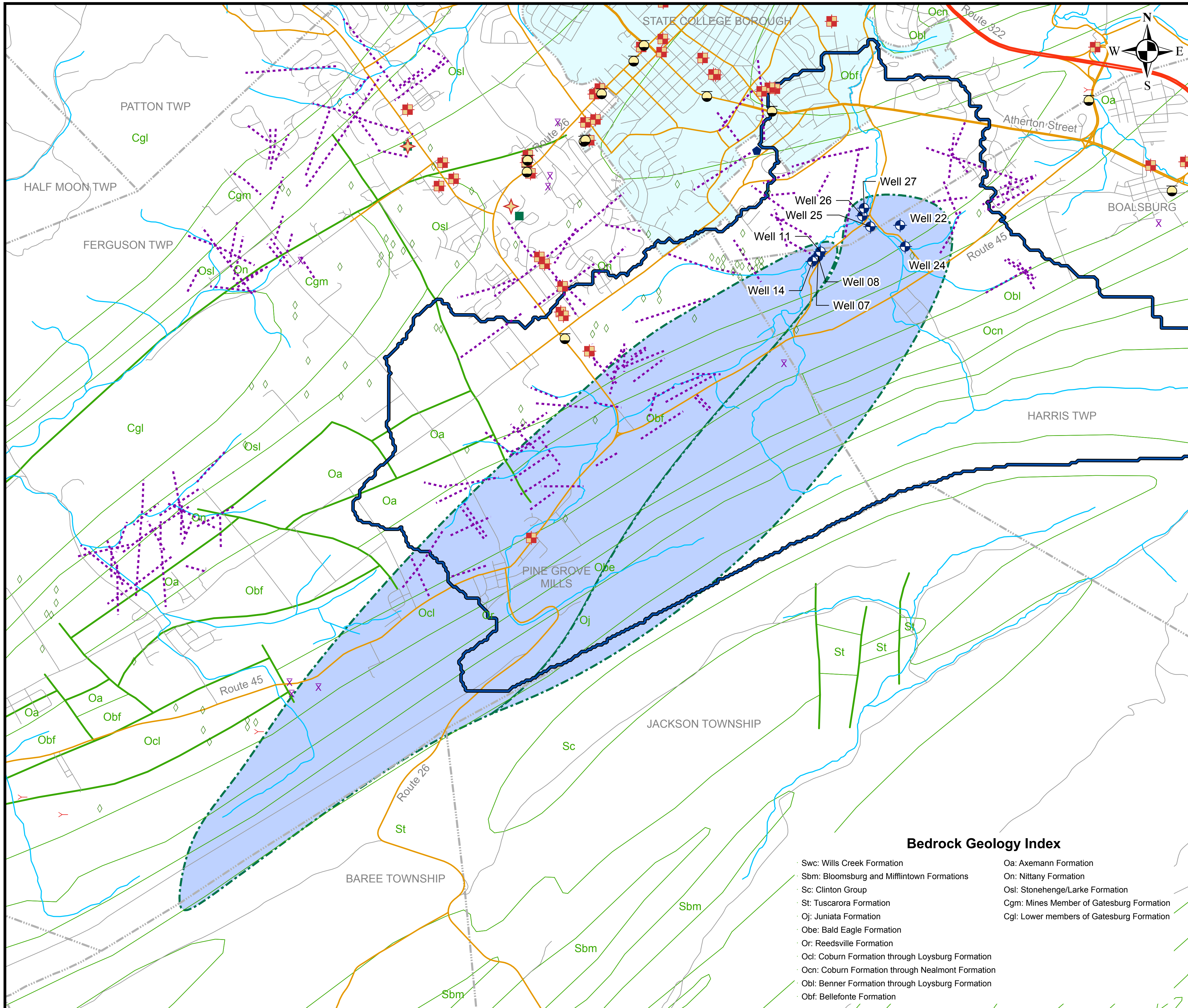
Oa
Axemann Formation

On
Nittany Formation

Figure 11
Conceptual Model of the Upper Slab Cabin Run Basin (angled aerial view toward southeast). The Critical Groundwater Recharge Area for Slab Cabin Run is shown as the Sinking Surface Water Zone.

sjw-067

Note: This figure is for conceptual purposes and is not drawn to scale.



LEGEND

- Highway
- State Road
- Local Road
- Municipality Boundary
- Stream
- Fracture Trace
- Fault
- Capture Zone
- Upper Slab Cabin Watershed
- SCBWA Well
- Leaky Underground Storage Tank
- National Pollutant Discharge Elimination System
- RCRA Small Quantity Generator
- Superfund Site
- Toxic Release Inventory Location

USGS Karst Feature

- Cave
- Sinkhole
- Surface Mine

Notes:

1. Map displayed in the Pennsylvania State Plane North Coordinate System, US Survey Feet, North American Datum of 1983 (NAD83).
2. Road data and municipality boundaries derived from shapefiles created by the Pennsylvania Department of Transportation, Harrisburg, PA, 2006.
3. Geology derived from Pennsylvania Bureau of Topographic and Geologic Survey, Department of Conservation and Natural Resources, Bedrock Geology of Pennsylvania shapefile, 2001.
4. Sinkhole mapping derived from W. Kochanov of Pennsylvania Geologic Survey.

0 2,000 4,000 8,000

Feet

FIGURE 12

Modeled Steady-State Capture Zone for SCBWA Wellfields 1 and 3 During Normal Pumping Conditions

State College Borough Water Authority, State College, Pennsylvania

N.A. Water Systems

Z:\databases\scwa\gisdata\arcmap_doc\2006\56002690-009.mxd; January 19, 2007

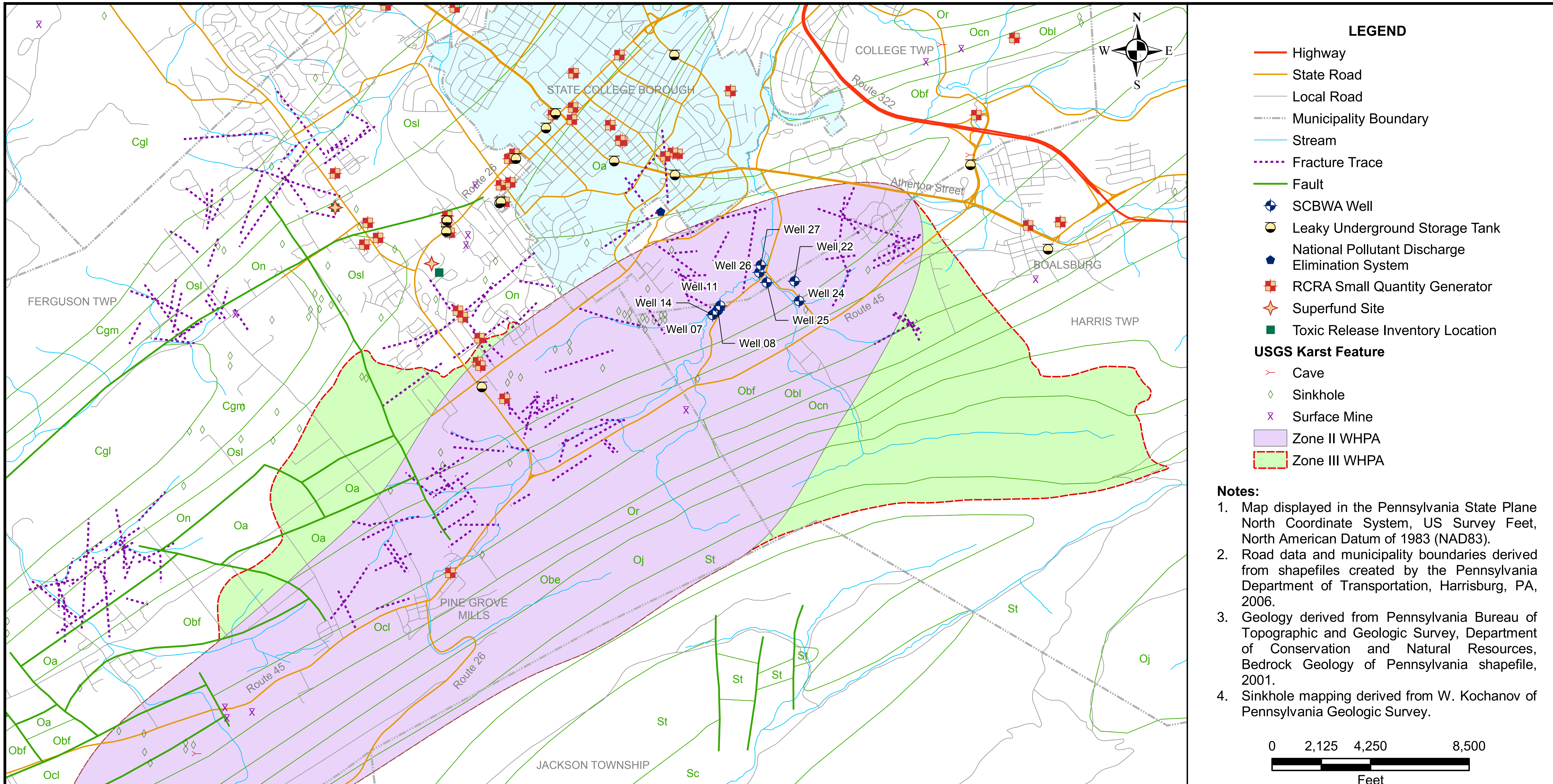


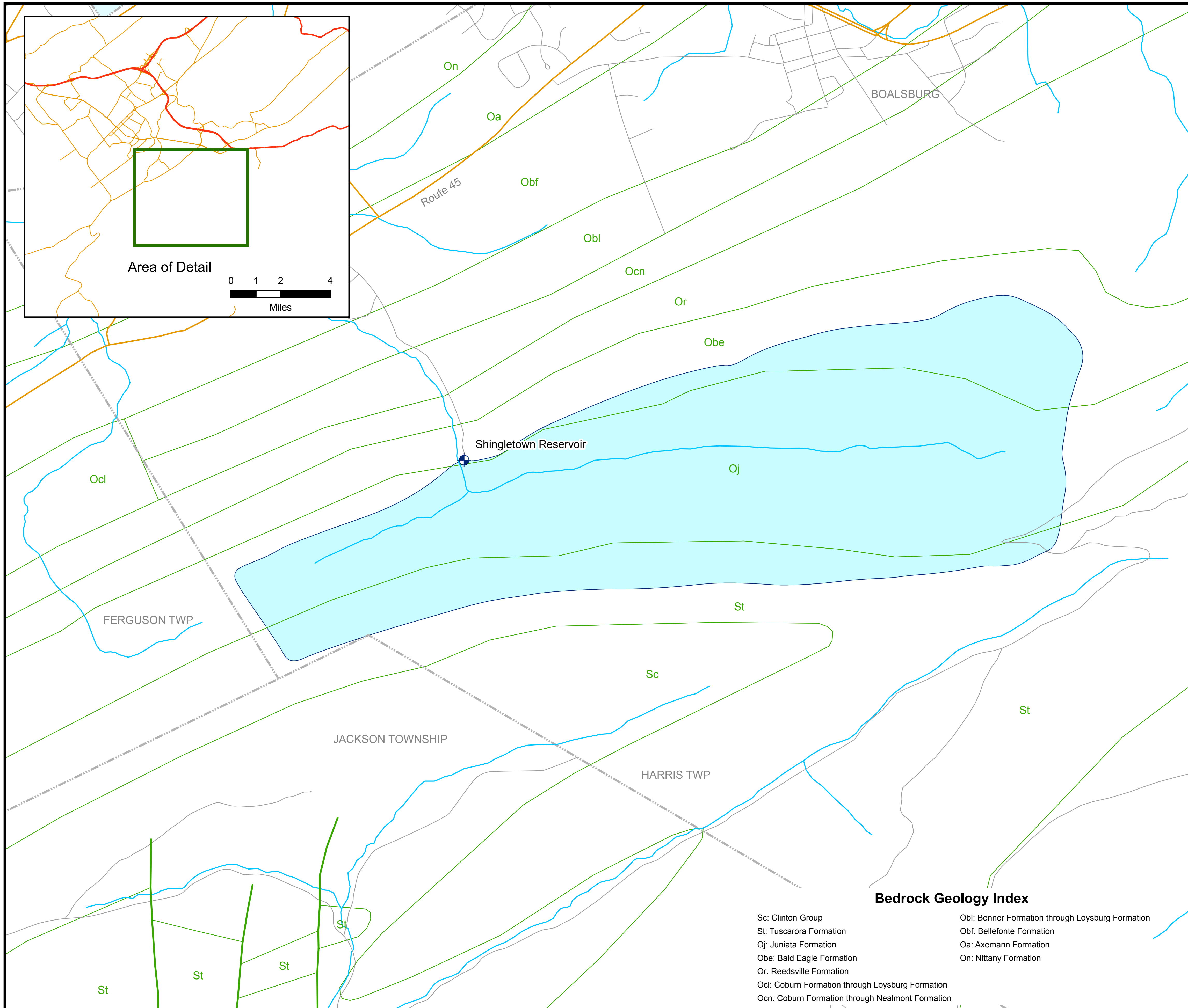
FIGURE 13

Wellhead Protection Area Delineations for SCBWA Wellfields 1 and 3 During Maximum Permitted Pumping Rates

State College Borough Water Authority, State College, Pennsylvania

N.A. Water Systems

Z:\databases\scwa\gisdata\arcmap_doc\2006\56002690-012.mxd; January 23, 2007



N
W E
S

LEGEND

- Highway
- State Road
- Local Road
- Municipality Boundary
- Stream
- Reservoir
- Source Water Protection Area
- Fault

Notes:

1. Map displayed in the Pennsylvania State Plane North Coordinate System, US Survey Feet, North American Datum of 1983 (NAD83).
2. Road data and municipality boundaries derived from shapefiles created by the Pennsylvania Department of Transportation, Harrisburg, PA, 2006.
3. Geology derived from Pennsylvania Bureau of Topographic and Geologic Survey, Department of Conservation and Natural Resources, Bedrock Geology of Pennsylvania shapefile, 2001.

0 1,000 2,000 4,000
Feet

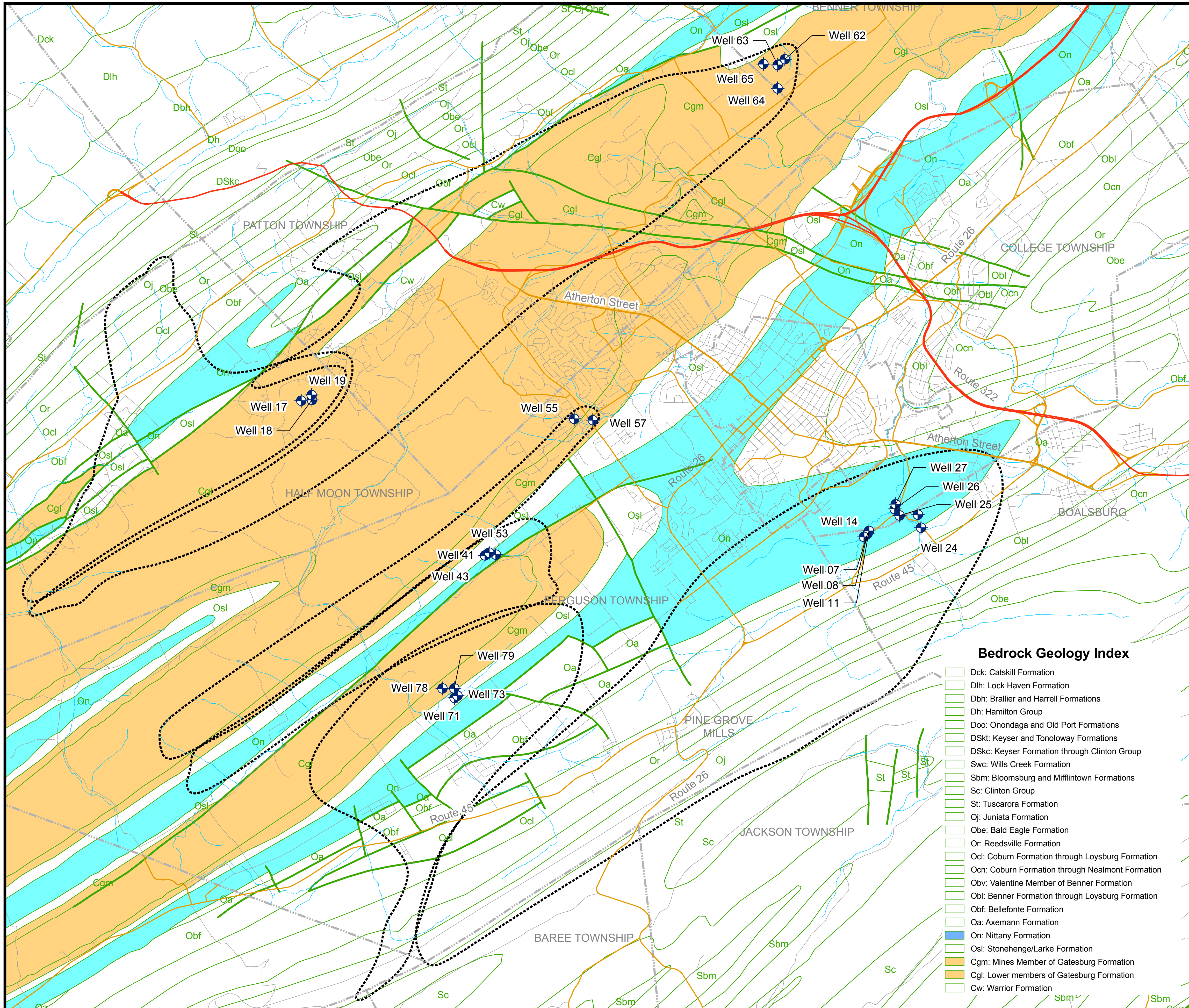
FIGURE 14

Source Water Protection Area Delineation for SCBWA's Shingletown Reservoir

State College Borough Water Authority,
State College, Pennsylvania

N.A. Water Systems

Z:\databases\scwa\gisdata\arcmap_doc\2006\56002690-021.mxd; January 19, 2007



N
W E
S

LEGEND

- Highway
- State Road
- Local Road
- Municipality Boundary
- Stream
- Fault
- SCBWA Well
- Zone II Wellhead Protection Area

Notes:

1. Map displayed in the Pennsylvania State Plane North Coordinate System, US Survey Feet, North American Datum of 1983 (NAD83).
2. Road data and municipality boundaries derived from shapefiles created by the Pennsylvania Department of Transportation, Harrisburg, PA, 2006.
3. Geology derived from Pennsylvania Bureau of Topographic and Geologic Survey, Department of Conservation and Natural Resources, Bedrock Geology of Pennsylvania shapefile, 2001.

0 3,250 6,500 13,000
Feet

FIGURE 15

New Groundwater Source Development Areas

State College Borough Water Authority,
State College, Pennsylvania

N.A. Water Systems

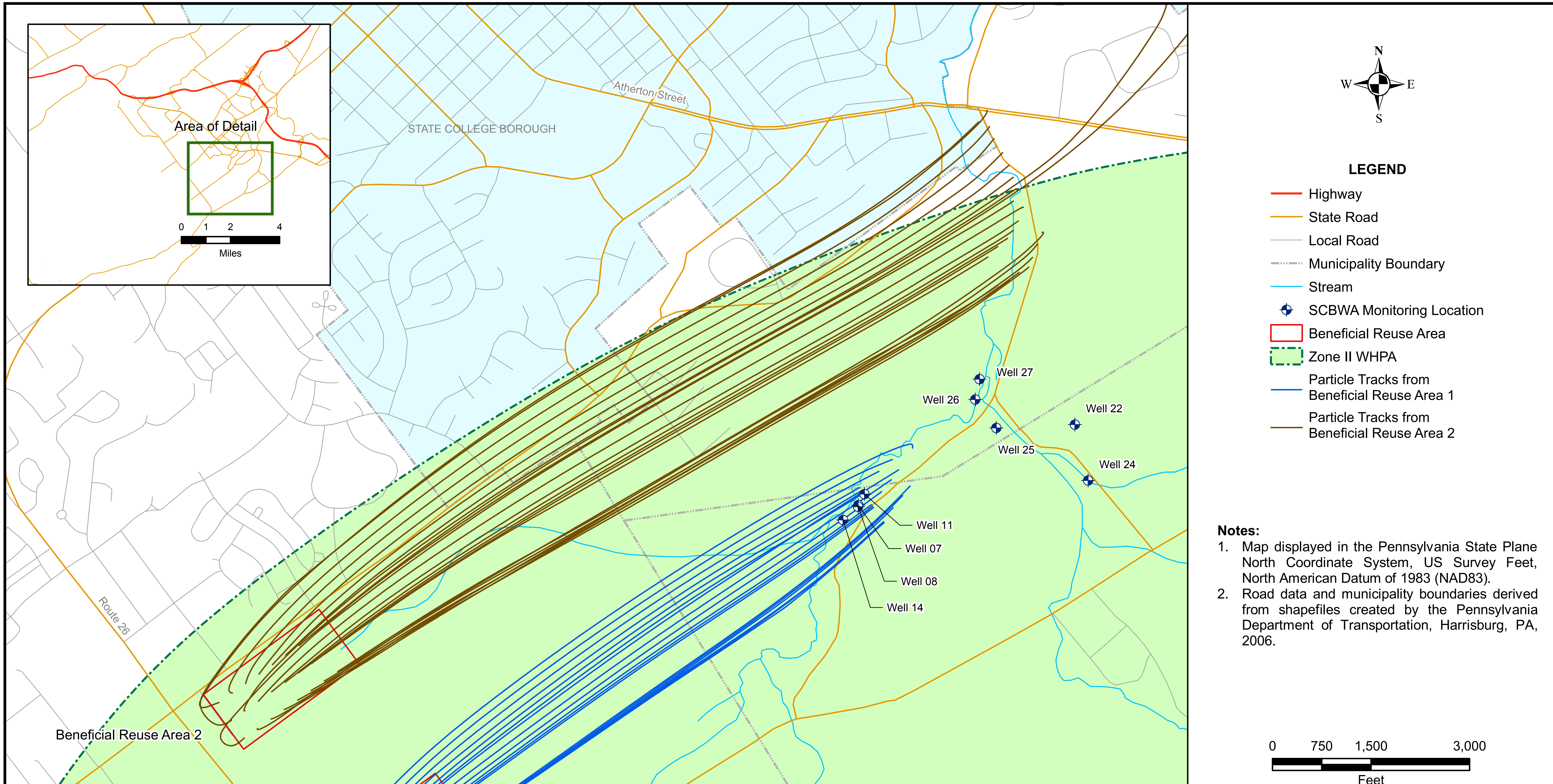


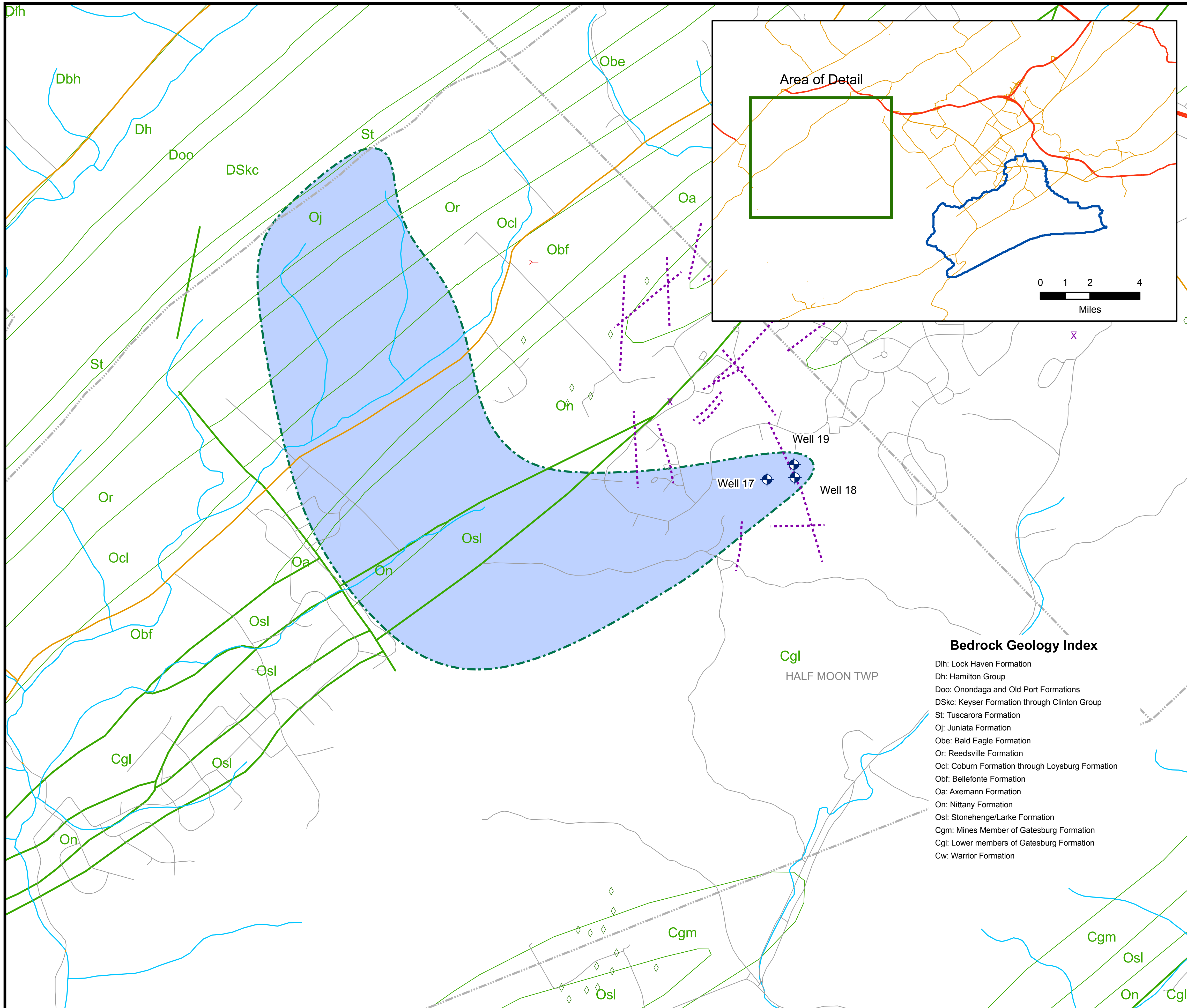
FIGURE 16

Modeled Particle Tracking Zone for SCBWA Wellfields 1 and 3 During Normal Pumping Conditions at Potential Beneficial Reuse Recharge Sites

State College Borough Water Authority, State College, Pennsylvania

N.A. Water Systems

Z:\databases\scwa\gisdata\arcmap_doc\2006\56002690-020.mxd; January 9, 2007



N
W E
S

LEGEND

- Highway
- State Road
- Local Road
- Municipality Boundary
- Stream
- Fracture Trace
- Fault
- Upper Slab Cabin Watershed
- Capture Zone
- SCBWA Well

USGS Karst Feature

- Cave
- Sinkhole
- Surface Mine

Notes:

1. Map displayed in the Pennsylvania State Plane North Coordinate System, US Survey Feet, North American Datum of 1983 (NAD83).
2. Road data and municipality boundaries derived from shapefiles created by the Pennsylvania Department of Transportation, Harrisburg, PA, 2006.
3. Geology derived from Pennsylvania Bureau of Topographic and Geologic Survey, Department of Conservation and Natural Resources, Bedrock Geology of Pennsylvania shapefile, 2001.
4. Karst survey completed on March 27, 2003 by N.A. Water Systems. Refer to associated field notes for additional information.

0 1,250 2,500 5,000

Feet

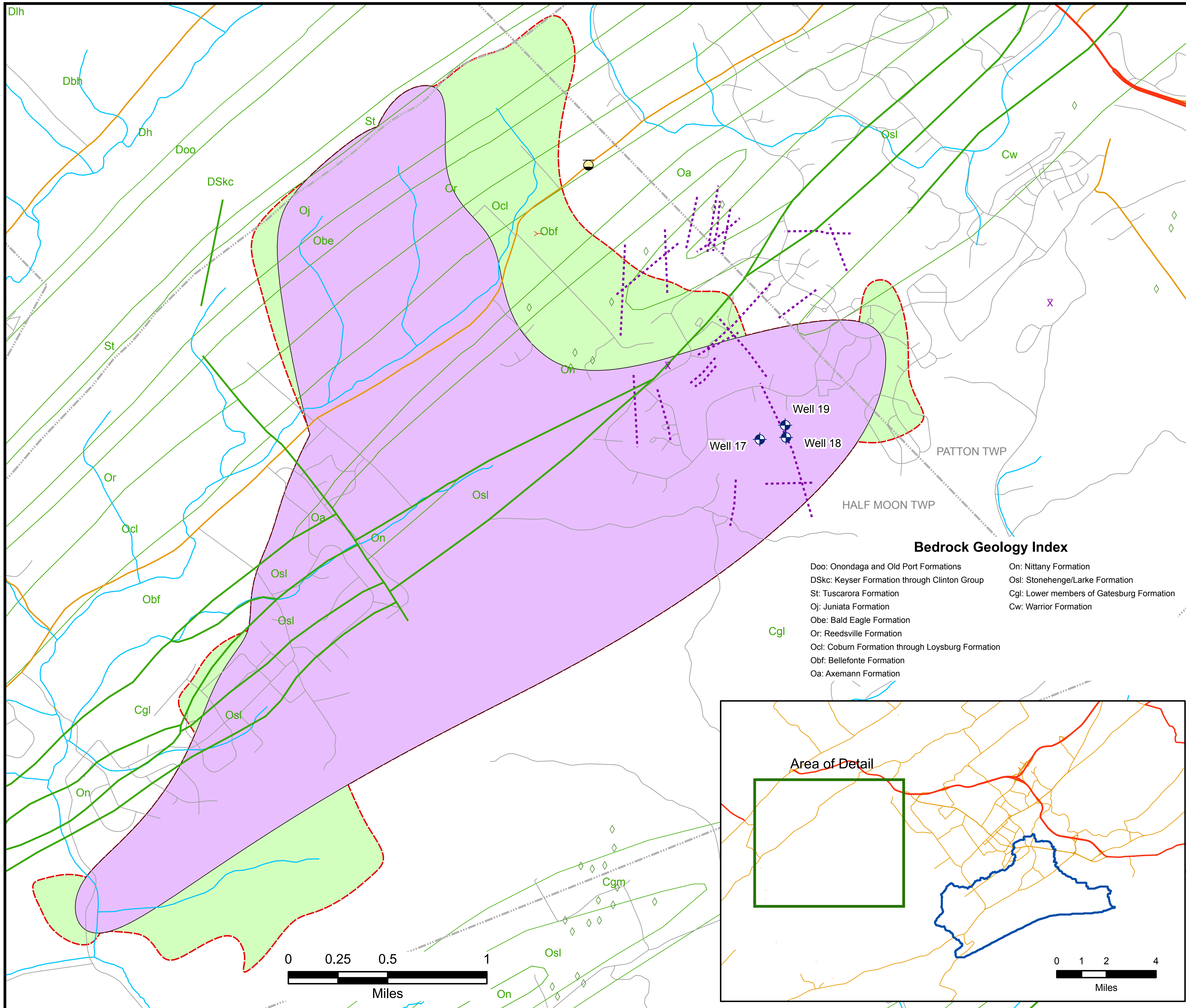
FIGURE 17

Wellfield 2 Capture Zone During Normal Pumping Conditions

State College Borough Water Authority,
State College, Pennsylvania

N.A. Water Systems

Z:\databases\scwa\gisdata\arcmap_doc\2006\56002690-013.mxd; January 19, 2007



N
W E
S

LEGEND

- Highway
- State Road
- Local Road
- Municipality Boundary
- Stream
- Fracture Trace
- Fault
- SCBWA Well
- Leaky Underground Storage Tank
- Zone II WHPA
- Zone III WHPA

USGS Karst Feature

- Cave
- Sinkhole
- Surface Mine

Notes:

1. Map displayed in the Pennsylvania State Plane North Coordinate System, US Survey Feet, North American Datum of 1983 (NAD83).
2. Road data and municipality boundaries derived from shapefiles created by the Pennsylvania Department of Transportation, Harrisburg, PA, 2006.
3. Geology derived from Pennsylvania Bureau of Topographic and Geologic Survey, Department of Conservation and Natural Resources, Bedrock Geology of Pennsylvania shapefile, 2001.
4. Karst survey completed on March 27, 2003 by N.A. Water Systems. Refer to associated field notes for additional information.

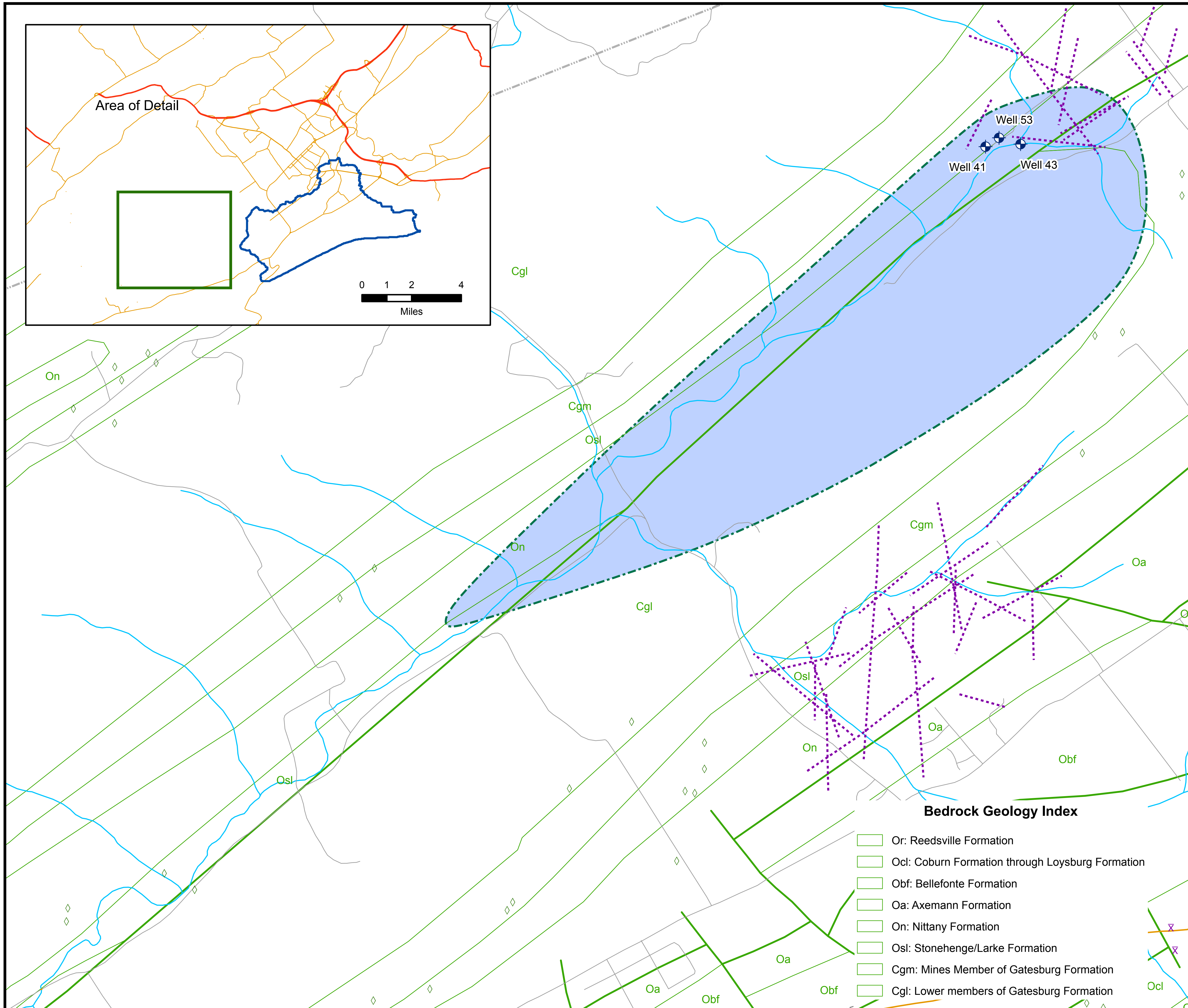
FIGURE 18

Wellfield 2 Delineated Wellhead Protection Area Map During Maximum Permitted Pumping Conditions

State College Borough Water Authority,
State College, Pennsylvania

N.A. Water Systems

Z:\databases\scwa\gisdata\arcmap_doc\2006\56002690-008.mxd; February 8, 2007



N
W E
S

LEGEND

- Highway
- State Road
- Local Road
- Municipality Boundary
- Stream
- Fracture Trace
- Fault
- SCBWA Well
- Upper Slab Cabin Watershed
- Capture Zone

USGS Karst Feature

- Cave
- Sinkhole
- Surface Mine

Notes:

1. Map displayed in the Pennsylvania State Plane North Coordinate System, US Survey Feet, North American Datum of 1983 (NAD83).
2. Road data and municipality boundaries derived from shapefiles created by the Pennsylvania Department of Transportation, Harrisburg, PA, 2006.
3. Geology derived from Pennsylvania Bureau of Topographic and Geologic Survey, Department of Conservation and Natural Resources, Bedrock Geology of Pennsylvania shapefile, 2001.
4. Sinkhole mapping derived from W. Kochanov of Pennsylvania Geologic Survey.

0 1,000 2,000 4,000

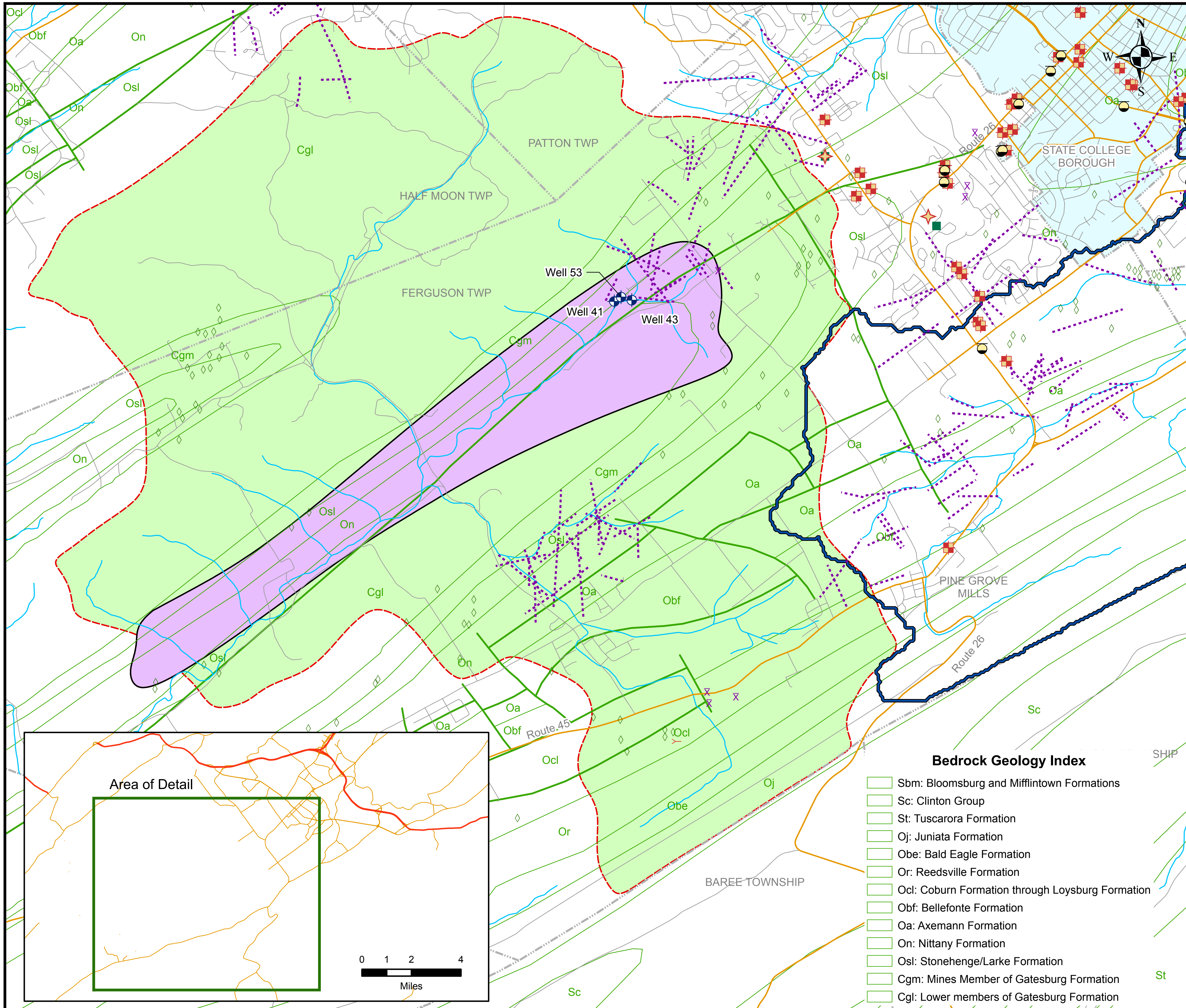
Feet

FIGURE 19

Wellfield 4 Capture Zone During Normal Pumping Conditions

State College Borough Water Authority,
State College, Pennsylvania

N.A. Water Systems



LEGEND

- Highway
- State Road
- Local Road
- Municipality Boundary
- Stream
- Fracture Trace
- Fault
- SCBWA Well
- Leaky Underground Storage Tank
- RCRA Small Quantity Generator
- Superfund Site
- Toxic Release Inventory Location

USGS Karst Feature

- Cave
- Sinkhole
- Surface Mine
- Upper Slab Cabin Watershed
- Zone II WHPA
- Zone III WHPA

Notes:

1. Map displayed in the Pennsylvania State Plane North Coordinate System, US Survey Feet, North American Datum of 1983 (NAD83).
2. Road data and municipality boundaries derived from shapefiles created by the Pennsylvania Department of Transportation, Harrisburg, PA, 2006.
3. Geology derived from Pennsylvania Bureau of Topographic and Geologic Survey, Department of Conservation and Natural Resources, Bedrock Geology of Pennsylvania shapefile, 2001.
4. Sinkhole mapping derived from W. Kochanov of Pennsylvania Geologic Survey.

0 2,000 4,000 8,000
Feet

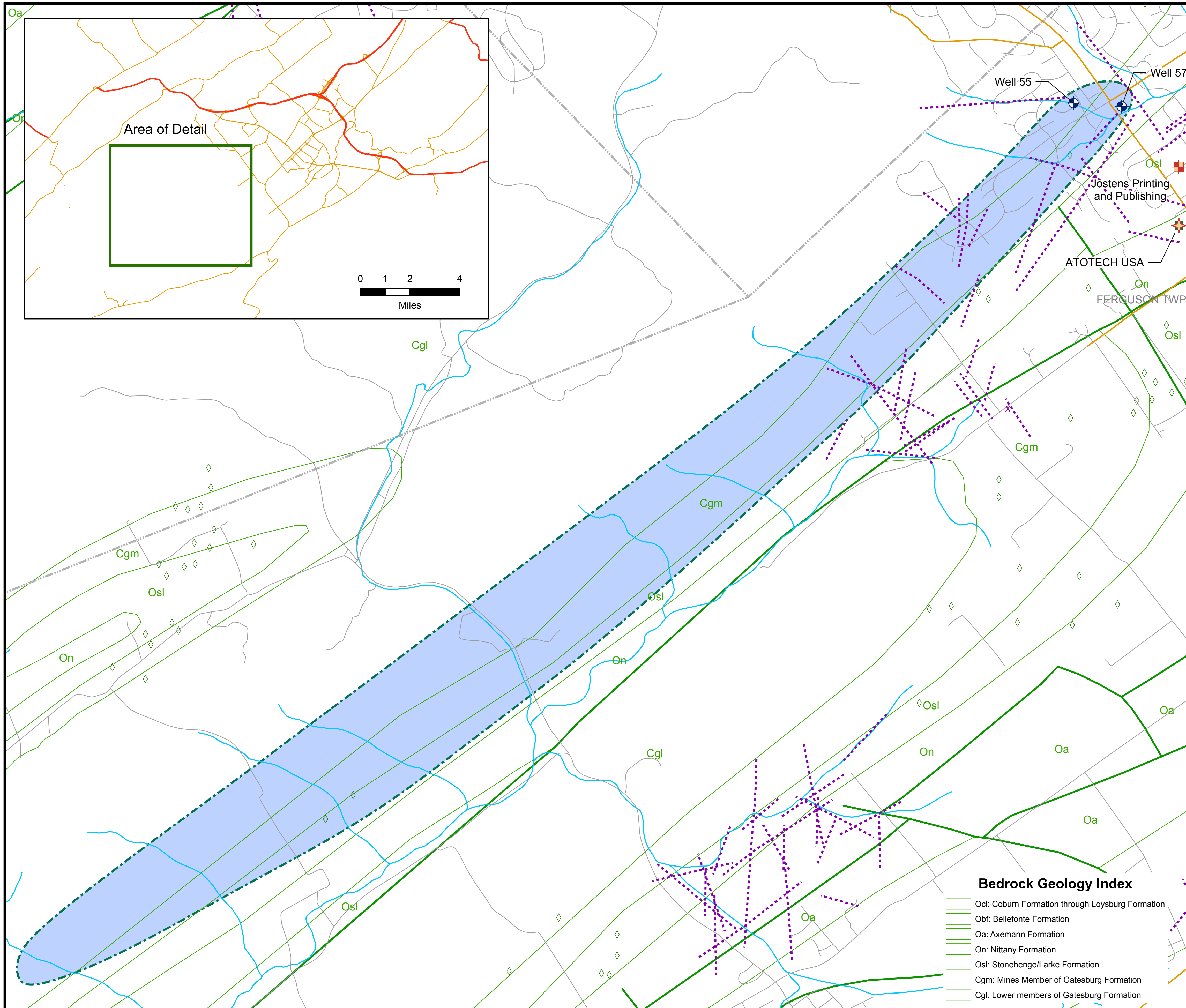
FIGURE 20

Wellfield 4 Delineated Wellhead Protection Area Map During Maximum Permitted Pumping Conditions

State College Borough Water Authority,
State College, Pennsylvania

N.A. Water Systems

Z:\databases\scwa\gisdata\arcmap_doc\2006\56002690-011.mxd; January 19, 2007



N
W E
S

LEGEND

- Highway
- State Road
- Local Road
- Municipality Boundary
- Stream
- Fracture Trace
- Fault
- SCBWA Monitoring Location
- RCRA Small Quantity Generator
- Superfund Site
- Toxic Release Inventory Location
- Capture Zone

USGS Karst Feature

- Cave
- Sinkhole
- Surface Mine

Notes:

1. Map displayed in the Pennsylvania State Plane North Coordinate System, US Survey Feet, North American Datum of 1983 (NAD83).
2. Road data and municipality boundaries derived from shapefiles created by the Pennsylvania Department of Transportation, Harrisburg, PA, 2006.
3. Geology derived from Pennsylvania Bureau of Topographic and Geologic Survey, Department of Conservation and Natural Resources, Bedrock Geology of Pennsylvania shapefile, 2001.
4. Sinkhole mapping derived from W. Kochanov of Pennsylvania Geologic Survey.

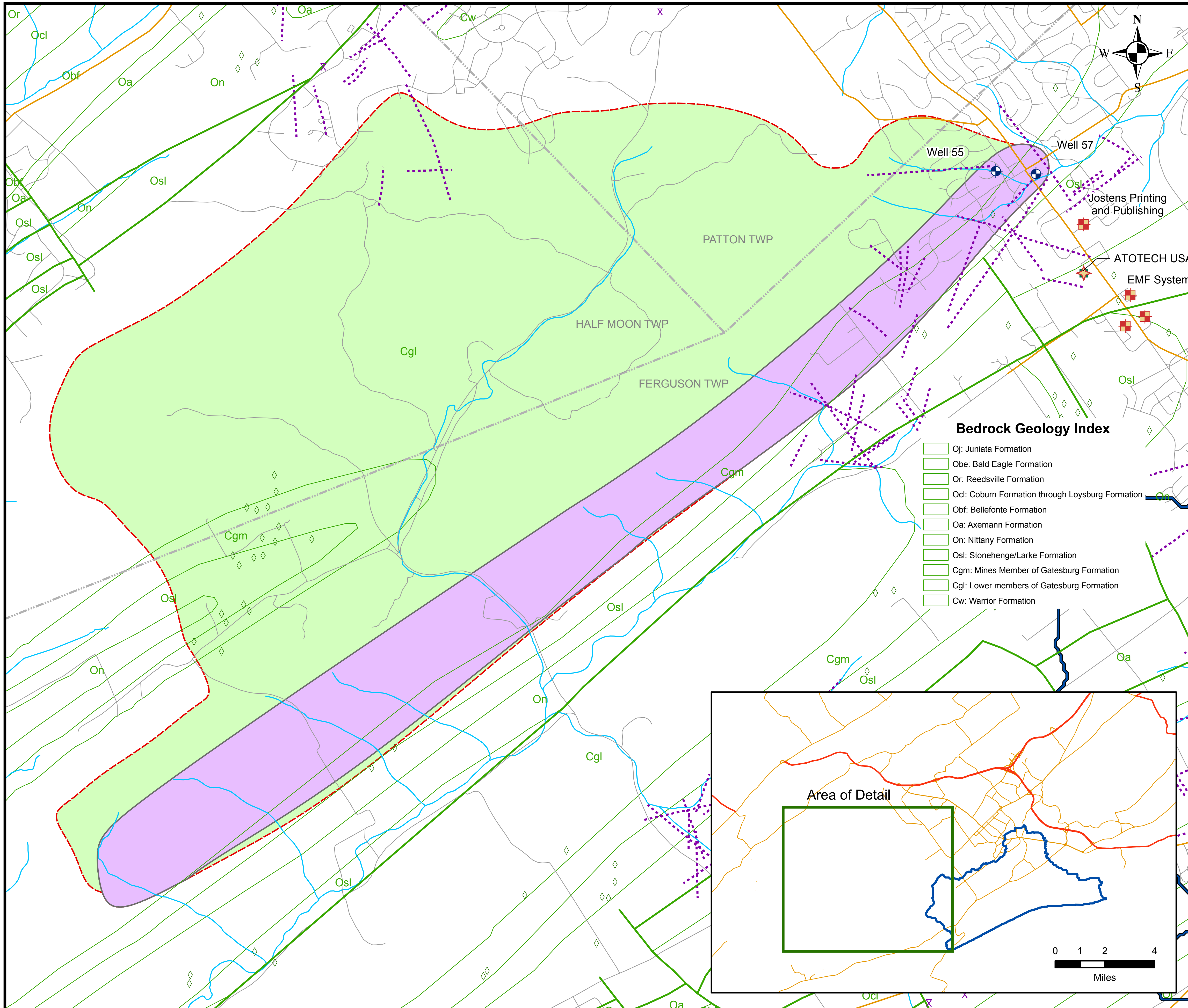
0 1,250 2,500 5,000
Feet

FIGURE 21

Wellfield 5 Capture Zone During Normal Pumping Conditions

State College Borough Water Authority,
State College, Pennsylvania

N.A. Water Systems



LEGEND

- Highway
- State Road
- Local Road
- Municipality Boundary
- Stream
- Fracture Trace
- Fault
- SCBWA Well
- Leaky Underground Storage Tank
- RCRA Small Quantity Generator
- Superfund Site
- Toxic Release Inventory Location

USGS Karst Feature

- Cave
- Sinkhole
- Surface Mine
- Zone II WHPA
- Zone III WHPA
- Upper Slab Cabin Watershed

Notes:

1. Map displayed in the Pennsylvania State Plane North Coordinate System, US Survey Feet, North American Datum of 1983 (NAD83).
2. Road data and municipality boundaries derived from shapefiles created by the Pennsylvania Department of Transportation, Harrisburg, PA, 2006.
3. Geology derived from Pennsylvania Bureau of Topographic and Geologic Survey, Department of Conservation and Natural Resources, Bedrock Geology of Pennsylvania shapefile, 2001.
4. Sinkhole mapping derived from W. Kochanov of Pennsylvania Geologic Survey.

0 1,500 3,000 6,000
Feet

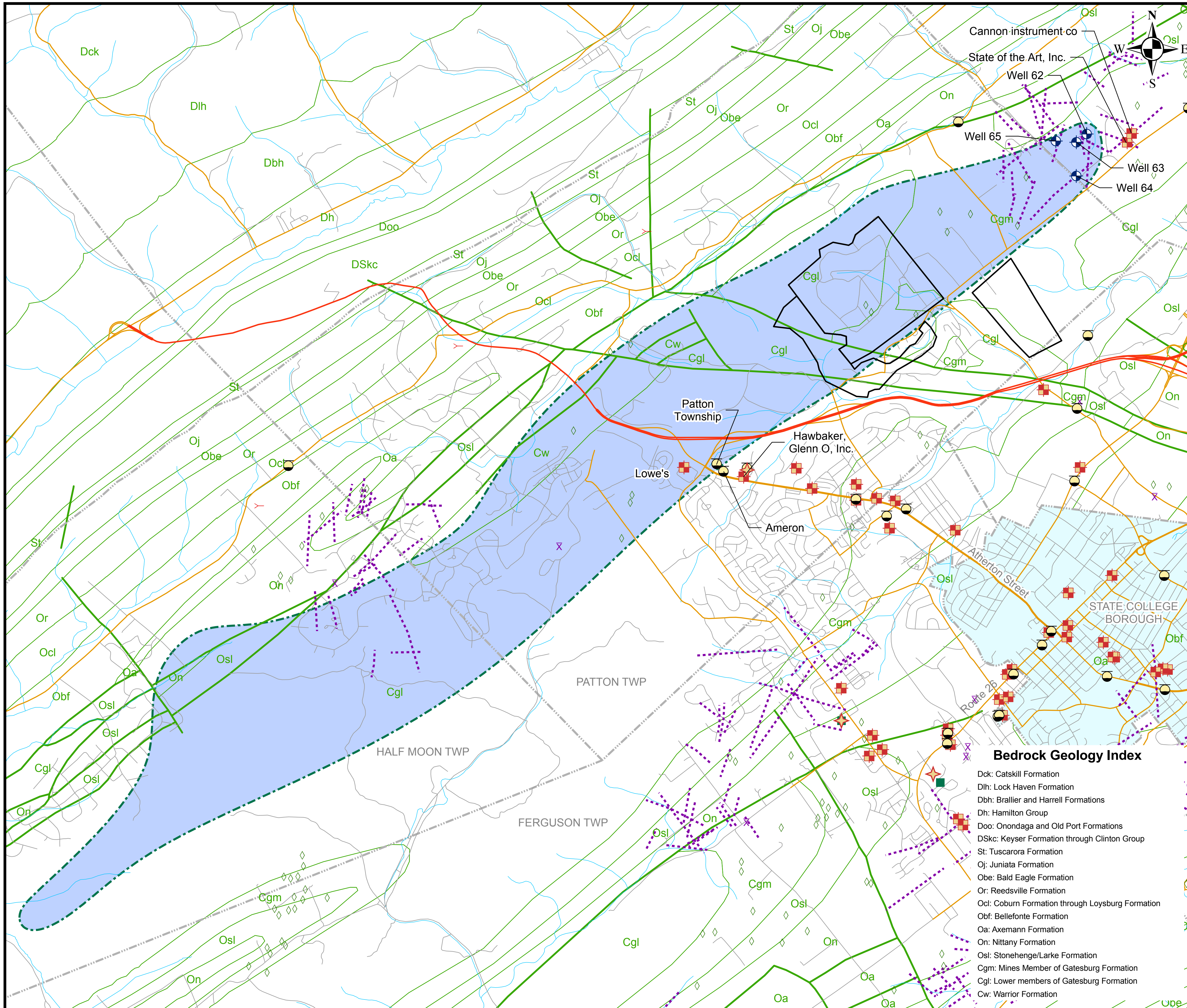
FIGURE 22

Wellfield 5 Delineated Wellhead Protection Area Map During Maximum Permitted Pumping Conditions

State College Borough Water Authority, State College, Pennsylvania

N.A. Water Systems

Z:\databases\scwa\gisdata\arcmap_doc\2006\56002690-014.mxd; January 19, 2007



LEGEND

- Highway
- Superfund Site
- State Road
- Local Road
- Municipality Boundary
- Stream
- Fracture Trace
- SCBWA Well
- Leaky Underground Storage Tank
- RCRA Small Quantity Generator
- Toxic Release Inventory Location

USGS Karst Feature

- Cave
- Sinkhole
- Surface Mine
- Fault
- Penn State Spray Field
- Capture Zone

Notes:

1. Map displayed in the Pennsylvania State Plane North Coordinate System, US Survey Feet, North American Datum of 1983 (NAD83).
2. Road data and municipality boundaries derived from shapefiles created by the Pennsylvania Department of Transportation, Harrisburg, PA, 2006.
3. Geology derived from Pennsylvania Bureau of Topographic and Geologic Survey, Department of Conservation and Natural Resources, Bedrock Geology of Pennsylvania shapefile, 2001.
4. Sinkhole mapping derived from W. Kochanov of Pennsylvania Geologic Survey.

0 2,250 4,500 9,000

Feet

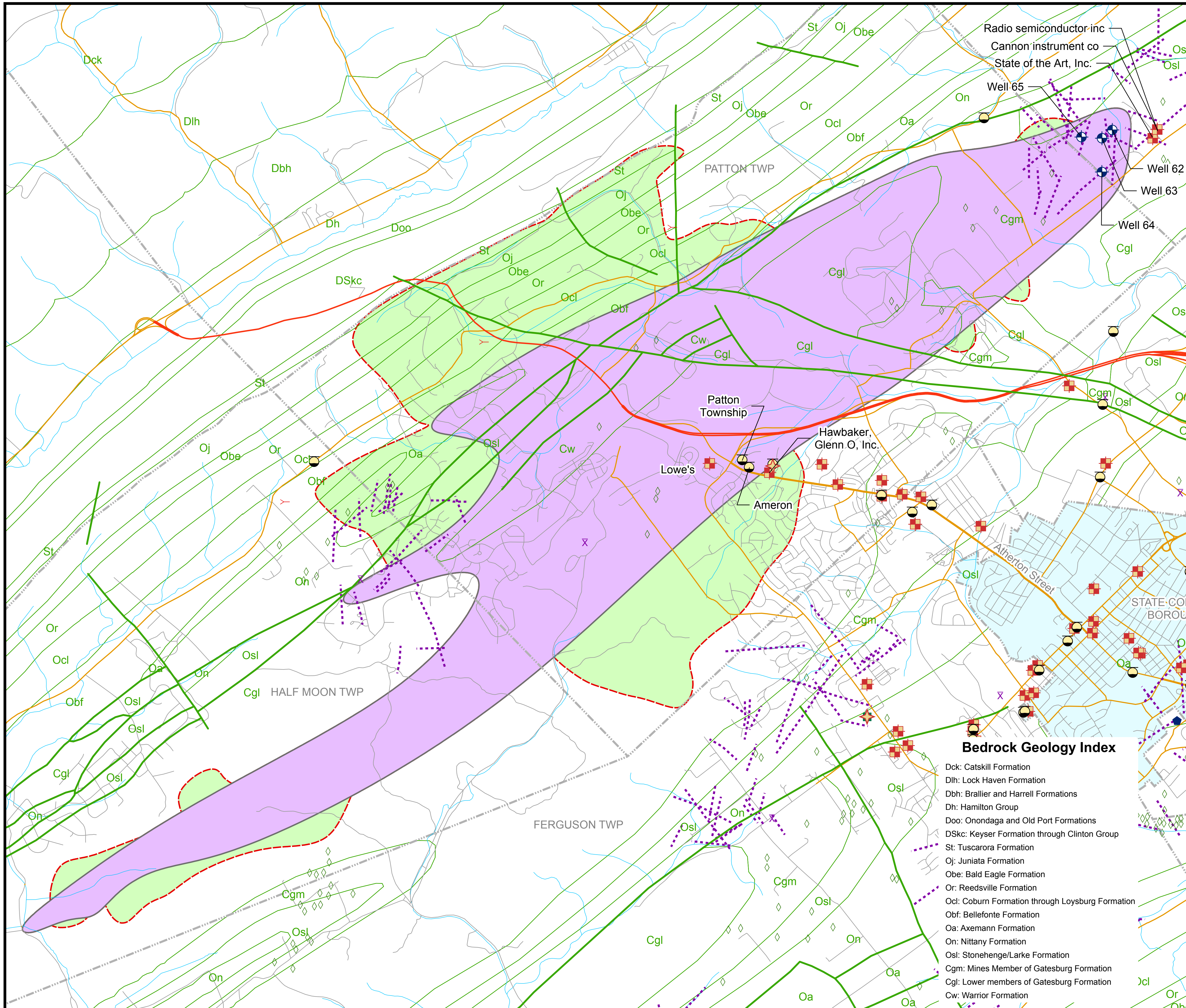
FIGURE 23

Wellfield 6 Capture Zone During Normal Pumping Conditions

State College Borough Water Authority,
State College, Pennsylvania

N.A. Water Systems

Z:\databases\scwa\gisdata\arcmap_doc\2006\56002690-018.mxd; January 19, 2007



N
W E
S

LEGEND

- Municipality Boundary
- Stream
- Fracture Trace
- Fault
- SCBWA Well
- Superfund Site
- Leaky Underground Storage Tank
- National Pollutant Discharge Elimination System
- RCRA Small Quantity Generator
- Toxic Release Inventory Location

USGS Karst Feature

- Cave
- Sinkhole
- Surface Mine
- Zone II WHPA
- Zone III WHPA

Notes:

1. Map displayed in the Pennsylvania State Plane North Coordinate System, US Survey Feet, North American Datum of 1983 (NAD83).
2. Road data and municipality boundaries derived from shapefiles created by the Pennsylvania Department of Transportation, Harrisburg, PA, 2006.
3. Geology derived from Pennsylvania Bureau of Topographic and Geologic Survey, Department of Conservation and Natural Resources, Bedrock Geology of Pennsylvania shapefile, 2001.
4. Sinkhole mapping derived from W. Kochanov of Pennsylvania Geologic Survey.

0 2,250 4,500 9,000
Feet

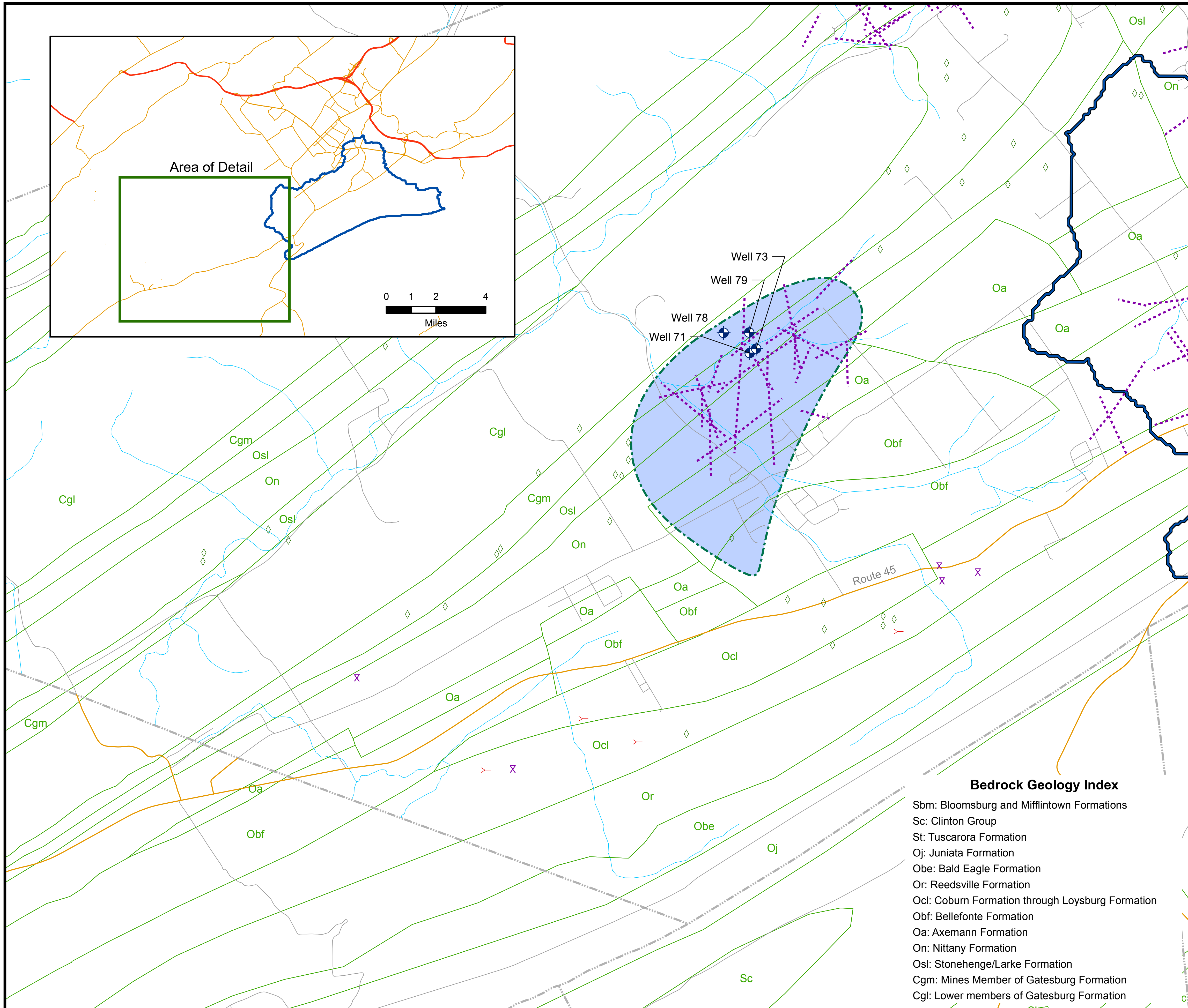
FIGURE 24

Wellfield 6 Delineated Wellhead Protection Area Map During Maximum Permitted Pumping Conditions

State College Borough Water Authority,
State College, Pennsylvania

N.A. Water Systems

Z:\databases\scwa\gisdata\arcmap_doc\2006\56002690-016.mxd; January 23, 2007



N
W E
S

LEGEND

- Highway
- State Road
- Local Road
- Municipality Boundary
- Stream
- Fracture Trace
- Upper Slab Cabin Watershed
- SCBWA Well
- Capture Zone

USGS Karst Feature

- Cave
- Sinkhole
- Surface Mine

Notes:

1. Map displayed in the Pennsylvania State Plane North Coordinate System, US Survey Feet, North American Datum of 1983 (NAD83).
2. Road data and municipality boundaries derived from shapefiles created by the Pennsylvania Department of Transportation, Harrisburg, PA, 2006.
3. Geology derived from Pennsylvania Bureau of Topographic and Geologic Survey, Department of Conservation and Natural Resources, Bedrock Geology of Pennsylvania shapefile, 2001.
4. Sinkhole mapping derived from W. Kochanov of Pennsylvania Geologic Survey.

0 1,500 3,000 6,000
Feet

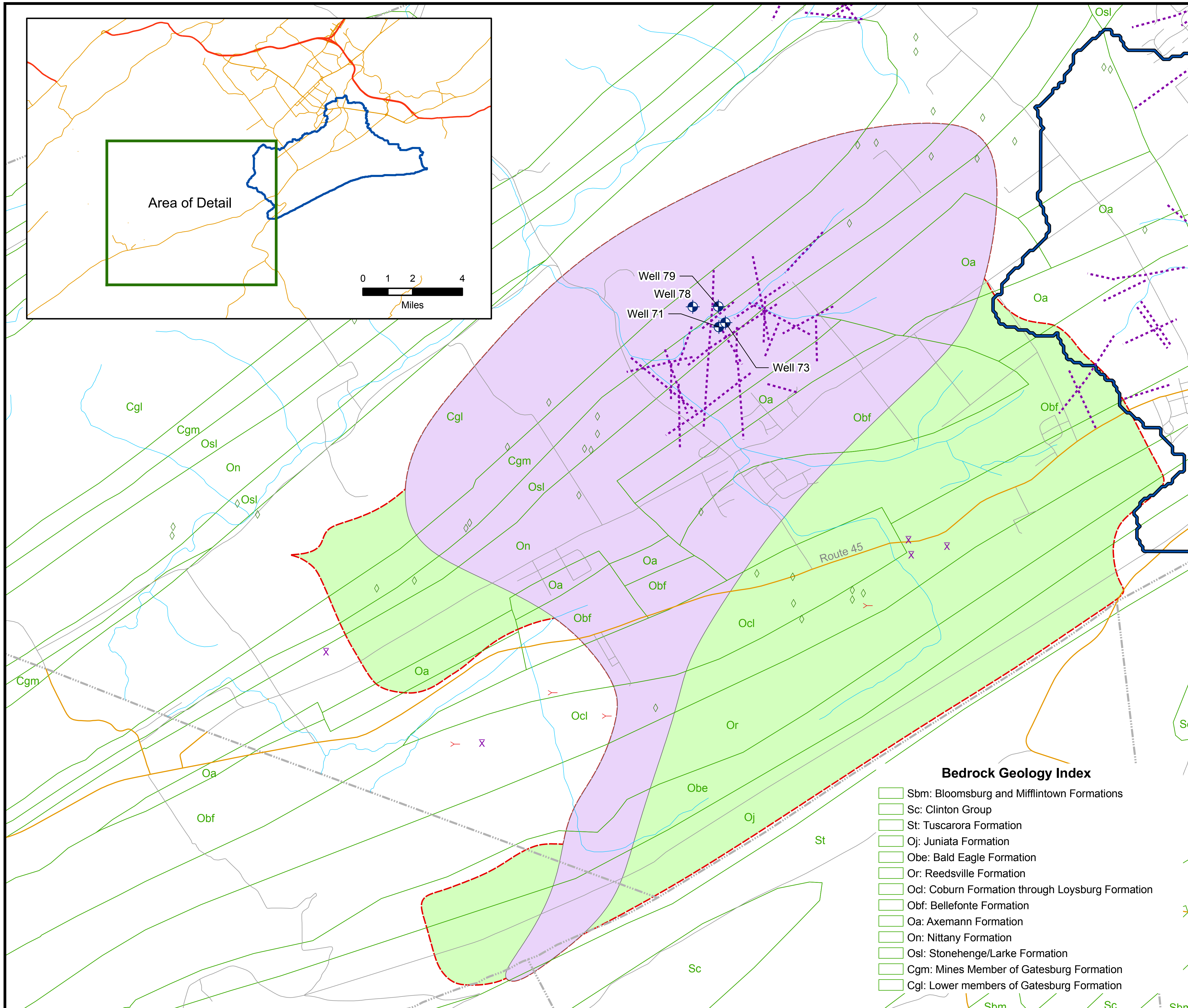
FIGURE 25

Wellfield 7 Capture Zone During Normal Pumping Conditions

State College Borough Water Authority, State College, Pennsylvania

N.A. Water Systems

Z:\databases\scwa\gisdata\arcmap_doc\2006\56002690-019.mxd; January 18, 2007



N
W E
S

LEGEND

- Highway
- State Road
- Local Road
- Municipality Boundary
- Stream
- Fracture Trace
- Upper Slab Cabin Watershed
- SCBWA Well
- Zone II WHPA
- Zone III WHPA

USGS Karst Feature

- Cave
- Sinkhole
- Surface Mine

Notes:

1. Map displayed in the Pennsylvania State Plane North Coordinate System, US Survey Feet, North American Datum of 1983 (NAD83).
2. Road data and municipality boundaries derived from shapefiles created by the Pennsylvania Department of Transportation, Harrisburg, PA, 2006.
3. Geology derived from Pennsylvania Bureau of Topographic and Geologic Survey, Department of Conservation and Natural Resources, Bedrock Geology of Pennsylvania shapefile, 2001.
4. Sinkhole mapping derived from W. Kochanov of Pennsylvania Geologic Survey.

0 1,500 3,000 6,000
Feet

FIGURE 26

Wellfield 7 Delineated Wellhead Protection Area Map During Maximum Permitted Pumping Conditions

State College Borough Water Authority,
State College, Pennsylvania

N.A. Water Systems

Z:\databases\scwa\gisdata\arcmap_doc\2006\56002690-017.mxd; January 18, 2007

TABLES

Table 1
Wellfield Characteristics Including Well Construction and Water-bearing Zones, State College Borough Water Authority

Wellfield Name	Well Number	Casing dimensions (diameter/length)	Open Interval (feet btoc)	Water-Bearing Zones (depth in feet btoc/est. yield in gpm)	Geologic Formation
1 (Thomas)	7	12"/71'	71-165'	>71'	Nittany Dolomite
1	8	12"/72.5'	72.5-165	>72.5'	Nittany Dolomite
1	11	20"/41.33', 14"/83'	83-155'	86', 95', 111', 121', 127-130', 142-146'	Nittany Dolomite
1	14	20"/57', 12"/82'	82-142'	91-96'	Nittany Dolomite
2 (Grays Woods)	17	20"/100', 16"/280', 12"/377'	377-696'	466-470'/200, 474-475'/200, 513-516', 551-554', 667-671', 676-680'	Gatesburg (Lower. Sandy Mbr.)
2	18	20"/70', 16"/179', 12"/273', 10"/318', 8"/406'	406-581'	412-416'/100, 562-571'/150	Gatesburg (Lower Sandy Mbr.)
2	19	20"/50', 16"/246', 12"/317', 10"/389'	389-703'	433-439'/100, 452-458'/200, 582-594'/400	Gatesburg (Lower Sandy Mbr.)
3 (Harter)	22	20"/38', 16"/76', 12"/153'	153-275'	154-158', 228-232'	Nittany Dolomite
3	24	20"/21', 16"/77'	77-300'	92-101', 103-106'	Nittany Dolomite
3	25	36"/15', 30"/7-42', 24"/61', 16"/57', 16" screen/57-97'	screen/57-97', open hole/97-131'	>57'	Nittany Dolomite
4 (Nixon)	41	26"/33.25', 20"/98', 12"/80-136.2', 12" screen/136.2-198', 8" screen/199-300'	136.2-300'	1,100	Nittany Dolomite
4	43	26"/20', 20"/101', 16"/64.33-128', 16" screen/128-214.45', 8" screen/215.45-285.5'	128-285.5'	185', 241-243'	Nittany Dolomite
4	53	26"/27.5', 20"/98', 16"/80-106', 16" screen/106-203.5', 8" screen/204.5-300'	106-300'	200-205', 290-300'	Nittany Dolomite
5 (Circleville)	55	20"/12.5', 16"/111', 12"/242'	242-500'	277-281'/370, 310-316'/50, 349-355'/25, 450-460'/25	Gatesburg (Upper Sandy Mbr.)
5	57	20"/19', 16"/39', 12"/212'	212-500'	(243-248', 266-267', 274-275', 307-309', 480', 481')/300	Gatesburg (Upper Sandy and Mines Mbrs.)
6 (Alexander)	62	20"/19', 16"/218', 12"/370'*	218-509'	247'/30, 272-275'/30, 325-328'/15, 356-357'/25, 428-435'/260	Gatesburg (Lower Sandy Mbr.)
6	63	20"/24.5', 16"/224', 12"/470'*	224-550'	269-271', 295-301', 311-312', 336-337'/100, 389-390', 490-492'	Gatesburg (Lower Sandy Mbr.)
6	64	20"/40', 16"/226', 12"/326'	326-507'	327-328'/60, 358-361'/40, 399-400'/100	Gatesburg (Lower Sandy Mbr.)
6	65	16"/209', 12"/277'* (packer at 267')	267-550'	235'/60	Gatesburg (Lower Sandy Mbr.)
7 (Kocher)	71	20"/14.5', 16"/76.5-116.5', 10"/211.5'	211.5-253.5'	220.5-221.5', (227.5-228.5', 229.5-231.5')/600	Stonehenge and Gatesburg (Mines Mbr.)
7	73	20"/5', 16"/77', 12"/218'*	77-230'	(97-98'/150, 127-128', 130-133', 229-233'/50, 233-250')/500, 250-254'	Stonehenge and Gatesburg (Mines Mbr.)
7	78	20"/23.5, 16"/85', 12"/140.5'	140.5-233'	(152-191', 207-210')/150-200	Stonehenge and Gatesburg (Mines Mbr.)
7	79	16"/79', 12"/323'* (grouted 0-110', K packer at 110')	110-399'	(110-111', 119-120', 149-154', 164-166')/50-100, (215-215.5', 244-245', 256-263', 297-300')/350-400, 340-341', 356-364'	Stonehenge and Gatesburg (Mines Mbr.)

Note:
* Casing is suspended and not grouted.

Table 2
Calculated Zone I,II and III Wellhead Protection Areas for Each Wellfield,
State College Borough Water Authority Wellfields,
State College, Pennsylvania.

Wellfield Name	Well Number	PaDEP-Permitted Pumping Rate (gpm)	Zone I WHPA Radius (feet)	Zone II WHPA (square miles)	Zone III WHPA (square miles)
1 (Thomas)	7	1,000	400	16.34**	21.50**
1	8	1,000	400		
1	11	1,600	400		
1	14	1,300	400		
2 (Grays Woods)	17	1,150	400	6.39	8.38
2	18	500	100		
2	19	1,050	400		
3 (Harter)	22	1,100	400	16.34**	21.50**
3	24	600	170		
3	25	1,500	400		
4 (Nixon)*	41	900	400	3.42	27.36
4*	43	900	400		
4*	53	900	400		
5 (Chestnut Ridge)	55	350	135	2.93	13.12
5	57	400	140		
6 (Alexander)	62	1,650	295	13.39	20.05
6	63	500	175		
6	64	590	330		
6	65	500	175		
7 (Kocher)	71	1,000	400	6.65	12.62
7	73	850	400		
7	78	1,100	400		
7	79	400	140		
Shingletown Reservoir		900	NA	NA	2.3***

Notes:
*-SRBC-permitted rate of 2,700 gpm was used for Wellfield 4 and evenly distributed to each well at 900 gpm.
**-This is the combined Zone II and III WHPA for Wellfields 1 and 3
***-This is the Zone C source water protection area for the Shingletown Reservoir

APPENDICES A-J
(on CD)