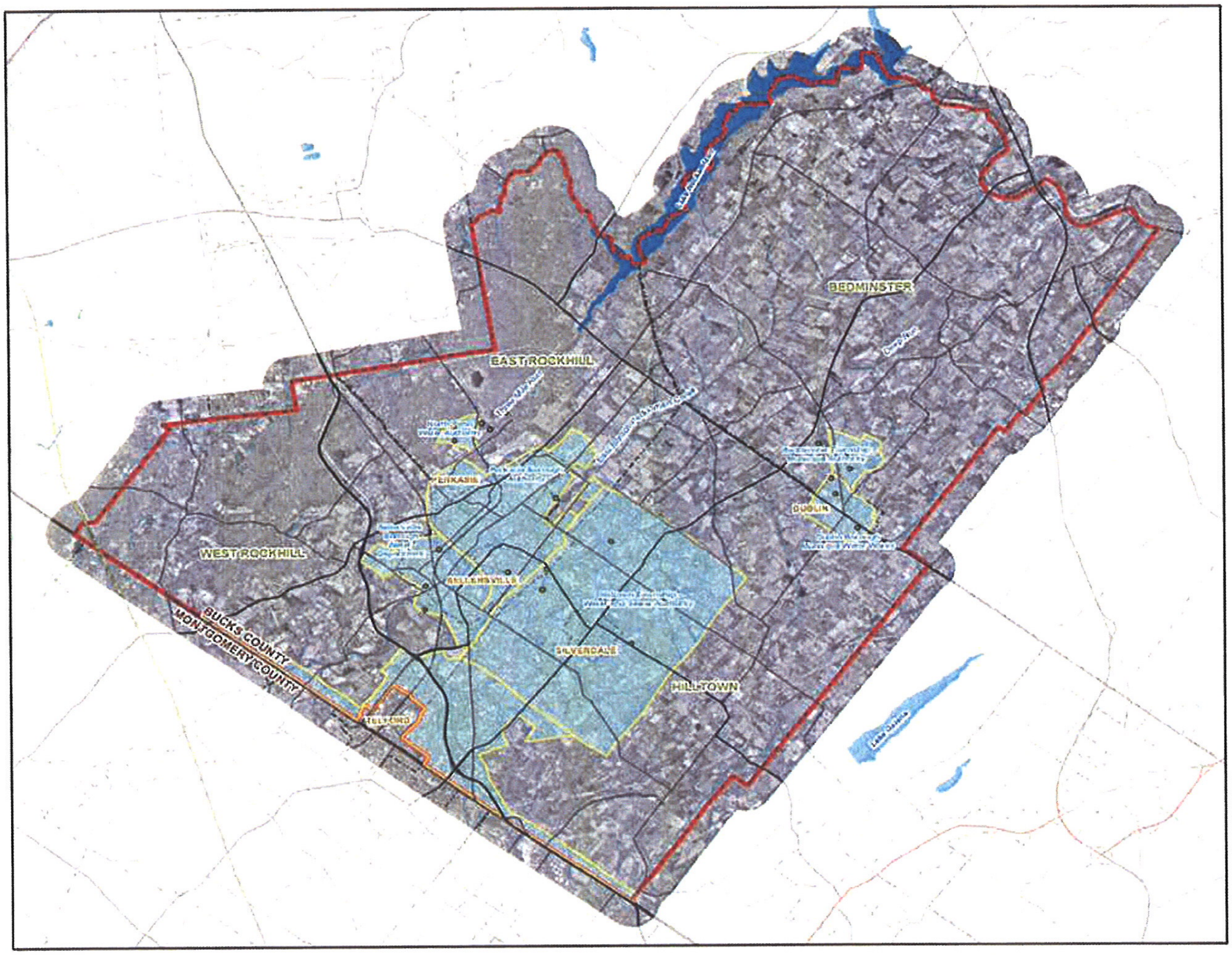
Pennridge Area

Source Water Protection Plan

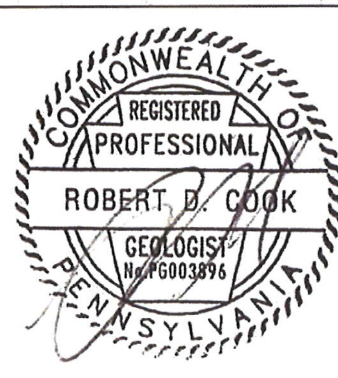
VOLUME I

June 30, 2009



Bucks County, Pennsylvania

Never doubt that a small group of thoughtful, committed citizens can change the world. Indeed, it is the only thing that ever has.
– Margaret Mead



Robert D. Cook, Ph.D., P.G.
PG003896

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Pennridge Area Water Suppliers

Bedminster Township Municipal Authority
Dawn Cook, Secretary
215-249-3320

Dublin Borough Water Department
Eleanor Sadorf, Manager
215-249-3310

Hilltown Township Water and Sewer Authority
Jim Groff, Manager
215-453-6065

North Penn Water Authority
Anthony Bellitto, Jr., P.E., Executive Director
215-855-3617

Perkasie Borough Authority
Gary Winton, Manager
Bruno Mercuri, P.G., Hydrogeologist
215-257-3654

Sellersville Borough Municipal Water Works
Alan Frick, Manager
215-257-5075

Pennridge Area Coordinating Committee

Bedminster Township
Eric Schaffhausen, Supervisor
Dorothy Longacre, Planning Commission

Dublin Borough
Eleanor Sadorf, Manager

East Rockhill Township
David Nyman, Supervisor/Planning Commission

Hilltown Township
Richard Manfredi, Supervisor

Perkasie Borough
Daniel Olpere, Manager

Sellersvillė Borough
Alan Frick, Manager

Silverdale Borough
Dennis Swanger, Councilman (Deceased, Dec. 2008)

Telford Borough
(Non-PACC-Member Participant)
Mark Fournier, Borough and TBA Manager

West Rockhill Township
Donald Duvall, Supervisor

Pennridge Chamber of Commerce
Betty Graver, Executive Director

Pennridge School District
Dr. Robert S. Kish, Superintendent
Terri Yates, School Director
Robert Reinhart, Business Manager

Bucks County Community College
Rodney Altemose, Director, Upper County Campus

Acknowledgements

Pennridge Area Source Water Protection Program Steering Committee

Education Representative
Kathy Michener, Science Teacher, Pennridge High School*

Fire Department Representatives
Robert Grunmeier, Jr., Hilltown Fire Department
Don Wilson, Sellersville Fire Department

Emergency Management Representative
William Devlin, Hilltown Township Emergency Management Coordinator

Farming Community Representative
Ken Beer, Farmer, Hilltown Township

Municipal Government Representative
Donald Duvall, Supervisor, West Rockhill Township

Health Department Representative
Dr. Eleanor Travers, MD, Director, Bucks County Department of Health*

Committee Chair and County Planning Representative
Dennis Livrone, Senior Planner, Bucks County Planning Commission

*Note: No longer in this position.

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Pennsylvania Rural Water Association
United States Geological Survey

Special thanks to Hilltown Township for hosting the PACC's web page.
Visit PACC's web page at <u>http://hilltown.org/pacc/</u> **

*****The new PACC website address is <u>http://pennridgepacc.webs.com/</u>***

Acknowledgements

Technical Consultants

Borton-Lawson Engineering
3893 Adler Place, Suite 100
Bethlehem, PA 18017
484-821-0470
www.borton-lawson.com
Paul DeBarry, P.E., Director, Hydrology and GIS Section*
Eric Yang, Ph.D., Water Resources Specialist

Hazlett-Kincaid, Inc.
(now H2H Associates, LLC)
27 Keystone Avenue
Reno, NV 89503
775-337-8803
www.h2hmodeling.com
Todd Kincaid, Ph.D., Group Leader
Kevin Day, P.G., Geologic Modeler
Brent Meyer, Groundwater Modeler

Cook Geologic, LLC
RR 9 Box 9240
Moscow, PA 18444
570-849-0077
www.cookgeologic.com
Robert Cook, Ph.D., P.G., Geologist

Spotts, Stevens and McCoy, Inc.
345 Wyomissing Boulevard
Reading, PA 19610
610-621-2000
www.ssmgroup.com
Dale Kratzer, P.E., D.E.E., Vice President
Eric Grindrod, P.G., Manager, Geoenvironmental Services
Al Giuseppe, P.G., Geologist

Boucher and James, Inc.
1456 Ferry Road, Building 500
Doylestown, PA 18901
215-345-9400
www.bjengineers.com
Philip Getty, P.G., Environmental Hydrogeologist

Acknowledgements

Regulatory and Grant Contacts

Pennsylvania Department of Environmental Protection
Rachel Carson State Office Building
400 Market Street
P.O. Box 8555
Harrisburg, PA 17105-8555
717-772-4048
www.depweb.state.pa.us
G. Patrick Bowling, P.G., Senior Geologist

Pennsylvania Department of Environmental Protection
Southeast Regional Office
2 East Main Street
Norristown, PA 19401
484-250-5900
www.depweb.state.pa.us
Benjamin Greeley, L.P.G., 484-250-5130
Michelle Clark, Geologic Specialist, 484-250-5117

Planning Assistance

Bucks County Planning Commission
1260 Almshouse Road
Doylestown, PA 18901
215-246-3400
www.buckscounty.org
Lynn Bush, Executive Director
Dennis Livrone, Senior Planner
Rea Monaghan, Environmental Planner

Glossary of Acronyms and Abbreviations
(Continue Updating)

EPA – Environmental Protection Agency
ERP – Emergency Response Plan
FEMA – Federal Emergency Management Agency
GFM – Geologic Framework Model
GIS – Geographic Information Systems
GPD – Gallons per Day
GPS (GPU) – Global Positioning System or Unit
GWM – Groundwater Flow Model
HKI – Hazlett-Kincaid, Inc.
PDA – Pennsylvania Department of Agriculture
PA DEP – Pennsylvania Department of Environmental Protection
PA DCNR – Pennsylvania Department of Conservation and Natural Resources
PA DOT – Pennsylvania Department of Transportation
PAGS – Pennsylvania Geologic Survey (PA Topographic and Geological Survey)
PFAS – Pennsylvania Facility Analysis System
PG – Professional Geologist
PRWA – Pennsylvania Rural Water Association
SDWA – Safe Water Drinking Act
SOC – Synthetic Organic Compounds
SWAP – Source Water Assessment and Protection
SWAPP – Source Water Assessment and Protection Program
SWP – Source Water Protection
SWPA – Source Water Protection Area
USGS – United States Geologic Survey
VOC – Volatile Organic Compounds
WHP – Wellhead Protection
WHPA – Wellhead Protection Area
WSP – Watershed Protection

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EXECUTIVE SUMMARY
PENNRIDGE AREA SOURCE WATER PROTECTION PLAN

Purpose

The purpose of the Plan is to protect public health, safety, and welfare through the preservation of the area's groundwater resources.

There are numerous examples of groundwater sources becoming contaminated from a variety of pollutants. These situations have resulted in either expenditures of large sums of money to treat the water, or forced the development of alternative, and often expensive, secondary sources of supply.

The Pennridge Area Coordinating Committee is undertaking a pro-active approach to minimizing the possible contamination of our common water resources.

Background

The Federal Safe Drinking Water Act (SDWA) and Pennsylvania Safe Drinking Water Act provide for wellhead protection, and in August 1996, major amendments to the federal law were signed. One key provision of those amendments deals with enhanced protection of drinking water sources.

Bucks County prepared a water supply plan and model wellhead protection study in 1997 (Bucks County Planning Commission, 1997).

Beneficiaries

Users of both community water systems and private individual wells will benefit from the Plan.

Summary of Project

There are eight municipalities located within the project area, and make up what is known as the Pennridge Area. They are: Bedminster Township, Dublin Borough, East Rockhill Township, Hilltown Township, Perkasie Borough, Sellersville Borough, Silverdale Borough, and West Rockhill Township.

There are six water authorities that participated in this project. They are Bedminster Municipal Authority, Dublin Borough Water Department, Hilltown Township Water and Sewer Authority, North Penn Water Authority, Perkasie Borough Authority, and Sellersville Borough Municipal Water Works.

Through the formation of a steering committee, the project was able to be guided with direct input from the municipalities and water authorities. Preliminary sources of potential pollution were identified that could impact the area's groundwater and surface water resources, and various management tools that will ultimately aid in mitigating current problems and preventing future contamination issues were reviewed by the Steering Committee. To gain insight into the area's current management policies, each municipality's zoning or subdivision ordinances, comprehensive plan, or similar documents were reviewed to identify certain elements relevant to wellhead protection.

I. INTRODUCTION

A. Water Resources Planning in the Pennridge Area

In 2001, the Pennridge Area Coordinating Committee (PACC) decided to embark on a planning effort to address the need for melding land use planning with water resources management and protection. That effort led to preparation of three innovative multi-municipal documents. They are (1) the *Pennridge Water Resources Plan* (PWRP), July 2002; (2) the *PWRP Implementation Component*, July 2006; and (3) the *Source Water Protection Plan for the Pennridge Area*, June 2009 (this document).

The *Pennridge Water Resources Plan* and its implementation are strongly based on the partnership amongst the eight municipalities of the Pennridge Area Coordinating Committee (PACC). Municipal officials in the Pennridge Area wish to improve their watersheds by addressing issues such as nonpoint source pollution, drinking water source protection, stormwater management, streambank erosion, and the overall health of the watersheds.

B. Pennridge Water Resources Plan

The *Pennridge Water Resource Plan*, July 2002 (PWRP), prepared by Bucks County Planning Commission et al, is a comprehensive water resources plan for eight municipalities in Bucks County known as the Pennridge Area. It addresses the impacts on and threats to water in an area where there is a steady conversion of the natural environment to the developed environment. The Plan provides a basis of information upon which to establish a long-range plan for restoring and protecting the water resources of the study area. Implementation of the Plan is coordinated with municipal land use planning documents (i.e., comprehensive plans, zoning ordinances, subdivision/land development ordinances, and sewage facilities plans), with the goal being to provide for the Pennridge Area's fair share of development, while at the same time providing for the long-term availability of water resources upon which the population depends.

The PWRP was funded in part by grants from the Pennsylvania Department of Environmental Protection (DEP) and the Pennsylvania Department of Community and Economic Development. The goal of the Plan is to address future growth and development in a proactive manner by developing and implementing a plan that addresses both water quantity and water quality issues. To begin to solve the problems associated with land development, the Plan will be coordinated with municipal land use planning documents during its implementation phase.

Several tasks make the PWRP innovative and unique. The coordination and cooperation amongst the eight municipalities of the Pennridge Area Coordinating Committee (PACC) is truly an incentive for other municipalities in Pennsylvania. In addition, the project involves a cooperative effort among various governmental agencies, citizen organizations, and stakeholders that have developed sources of information and data relevant to the Plan. Public access to information on the study is available on the PACC website at http://pennridgepacc.wells.com.

The PWRP coordinates with current and future Act 167 stormwater management planning in the four major watersheds of the Pennridge Area (East Branch Perkiomen; Perkiomen; Tohickon; and Unami). In addition, during the implementation phase (following completion of the Plan and adoption by the PACC) a water budget interface should be developed using a Geographic

Information Systems (GIS) database. The GIS database will be used to convert the mapped products of the Plan into a modeling and analysis system to create an integrated protection program for water resources.

The *Pennridge Water Resources Plan's* main objectives are to:

- Protect the supply of surface water and groundwater resources for existing and future recreational, industrial, household and commercial users; and
- Protect surface water and groundwater resources from point and nonpoint pollutants.

C. Purpose of the *Pennridge Area Source Water Protection Plan*

One of the implementation tasks of the *Pennridge Water Resources Plan* is a Source Water Protection (SWP) Program. Subtasks of the SWP program include: assessment and prioritization; surface water sources; delineation of wellhead protection areas; water conservation and reuse program; well static level; and GPS (Geographic Positioning System) location.

In the Pennridge Area there are seven municipal water suppliers that meet the definition of a community water system in a variety of environmental settings, and their drinking water sources vary, as does the land use surrounding their origination. Since the population of the Pennridge Area is expected to continue to grow steadily over the next 10 - 20 years, proper planning, water resource management, and pollution prevention are critical to ensure that future drinking water needs will be met.

The *Bucks County Water Supply Plan and Model Wellhead Protection Study,* completed in 1996, followed a step-by-step approach to completing a wellhead protection program for seven municipal wells in various Bucks County locations. The results of the studies conducted on the seven demonstration wells were intended for use by other community water suppliers to develop wellhead protection programs. Also at that time, Telford Borough Authority (TBA) was developing a wellhead protection plan. The Pennridge Area water suppliers are now taking action by producing this document to provide what is needed for a DEP approved wellhead protection plan.

The water suppliers in the PACC communities recognize the possibility of potential threats to community water supplies. In an effort to address the potential problems that could affect the source, the water suppliers, with guidance from the Pennridge Area Source Water Coordinating Committee (PACC) and the Bucks County Planning Commission (BCPC), established the Pennridge Area Water Protection Steering Committee to make recommendations to water authorities of the Pennridge Area, Bucks County.

Source Water Protection plans are necessary to protect the water source from contaminants that are difficult and costly to treat in a clean-up mode. A Source Water Protection Plan clearly identifies actual and potential sources of contamination. Secondly, it allows communities to effectively educate the public on the importance of protecting their drinking water source. Third, the plan serves as the first step for long-term planning for the sustainability of community water supplies. Finally, it provides a comprehensive action plan in case of a source water emergency.

D. The Study Area

The Pennridge Area is a 93 square-mile study area of Bucks County, Pennsylvania composed of the eight municipalities that make up the Pennridge School District and is located in what is locally known as "Upper Bucks." The study area is displayed in Figure 1. The Pennridge Area Coordinating Committee (PACC) is an intermunicipal partnership among the eight municipalities, the Pennridge School District, the Pennridge Chamber of Commerce, and the Bucks County Community College. Table 1 lists the communities on the PACC. Representatives on the committee meet monthly to discuss issues of mutual concern, and staff members of the Bucks County Planning Commission advise the PACC. Telford Borough, although not a member of the PACC, has been kept informed of the progress of the study and is participating in the water resources planning effort; the Telford Borough Authority has water supply wells in the Pennridge Area and provides water service to customers in the study area. The Delaware River Basin Commission (DRBC) and the local water/wastewater utilities are also supporting and participating in the study and will be asked to serve on an "Implementation Subcommittee."

Table 1. Communities on the Pennridge Area Coordinating Committee (PACC).

Bedminster Township	Perkasie Borough
Dublin Borough	Sellersville Borough
East Rockhill Township	Silverdale Borough
Hilltown Township	West Rockhill Township

The Pennridge Area is predominantly rural. Growth and development have been steady, primarily in the form of single-family detached dwellings and commercial developments. Due to public water and sewer availability and a strong presence of commercial and industrial uses, the growth trend is expected to increase at a slightly higher rate. The area's natural features – watersheds and streams; floodplains and wetlands; topography and steep slopes; geology and soils; woodlands and significant natural areas – make it attractive to homebuilders and homebuyers.

The boundary of the study area coincides with the boundary of the Pennridge School District and encompasses headwater areas of eleven DRBC-designated watersheds, shown in Figure 2. The East Branch Perkiomen watershed occupies the largest area, extending southward into Montgomery County. The study area also includes large areas of Unami–Ridge Valley Creeks, Tohickon Creek–Three Mile Run, Tohickon Creek–Lake Nockamixon, Tohickon Creek–Deep Run, Tohickon Creek–Geddes Run–Cabin Run, North Branch Neshaminy Creek, and West Branch Neshaminy Creek Basin watersheds. Small areas of Tohickon–Beaver–Morgan Creeks, Dimple Creek, and Upper Reach Skippack Creek watersheds are also found in the study area.

Lake Nockamixon borders the northwest corner of the study area. Major streams within the study area include the East Branch Perkiomen Creek, Three Mile Run, and the northern reaches of Neshaminy Creek. The region is generally rural and agricultural with commercial, industrial, and high-density residential areas clustered along main road corridors such as S.R. 309 and S.R. 313.

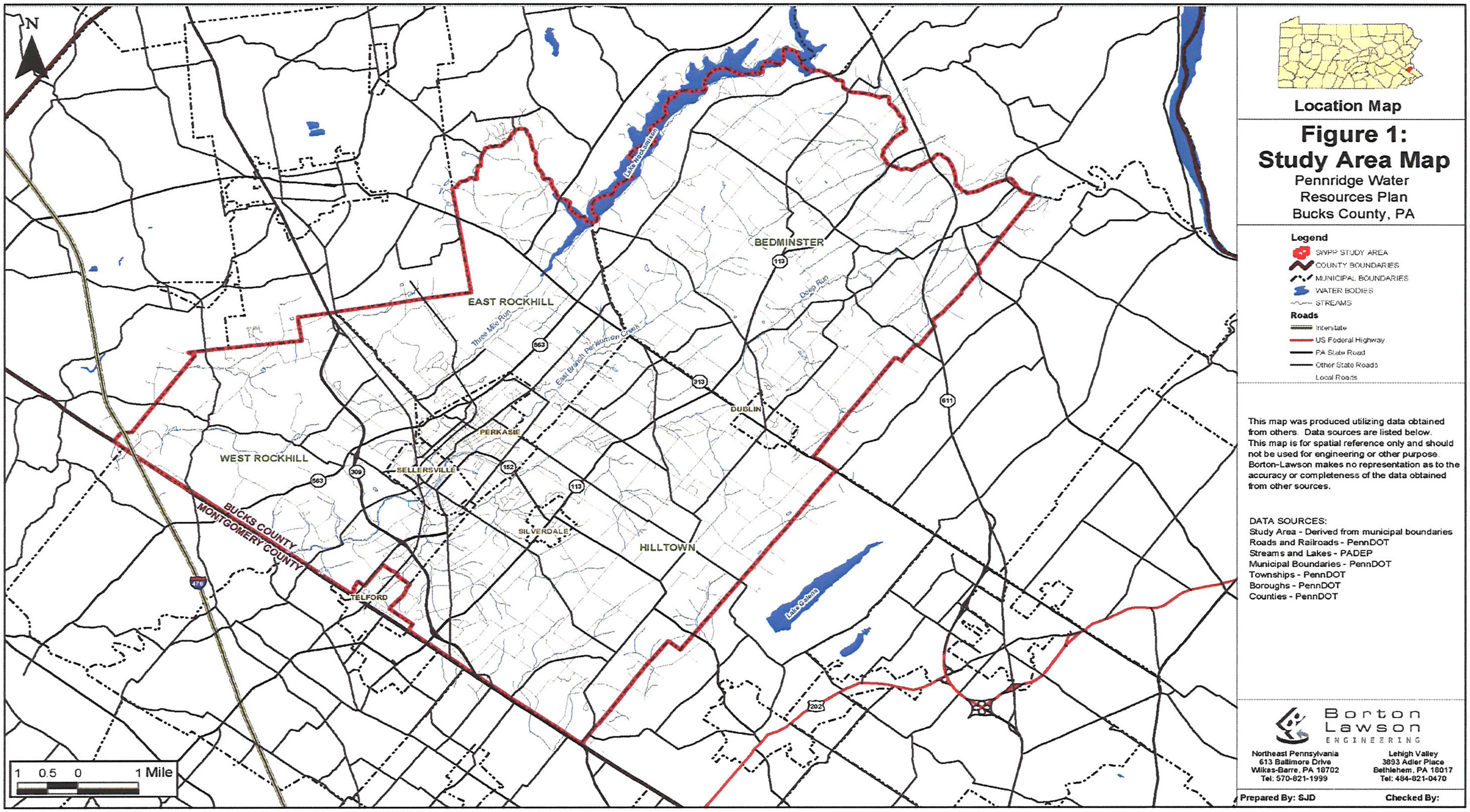

Figure 1. Study Area Map.

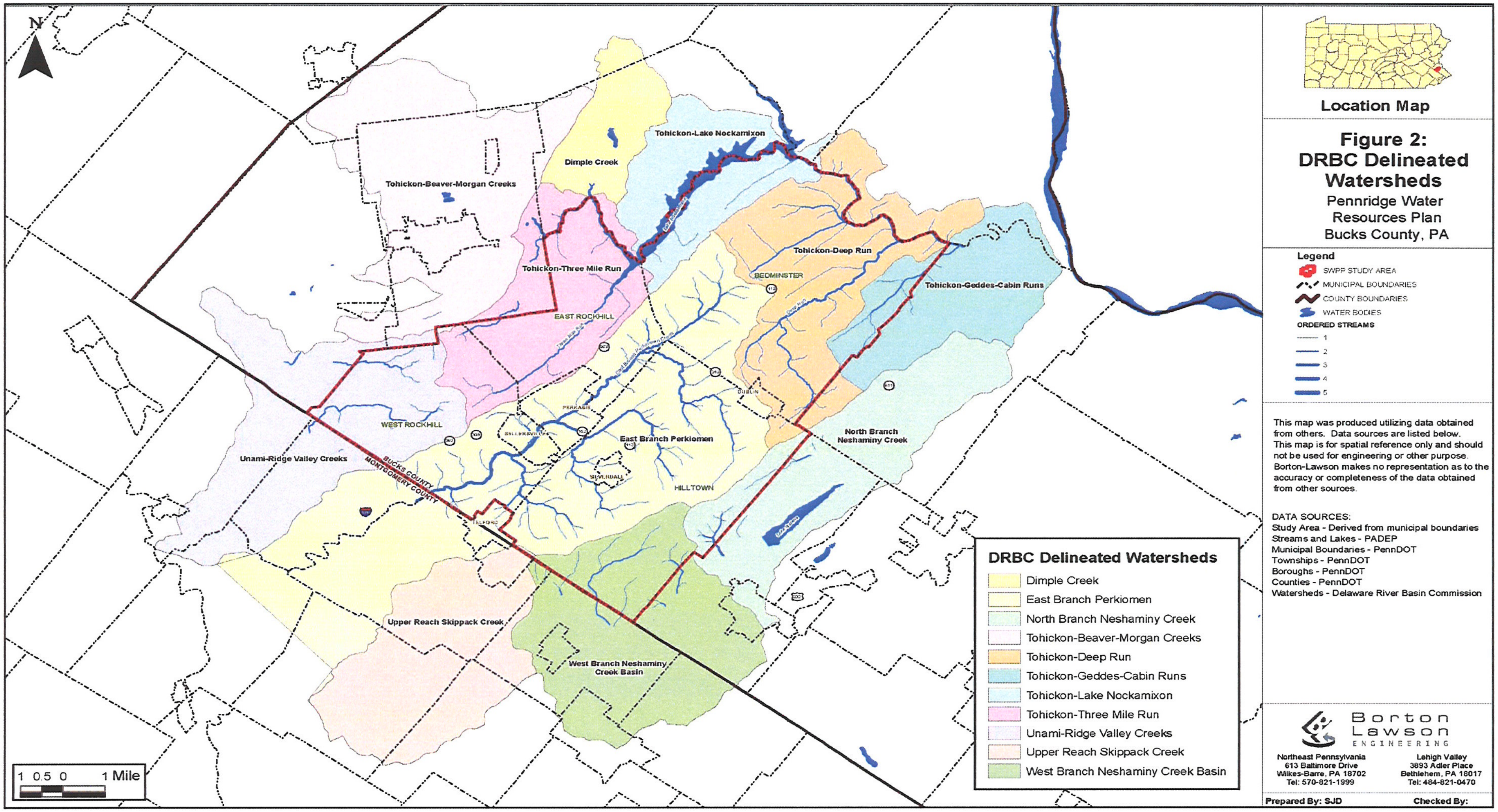

Figure 2. DRBC Delineated Watershed.

E. Climate and Precipitation

Bucks County has a humid continental climate characterized by warm summers and moderately cold winters. The average yearly temperature in the region is approximately 50° to 55° F. The normal mean temperature for January, the coldest month, is approximately 30° F, and the normal mean temperature for July, the warmest month, is approximately 74° F (Sloto and Schreffler, 1994). Tropical storms and hurricanes that move inland from the Atlantic coast and/or the Gulf of Mexico occasionally reach Bucks County and bring heavy rainfall. Winter precipitation is often light but frequent.

There are usually several snowfalls each winter, and more frequent snowfalls have been seen in recent years. Heavy snows (greater than 12 inches) occasionally blanket the study area. Spring and fall are characterized by rapidly changing weather patterns in which alternate periods of freezing and thawing are common during both seasons. The length of the growing season ranges from 120 to 200 days.

Currently, the National Oceanic and Atmospheric Administration (NOAA) precipitation station at Sellersville is the only official station in the study area. The Sellersville station, while being the closest station to the Study Area, provides only eight years of data from 1948 to 1951 and 1996 to 2001 with a lack of data from 1951 to 1996. Therefore, an average annual precipitation value was derived using values for surrounding areas: Neshaminy Creek Watershed Plan (45"), Doylestown data 1968 to 2000 (46"), Allentown data 1912 to 1991 (45") and data from Sustainable Watershed Management for Northern Chester County Watersheds (45"). This led to the determination of an average annual precipitation for the Pennridge Area of 45 inches per year (Bucks County Planning Commission, et al. 2002).

F. Demographics

Although the percentage of residential land use, compared to all land uses, remained fairly constant between 1970 and 1990, the percentage of nonresidential development in the study area during the same period increased from 3 percent to 9 percent. Also, agricultural and vacant land uses decreased from 68 percent to 60 percent in the same period. Housing increased approximately 13 percent between 1990 and 2000 and is projected by the BCPC to increase another 11 percent between 2000 and 2010. Thus, it can be noted that the Pennridge Area is experiencing a fairly moderate but steady rate of growth that is expected to continue for the foreseeable future (Pennridge Water Resources Plan, 2002). Appendix A presents a summary of Pennridge Area demographics.

Regional context has played a significant role in past development trends and will continue to play a significant role in the future development patterns of the Pennridge Area. The Pennridge Area is predominantly rural in nature, with quaint villages and small boroughs. However, its scenic qualities and location make it attractive for residents and businesses alike.

G. Description of Water Supply

Currently, many Pennridge Area residents rely on individual private wells, while others in the more densely populated boroughs and development districts are served by either municipal or private community water systems that draw from both surface and groundwater sources. It is estimated that approximately 50 percent of the population in the Pennridge Area was served by municipal

community water supplies in 2000. Groundwater provides the Pennridge Area with the majority of its water supply, while surface water only makes up a small percentage of the water supplies in the Pennridge Area (Bucks County Planning Commission et al, 2002). Residents and industry located within the Pennridge Area depend on numerous wells to provide them with the source of their daily water supply.

In the Pennridge Area there are seven municipal water suppliers that meet the definition of a community water system. These water supplies are found in a variety of environmental settings, and their drinking water sources vary, as does the land use surrounding their origination. Table 2 lists the water suppliers in the Pennridge Area. The table also lists the municipalities or portions of the municipalities served by each water supplier in the Pennridge Area, with drinking water from groundwater/surface water. Since the population of the Pennridge Area is expected to continue to grow steadily over the next 10 – 20 years, proper planning, water resource management, and pollution prevention are critical to ensure that future drinking water needs will be met.

Table 2. Municipal Water Supplies in the Pennridge Area and Their Service Areas.

Pennridge Area Municipal Water Supplier	Municipalities Served
Bedminster Municipal Authority	Bedminster Township
Dublin Borough Water Department	Dublin Borough
Hilltown Township Water and Sewer Authority	Hilltown Township, Silverdale Borough
North Penn Water Authority	East Rockhill, Hilltown Township
Perkasie Borough Authority	Perkasie Borough, East Rockhill Township, Hilltown Township
Sellersville Borough Municipal Water Works	Sellersville Borough, West Rockhill Township
*Telford Borough Water Authority	Telford Borough, Franconia Township, Hilltown Township

*Note: Telford Borough Water Authority has a separate DEP approved Wellhead Protection Program (*Wellhead Protection Program for Telford Borough Authority*, March 1998, Revised January, 1999).

The following water supply inventory, Table 3, was developed to assist in the management of groundwater and surface water in the Pennridge Area.

Data for this inventory were gathered from various sources, including the Bucks County Department of Health, Delaware River Basin Commission, and the Pennsylvania Department of Environmental Protection. Well data tables are located in Appendix E– Water Supply Inventory Data of the *Pennridge Water Resources Plan* (Bucks County Planning Commission and et al., 2002), which also contains a list of contacts for the community water suppliers serving the study area. Data included in those tables are Facility Name, Municipality, Basin (DRBC-designated watershed), Daily Use, and Rates of Withdrawal. Tables in the aforementioned Appendix E designate which facilities are responsible for the largest withdrawals in each basin. The following summary table shows the results.

Table 3. Community Water Suppliers Summary.

SUPPLIER	OWNERSHIP	DOMESTIC POPULATION SERVED	PER CAPITA WATER USE (Gal/Day)	AVERAGE DAILY USE (Gal/Day)	ANNUAL WATER USE (MG)
		2000	2000		2000
Bedminster Twp. Mun. Authority	Authority	1,000	43	43,000	15.70
Dublin Borough Municipal Water Works	Municipal	1,700	50	85,000	31.03
Hilltown Twp. Water and Sewer Auth.	Authority	3,050	75	228,750	83.49
North Penn Water Authority--East Rockhill	Authority	420	62	26,040	9.50
North Penn Water Authority--Hilltown	Authority	133	50	6,650	2.43
Perkasie Boro. Authority	Authority	10,000	53	530,000	193.45
Sellersville Boro. Mun. Water Works	Municipal	4,500	75	337,500	123.19
Telford Boro. Authority	Authority	7,050	50	352,500	128.66
Small Water Systems (7)	Private	1,160	50	**58,000**	**21.17**
TOTALS		**29,013**	**57**	**1,667,440**	**608.62**

Table 4. Estimated Groundwater Withdrawals.

Basin Name	Total Groundwater Withdrawals from Respective Basins (Mgal/Yr)
East Branch Perkiomen–Morris Run	269.443
East Branch Perkiomen–Indian Creeks	43.445
East Branch Perkiomen–Mill Creeks	296.780
North Branch Neshaminy Creek	0.024
Tohickon–Deep Run	50.123
Tohickon–Geddes–Cabin Runs	5.259
Tohickon–Three Mile Run	144.872
Unami-Ridge Valley Creeks	10.192
Upper Reach Skippack Creek	34.493
W. Branch Neshaminy Creek Basin	47.152
Total	901.783

The DRBC-designated watersheds that include the Pennridge Area consume approximately 900 million gallons of groundwater per year. The largest withdrawals occur in East Branch Perkiomen–Morris Run and East Branch Perkiomen–Mill Creeks Basins that collectively account for nearly 63 percent of total withdrawal in the Pennridge Area.

H. Topography

Elevated areas bound the Study Area to the west and east with a broad valley running northeast/southwest through the approximate center. Elevations range from approximately 270 feet to 840 feet above mean sea level. The highest point is Rock Hill located in East Rockhill Township, along the western boundary. The lowest elevations are at the north end of the Study Area along Tohickon Creek and at the south end of the Study Area along the East Branch Perkiomen Creek. The topography of the study area is shown in the format of Digital Raster Graphics (DRG), Digital Elevation Model (DEM) and slopes and contours in Figures 3, 4, and 5, respectively.

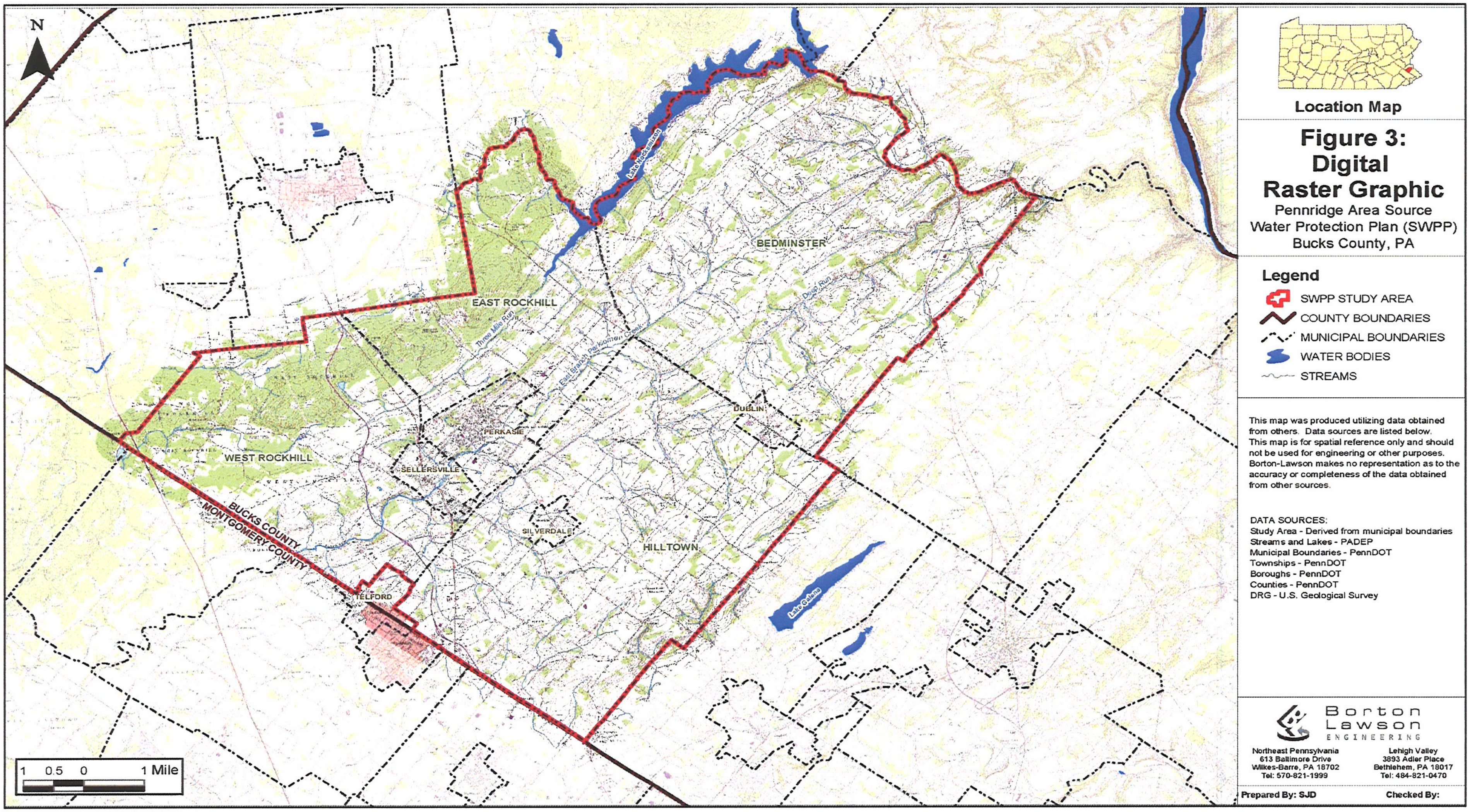

Figure 3. Digital Raster Graphic.

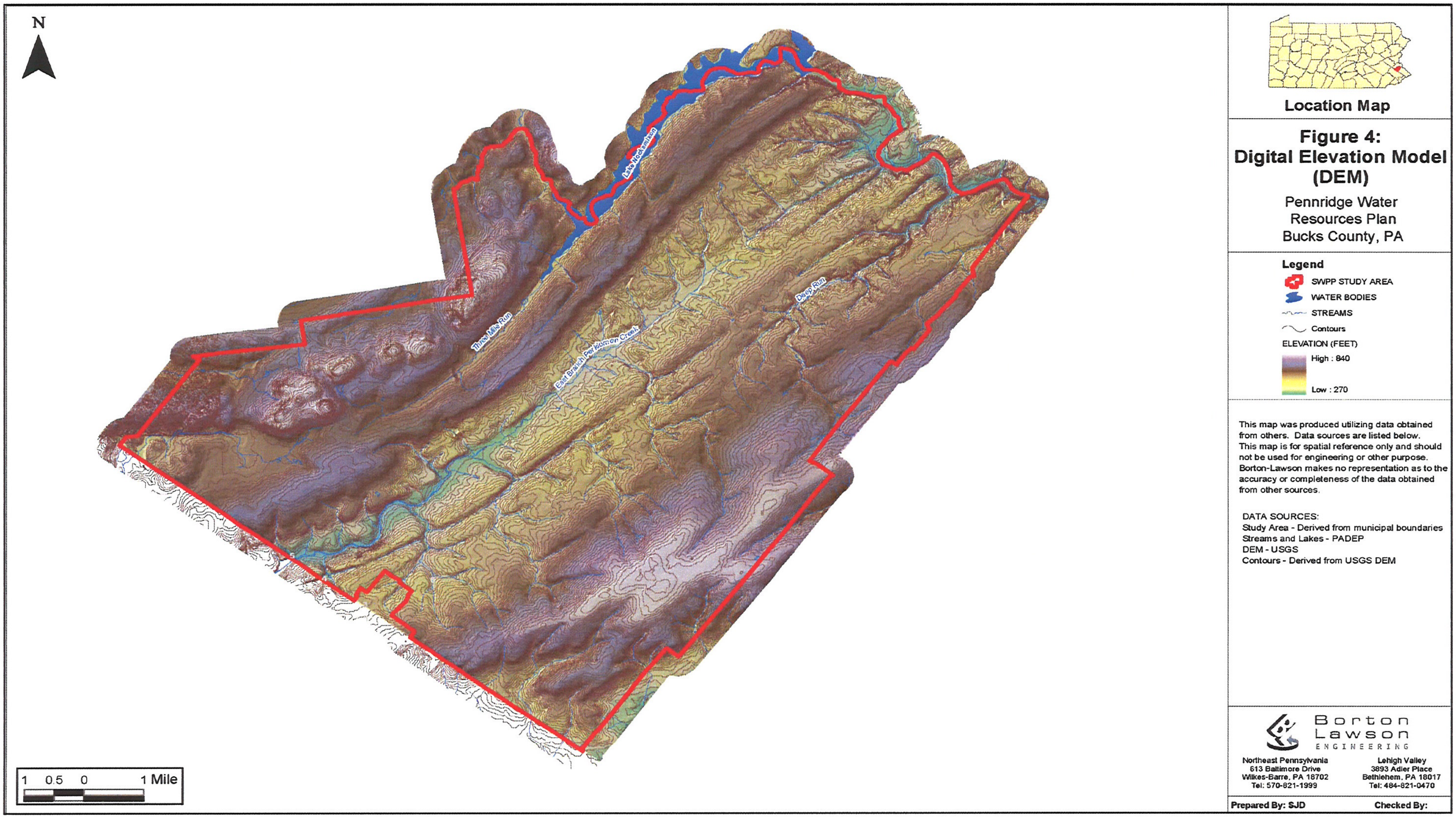

Figure 4. Digital Elevation Model (DEM).

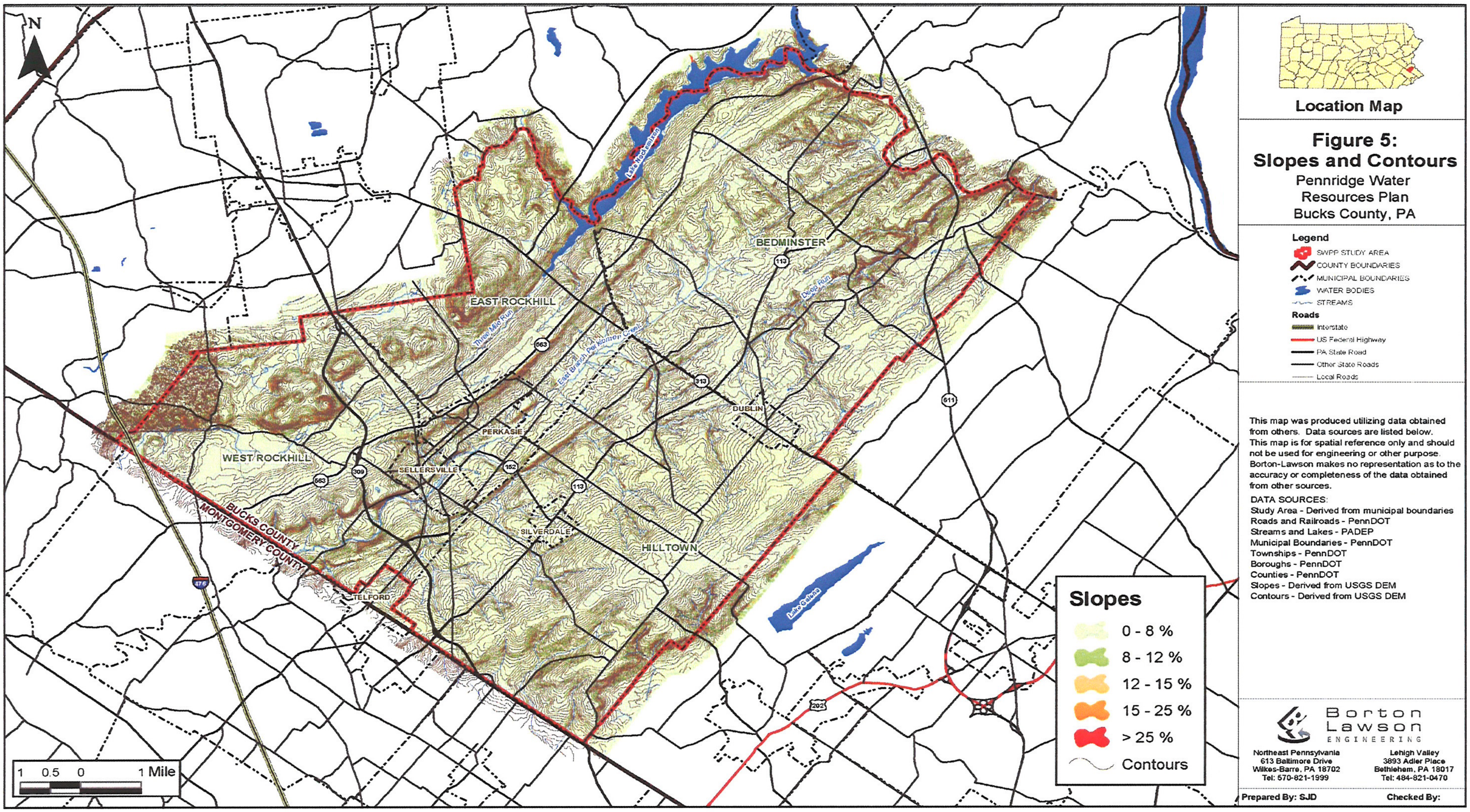

Figure 5. Slopes and Contours.

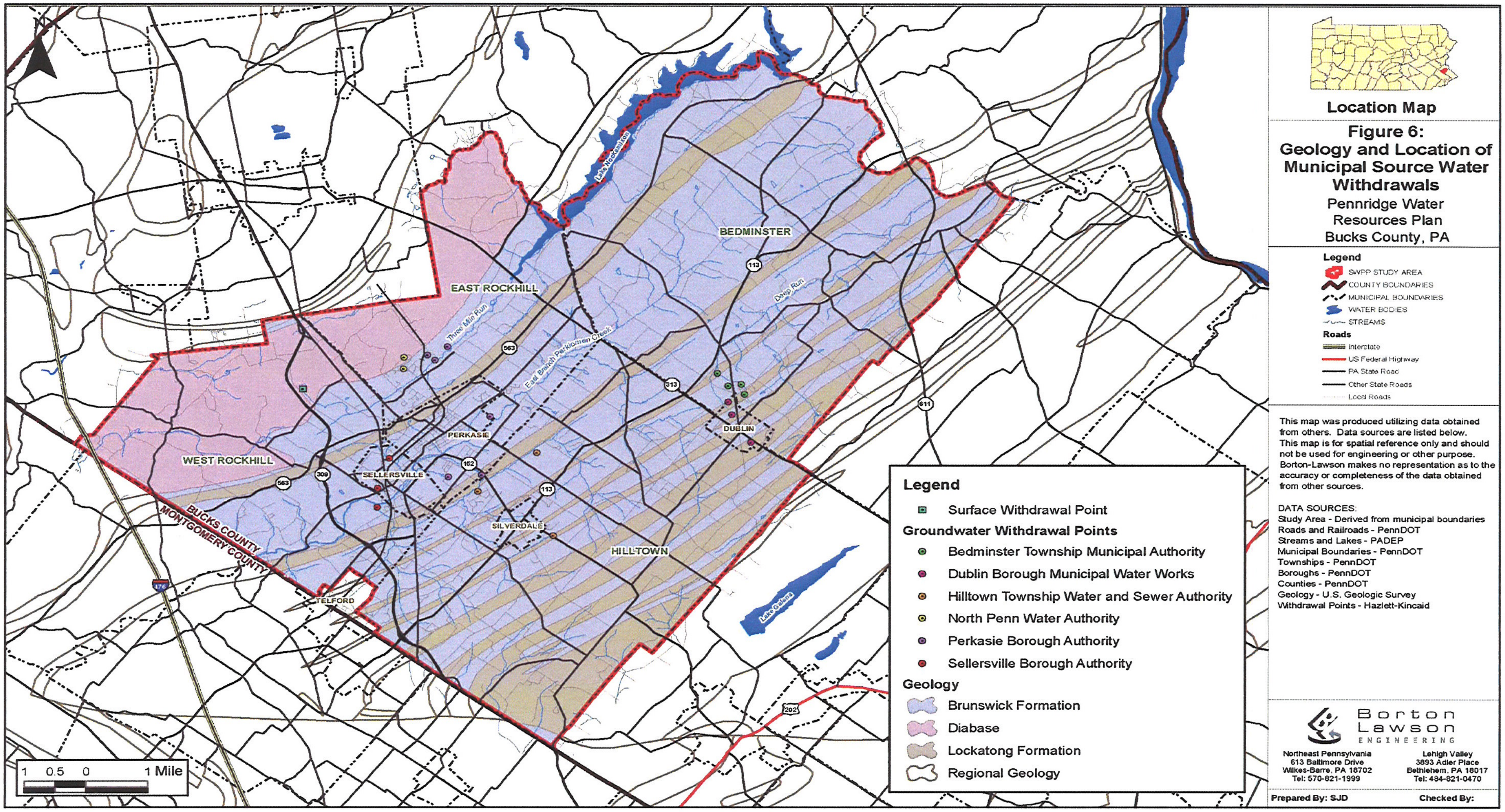

Figure 6. Geology and Location of Municipal Source Water Withdrawals (Copied from Figure 5 of Grant Application).

I. Hydrogeologic Setting

The geology for the study area was determined from the digital geology coverage for Bucks County created by the Environmental Resource Research Institute (ERRI) and supplemented with data from the report entitled Groundwater Resources of Bucks County (Greenman, D.W., 1955). Geology data are displayed graphically in Figure 6 (Figure 6 also shows the locations of municipal source water withdrawals). Geology plays a direct role in establishing a water resource plan because it affects soil types within the watershed through parent material breakdown, and it stores water that percolates from the surface and discharges water to maintain baseflow in streams. There are three primary types of bedrock geology in the Study Area as described below.

Bucks County can be divided into seven distinct hydrogeologic units or aquifers based on similar characteristics of geologic units. There are three hydrogeologic units in the study area and their characteristics are summarized below (Sloto and Schreffler, 1994). Table 5, Hydrogeologic Parameters for the Hydrogeologic Units in Bucks County, provides information on the typical water bearing capability of each of the geologic formations across the county (Bucks County Planning Commission et al., 2002).

BRUNSWICK FORMATION

The Brunswick Formation is composed of reddish-brown shale, siltstone, and mudstone, containing a few green and brown shale interbeds; red and dark-gray, interbedded argillites near base. This formation is highly fractured allowing a large volume of water storage and therefore relatively high-yielding wells. The Brunswick formation underlies the eastern two-thirds of the Study Area and is interspersed with the Lockatong Formation.

Groundwater in the Brunswick Formation flows primarily through fractures and closely spaced joints in the siltstone and shale. In the shallow, weathered portions of the aquifer, groundwater is under unconfined conditions. The deeper fracture zones within the formation are more permeable and unweathered. Groundwater is under confined conditions in the deeper portions of the aquifer. The hydrogeologic parameters for the Brunswick Formation are summarized in Table 5.

DIABASE FORMATION

The Diabase Formation is medium to coarse-grained, quartz-normative tholeiite composed of labradorite and various pyroxenes. It occurs as dikes, sheets, and a few small flows. Diabase is hard and dense and weathers into large boulders which in turn break down into buff-colored, granular sand and ultimately into tight, sticky, red clay. Diabase is slow to weather and forms the hills and ridges found in the western portion of the Study Area. There are few fractures within this formation resulting in very poor yielding wells. Due to the clay-like nature of soil that originates as Diabase, runoff is high, and water recharge is low.

Groundwater encountered in the diabase hydrogeologic unit primarily comes from the weathered zone within the diabase. Other significant fractures within the diabase usually do not exceed 100 – 150 feet. No primary porosity is in the diabase and all groundwater moves

through fractures. Nearly all groundwater storage is within the weathered portions of the unit. The hydrogeologic parameters for the diabase unit are summarized in Table 5.

LOCKATONG FORMATION

The Lockatong Formation is dark-gray to black, thick-bedded argillite containing a few zones of thin-bedded black shale. It may also have thin layers of impure limestone and calcareous shale. This formation has no primary porosity or permeability. Groundwater flows through tight, poorly connected fractures and fissures which results in relatively low yielding wells.

Groundwater in the Lockatong Formation flows primarily through widely spaced joints and fractures, which are poorly interconnected and relatively tight in the siltstone and shale. The groundwater occurs under unconfined and confined conditions. Recharge to this hydrogeologic unit is low due to weathered clay clogging fractures and joints and the high elevations of the Lockatong Formation. The hydrogeologic parameters for this unit are summarized in Table 5.

Detailed geological and hydrogeological information for each water authority service area in the Pennridge Area could be found in Volume II of the Plan for each water supplier.

J. Wellhead Protection Beneficiaries

While wellhead protection is typically considered to be a program to benefit users of community water systems, it is possible the greatest beneficiaries could be those residences and businesses that lie within the wellhead protection areas but rely on their own private wells. This is especially true where the water system to be protected lies in one municipality but the area required to provide the protection lies in another municipality or other municipalities. If something does happen to a community water supply, e.g., contamination, those users have an organization (Borough Council, Township Supervisors, Authority Board) they can expect to do something to address the problem. People utilizing their own private wells in the same area, however, often have no one to help them to address similar problems. Therefore, as a result of a wellhead protection project, these people may become the greatest beneficiaries of the project.

Table 5. Hydrogeologic Parameters for the Hydrogeologic Units in Bucks County.

PARAMETERS	HYDROGEOLOGIC UNITS Unconsolidated Sediments	Diabase	Brunswick Formation	Lockatong Formation	Stockton Formation	Carbonate Rocks	Crystalline Rocks
Aquifer Type	Unconfined[1]	Unconfined[1]	Unconfined / Confined[1]	Unconfined / Confined[1]	Unconfined / Confined[1]	Unconfined / Confined[1]	Unconfined[6]
Aquifer Conductivity	1x10E4[2] (gal/day/ft^2)	1x10E-4[2] (gal/day/ft^2)	1x10E-4[9] (cm/s)	1x10E-3[2] (gal/day/ft^2)	0.025[7] (gal/day/ft^2)		1x10E2[2] (gal/day/ft^2)
Aquifer Transmissivity (gpd/ft)			73,633[10]		16,357[7]		
Aquifer Storativity	0.01 - 0.30[2]	0.01 - 0.30[2]	0.00025[10]		4.3x10E-4[7]	1x10E-1[2]	0.0003 - 0.08[5]
Aquifer Specific Capacity (gpm/ft)			42[10]	1.5[5]	2.8[7]		0.67[5]
Aquifer Porosity (%)	25% - 50%[2]	0% - 5%[2]	0% - 30%[2]	0% - 30%[2]	16%[7]	0% - 20%[2]	0% - 10%[2]
Aquifer Saturated Thickness (feet)	>50[3]		20[9]	50[6]	88[7]		260 – 280[5]
Recharge Rate (gpd)	228,854 - 949,960[3]	228,854 - 949,960[3]	228,854 - 949,960[3]	228,854 - 949,960[3]	228,854 - 949,960[3]	228,854 - 949,960[3]	228,854 - 949,960[3]
Average Yield of Wells in Aquifer (gal/min)		5[8]	60[3]	7[8]	85[7]		25[5]
Aquifer Yield (mgd/mi^2)	0.42[4]		0.14[4]	0.06[4]	0.17[4]	0.37[4]	
Aquifer Boundaries	Delaware River Bedrock		Delaware River	Delaware River	Delaware River		
Directional and Aerial Variation in Hydrogeologic Parameters	Isotropic[2]		Anisotropic[1] Highest Permeability in Direction of Strike [1] Strike = N 45° E[1]	Anisotropic[1] Highest Permeability in Direction of Strike [1] Strike = N 45° E[1]	Anisotropic[1] Highest Permeability in Direction of Strike [1] Strike = N 45° E[1]		

[1] U.S.G.S Water Resources Investigation Report #94-4109
[2] Freeze and Cherry, 1979
[3] Special Groundwater Study Basinwide Report and Executive Summary, DRBC, October, 1992
[4] State Water Plan, Subbasin 3 – Lower Delaware River, July 1986
[5] State Water Plan, Subbasin 2 – Central Delaware River, July 1986
[6] Water Resources of Springfield Township, Richard S. Cowan and Associates, 1978
[7] Rima, Meisler and Longwill, 1962
[8] Doylestown Township Groundwater Resource Assessment, BCM, November 1989
[9] Hydrogeology of the Brunswick (Passaic) Formation and Implications for Groundwater Monitoring Practice, A. Michalski, 1990
[10] Directional Hydraulic Behaviour of a Fractured-Shale Aquifer in New Jersey, J. Vecchioli

NOTE. The parameters listed are examples of values or ranges of values reported from each hydrogeologic unit. The values may not be representative or average values for the units and do not necessarily reflect the values used for the geologic layers comprising the groundwater flow model

II. OVERVIEW OF REGULATIONS AND REQUIREMENTS

The 1986 amendments to the Federal Safe Drinking Water Act (SDWA) required states to develop wellhead protection (WHP) programs to protect from contamination groundwater sources used by public water systems. Pennsylvania's WHP Program, administered by the Pennsylvania Department of Environmental Protection obtained approval from the U.S. Environmental Protection Agency (EPA) in March 1999. The responsibilities for WHP are shared among many stakeholders, but the foremost responsibility for ensuring that groundwater is adequately protected is at the local government level because the authority to regulate land use resides there. WHP is a cooperative, pro-active, positive approach to protecting groundwater supplies and should not be interpreted as an adverse action. The program involves the delineation of wellhead protection areas for wells and springs, identification of potential sources of groundwater contaminants, and the development of management measures as a means to reduce the potential for contamination of the groundwater supply.

A. Federal Program

The 1986 amendments require states to develop programs for protecting areas around wells supplying public drinking water systems from contamination that could harm health. It also requires the state wellhead protection program to define responsibilities of state and local governments and water systems, and meet other requirements. States are given three years to submit the plan to the EPA. The EPA then provides criteria to states for defining areas within one year of enactment. Upon approval, states are eligible for EPA grants for 50 percent of costs (determined by EPA) of plan development and implementation. Funds after three years of enactment are only available to implement protection. States must start implementing a plan within two years of submittal and provide biannual status reports to the EPA.

B. Pennsylvania's Program

Although development of a local WHP program is voluntary, Pennsylvania Department of Environmental Protection regulations do require some basic wellhead protection measures for new public water supply wells, springs, or infiltration galleries. Each new groundwater source must establish an innermost protection zone (Zone I WHP area) with a fixed radius of 100 – 400 feet depending on certain site-specific characteristics. The water supplier must show that it has ownership of, or substantially controls by a deed restriction or other acceptable means, the Zone I WHP area. In addition to this delineation, communities are encouraged to establish wellhead protection programs, which include the following:

A. The formation of a steering committee to establish and implement the wellhead protection program whose role it is to conduct a potential contaminant source inventory, provide options for the management of the WHP area (also known as the source water protection area), seek public input into the creation of the WHP plan, seek approval of the WHP program and implement the WHP program.

B. Development of a public education program.

C. Delineation of the contributing areas of the water sources.

D. Identification of potential contamination sources within the wellhead protection area.

E. Development and implementation of wellhead protection area management actions to protect the water sources.

F. Development of an Emergency Contingency Plan for alternative water supply sources in the event the groundwater supply becomes contaminated and emergency response planning for incidents that may impact water quality.

G. Conduct new water source planning to insure the protection of new water source locations and to augment current supplies.

Wellhead protection is a voluntary program, but water systems across the state are encouraged to take the above steps in protecting all groundwater sources. In addition, Pennsylvania Department of Environmental Protection has issued a set of guidelines that outline the minimum elements necessary for a local WHP program to obtain DEP approval. These guidelines are provided in Appendix C of this plan. DEP approval of local WHP programs will allow proper tracking and coordination so that local WHP efforts will be supported and recognized.

Pennsylvania Department of Environmental Protection has developed forms for submittal of WHP plans for review and approval. These completed forms, along with three copies of the plan, can be submitted to the DEP Regional Office for review, recommendations and approval. Electronic copies of these forms can be obtained at www.dep.state.pa.us and typing "Source Water" in the direct Link box or you can contact the Bureau of Watershed Management at 717-787-5259.

The focal point of a local WHP program is the delineated wellhead protection area (WHPA). The Safe Drinking Water Act defines a wellhead protection area as the surface and subsurface area surrounding a water well or wellfield supplying a public water system, through which contaminants are reasonably likely to move toward and reach such water well or wellfield. The Pennsylvania DEP Safe Drinking Water Regulations define a three-tiered WHPA as described below in Section V.

C. Bucks County Wellhead Protection Plans

In 1997, the Bucks County Planning Commission (BCPC) completed the report, *Bucks County Water Supply Plan and Model Wellhead Protection Study.* The WHP portion of the study includes a description of WHP planning similar to this report and then develops wellhead protection case studies for seven municipalities in Bucks County. The wellhead protection process was applied to the wells listed in Table 6.

Table 6. Wells Studied in the *Bucks County Water Supply Plan and Model Wellhead Protection Study.*

Well Name	Well Owner
Bristol Borough Edgely Wellfield	Bristol Borough Water and Sewer Authority
Doylestown Borough Well #9	Doylestown Borough Water Department
Hilltown Township Well #1	Hilltown Township Water and Sewer Authority
Milford Township Well #1	Milford Township Water Authority
Riegelsville Borough Well #2	Riegelsville Borough Water Company
Solebury Township Well #S-1	Bucks County Water and Sewer Authority
Warrington Township Well #5	Warrington Township Water and Sewer Department

While these seven case studies were developed as specific Bucks County examples of how to define a WHPA, to identify the types of potential contamination sources that can be found in a WHPA and to suggest possible management strategies, the basic recommendation of the study is to encourage municipalities to implement measures to protect groundwater resources through wellhead protection. While this is aimed primarily at new water supply wells (those developed after October 1995), the Telford Borough Authority, for example, is strongly concerned about protecting its existing well supplies as much as possible. The BCPC study also includes a model ordinance, which may be used as a basis to develop a WHP program.

D. Overview of the Source Water Assessment and Protection Program

To expand the benefits realized from WHP efforts, the 1996 Safe Drinking Water Act reauthorization requires (under Section 1453) states to develop a Source Water Assessment and Protection (SWAP) Program. The SWAP program assesses the drinking water sources serving public water systems for their susceptibility to pollution. This information will be used as a basis for building voluntary, community-based barriers to drinking water contamination.

Pennsylvania's assessment program will:

A. Delineate the boundaries of the areas providing source waters for all public water systems.

B. Identify (to the extent practicable) the origins of regulated and certain unregulated contaminants in the delineated area to determine the susceptibility of public water systems to such contaminants.

These assessments are of the raw water quality, not the finished water compliance. DEP will conduct assessments for community water systems supplied primarily by groundwater and serving a population of 3,300 or more. The groundwater sources of public water systems serving less than 3,300 will be initially assessed using readily available data from the program's geographic information system (GIS). Assessments for the larger community water systems supplied primarily by surface water sources will be conducted through contracted services. DEP staff will conduct assessments for community water systems supplied by surface water in basins less than 100 square miles and 90 percent forested.

Acknowledgement

Standard language used within this document describing potential contaminant sources and management of those sources was provided by Acer Engineering of Lancaster, Pennsylvania. The original template was designed by Pennsylvania Rural Water Association and was partially based on previous plans developed by Moody and Associates of Meadville, Pennsylvania, and Spotts, Stevens and McCoy of Wyomissing, Pennsylvania. Review and revisions to the template were made by Pennsylvania Rural Water Association (PRWA) and Pennsylvania Department of Environmental Protection (PaDEP).

III. STEERING COMMITTEE AND PUBLIC PARTICIPATION

The PACC Steering Committee consisted of township(s) officials, residents and county representatives. Borton-Lawson subcontracted technical assistance. Table 7 and 8 lists members of the Steering Committee and consultants. All meetings were open to the public. Table 9 lists steering committee meeting dates. A public meeting for comment on the draft plan was held on March 31, 2009.

One key activity of the Steering Committee was to review the various management tools identified as being suitable for wellhead protection. A table summarizing them is located in Appendix B - Wellhead Protection Management Tool Matrix, taken from EPA's "Wellhead Protection: A Guide for Small Communities" (EPA, 1993, EPA/625/R-93/002).

The Steering Committee subsequently met several times to discuss wellhead protection and the associated management tools. The meetings entailed a review of wellhead protection planning; a review of the Pennridge Area specific wellhead protection situation; and a presentation of the Bucks County model wellhead protection study. Meetings also allowed for review; discussion and recommendation of the wellhead protection tools most likely to be accepted and implemented by the municipalities falling within the delineation area. The committee recommended adoption of the plan by the Pennridge Area Coordination Committee and its member municipalities.

Table 7. Steering Committee.

Name	Role	Title	Represent	Phone Number
Dennis Livrone	Chairperson	Senior Planner	Bucks County Planning Commission	215-345-3422
Ken Beer		Farmer	Hilltown Township	
William Devlin		Emergency Management Coordinator	Hilltown Township	
Kathleen Michener		High School Teacher	Pennridge School District	
Don Duvall		Township Supervisor	West Rockhill Township	
Rea Monaghan Paul Gordon		Environmental Planners	Bucks County Planning Commission	215-345-3267 215-345-3884

Table 8. Consultants.

Name	Role
Borton-Lawson Engineering, Inc.	Leading Consultant-Coordinate, Scheduling, Billing and Report
Spotts, Stevens and McCoy, Inc.	Subcontract-Environmental Assessment
Hazlet-Kincaid, Inc.*	Subcontract-Wellhead Delineation
Boucher and James	Subcontract-Local Expertise

*Note: Works with Registered Professional Geologist, Robert Cook, from Keystone College

Table 9. Steering Committee Meeting Dates.

Date	Location	Purpose
1/18/2006	Upper County Campus, Bucks County Community College, Perkasie Borough, Pennsylvania	Introduction of Source Water Protection Plan; introduction of reporting and billing procedure; Scope of Work summary; roles of consultants; and project schedule.
9/20/2006	Upper County Campus, Bucks County Community College, Perkasie Borough, Pennsylvania	Project Progress Summary; municipal authority reporting/billing; project progress and preliminary results; additional meeting requirements; and project schedule.
5/21/2007	Upper County Campus, Bucks County Community College, Perkasie Borough, Pennsylvania	Project progress summary; municipal authority reporting/billing; project progress and preliminary results; additional meeting requirements; and project schedule.
7/8/2008	Upper County Campus, Bucks County Community College, Perkasie Borough, Pennsylvania	Project progress summary; municipal authority reporting/billing; groundwater modeling and wellhead zone delineations; and project completion schedule.
3/31/2009	West Rockhill Township Municipal Building, Sellersville Borough, Pennsylvania	Public meeting to present draft plan (see Press Release in Appendix D).

IV. WELLHEAD PROTECTION AREA DELINEATION

A. Wellhead Protection Area Zones

The objective of the wellhead protection area is to delineate the region from which water pumped from a well or well field originates. That region can be subdivided into zones based on the medium through which water travels between its source as rainfall and the well or well field. The portion of a wellhead protection area that includes the underlying aquifer through which water is transmitted to the well or well field is referred to as the capture zone. A projection of the maximum aerial extent of the aquifer volume onto the land surface is defined as the area of diversion (Brown, 1963). The area of diversion and any adjacent areas that contribute water to the capture zone are referred to collectively as the area of contribution (Risser and Madden, 1994). The area of contribution may be the same as the capture zone, or, as is often the case, it may be much larger. In cases where capture zones intersect streams, the up-gradient drainage basin for the stream is part of the contributing area.

A capture zone can itself be divided based on the time it will take water to travel through the aquifer to the well or well field. A capture zone representing a specified travel time is referred to as a time-of-travel capture zone. Specification of duration for a time of travel capture zone is commonly based on the duration that contaminants and their degradation products can remain in the groundwater system at harmful concentrations. For control against discharges of viruses and

bacteria, travel times of 50 to 250 days are often used as a standard (Frind and others, 2002; USEPA, 1997). Petroleum products, on the other hand, may persist in the aquifer at dangerous levels for years or decades and chlorinated solvents may require decades to centuries before they degrade to harmless levels (Pankow and Cherry, 1996; USEPA, 1997). Five to ten year time-of-travel capture zones are most often used to establish wellhead protection areas because such zones have been found to protect against most common contaminant types and, in most hydrogeologic settings, are of manageable size.

Delineation of the three WHP Zones specified by Pennsylvania Department of Environmental Protection regulation embrace the capture zone and zone of contribution concepts described above and are defined as follows.

Zone I is a protective zone immediately surrounding a well, spring or infiltration gallery, which shall be 100 to 400 feet in radius depending on site-specific source and aquifer characteristics. For new water sources, this area must be controlled by the water supplier. Zone I may be determined by Pennsylvania Department of Environmental Protection's Zone I graphs or by a qualified consultant directly calculating the area using site-specific data. For wells permitted before the October 1995 Zone I requirement, an acceptable Zone I could also be the permitted isolation distance, which is typically a 100-foot radius around the well.

Zone II encompasses all or part of the capture zone for the water source, which is the portion of the aquifer through which water flows to the well, spring, infiltration gallery, or other type of water source. Pennsylvania Department of Environmental Protection defines Zone II as a one-half mile radius around the source unless a more detailed delineation (the purpose of this study) is performed and approved. In this study and report, Zone II for each of the municipal water supply wells is defined as the 10-year time-of-travel capture zone for the respective well as defined by the Pennridge groundwater model.

Zone III is the zone beyond Zone II that contributes significant surface water and/or groundwater to Zone I and Zone II. Zone III is equivalent to the area of contribution minus the capture zone as defined above.

B. WHP Model

1. Overview

An effective WHP program is predicated on a hydrogeologically sound definition of the WHPA. More specifically, Zones II and III of the WHPA must be defined such that the boundaries encompass all regions where the water supply is vulnerable to contamination. For both surface water and groundwater supplies, the vulnerable areas include those regions from which water will flow either above or below ground to water supply reservoirs, or municipal wells or springs.

Both the EPA and Pennsylvania Department of Environmental Protection provide recommendations as to how such delineations should be accomplished and are based on the most practicably available sound science or on arbitrary distances when no such guidance is available. In recognition of the importance of source water and well head protection, the PACC recommended that the member municipalities cooperate in the development of a basin-scale groundwater and surface water model to be used as the primary tool with which

to delineate the Zone II and Zone III components of the WHPA. The basin-scale model-based approach was considered the best method for WHPA delineation for the following reasons.

a. Groundwater and surface water flow patterns that supply water to the municipalities are not bound by political boundaries but rather by natural hydrologic divides. The basin-scale approach therefore provides for the assessment of flow patterns that reach beyond the boundaries of any one of the member municipalities in the effort to define water resource vulnerability.
b. A properly constructed WHP model provides for the synthesis of all available geologic and hydrologic data into the characterization of groundwater and surface water flow patterns thereby providing for a better definition of the WHPA.
c. Numerical modeling is currently the best method of assessing complex hydrologic interactions over large scales, defining groundwater divides, and predicting aquifer vulnerability.
d. Once constructed, the WHP model can be continually used to assess various scenarios that are likely to impact water resources such as development, drought, flood, and the emergency management of contamination spills.

Numerical models are, however, only as good as the data and scientific assumptions used in their construction. Sound models must therefore honor geologic and hydrologic data that describe the pertinent surface and subsurface conditions that govern water flow across the basin; and they must not depend on simplifying assumptions that ignore controlling hydrogeologic complexities such as heterogeneity and anisotropy. Otherwise, the resulting model-defined WHPA and vulnerability predictions will not be reliable. These issues are particularly relevant in the Pennridge Area due to the geologic complexity that characterizes the region. In particular, the stratigraphic orientation of the water-bearing and confining beds, and fracturing, define an environment in which models that assume some combination of homogeneity, isotropy, and 2-D flow are inappropriate and will not produce reliable results.

In order to construct a reliable model, Hazlett-Kincaid as modeling subcontractor for the Pennridge Area wellhead and source water protection projects, used a *Dual Modeling Approach* to construct the WHP model. This approach first involved the construction of a detailed Geologic Framework Model (GFM) that synthesized available geologic data into a 3-D digital model of the surface and subsurface conditions within the study area. In the second phase of the modeling approach, a steady-state groundwater flow model was developed that incorporated all of the geologic complexities defined in the GFM, honored hydrologic data describing groundwater / surface water interactions in the numerous streams and lakes within the study area, and calibrated to available hydraulic data describing groundwater levels and pumping rates. Model-predicted groundwater flow patterns, specifically particle tracks, were then used to define the actual WHPA zones.

2. Geologic Framework Model (GFM)

A GFM is a 3-D, computer-generated, solids model that depicts and describes the stratigraphic and structural orientation of subsurface geologic units within a modeled region and the relationships between those units and other relevant features such as hydrologic features, engineered structures, contaminant plumes, etc. The purpose of the Pennridge

GFM is to (1) capture all relevant geologic complexities that control groundwater flow patterns in the Pennridge Area in a digital framework that will be used as the basis for groundwater flow modeling and the subsequent delineation of wellhead protection zones; and (2) provide an effective platform for visualization, interpretation, and dissemination of modeling results.

The key geologic complexities that affect groundwater flow patterns in the Pennridge Area are the distribution and orientation of fractures in the bedrock. However, data describing the fracture network in this region is lacking. Therefore, in order to capture these complexities in a model framework, the GFM was constructed to include the broader geologic fabric that could be described in relative detail from published data. Primarily, the geologic fabric consists of the orientation, thickness, and repetitive stacking of the Brunswick and Lockatong Formations, and the orientation of the Diabase. The structural orientation of these units and the difference in hydraulic conductivity between the units creates a general NE-SW anisotropy across the modeled region that provides a large-scale proxy for the fracture permeability in the aquifer.

a. Data

A GFM is typically constructed from detailed borehole data that indicates the elevation of stratigraphic contacts, the thickness of the units, and the trend and elevation of formation outcrops provided by published geologic maps or field mapping. Very few detailed boring logs are available for the Pennridge Area, and field mapping was beyond the scope of this investigation. The Pennridge GFM, therefore relied upon published geologic maps and cross-sections. The primary data consisted of outcrop trends and elevations, and strike and dip measurements taken from regional and statewide geologic maps that were qualitatively supplemented by the interpreted structural orientation of unit surfaces described by accompanying cross-sections (Willard et. al, 1950; Berg et. al, 1980; Schlische, 1992; PAGS, 1999).

Data describing the depth and type of soils in the surficial zone above bedrock was extracted from GIS map coverages developed by Borton-Lawson Engineering (Bucks County Planning Commission, et al., 2002) and the U.S. Department of Agriculture (U.S. Department of Agriculture, 2006). These maps were based on soil type classifications defined by the U.S. Department of Agriculture, Natural Resources Conservation Service for Bucks County, Pennsylvania. At the time of the GFM development no such data was available for Montgomery County, which extends into the GFM domain on the west and northwest sides.

The topographic surface, defining the uppermost surface of the GFM, was extracted from USGS Digital Elevation Model (DEM) 7.5-minute 30-meter grids. The set of grids used for the model includes: Allentown East, Ambler, Bedminster, Buckingham, Collegeville, Doylestown, Frenchtown, Hatboro, Hellertown, Lansdale, Lumberville, Milford Square, Perkiomenville, Quakertown, Riegelsville and Telford. The DEM grids were imported directly into EarthVision and joined into a single grid covering the model domain.

Data describing the position, depth, and open-hole interval for all water supply wells depicted in the GFM were provided by the participating municipalities and Borton-Lawson Engineering.

b. Model Boundaries

The Pennridge GFM was constructed in the Pennsylvania State Plane Zone 3702, NAD83 feet coordinate system. The model boundary is an irregular polygon that extends slightly beyond the chosen boundaries of the Pennridge groundwater model, which were defined by surface watershed divides. The perimeter of the model boundary is 74.24 miles long that encompasses an area of 197.2 square miles. The bounding coordinates are 2,602,264 – 2,715,603 feet in the easting direction and 346,559 – 433,378 in the northing direction.

c. Modeling Software and Data Interpolation Techniques

The Pennridge GFM was constructed with the EarthVision™ (EV) modeling software developed by Dynamic Graphics, Inc. of Alameda, California. EV is a family of integrated software applications specifically designed for geospatial analysis and visualization. EV is commonly used in the oil and gas industry for reservoir characterization and analysis, and is widely regarded in the geological industry as the most robust and advanced subsurface modeling and visualization software commercially available.

The EV model development process consists of creating a series of 2-D elevation (X, Y, elevation) or thickness (X, Y, thickness) grids for each geologic layer to be included in the model, and then stacking the units into their stratigraphic position using a set of depositional rules to control how each unit is truncated by the overlying surface. 3-D property (X, Y, Z, property) grids can then be incorporated into, above, or below the structural surfaces to define the distribution of the property (contaminant concentration, temperature, salinity, etc.) throughout the 3-D model space. Finally, engineered structures (utilities, tunnels, boreholes, grout curtains, containment walls, etc.) can be described by their position, trend, and size and can be incorporated into the 3-D models as overlays or intersections.

The 2-D and/or 3-D grids that form the core of the 3-D block models can be developed in EV using trend gridding, kriging, or minimum tension gridding algorithms. Minimum tension gridding (Paradis and Belcher, 1990; Belcher and Paradis, 1992) is most often used because it provides a robust method of generating deterministic interpolations that minimize extrapolation error. Minimum-tension gridding uses a two-step interpolation process to assign estimated parameter values at grid nodes in a 2-D or 3-D model. The first step is an initial estimate of the parameter value based on the value of the nearest data points encountered in a progressively broadening octant search pattern. The initial estimates are based only on the nearest data points but the search distance will increase until a data point is encountered. In the second step, a biharmonic cubic spline function is fitted to the grid node values and the process is iterated using feedback from the initial scattered data until a balance is achieved between the initial scattered data and the curvature (2nd derivative) of the function (Briggs, 1974). The resolution of the grids and thus the model components is defined by the spacing between nodes where the optimal spacing is one-half the distance between the closest set of data points showing significant variation.

The 3-D geologic model is then created by stacking the grids, produced by any of the available methods, into the appropriate stratigraphic configuration. Continuous units can be readily positioned using a structural surface grid that describes the elevation of the unit top across the model region. Discontinuous units must be positioned by adding or subtracting the unit thickness to or from an upper or lower surface (*Reference Horizon*) to determine the intermediate position of the unit top. Such units are described in the model as *Intermediate Surfaces*.

As the grids are stacked into their stratigraphic positions, three types of depositional rules (deposition, unconformity, and channel erosion) are available to control the result of grid intersections. The deposition rule prevents a grid from truncating any underlying surfaces and defines the top of units that are only present where the unit surface grid falls above all underlying grid surfaces. The unconformity rule allows a unit surface grid to truncate any underlying surfaces and defines the top of units that are only present where the unit surface grid falls above all underlying grid surfaces. The channel erosion rule allows a unit surface grid to truncate any underlying surfaces but does not allow deposition in regions where the unit surface falls above underlying grid surfaces.

d. GFM: Surficial Geology

The Surficial Geology component of the Pennridge GFM was derived from a combination of the Hydrologic Soil Groups (HSG) and the Soil Associations (SA) GIS coverage maps developed by Borton-Lawson Engineering (Bucks County Planning Commission, et al., 2002), a state-wide soil depth coverage map (U.S. Department of Agriculture, 2006), and an extrapolation of soil types performed by HKI for regions outside of those data coverages. No soil type data was publicly available for regions within the GFM boundary but outside of the Pennridge political boundary at the time of the GFM development.

The HSG coverage identified four soil types that were mapped across a region defined by the Pennridge Area political boundaries. Those soil types were:

A. sand, loamy sand, or sandy loam
B. silt loam or loam
C. sandy clay loam
D. clay loam, silty clay loam, sandy clay, silty clay or clay

The SA coverage map and statewide soil depth maps were used to define the total thickness of the surficial zone. The four soil types were then assumed to extend uniformly through the entire surficial thickness underlying the regions where each zone was identified by the HSG coverage map.

In order to extrapolate the available soil type data over the broader GFM model region, HKI developed a process to predict soil types based on distribution of soil types within the known area. The process was based on a trial and error approach using topographic elevation and slope as the variables to determine soil type at any location. The process was applied to the entire model region and calibrated to the available soil-type data. The result adequately simulated the distribution of soil types C and D and the distribution of grouped soil types A and B within the

Pennridge political boundaries. The final parameters used to define the soil types throughout the GFM were based on the following rules.

E. Soil Type Group A/B was assigned to all regions where the topographic elevation is over 575 feet.
F. Soil Type C was assigned to all regions where the topographic elevation is less than 575 feet and the slope is greater than 0.059 feet/foot.
G. Soil Type D was assigned to all other regions.

The final thickness of the model surficial zone ranged between 15 and 27 feet and delineates the three soil types described above throughout the model region. The underlying surface, which corresponds to the bedrock surface, was defined by subtracting the thickness of the surficial zone from the land surface elevations and smoothing the resulting grid to attenuate the sharp topographic slopes that characterize some regions of the model domain.

After the GFM was finished but before the flow model was completed, the USDA Natural Resources Conservation Service released the soils dataset for Montgomery County (U.S. Department of Agriculture, 2006). This soil dataset contains a highly detailed soil coverage containing 176 distinct classifications, composed of 37 soil series, which are further sub-categorized by topographic slope and urban proximity. The soils are generalized into 4 Hydrologic Soil Groups, including an Urban Areas sub classification. This updated data set was subsequently incorporated into the Pennridge Groundwater Flow Model but not included in the GFM.

e. GFM: Bedrock Geology

All of the mapped geologic unit contacts described on the data source maps were converted to individual elevation datasets by digitizing the contact into a GIS. Strike and dip symbols on the maps were then digitized and converted into azimuths and magnitudes and used to project the elevation of each unit in the subsurface at increasing distances away from the mapped contact. For all continuous surfaces, the mapped and projected elevation points were converted into structural surface grids using the minimum tension algorithm. For all discontinuous surfaces (i.e. units that pinch out in one or more directions), the mapped and projected data was converted to unit thickness and then converted into unit thickness grids using a special form of the minimum tension gridding algorithm called isopach gridding. Isopach gridding is performed exactly as minimum tension gridding except that zero-thickness contours are not drawn through all zero-thickness points but rather proximal to those points at distances defined by the trend in positive thickness values.

After the appropriate gridding method was used to model each individual structural member, the grids were stacked into a 3-D block model representing the geology of the Pennridge Area that effectively reflects the complexity of the alternating Brunswick and Lockatong Formations as well as the igneous intrusive diabase and associated hornfels in the northwest, and to a smaller extent in the northeastern portion of the model area. An additional structural surface grid was developed to simulate the left-lateral strike-slip fault that transects the southern part of Bucks County. The stratigraphic sequence of grids was constructed independently on either

side of the fault resulting in a simulation of unit displacements across the fault surface.

f. Results

The resulting GFM simulated 60 interbedded lithologic units of varying thickness, geometry, and permeability that have been structurally tilted in a synclinal basin, faulted at one end, and then intruded by the diabase. Four of the 60 units are present on the south side of the fault and all 60 of the units are present on the north side of the fault. In general, the interbedded units in the model framework consist of a repeating sequence of the Brunswick and Lockatong Formations that generally trend at between N47E and N50E in Strike and Dip at between 12 and 15 degrees to the northeast. This sequence is bounded on the northwest by a near-vertical diabase intrusion buffered by thinner near-vertical units of hornfels. The entire block model is then faulted on the south side by a left-lateral strike-slip fault showing more than 4.5 miles of displacement between corresponding Brunswick and Lockatong contacts on the north and south sides of the fault.

Figure 7 provides a regional perspective view of the GFM that uses a chair-cut through some of the individual units to reveal the land surface elevations, general thickness of the surficial zone, and orientation and dip of the bedrock units throughout the model region. Figures 8 and 9 provide plan view maps of the bedrock and surficial geology defined by the GFM relative to pertinent cultural features in the region and topographic contours exported from the topographic component of the GFM. More detailed perspective and cross-sectional views of the simulated hydrogeologic framework in the vicinity of the municipal water supply wells are provided in Volume II of this report.

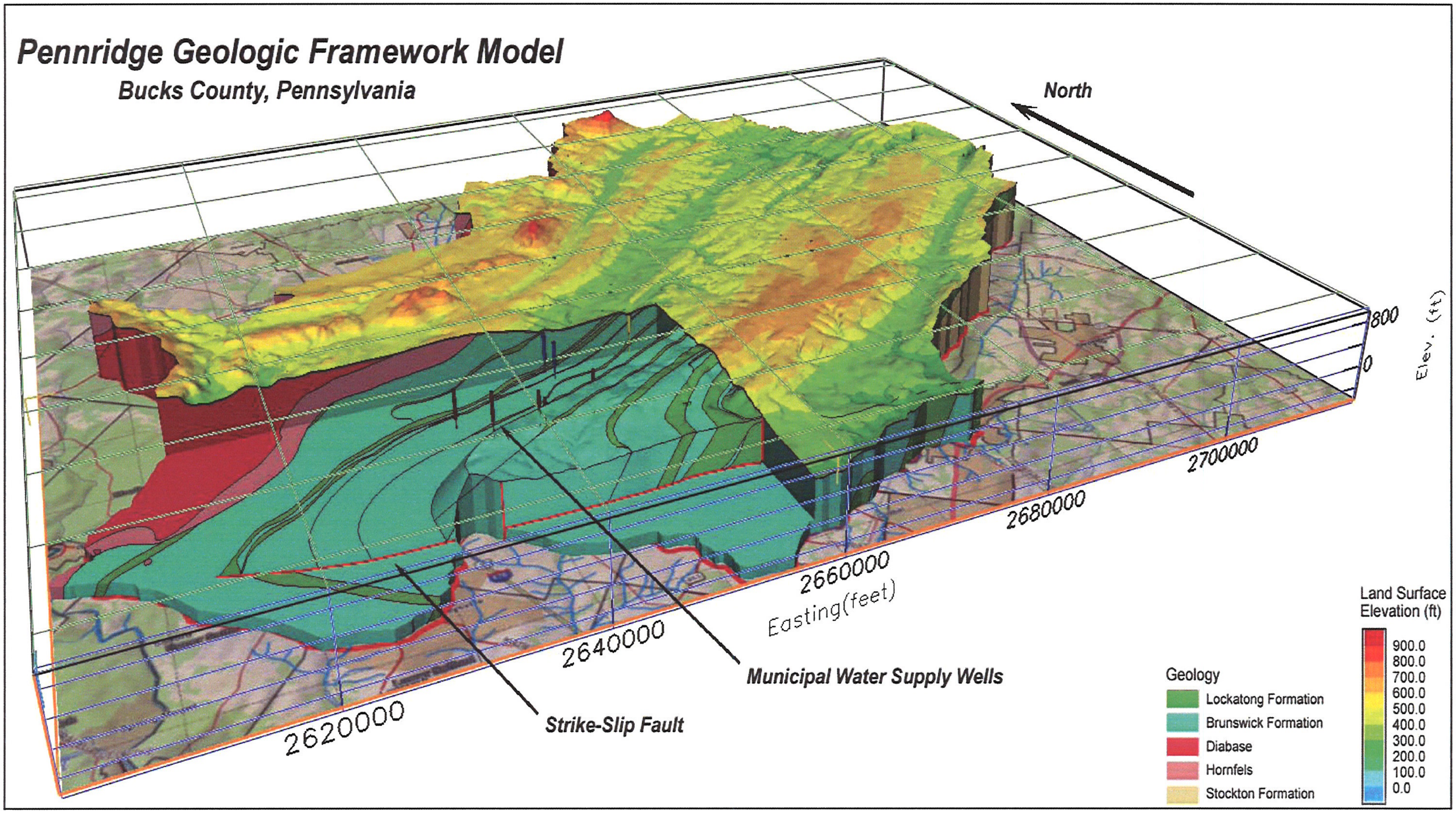

Figure 7. Oblique regional view of the Pennridge Geologic Framework Model, Bucks County, Pennsylvania.

g. GFM Limitations

Every GFM is a synthesis of geologic data and interpretations of geologic structures, i.e., strike and dip, unit thickness, and fault orientation, and displacement throughout a model region. Limitations of a GFM pertain to the ability of the model to simulate geologic structures defined by the available data and the confidence in the model-defined geologic structures beyond the regions of data control. Typically, larger models are less capable of honoring highly variable site-specific data than smaller models due to computational limitations, and confidence in the model-defined geologic structures decreases with the distance away from the input data.

The most significant limitation of the Pennridge GFM stems from the lack of borehole data with which geologic interpretations could be calibrated below the land surface. The model compares favorably to the source data maps in all of the outcrop regions and along all of the published cross-sections. Confidence in the model-defined geologic structure therefore declines with depth below the outcrop elevations and distance away from the strike and dip measurements that were reported on the input maps.

The most significant margin of error associated with the interpretation of structural orientations applies to the diabase and hornfels contacts. Three different interpretations of the subsurface diabase structure were included on the published geologic maps. One showed the diabase as a shallow lens that intruded as a sill over top of the pre-existing units and not coincident with the structure. Another showed the diabase as a vertical intrusion that cross-cuts the pre-existing structure, and the third shows it as an intrusion coincident with the pre-existing structure. This third interpretation was the one adopted for this model. However, the multiple published hypotheses indicate that the confidence in this interpretation, and therefore the model-defined contact between the diabase/hornfels and Brunswick and Lockatong units, is less than that associated with the Brunswick and Lockatong structure internal to the model.

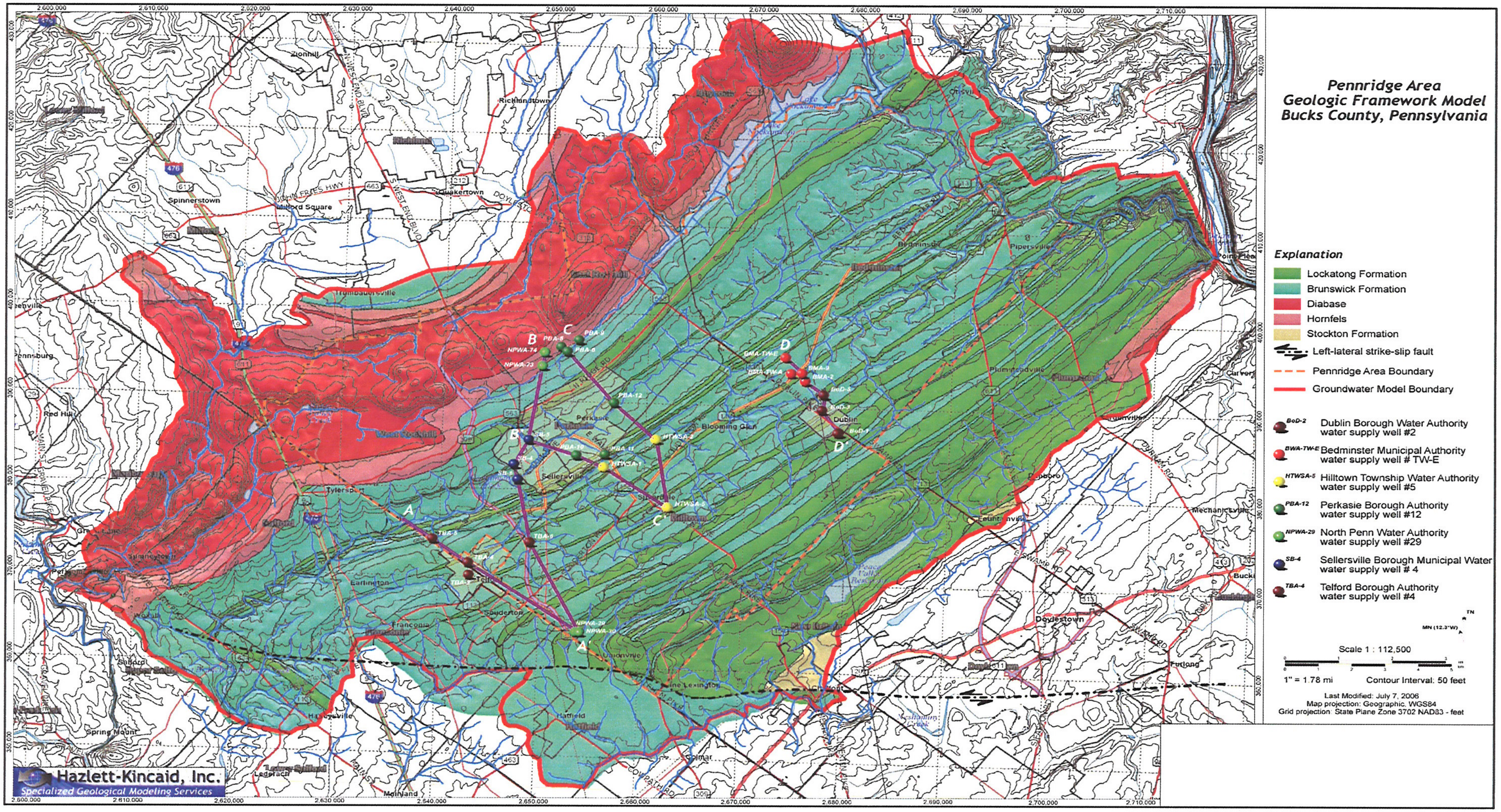

Figure 8. Bedrock geology as defined by the Pennridge Geologic Framework Model, Bucks County, Pennsylvania. Heavy red lines mark the boundaries of the Pennridge groundwater flow model. Colored dots mark the locations of the municipal water supply wells used for groundwater model calibration.

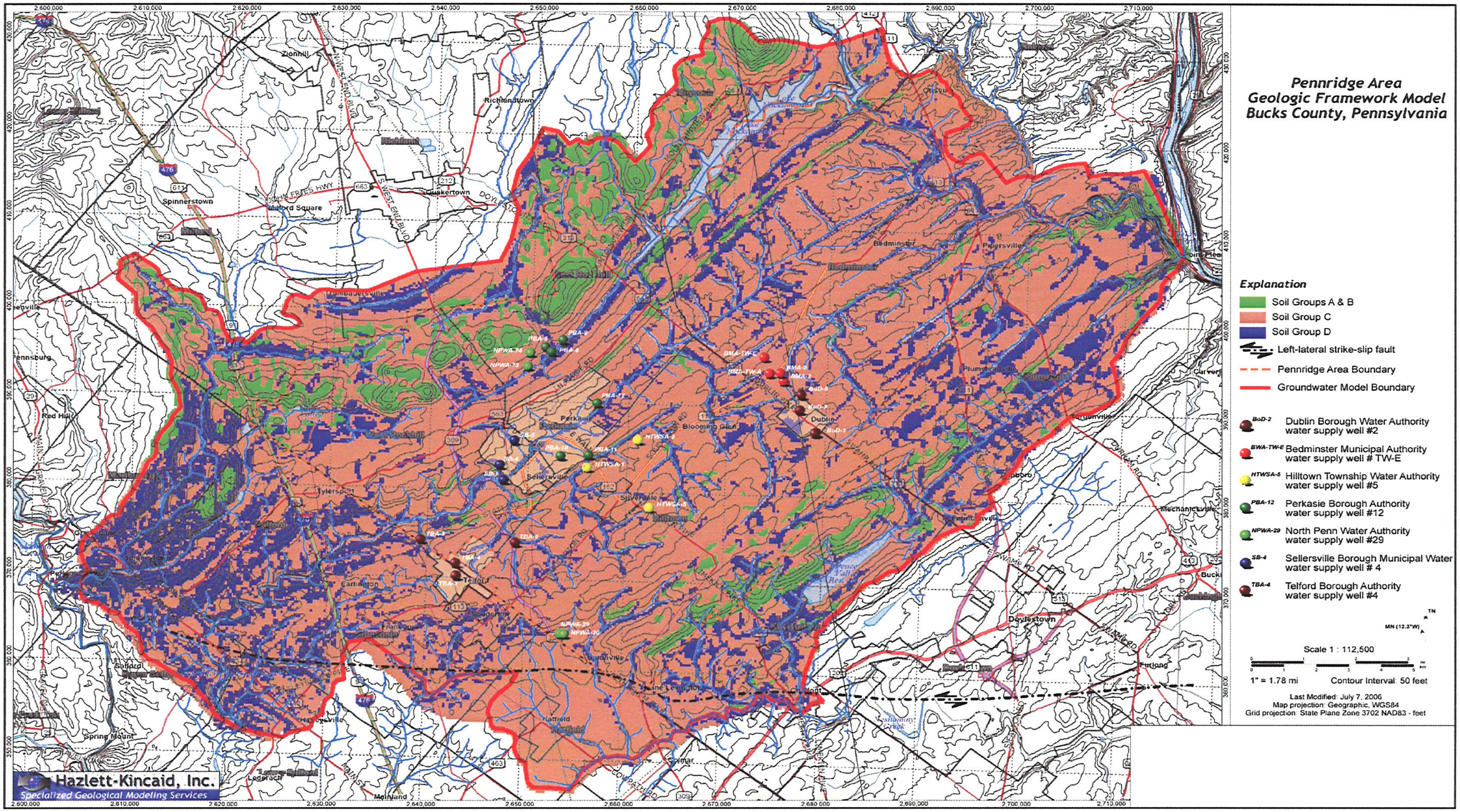

Figure 9. Map showing the distribution of soil types as defined by the Pennridge Geologic Framework Model, Bucks County, Pennsylvania. Heavy red lines mark the boundaries of the Pennridge groundwater flow model. Colored dots mark the locations of the municipal water supply wells used for groundwater model calibration.

3. Groundwater Flow Model (GWM)

A GWM is a tool used to simulate groundwater flow through a conceptualized hydrogeologic environment. A GWM, can be 1-D, 2D, or 3-D, can be numerical, analytical, or statistical, and can be regional or site-scale in focus. The accuracy of the model predictions is primarily dependent on the degree to which the conceptualized model framework honors the real-world environment and the accuracy of the explicit and implicit assumptions underlying the modeling approach. As such, the over-riding objective in our construction of the Pennridge GWM was to (1) replicate the real-world hydrogeologic framework as accurately as possible in the model design; (2) choose a modeling approach that addresses the fundamental hydrogeologic conditions as directly as possible; (3) minimize the number of required assumptions in the modeling process; and (4) ensure that all required assumptions can be supported by data or sound hydrogeologic reasoning.

a. Conceptualized Hydrogeologic Framework

In the Pennridge Area, groundwater flows through a fractured bedrock aquifer comprised of multiple tilted rock layers of differing permeabilities stacked into a 3-D block where the permeability is predominantly in the fractures which are predominantly aligned parallel to the strike of the bedrock layers. The conceptualized geologic environment is described by the GFM (*Section V.B.2*), which was specifically designed to create a model framework that matches the real-world conditions to the best degree possible. *Figures 10 and 11* provide views of the modeled region and the hydrogeologic framework as conceptualized in the GFM.

The Pennridge GWM was therefore designed as a 3-D model in order to accurately incorporate the geologic controls on recharge and flow created by the orientation of the rock layers. Each of the six municipalities are extracting groundwater from one or more of the geologic layers within the 3-D block of rock that supply groundwater to the Pennridge Area groundwater basins. The model was regional in extent and bounded to the maximum practicable extent by surface water hydraulic divides, rather than by arbitrary or political boundaries. The regional configuration was chosen because the model boundaries needed to be sufficiently distant from the municipal pumping wells to allow predictions of the inter-relationships between local groundwater basin boundaries and pumping from adjacent municipalities, and the size and shape of the model-predicted well capture zones.

The key hydraulic features incorporated into the model were rivers and streams; four reported and mapped dewatered quarries, the municipal pumping wells, and two USGS monitoring wells. In order to address both the 3-D hydrogeologic framework and the effects of the identified hydraulic features on groundwater flow patterns, HKI chose a numerical modeling approach to construct the Pennridge GWM. In general, the approach used 3-D numerical groundwater flow equations to simulate recharge to the aquifer through the land surface and streambeds that generates groundwater flow through the conceptualized hydrogeologic framework to the municipal supply wells and quarries. The WHP Zones were then delineated from the model-predicted well capture zones predicted by the numerical model.

b. Numerical Approach and Modeling Software

HKI used a finite-element approach (Wang and Anderson, 1982) to develop the GWM because it provided the best possible venue for addressing the complex geometries that define the layering of hydrogeologic units and stream traces in the Pennridge Area. We used the modeling software FEFLOW™ (Diersch, 2005) to construct the GWM, which uses the Pre-Conditioned Conjugate Gradient (PCG) iterative solver to solve the groundwater flow equations (Appendix I).

The finite-element approach involves covering the modeled area with a mesh of typically triangular or quadrilateral elements that consist of nodes connected by vertices. Material properties (such as hydraulic conductivity and storativity) are assigned element-wise and the variables, in our case here, are solved for at the nodes. The model simulation is then bounded in value by conditions (such as no-flow, constant head, or constant flux and recharge) set on the boundaries of the model domain. Higher resolution model predictions can be achieved at the expense of computational efficiency by using smaller elements. One of the major strengths of the finite-element method is the ability to define variably sized elements at any location across the mesh and thereby attain any desired model resolution at precisely the places of concern, while minimizing the number of unnecessarily small elements and therefore the computational burden.

c. GWM Boundaries and Boundary Conditions

The modeled region encompassed the entire Pennridge Area (East Rockhill, West Rockhill, Bedminster, and Hilltown townships, and Sellersville, Perkasie, Dublin, and Silverdale boroughs) and reached beyond the political boundaries to the nearest definitive watershed divides. The resulting modeled region covered 4.96E8 m^2 (191 square miles) and encompassed the majority of Lake Nockamixon, and Perkiomen, North Neshaminy, and Tohickon Creek watersheds in northern Bucks and eastern Montgomery Counties. Telford Borough falls within the modeled region. Their well data was incorporated into the design of the model but capture zones and WHP zones were not defined for those wells as part of this project.

Boundary conditions are used to define how groundwater is allowed to flow across the model boundaries. Generally speaking, there are six boundaries to any roughly block-shaped 3-D model: top, bottom, and four sides. The conditions along any or all of those boundaries can be constant or variable with respect to both space and hydrostratigraphic unit. For instance, 3-D models are typically designed to be thick enough to accommodate an assumption that there is no flow across the entire bottom of the model. Alternatively, the top of the model should be designed to accommodate spatially variable recharge to the aquifer. Similarly, the model sides sometimes cross multiple hydrologic regions, such as streams or rivers that receive groundwater discharge (constant head or constant flux), and/or topographic ridges that are probable divides between different groundwater basins (no-flow). In some cases, computational restrictions on model size or shape necessitate that model boundaries be drawn across groundwater basins where they must be defined by measured or estimated groundwater elevations (constant head). In the ideal case, model boundaries should be drawn such that they follow natural hydrologic boundaries that have been adequately defined by data such as rivers or groundwater basin divides.

Boundary conditions can also be defined internal to the model. For example, pumping wells, injection wells, springs, and gaining or losing streams that fall within a model domain are localized sinks or sources for groundwater flow within the model. They can be defined as boundaries that extract or deliver water to the modeled groundwater system at specified rates or as rates that are dependent on model-predicted hydraulic conditions. When the rates are thought to be constant, the features can be designated as points of constant flux. When they are thought to be variable and dependent on water table or potentiometric surface elevations, they can be designated as constant head or transfer boundaries. Constant head boundaries allow water to flow into or out of the model but hold the head at the assigned point constant where the inflow or outflow rate is determined by the simulated hydraulic gradient and the assigned hydraulic conductivity. Transfer boundaries allow water to flow into or out of the model but allow the head at the assigned point to be determined by the model where the simulated inflow or outflow rate is dependent on the gradient between the boundary nodes and the simulated water table surface and a specified transfer rate.

The Pennridge GWM model boundaries were drawn such that they followed probable groundwater divides, such as significant topographic ridges and major watershed divides, as much as possible. Wherever that condition was met, or could be approximated, the model boundary condition was set to no-flow. In other places, the model boundaries follow parts of major streams and were set to a transfer condition. All municipal pumping wells were conceptualized as internal groundwater sinks where the flux out of the model was generally set to match the maximum permitted pumping rate[1]. *Table 10* provides a list of all the municipal pumping wells addressed in the GWM with their reported and permitted pumping rates and the rate set for the respective wells in the GWM.

All rivers and streams internal to the model were classified as either perennial or ephemeral based on published designations on topographic maps. The perennial sections were designated as transfer boundaries. Ephemeral sections were used as a reference to constrain the predicted water table surface but not forced to be dry. Where the calibrated model indicated flooding within ephemeral stream drainage, the stream was assigned as a transfer boundary to allow discharge and eliminate flooding. *Figure 11* provides an area map showing the GWM boundaries and their condition assignment relative to local watershed divides the orientation of perennial and ephemeral streams, the location of the municipal pumping wells and quarries, and relevant political boundaries.

d. 3-D Model Framework

The GWM framework was constructed in FEFLOW by creating a mesh of triangular elements across the modeled region such that the element size was very small in the areas of interest (wells and streams) and larger elsewhere. The mesh was then replicated for each of the key hydrogeologic units or groups of units that were previously defined in the GFM. The layers were then stacked and connected to each other with vertical vertices in the finite-element mesh resulting in a 3-D structure comprised of 5-sided prisms that honors the hydrostratigraphic relationship between the water bearing and confining units, the land surface, and an estimated thickness (~675 feet) of the aquifer.

It was not computationally possible to incorporate all of the 65 individual units depicted in the GFM in the GWM. As a result, some units, particularly very thin units, were grouped together and incorporated into the GWM as single hydrostratigraphic layers. Preference for the grouping strategy was also given to neighboring units that were reported by Phil Getty, P.G., of Boucher and James, Inc. as having similar hydraulic properties based on their experience with water well development in the region. The final GWM contained 34 separate units representing repeated occurrences of the Brunswick, Lockatong, and Stockton Formations and diabase intrusions with hornfels transition zones. Comparative 3-D views of the GFM and GWM are provided in *Figures 12 and 13*. *Table 11* provides a chart correlating the GFM and GWM units.

Notes:

1) Data obtained for all pumping wells except the Sellersville wells (SB-4, SB-5, and SB-6) indicated that municipalities were consistently pumping at or near the maximum permitted rate and therefore the maximum rate setting in the model is indicative of existing conditions. The pumping data indicates that the Sellersville wells pump well below their maximum permitted values thus the average reported values were assigned in the model. Calibration could not be achieved using higher than reported rates and preliminary scenario testing indicated that such rates are not sustainable.

Table 10. Reported and Permitted Pumping Rates for the Municipal Water Supply Wells Incorporated into the Pennridge GWM and the Associated Model Designated Values.

Well ID	Reported Max m^3/d (gpm)	Reported Ave m^3/d (gpm)	Number of Measurements	Permit Max m^3/d (gpm)	GWM Value m^3/d (gpm)	Data Source
TBA-1	1,202 (220)	1,102 (202)	548	1,090 (200)	1,090 (200)	1
TBA-3	1,519 (279)	1,352 (248)	548	1,200 (220)	1,200 (220)	1
TBA-4	1,446 (265)	1,349 (247)	548	1,635 (300)	1,635 (300)	1
TBA-5	1,725 (316)	1,476 (271)	548	1,526 (280)	1,526 (280)	1
TBA-6	986 (181)	853 (156)	548	8,18 (150)	818 (150)	1
PBA-5	3,352 (615)	989 (181)	912	9,76 (179)	976 (179)	2
PBA-6	2,874 (527)	1,765 (324)	912	1,897 (348)	1,897 (348)	2
PBA-9	1,363 (250)	441 (81)	912	518 (95)	518 (95)	2
PBA-10	3,367 (618)	1,284 (236)	889	1,199 (220)	1,199 (220)	2
PBA-11	11,747 (2155)	2,628 (482)	910	2,726 (500)	2,726 (500)	2
PBA-12	4,648 (853)	1,907 (350)	912	1,951 (358)	1,951 (358)	2
HTWSA-1	1,704 (313)	284 (52)	3,193	790 (145)	790 (145)	3
HTWSA-2	1,844 (338)	595 (109)	3,516	1,908 (350)	1,908 (350)	3
HTWSA-5	238 (44)	69 (13)	2,675	245 (45)	245 (45)	3
DB-1	436 (80)	436 (80)	181	227 (42)	227 (42)	1
DB-3	859 (158)	692 (127)	181	709 (130)	709 (130)	1
DB-5	227 (42)	196 (36)	181	216 (40)	216 (40)	1
SB-4	1,537 (282)	657 (121)	361	1,893 (347)	1,554 (285)	1
SB-5	3,241 (594)	335 (61)	294	1,893 (347)	954 (175)	1
SB-6	1,147 (210)	855 (157)	363	1,893 (347)	1,177 (216)	1
BMA-2	*NR*	169 (31)	1	218 (40)	218 (40)	4
BMA-9	*NR*	169 (31)	1	589 (108)	589 (108)	4
BMA-A[1]	*NR*	1,363 (250)	1	*NR*	1,363 (250)	4
BMA-E[1]	*NR*	1,363 (250)	1	*NR*	1,363 (250)	4
NP-29	*NR*	*NR*	*NR*	250 (46)	250 (46)	4
NP-30	*NR*	*NR*	*NR*	337 (62)	337 (62)	4
NP-73	*NR*	14 (3)	*NR*	338 (71)	338 (71)	4
NP-74	169 (31)	140 (26)	*NR*	382 (70)	382 (70)	4
Totals	*45,631 (8,370)*	*22,484 (4,124)*		*27,474 (5,040)*	*28,156 (5,165)*	

Data Sources

1) Data provided by Spotts Stevens McCoy, Inc., Reading Pennsylvania
2) Data provided by Borton Lawson Engineering, Bath, Pennsylvania
3) Hilltown Water and Sewer Authority – Annual Water Supply Reports, Hilltown Township, Pennsylvania
4) Delaware River Basin Commission – Water Supply Permits, Trenton New Jersey

Notes

1) Wells are not yet in operation. The listed pumping rate was reported as the rate used for a 48-hour pumping test conducted for the well development permit. The GWM used that value as a probable future pumping rate.
2) Pumping from the wells was simulated as a constant extraction (24 hours per day – 365 days per year) at the rates listed above.
3) *NR* = no record.

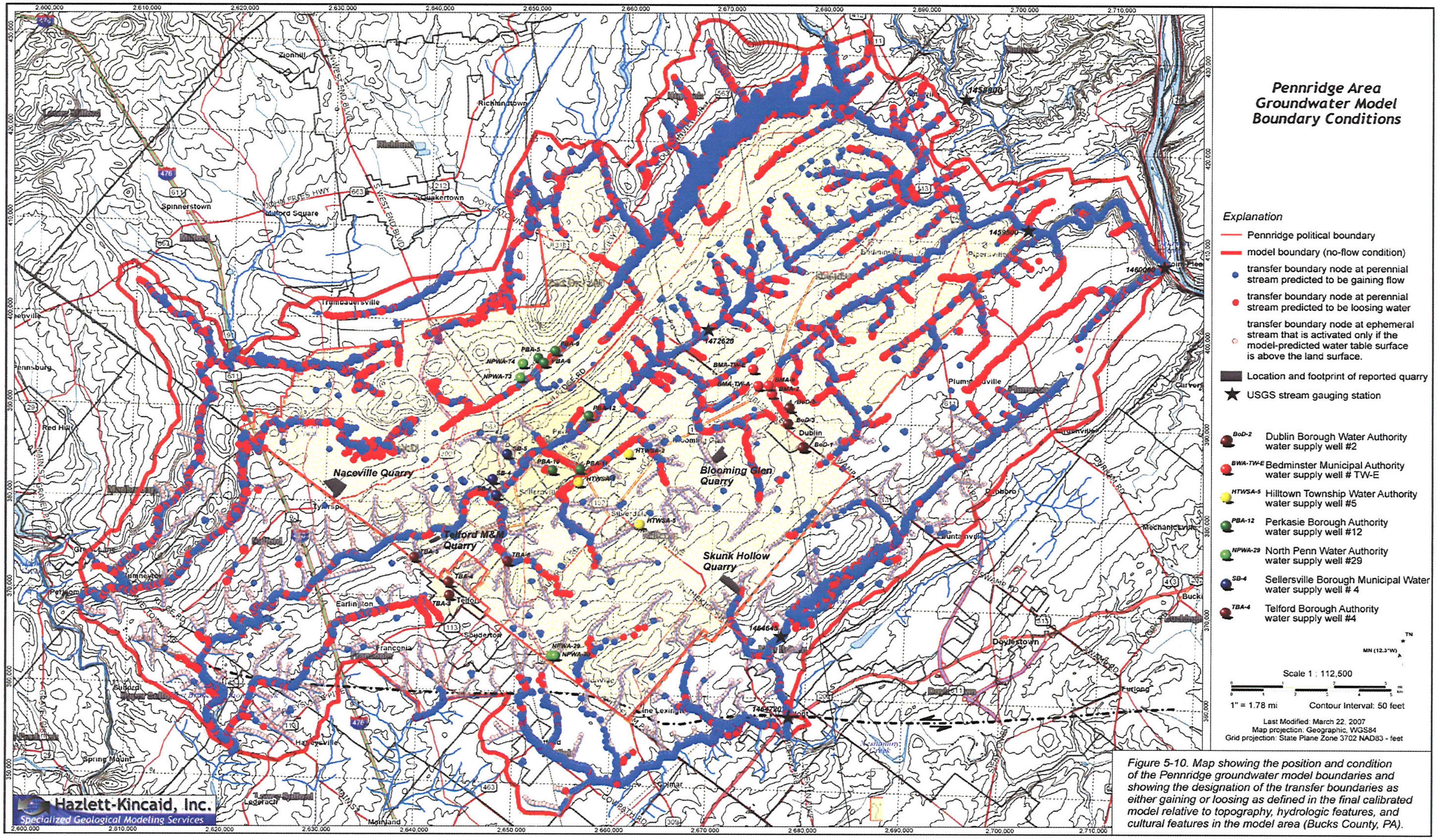

Figure 10. Map showing the position and condition of the Pennridge Groundwater Model (GWM) boundaries and the designation of transfer boundaries as either gaining or losing as defined in the calibrated GWM relative to topography, hydrologic features, and cultural features in the model area (Bucks County, Pennsylvania).

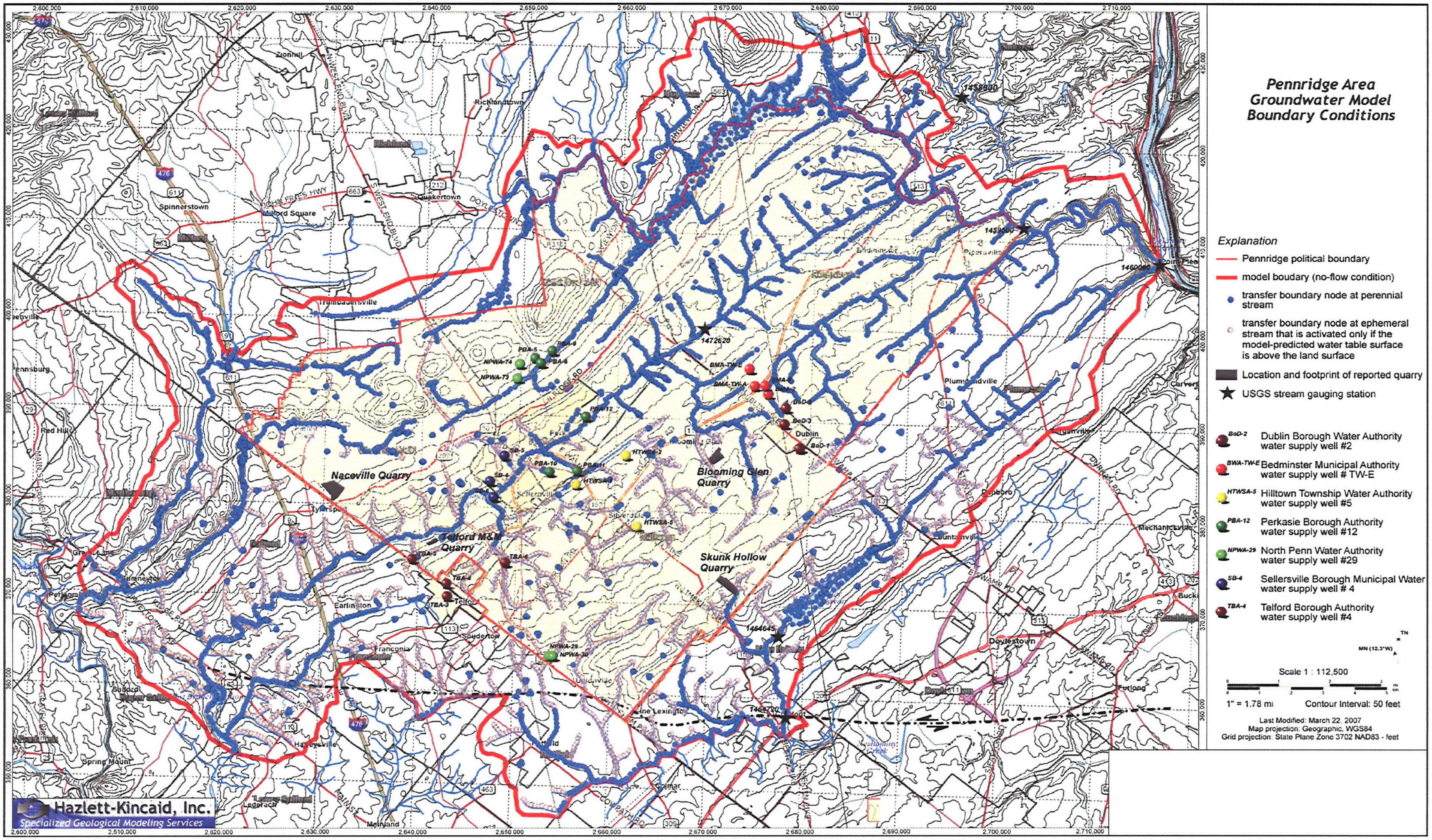

Figure 11. Map showing the Pennridge Groundwater Model (GWM) boundaries and their condition relative to topography, hydrologic features, and cultural features in the model area (Bucks County, Pennsylvania).

Table 11. Correlation between GFM Layers and GWM Layers.

GEOLOGY	GFM LAYER	GFM #	FEM LAYER	FEM #	COMMENTS
Brunswick	Bedrock	1	Diabase-1	1	Limited geologic data was available to constrain the units contacts north of the diabase. These units were grouped as a diabase because it is the largest and most confidently defined unit in the group.
Hornfels	hf_nw_outer	2			
Diabase	db_nw_outer	3			
Hornfels	hf_nw_inner	4			
Diabase	db_nw_inner	5			
Hornfels	db_east	6	Bruns-Hornfel-1	2 3 4	GFM layers 6 and 7 were merged and then two numerical layers were created to accommodate the top and bottom of wells terminating in the Bruns-Hornfel-1 layer.
Brunswick	hf_se	7			
Lockatong	Trl15	8	Lockatong-1	5	
Brunswick	Trb13	9	Brunswick-1	6	
Lockatong	Trl14	10	Lockatong-2	7	
Brunswick	Trb12	11	Brunswick-2 Brunswick-2a	8 9	Brunswick 2a is a numerical layer added to accommodate the bottom of wells terminating in the Brunswick 2 layer.
Lockatong	Trl13a	12	Lockatong-3	10	
Brunswick	Trb11a	13	Brunswick-3	11	
Lockatong	Trl13	14	Lockatong-4	12	GFM layer 15 (Trb11) is very thin and was omitted for simplicity in the groundwater model.
Brunswick	Trb11	15			
Lockatong	Trl12	16			
Brunswick	Trb10	17	Brunswick-4 Brunswick-4a Brunswick-4b	13 14 15	GFM layers 18 and 20 are very thin and were omitted for simplicity allowing layers 17-21 to be grouped as one large Brunswick layer. Brunswick-4a and -4b are numerical layers added to accommodate the top and bottom of wells terminating in the Brunswick-4 layer.
Lockatong	Trl11a	18			
Brunswick	Trb9a	19			
Lockatong	Trl11	20			
Brunswick	Trb9	21			
Lockatong	Trl10	22	Lockatong-5	16	
Brunswick	Trb8	23	Brunswick-5 Brunswick-5a	17 18	Brunswick-5a is a numerical layer added to accommodate the bottom of wells terminating in the Brunswick-5 layer
Lockatong	Trl9	24	Lockatong-6	19	
Brunswick	Trb7	25	Brunswick-6 Brunswick-6a	20 21	Brunswick-6a is a numerical layer added to accommodate the bottom of wells terminating in the Brunswick-6 layer
Lockatong	Trl8b	26	Lockatong-7	22	GFM layer 27 is very thin and was omitted for simplicity.
Brunswick	Trb6a	27			
Lockatong	Trl8	28	Lockatong-8 Lockatong-8a	23 24	Lockatong-8a is a numerical layer added to accommodate the bottom of wells terminating in the Lockatong-8 layer
Brunswick	Trb6	29	Brunswick-7	25	GFM layer 30 is very thin and was omitted for simplicity allowing layers 29-31 to be grouped as one larger Brunswick unit.
Lockatong	Trl7b	30			
Brunswick	Trb5d	31			
Lockatong	Trl7a	32	Lockatong-9 Lockatong-9a	26 27	GFM layer 33 is very thin and was omitted for simplicity. Lockatong-9a is a numerical layer added to accommodate the bottom of wells terminating in the Lockatong-9 layer.
Brunswick	Trb5b	33			
Lockatong	Trl7	34	Lockatong-10	28	GFM layer 35 is very thin and was omitted for simplicity allowing layers 34-36 to be grouped as one large Lockatong unit.
Brunswick	Trb5a	35			
Lockatong	Trl6b	36			
Brunswick	Trb5	37	Brunswick-8	29	GFM layer 38 is very thin and was omitted for simplicity allowing layers 37-39 to be grouped as one large Brunswick unit.
Lockatong	Trl6a	38			
Brunswick	Trb4a	39			
Lockatong	Trl6	40	Lockatong-11	30	

Brunswick	Trb4	41	Brunswick-9	31	
Lockatong	Trl5	42	Lockatong-12 Lockatong-12a	32 33	These layers are located distant from the region of interest and many are very thin. The layers were grouped to improve the computational efficiency of the model in a region that would have the least impact on the predictions of flow to the wells. They were assigned as a Lockatong unit because it is the stratigraphically highest unit in the group and thus borders the next higher layer in the GWM. Lockatong-12a is a numerical layer added to accommodate the bottom of wells terminating in the Lockatong-12 layer.
Brunswick	Trb3a	43			
Lockatong	Trl4a	44			
Brunswick	Trb3	45			
Lockatong	Trl4	46			
Brunswick	Trb2	47			
Lockatong	Trl3a	48			
Brunswick	Trb1b	49			
Lockatong	Trl3	50			
Brunswick	Trb1a	51			
Lockatong	Trl2a	52			
Brunswick	Trb1	53			
Hornfels	hf_sesill_upper	54			
Diabase	db_se	55			
Hornfels	hf_sesill_lower	56			
Lockatong	Trl2	57			
Stockton	Trs2a	58			
Lockatong	Trl1	59			
Stockton	Trs2	60			

Notes

1) Shaded rows indicate units that have the same horizontal hydraulic conductivity in the final model simulations.
2) Number designators in the FEM LAYER column represent the sequential order of the respective rock-types from stratigraphic top to stratigraphic bottom in the model sequence, which reflects the northwest trending dip in the units.

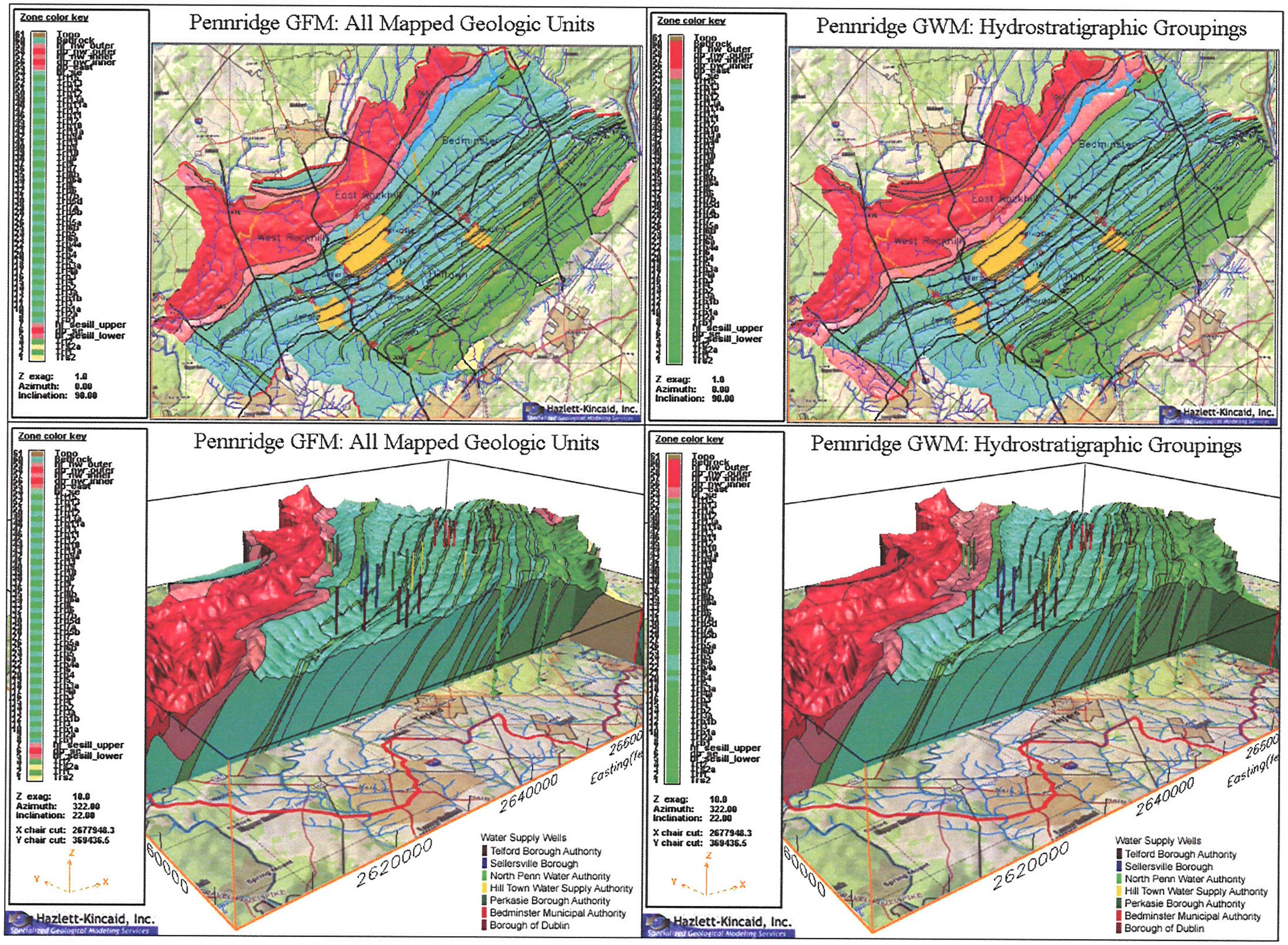

Figure 12. 3-D views comparing the layer assignments in the Pennridge geologic framework model (GFM) and the Pennridge groundwater model (GWM). Legend keys show how the GFM layers were grouped in the construction of the GWM. Top – plan view maps. Bottom – perspective chair-cut views showing the position of the municipal water supply wells projected above land surface for ease of visualization.

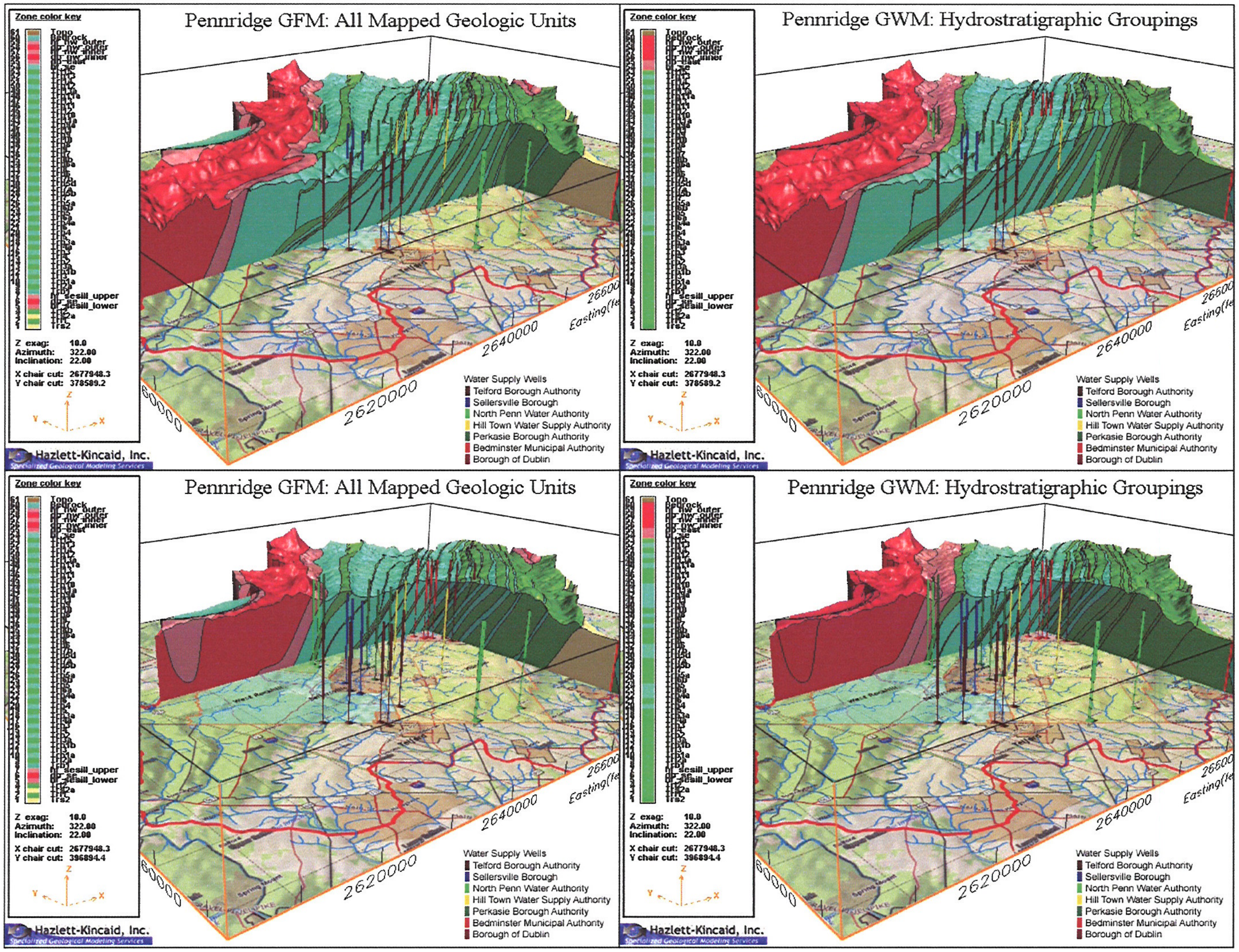

Figure 13. 3-D views comparing the layer assignments in the Pennridge geologic framework model (GFM) and the Pennridge groundwater model (GWM). Legend keys show how the GFM layers were grouped in the construction of the GWM. Top and Bottom – perspective chair-cut views showing the position of the municipal water supply wells projected above land surface for ease of visualization.

e. Model Assumptions

Any model is a simulation of the real-world environment being investigated and never captures all of the complexities characteristic of the region or the site. To address this limitation, models use various forms of simplifying assumptions to reduce the complexities into tractable problems that can be simulated using available technologies. Modeling techniques that require fewer assumptions by correctly addressing more of the real-world complexities, and that are based on assumptions that accurately describe the complexities that are not explicitly addressed, result in more realistic simulations and therefore more accurate predictions. All assumptions rather implicit or explicit to the model design and function should be fully described to ensure that the modeling approach is appropriate for the hydrogeologic setting.

The assumptions underpinning the Pennridge GWM are as follows.

- *Aquifer Dimensionality*
  Groundwater models can be 1-D, 2-D, or 3-D in dimensionality where the complexity of the equations and solutions increases in higher dimensional simulations. 1-D models are the most simplistic and are typically only used to develop a cursory understanding of the most probable variables controlling groundwater flow or contaminant transport.

  2-D models are most useful in simple, shallow hydrogeologic environments where the following assumptions are applicable. (1) The aquifer is homogeneous with respect to depth, i.e., there is only one aquifer in the subsurface. (2) All flow is horizontal. (3) The surface expression of a hydrogeologic unit represents its full spatial extent, i.e., all layer contacts are vertical. (4) All sources and sinks for groundwater flow fully penetrate the aquifer, i.e., rivers, springs, wells, quarries, etc.

  In more complex hydrogeologic environments, such as the Pennridge Area, the assumptions underlying 2-D models do not apply. The aquifer is comprised of a non-horizontal, dipping sequence of variably thick hydrogeologic units with different hydraulic properties. The only way to effectively simulate flow through such an environment is with the use of a 3-D model wherein the layer stacking and variable penetration of hydraulic features such as rivers and wells can be explicitly defined and simulated.

- *Aquifer Thickness*
  The aquifer thickness was assumed to be approximately 675 feet and relatively constant. The value was determined from the reported depth of the deepest water bearing zones and fracture density in the model region and was set such that the modeled aquifer captured the entire depth of all municipal supply wells in the region. This assumption constrains the depth to which groundwater is allowed to circulate in the groundwater flow model, which impacts the prediction of groundwater velocities and thus the extent of the Zone II WHPZ delineations. Holding all other variables constant, a thicker aquifer will result in slower predicted velocities and therefore smaller capture zones.

- *Steady-State*
  Groundwater models can be designed to address average or fluctuating hydraulic conditions. Models that address average conditions are termed steady-state and those that address fluctuating conditions are termed transient. Steady-state models produce simulations of groundwater levels, flow directions, and velocities that are in equilibrium with the simulated sources and sinks for groundwater flow and should therefore be considered to represent long-term average conditions that may not be observed during any one particular time period.

  Transient models produce simulations of groundwater levels, flow directions, and velocities that fluctuate with changing hydraulic conditions such as seasonal fluctuations in rainfall, varying pumping rates, river stage, etc. Transient models rarely reach equilibrium with respect to sources and sinks. Such models require transient data, meaning data with long-term records of daily, monthly, or seasonal fluctuations. Transient data was available for some, but not all of the municipal pumping wells, for rainfall and therefore recharge, but not for stream flows, which provide the most important constraint on water budgets in the region. The lack of sufficient stream flow data in the Pennridge Area rendered the development of a transient groundwater model impracticable and the model was therefore steady-state.

- *Bedrock Hydraulic Conductivity*
  Hydraulic conductivity (K) can be defined as the capacity of a material to transmit water. Understanding and describing how hydraulic conductivity varies throughout an aquifer is critical to the accurate simulation of groundwater flow. An aquifer can be said to be homogeneous if the hydraulic conductivity is constant throughout the region, which is rarely true in any but the simplest hydrogeologic environments, i.e., a single rock type of uniform material. Otherwise, the aquifer is described as heterogeneous, meaning that the hydraulic conductivity varies throughout the region. Similarly, if the propensity for water to flow through the aquifer is equal in all directions at any given point, it is described as isotropic ($K_{xx} = K_{yy} = K_{zz}$). Otherwise it is described as anisotropic, meaning that the aquifer contains preferential flow directions. Fractured bedrock aquifers are typically strongly anisotropic wherein preferential flow directions are aligned with the primary orientation of the fractures.

  The aquifer in the Pennridge Area (similar to most of Pennsylvania) is comprised of multiple, highly fractured rock layers that have different compositions and therefore different hydraulic conductivities. Furthermore, it is commonly recognized that the aquifer only produces significant quantities of water in wells that penetrate fractured zones within the rock layers (commonly called water bearing zones). The aquifer must therefore be considered to be heterogeneous and anisotropic where the heterogeneity is created by the distribution and thickness of the rock layers comprising the aquifer and the anisotropy is created by the fractures.

  In the ideal case, a numerical groundwater flow model in regions like the Pennridge Area would explicitly address flow through and between the rock

matrix and fracture network. Such models are termed dual porosity models. In order to work, however, one must be able to describe the fracture network that provides the primary permeability in the dual porosity medium, in terms of their aerial extent, aperture, and interconnectivity. Unfortunately, the required data did not exist when the Pennridge GWM was constructed, and it was beyond the scope of the project to collect it.

Instead, HKI used three assumptions in the construction of the GWM to incorporate a reasonable approximation of the fracture control on groundwater flow into the model framework. First, we assumed that the primary direction of fracturing in the bedrock is parallel to the strike of the rock units, that is, parallel to the contacts between adjacent rock layers. Second, we assumed that the hydraulic conductivity of the units is constant throughout the extent of the unit and isotropic with respect to the X and Y directions. Finally, we assumed that the hydraulic conductivity is aniotropic with respect to the vertical direction and significantly lower in the vertical direction than in the horizontal direction, i.e. $Kxx = Kyy >> Kzz$.

By making these assumptions the structure of the bedrock units, primarily the Brunswick-Lockatong sequences, and the differing hydraulic conductivities in the respective units ($K_{Brunswick} >> K_{Lockatong}$ - *See Table 16*) create a model framework that favors flow parallel to strike and thus simulates fracture flow in the bedrock aquifer. Since the GFM incorporates the 3-D structure of the bedrock layering to the extent described on published geologic maps, the model structure incorporates all of the available data into a description of the probable primary orientation of bedrock fractures that control groundwater flow.

- *Fracture Density*
  Low and others (2002) report that the number of water bearing zones (presumably related to the fracture density) in the bedrock aquifer generally decreases with depth. The highest fracture densities in the Brunswick Formation occur between 51 to 200 feet below land surface and diminish significantly below 350 feet. The Lockatong Formation contains a bimodal distribution of water bearing zones with primary occurrences between 51 and 200 feet and another between 501 and 550 feet below land surface. The total number of water bearing zones in the most productive intervals in the Lockatong Formation is an order of magnitude fewer than in the Brunswick Formation.

  The GWM assumes that the hydraulic conductivity in the units is proportional to fracture density wherein hydraulic conductivity in the Brunswick Formation is generally an order of magnitude higher than in the Lockatong Formation. We attempted to incorporate the observed vertical zonation in fracture density into the model design, however the required configuration was too computationally complex for the scope of this project. The model therefore incorporates an assumption that the fracture density is constant throughout the thickness of the bedrock portion of the model framework.

- *Soil Hydraulic Conductivity*
  Soil maps showed that most of the soil groups within the model area can be classified as some type of silt loam. Based on this observation and the relative

thickness of the soil layer compared to the bedrock thickness, hydraulic conductivity in the soil layer was assumed to be homogeneous and anisotropic where $Kxx = Kyy << Kzz$. In effect, this assumption stems from the intent of this model to simulate flow through the bedrock aquifer. The relatively high vertical conductivity compared to horizontal conductivity provided for rapid infiltration to the bedrock aquifer where the simulated water table elevation was lower than the bedrock surface but realistic horizontal flow through the soil zone where the simulated water table elevation was higher than the bedrock surface. The influence of soil permeability on recharge was not explicitly addressed but rather incorporated into a spatially variable distribution of recharge.

- *Well Depths*
  The groundwater flow equations assume that pumping wells fully penetrate the aquifer or hydrogeologic unit from which the water is extracted. This assumption allows the model to calculate horizontal flow to the wells rather than a combination of horizontal and vertical flow that may occur when wells do not fully penetrate the aquifer.

  Most of the wells in the Pennridge Area were, however, found to partially penetrate the primary hydrogeologic unit from which they are extracting water. In order to address the discrepancy between the assumption implicit to the calculations and the actual depth of the wells, additional (numerical) layers were added to the model such that all wells fully penetrated the model layers from which they were extracting water. Such numerical layers simply split a given hydrogeologic layer into two or more simulated layers identical with respect to hydraulic parameters and similar with respect to 3-D orientation.

- *Laminar Flow*
  Darcy's Law provides the underpinning equation for groundwater flow from which the GWM was constructed. It states that groundwater flow through a porous media is a function of the hydraulic gradient and hydraulic conductivity of the material. The relation holds only for porous material where flow through the material is laminar, meaning that it is relatively slow and essentially evenly distributed in the cross-sectional area of the material through which the water is flowing. In using this equation, we are (1) using the best possible technology given the data constraints and (2) assuming that our model of the hydrogeologic framework is sufficiently detailed to simulate the fractured rock aquifer as a stack of porous layers with different hydraulic properties.

- *Porosity and Aquifer Storativity*
  Porosity is the ratio of the volume of void space in a rock to the volume of the rock and describes the total amount of void space in an aquifer available to store and transmit water. It is closely related to the aquifer storativity, which is defined as the volume of water an aquifer takes into or releases from storage due to changes in head. These values are hard to measure in the field and are therefore most often assigned based on published studies of similar rock types and/or set during the model calibration process if transport times are well known. For the Pennridge model, storativity was set to 0.001 for the bedrock layers and 0.2 for the soil layer, which represent low and median published values for bedrock and surficial aquifers respectively (Fetter, 1980; Driscoll, 1986).

f. Calibration

The fundamental problem with groundwater modeling is the non-uniqueness of the model results. Predicted head configurations, flow paths, and groundwater velocities are all subject to the assignments of often numerous parameters that can vary over fairly wide ranges and are rarely thoroughly measured in the field. Modelers address this problem through a process called calibration in which input parameters are varied such that the model results compare favorably to observations of real-world conditions. The underlying assumption is that models that produce more accurate simulations of observed conditions are based on more accurate parameter values and therefore produce more reliable predictions of future or non-observable conditions.

In following this assumption, HKI strives to calibrate models to as many observable hydraulic conditions as possible. At a minimum, our calibration process addresses observed heads and the observed or estimated water balance. If possible, we also focus on other observable hydraulic conditions or patterns such as spring and/or stream flows, travel times or groundwater velocities, aquifer response to stressors such as pumping and/or quarrying, and observed or inferred flow paths.

There was limited available data for calibration in the construction of the Pennridge GWM. The primary calibration variables were the estimated water balance and observed heads under static and pumping conditions at the municipal supply wells and two USGS monitoring wells. An acceptable water balance was determined by estimated aquifer-stream interactions as defined by reported gaining or losing conditions in the mapped rivers and streams, reported discharge from the four quarries, and reported discharge from the municipal water supply wells. In close approximation to reported groundwater levels, the elevation of mapped perennial streams was used as the criteria for acceptable head configurations.

Water Balance

Exchange of water between the aquifer and the rivers and streams, and the discharge of groundwater from the dewatered quarries were considered the primary controls on the regional groundwater flow system from which the municipal supply wells are extracting groundwater. Very little data was available to constrain either of those two variables; however, a qualitative assessment of predicted aquifer-stream interactions was used as a preliminary calibration criteria and to provide cursory constraint on the simulated water table configuration.

Only four USGS stream gauging stations were identified within the modeled region that would provide relevant data (station 1459500 on Tohickon Creek near Pipersville, station 1464645 on NB Neshaminy Creek below Lake Galena near New Britain, station 1464720 on NB Neshaminy Creek at Chalfont, and station 1472620 on EB Perkiomen Creek near Dublin – *See Figure 11*). The data coverage was considered insufficient to be used directly in the model calibration because it could not be used to estimate the total surface water discharge out of the model region. Furthermore, only one station (EB Perkiomen Creek) is in the immediate region of interest (near the municipal water supply wells) but it lies upstream of the wells and could therefore not be used to estimate stream flow in or below the probable zone of influence.

Quarry data was limited to pit footprints and discharges obtained from the Pennsylvania Department of Environmental Protection (Bollinger, personal communication); however, that data was limited to reported values and was not accompanied by local monitoring well data.

Instead of calibrating to specific river and stream flows, the GWM was calibrated to observed aquifer-stream interactions through an evaluation of the simulated gaining or losing conditions in the incorporated streams and rivers. To accomplish this, all mapped rivers and streams were classified as perennial or ephemeral based on an evaluation of the 7.5 minute topographic quadrangles covering the modeled region. Model simulations were then constrained through a calibration process such that the model-predicted water table configuration permitted discharge to most of the upper-most sections of mapped perennial streams. Particular focus in that regard was directed to Perkiomen Creek and the associated tributaries because most of the municipal supply wells are situated in that watershed. The constraint was less rigorous for streams near the model boundaries because the model-predicted water table surface in those regions has less impact on the simulated well capture zones.

Figure 10 shows the final calibrated model-simulation of gaining and losing reaches of the mapped perennial streams that were incorporated in the GWM. The model shows that most of the mapped perennial streams are gaining water at the upper-most points of their respective tributaries but indicates that some sections of the largest streams are losing water to the aquifer. This condition was deemed acceptable because there is no record of stream flow gains and losses with which to further constrain the model prediction.

The reported quarry discharges were also used in the calibration process. Quarry pit elevations were assigned as constant head values to an approximated footprint of the quarry floor based on the data received from Pennsylvania Department of Environmental Protection (Bollinger, personal communication) and the topographic footprint of the quarries as described by digital orthophoto quads (DOQs). The model-predicted flux out of the constant head boundaries was evaluated for the model simulations and compared to the reported discharge values. Acceptable simulations were constrained to those where the predicted flux out of the quarries fell within half an order of magnitude of the reported values, preferring over-estimates to under-estimates for the sake of conservativeness. *Table 12* shows the reported vs. simulated quarry discharges from the final calibrated model for each of the four quarries contained in the modeled region.

Table 12. Reported vs. Simulated Quarry Discharges in the Pennridge Groundwater Model.

Quarry	Reported Pit Elev. m (ft) – *amsl*	Reported Discharge m^3/d (cfs)	Simulated Flux m^3/d (cfs)	% Diff.
Naceville	122 (400)	345 (0.14)	540 (0.22)	56.32%
MandM Telford	0 (0)	4359 (1.78)	8181 (3.34)	87.69%
Blooming Glen	76 (250)	2581 (1.06)	7139 (2.92)	176.56%
Skunk Hollow	140 (460)	1540 (0.63)	2288 (0.94)	48.59%

A broader measure of the model performance and accuracy is the simulated water balance, which is a measure of the total simulated water inputs and outputs. For the

Pennridge GWM, the primary water input is recharge because the model boundaries follow probable groundwater basin divides and only cross two small streams that bring water into the model area near Lake Nockamixon (*Figure 11*). A recharge rate of approximately 7 inches per year was used as the target average input value for the whole model region. That value was based on an estimate of 6.7 inches per year established by the William Penn Foundation (1997) using stream flow records from USGS gauging station 01458900, which is located on Tinicum Creek in Tinicum Township, approximately 0.5 miles east of the northeastern model boundary (*Figure 11*).

Table 13. Pennridge GWM Water Balance.

Budget Category	Flow m^3/d (cfs)
Recharge	2.42E+05 (98.9) – *7in/yr*
Discharge to Rivers	-1.96E+05 (-80.1)
Discharge to Quarries	-1.81E+04 (-7.42)
Discharge to Wells	-2.82E+04 (-11.5)
Model Imbalance	-1.02E+02 (-0.04)

Table 13 provides an accounting of the simulated water balance for the GWM. The balance chart shows that the simulated total influx from recharge is approximately 7 in/yr, which calibrates well with the reported value for the region. Total simulated discharge to quarries is approximately 7.42 cfs where most of that is to the M & M Telford and Blooming Glen quarries. The total simulated average discharge to all streams within the modeled region is approximately 80.1 cfs, which is probably a reasonable estimate of the long-term average output given that the median reported flow at the East Branch Perkiomen Creek station is 16 cfs. Total discharge from all the municipal supply wells is approximately 11.5 cfs, which was set as described in *Section IV.B.3.c.* The total model imbalance (total inputs – total outputs) is less than 0.05 cfs.

Observed Heads

The most commonly used calibration parameter is hydraulic head wherein model-predicted values are compared to observed groundwater levels in water wells. Ideally, a calibration dataset is constructed from long-term records in monitoring wells distributed across the entire model region. It is sometimes supplemented with one-time measurements obtained during well installations or data from active pumping wells.

Hydraulic head was the primary calibration criteria used in the Pennridge GWM, but there was limited reliable data with which to construct a standard dataset. The bulk of the available data described water levels in the municipal water supply wells under static (non-pumping) and pumping conditions. That dataset was supplemented with seven dedicated monitoring wells: two maintained by the USGS, four by private landowners, and one by Hilltown Water and Sewer Authority. Data was obtained from four additional recently installed water supply wells that are not yet in operation: Bedminster Township wells BMA-A and BMA-E, Telford Borough well TBA-7, and Perkasie Borough well PBA-7.

The GWM was calibrated to both static and pumping conditions. The static condition calibration was performed by turning off all of the pumping wells and comparing the model-predicted heads at the pumping and observation wells against the reported ranges in static-condition water levels at both the pumping wells and observations wells. The pumping condition calibration was performed by activating all of the wells at the rates listed in *Table 10* and comparing the model-predicted heads against the reported ranges in pumping-condition water levels in the pumping wells and the reported ranges in the static condition water levels in the observation wells. The purpose of the two-step calibration process was to maximize the utility of the available data and to test the model settings under both stressed and non stressed aquifer conditions. The reported ranges in water levels were used for calibration rather than specific values (e.g., average heads) because most of the wells used for calibration were pumping wells that displayed variable pumping rates and pumping times resulting in highly variable reported water levels.

Tables 14 and 15 provide a tabulation of the range of reported water levels for all the wells used in the static and pumping calibration simulations and the model-simulated values for the respective wells. *Figures 14 and 15* show how the simulated heads compared to the observed average heads and the associated range in head at each of the calibration wells for the static and pumping condition simulations. Upper and lower bounds on the target simulated heads were set to the highest and lowest reported water levels plus 5 percent and minus 5 percent of the total observed range in water level across the model region. *Figure 16* provides a regression plot of observed vs. simulated heads for both the static and pumping condition simulations. The variance in the static condition simulation was less than the variance in the pumping condition simulation, which was expected given the larger range in reported water levels when the pumps were active. Both plots, however, show a good correlation between observed and modeled water level values.

With minor exceptions, both the static and pumping condition GWM simulations are well calibrated to all of the available hydrologic data in the Pennridge Area (static and pumping water level observations, pumping rates, quarry pit elevations and discharges, average regional recharge, and basic stream flow configurations). The Pennridge GWM can therefore be considered to effectively simulate long-term average groundwater flow conditions in the modeled region under both stressed and non stressed conditions in the bedrock aquifer.

Table 14. Observed and Model-simulated Static Condition Water Levels at all Pumping and Observation Wells Included in the Pennridge GWM.

Owner	Well Type	Well ID	Min Water Table Elevation m (ft)	Max Water Table Elevation m (ft)	Avg Water Table Elevation m (ft)	GWM Water Table Elevation m (ft)
Telford	Production	TBA-1	97 (318)	108 (354)	103 (338)	110 (362)
Telford	Production	TBA-3	97 (318)	109 (358)	103 (338)	103 (338)
Telford	Production	TBA-4	80 (262)	88 (289)	84 (276)	84 (275)
Telford	Production	TBA-5	70 (230)	80 (262)	75 (246)	85 (280)
Telford	Production	TBA-6	98 (322)	106 (348)	102 (335)	106 (347)
Telford	Calibration	TBA-7	86 (282)	96 (315)	94 (308)	98 (320)
Perkasie	Production	PBA-5	112 (367)	149 (489)	140 (459)	139 (457)
Perkasie	Production	PBA-6	116 (381)	138 (453)	135 (443)	138 (451)
Perkasie	Calibration	PBA-7	138 (453)	142 (466)	141 (463)	134 (439)
Perkasie	Production	PBA-9	134 (440)	146 (479)	144 (472)	135 (443)
Perkasie	Production	PBA-10	82 (269)	93 (305)	88 (289)	100 (328)
Perkasie	Production	PBA-11	94 (308)	99 (325)	98 (322)	99 (325)
Perkasie	Production	PBA-12	70 (230)	103 (338)	91 (299)	99 (326)
Hilltown	Production	HTWSA-1	94 (308)	104 (341)	101 (331)	101 (330)
Hilltown	Production	HTWSA-2	85 (279)	111 (364)	104 (341)	107 (351)
Hilltown	Production	HTWSA-5	122 (400)	147 (482)	135 (443)	129 (425)
Hilltown	Observation	HTWSA-5.1	131 (430)	151 (495)	141 (463)	137 (449)
Dublin	Production	DB-1	181 (594)	183 (600)	182 (597)	165 (540)
Dublin	Production	DB-3	120 (394)	123 (404)	122 (400)	131 (429)
Dublin	Production	DB-5	*NR*	*NR*	*NR*	140 (460)
Sellersville	Production	SB-4	*NR*	*NR*	*NR*	99 (326)
Sellersville	Production	SB-5	*NR*	*NR*	*NR*	110 (361)
Sellersville	Production	SB-6	80 (262)	87 (285)	84 (276)	98 (322)
Bedminster	Production	BMA-2	*NR*	*NR*	*NR*	143 (469)
Bedminster	Calibration	BMA-9	*NR*	*NR*	*NR*	137 (451)
Bedminster	Production	BMA-A	*NR*	*NR*	*NR*	132 (433)
Bedminster	Calibration	BMA-E	*NR*	*NR*	*NR*	133 (438)
North Penn	Production	NP-29	*NR*	*NR*	*NR*	120 (393)
North Penn	Production	NP-30	*NR*	*NR*	*NR*	121 (397)
North Penn	Production	NP-73	*NR*	*NR*	*NR*	142 (467)
North Penn	Production	NP-74	*NR*	*NR*	*NR*	144 (472)
Private	Observation	MW-61	135 (443)	144 (472)	141 (463)	144 (471)
Private	Observation	MW-64	139 (456)	143 (469)	142 (466)	135 (444)
Private	Observation	MW-66	92 (302)	93 (305)	93 (305)	98 (322)
Private	Observation	MW-67	92 (302)	94 (308)	93 (305)	98 (323)
USGS	Observation	MG-917	102 (335)	104 (341)	103 (338)	105 (343)
USGS	Observation	BK-929	131 (430)	137 (449)	136 (446)	133 (436)

Notes
1) Well type "Calibration" denotes wells that have been drilled for future use as production wells but are not currently active. They were used as observation wells in the static model calibration.
2) *NR* = No Record / No head data was provided but the simulated heads are provided for future comparison.

Table 15. Observed and Model-simulated Pumping Condition Water Levels at all Pumping and Observation Wells Included in the Pennridge GWM.

Owner	Well Type	Well ID	Min Water Table Elevation m (ft)	Max Water Table Elevation m (ft)	Avg Water Table Elevation m (ft)	GWM Water Table Elevation m (ft)
Telford	Production	TBA-1	81 (266)	100 (328)	90 (295)	83 (274)
Telford	Production	TBA-3	77 (253)	95 (312)	87 (285)	81 (267)
Telford	Production	TBA-4	30 (98)	48 (157)	41 (135)	35 (115)
Telford	Production	TBA-5	62 (203)	73 (239)	70 (230)	63 (206)
Telford	Production	TBA-6	94 (308)	101 (331)	97 (318)	97 (318)
Perkasie	Production	PBA-5	101 (331)	131 (430)	127 (417)	105 (344)
Perkasie	Production	PBA-6	112 (367)	124 (407)	118 (387)	113 (370)
Perkasie	Calibration	PBA-7	138 (453)	142 (466)	141 (463)	133 (438)
Perkasie	Production	PBA-9	104 (341)	126 (413)	115 (377)	128 (419)
Telford	Calibration	TBA-7	86 (282)	96 (315)	94 (308)	94 (309)
Perkasie	Production	PBA-10	55 (180)	77 (253)	70 (230)	52 (171)
Perkasie	Production	PBA-11	76 (249)	99 (325)	83 (272)	75 (247)
Perkasie	Production	PBA-12	28 (92)	103 (338)	53 (174)	53 (175)
Hilltown	Production	HTWSA-1	47 (154)	100 (328)	96 (315)	83 (274)
Hilltown	Production	HTWSA-2	57 (187)	94 (308)	79 (259)	77 (253)
Hilltown	Production	HTWSA-5	92 (302)	138 (453)	121 (397)	120 (395)
Dublin	Production	DB-1	*NR*	*NR*	*NR*	134 (440)
Dublin	Production	DB-3	117 (384)	120 (394)	119 (390)	100 (328)
Dublin	Production	DB-5	105 (344)	110 (361)	108 (354)	131 (431)
Sellersville	Production	SB-4	*NR*	*NR*	*NR*	67 (221)
Sellersville	Production	SB-5	*NR*	*NR*	*NR*	87 (285)
Sellersville	Production	SB-6	48 (157)	52 (171)	50 (164)	57 (188)
Bedminster	Production	BMA-2	*NR*	*NR*	*NR*	135 (443)
Bedminster	Calibration	BMA-9	*NR*	*NR*	*NR*	120 (395)
Bedminster	Production	BMA-A	*NR*	*NR*	*NR*	109 (356)
Bedminster	Calibration	BMA-E	*NR*	*NR*	*NR*	96 (316)
North Penn	Production	NP-29	*NR*	*NR*	*NR*	113 (372)
North Penn	Production	NP-30	*NR*	*NR*	*NR*	114 (373)
North Penn	Production	NP-73	102.5 (336)	145.5 (477)	137.5 (451)	134 (440)
North Penn	Production	NP-74	122 (400)	144 (472)	138.1 (453)	127 (417)

Notes
1) Well type "Calibration" denotes wells that have been drilled for future use as production wells but are not currently active. They were used as observation wells in the pumping model calibration.
2) PBA-7 and TBA-7 were used as observation wells in the pumping model calibration.
3) BMA-A and BMA-E were considered production wells where development data was used for calibrating the pumping condition model.
4) *NR* = No Record / No head data was provided but the simulated heads are provided for future comparison.

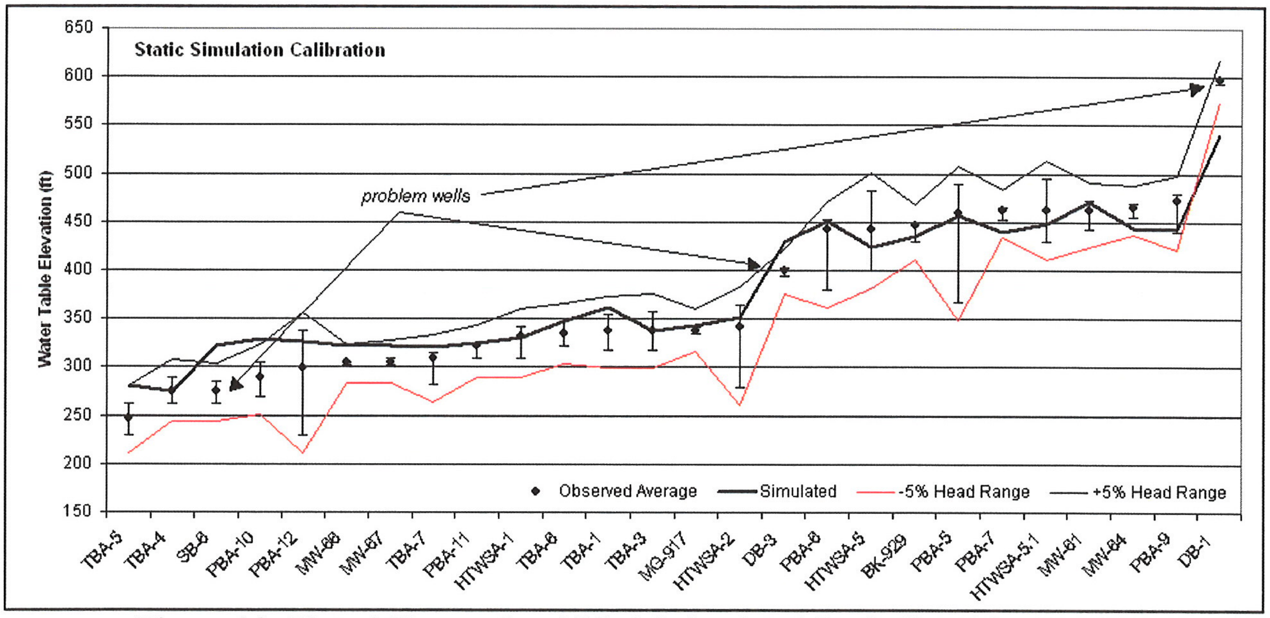

Figure 14. Plot of Observed and Model-simulated Static Condition Heads. The dark black line shows the simulated values. The points with error bars show the reported range in static water level above and below the average value at each well. The upper and lower bounds on acceptable model values represent the highest and lowest observed water levels plus and minus 5 percent of the total observed range in static water level across the modeled region. The most problematic wells are SB-6, DB-3, and DB-1.

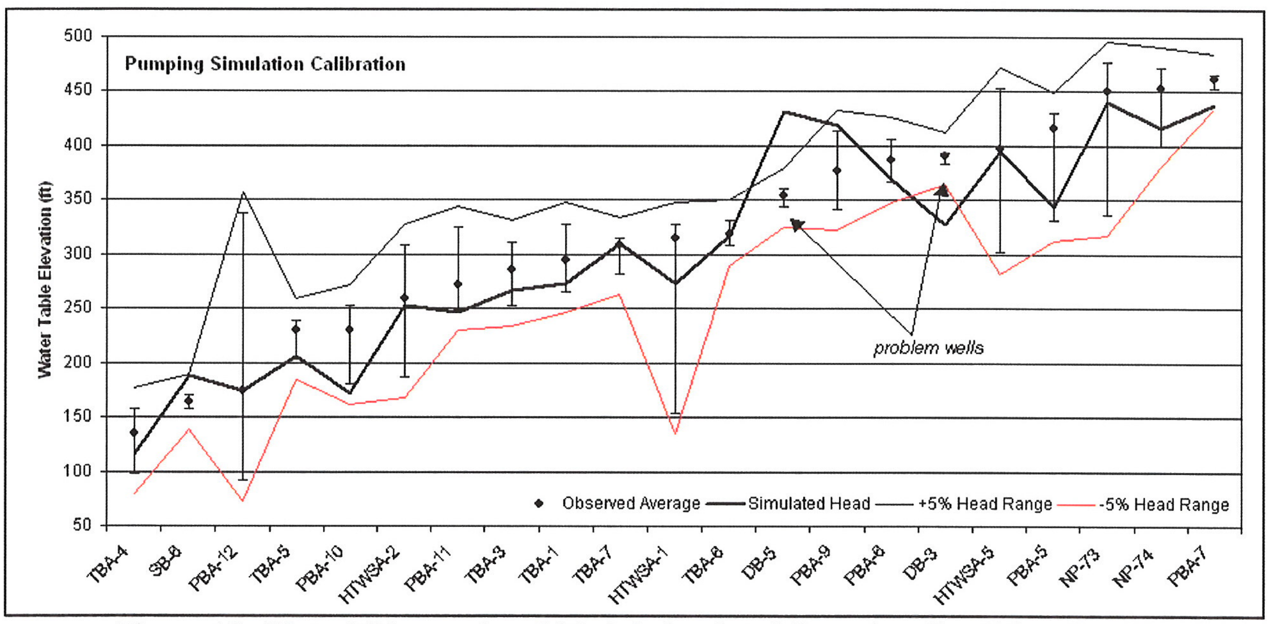

Figure 15. Plot of Observed and Model-simulated Pumping Condition Heads. The dark black line shows the simulated values. The points with error bars show the reported range in water level at each well when the pumps were active above and below the average values. The upper and lower bounds on acceptable model values represent the highest and lowest observed water levels plus and minus 5 percent of the total observed range in pumping water levels across the modeled region. The most problematic wells are DB-5 and DB-3.

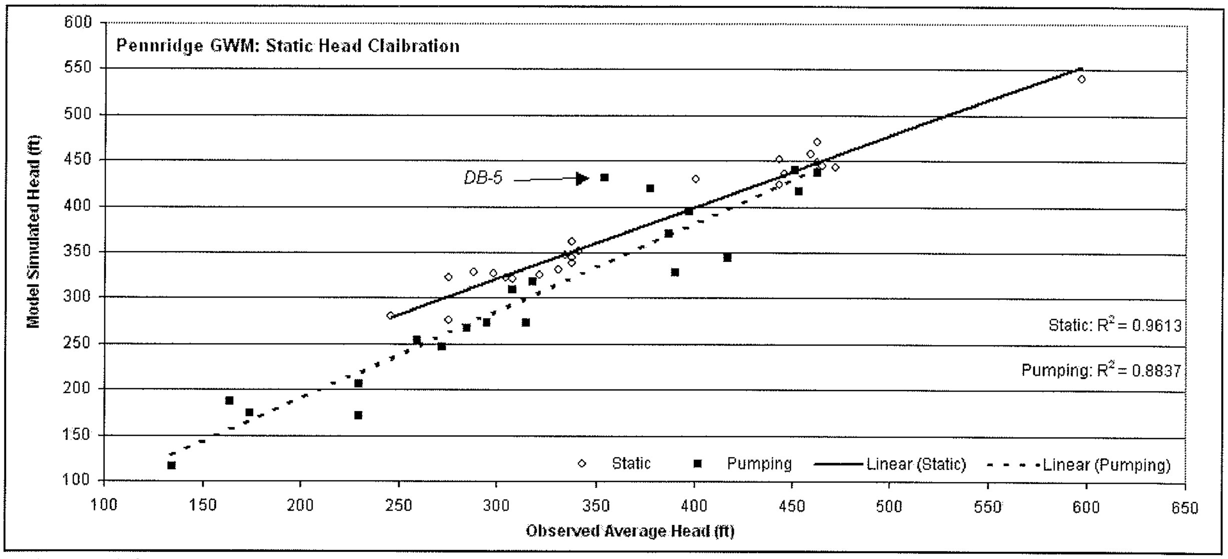

Figure 16. Regression of Observed vs. Model-simulated Heads Showing that the Variance in the Static Condition Simulation Is Less than the Variance in the Pumping Condition Simulation.

This was expected given the larger range in reported water levels when the pumps were active. Both plots show a good correlation between observed and modeled water level values.

The most significant deviations from the head calibration criteria are at Sellersville well SB-6 and Dublin wells DB-1, DB-3, and DB-5 where DB-3 and DB-5 were problematic in both the static and pumping conditions simulations. For each well significant effort was invested in model refinements and adjustments to address the problems; however, no other tested configuration resulted in improved head calibration at these wells without degrading the calibration at other wells and/or quarries. It is likely that the relatively poor calibration is a result of the model resolution, meaning that site-scale conditions that were not incorporated into the model design likely have significant influence on local groundwater flow near the wells.

At SB-6 and DB-3, changes in the hydraulic characteristics of the bedrock layers from which the wells are completed impact wells, quarries, and/or streams that are open to the same layers. The final calibration therefore represents the best possible balance between reaching the calibration targets at SB-6 and DB-3 and the associated impact on the calibration at inter-related features (*See Table 15*).

DB-5 is similarly influenced by probable site-scale complexities that were not included in the model design; however, calibration was made more problematic by apparent inconsistencies in the datum from which water levels in the well were measured. Water levels from this well were reported in terms of feet above the pump where the pump placement apparently moved by 100 feet during the 6-month period of record. Confidence in the water level measurements was therefore less than those from other wells that intersect the same hydrologic units and the reported discharge from the Blooming Glen Quarry (*See Table 15*).

Confidence in the water level measurements at DB-1 was low because the well was only operated for approximately 15 minutes per day during the period of record. It is

therefore doubtful that the reported water levels represent the actual water level in the well associated with the reported pumping rate. Since the model assumes that the pump operates constantly, well number DB-1 was disregarded in the pumping condition calibration. The low head in the static condition simulation is likely related to the location of the well on a local ridge top and the resolution of the model in that region.

Calibration Parameter Settings

The two primary parameters that were varied during the model calibration process were recharge and hydraulic conductivity. Recharge was varied spatially through the assignment of zones across the model surface in which the recharge rate was assigned as a constant within each zone but independently of the value in other zones. The magnitude of the assignments was constrained by keeping the total recharge over the entire model close to the 6.7 inches per year, which is the reported average (William Penn Foundation, 1997). An initial zonation for recharge was established by evaluating soil types, slope, and land use across the model region where higher recharge was assigned to relatively flat non-urban areas with permeable soils. As the model calibration process progressed, recharge was reduced or raised within the zones as necessary to control the simulated water table elevation relative to the land surface, distribution of perennial streams, and reported groundwater elevations in wells. *Figure 17* provides a map showing the distribution and magnitude of recharge as it was assigned in the final calibrated model simulations.

In general, the areas of highest recharge shown in *Figure 17* (red zones) correspond to regions characterized by higher permeable soils and/or higher flat ridges. The lowest recharge zone (dark blue) corresponds to the regions underlain by diabase, which has a very low vertical permeability and thin soil coverage. Urban areas (light blue) were also characterized as having lower than average recharge. Recharge in the remaining zones varied as needed to achieve calibration but were generally close in magnitude to the regional average.

There was limited available data defining the hydraulic conductivity of the bedrock layers defined in the groundwater model. Aquifer pumping tests performed as part of other studies in the model region provided some transmissivity values for the Brunswick, Lockatong, and a combination of the two units (Sloto and Schreffler, 1994; Philip S. Getty, 2006). Assuming an aquifer thickness of 600 feet, those data show that hydraulic conductivity ranges from 0.16 to 3.7 ft/day for the Brunswick Formation, 0.43 to 3.7 ft/day for the Lockatong Formation, and 0.5 – 0.6 ft/day for a unit comprised of about ½ Brunswick and ½ Lockatong. A groundwater model developed by the William Penn Foundation (1997) reported similar ranges: 0.21 – 60 ft/day for the Brunswick Formation and 0.05 – 3.8 ft/day for the Lockatong Formation. They also reported a hydraulic conductivity in the diabase of between 0.03 to 0.68 ft/day. The general consensus was that the Brunswick Formation is more permeable than the Lockatong Formation by as much as one order of magnitude. All of these values fall within the reported range in hydraulic conductivity for fractured rocks of between 0.002 and 85 ft/day. *Table 16* provides a compilation of the reported hydraulic conductivity for these and similar rocks.

In the development and calibration of the GWM, hydraulic conductivity, particularly hydraulic conductivity in the horizontal direction, was varied on a unit-by-unit basis to control the simulated water table elevation at the wells and along the perennial streams, as well as the simulated discharge to the quarries. Hydraulic conductivity was not varied at less than the full unit-scale as defined in *Tables 11 and 16* and *Figures 11 and 12*. Assignment values were roughly constrained by the ranges listed in *Table 16* but were allowed to deviate within those ranges as necessary to achieve the optimal calibration given reasonable recharge assignments. Thus, the final hydraulic conductivities were more unit specific than formation specific. *Table 17* shows the hydraulic conductivity values for each of the model layers as they were assigned in both the final static condition and pumping condition simulations of the calibrated GWM.

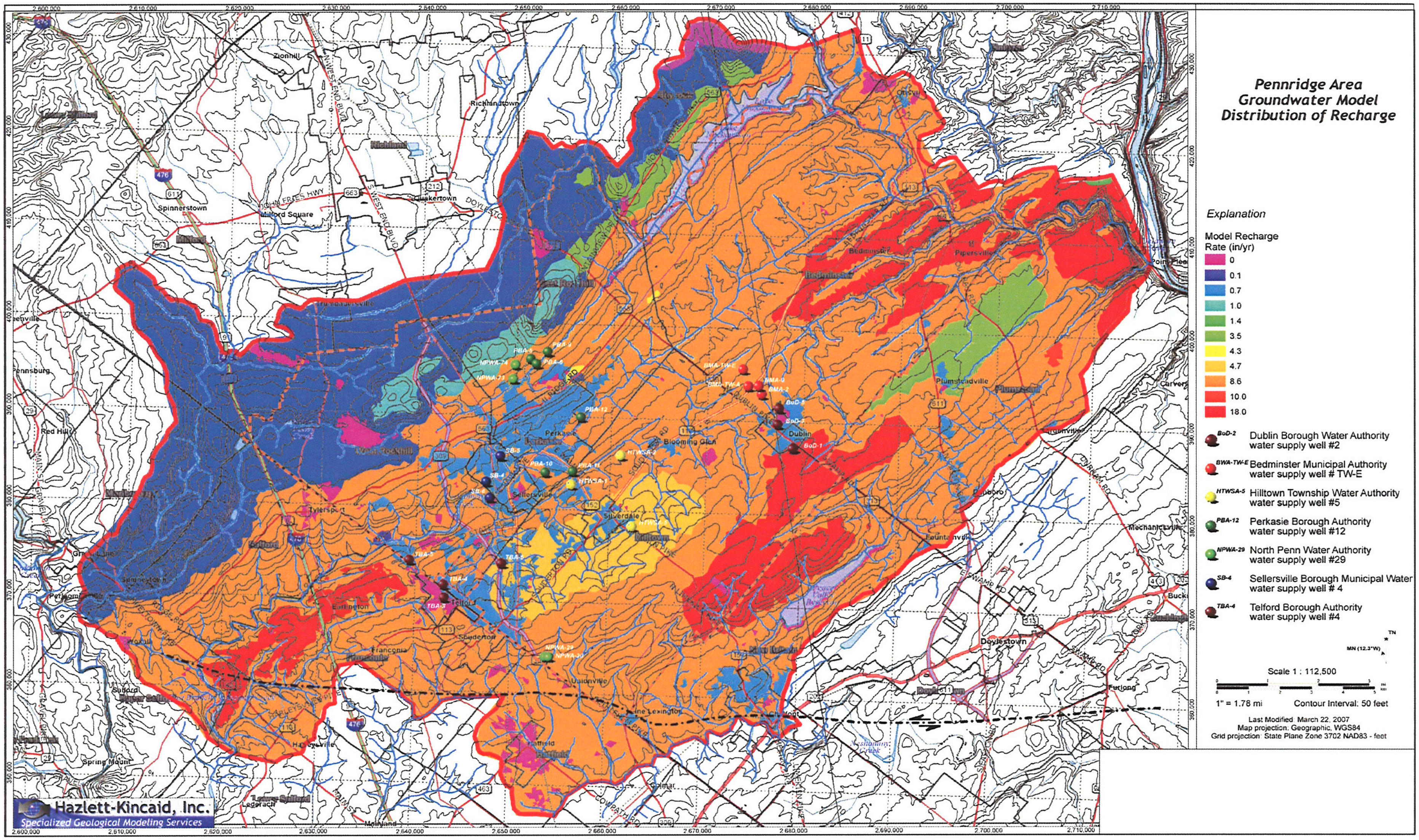

Figure 17. Map showing the distribution and magnitude of recharge assigned in the calibrated Pennridge Groundwater Model (GWM) relative to topography, hydrologic features, and cultural features in the model area (Bucks County, Pennsylvania).

Table 16. Reported Hydraulic Conductivity Ranges for Rock Types Similar to Those Incorporated into the Pennridge Groundwater Model (GWM).

Formation or Rock Type	High K m/s (ft/day)	Low K m/s (ft/day)	Data Source
Brunswick Formation	2.1E-04 (60)	7.4E-07 (0.21)	(William Penn Foundation, 1997)
Lockatong Formation	1.3E-06 (0.37)	1.8E-07 (0.05)	(William Penn Foundation, 1997)
Diabase	2.4E-06 (0.68)	1.1E-07 (0.03)	(William Penn Foundation, 1997)
Brunswick Formation	1.3E-05 (3.7)	5.5E-07 (0.16)	(Sloto and Schreffler, 1994)
Lockatong Formation	8.8E-06 (1.4)	4.8E-06 (2.5)	(Sloto and Schreffler, 1994)
Lockatong Formation	1.3E-05 (3.8)	7.3E-07 (0.2)	(Philip S. Getty, 2006)
Brunswick/Lockatong Mix	2.2E-06 (0.6)	1.7E-06 (0.5)	(Philip S. Getty, 2006)
Shale	2.0E-09 (5.7E-04)	1.0E-13 (2.8E-08)	(Domenico and Schwartz, 1990)
Fractured Crystalline Rock	3.0E-04 (85)	8.0E-09 (0.002)	(Domenico and Schwartz, 1990)
Unfractured Crystalline Rock	2.0E-10 (5.7E-05)	3.0E-14 (8.5E-09)	(Domenico and Schwartz, 1990)

Storativity was set to 0.001 for the bedrock layers and 0.2 for the soil layer in the model and not varied during the model calibration. 0.001 represents the low end of the observed range for bedrock aquifers (Fetter, 1980; Driscoll, 1986) which was used because the majority of groundwater flow in the region is known to be restricted to a limited number of fractured water-bearing zones in the bedrock layers. It was also chosen to render conservative estimates of travel-time for the well capture zone and WHP Zone delineations.

g. Model Results

Figures 18 through 20 present the GWM results as maps of the simulated water table surface under pumping conditions, well capture zones, and location of pumping impacts to streams. *Figure 18* shows the simulated steady-state water table surface under pumping conditions for the full Pennridge model region. The water table surface represents a compilation of the simulated long-term average groundwater levels in each of the 33 model layers in equilibrium with the distribution and magnitude of recharge, discharge to streams, and extractions at all of the municipal water supply wells pumping full-time at the rates specified in *Table 10*. The simulation conforms to expectations in that the water table grossly mimics the topographic surface. Groundwater levels are high beneath ridges and slopes downward to adjacent stream valleys such that the perennial streams are largely gaining (*See Figure 11*). The simulated pumping condition water table surface provided the basis for all of the subsequent output simulations including the delineation of the Zone II and Zone III WHP zones.

Figure 19 shows the simulated capture zones for all of the wells and quarries in the modeled region. The capture zones are defined by particle tracks that trace the source of the water from each well to the recharge area (region at the land surface where rainfall enters the aquifer) regardless of the travel-time necessary for the water to make the journey. The combined set of particle tracks for each well represent aerial projections of the volume of aquifer from which the well draws groundwater once the aquifer has reached equilibrium with the respective pumping rate. In the Pennridge Area, the GWM indicates that very nearly all of the water will travel from the recharge areas to the wells within 10 years. Thus, the full extent of nearly all of the capture zones falls within the 10-year time of travel zone used to define WHP Zone II.

Table 17. Horizontal and Vertical Hydraulic Conductivity Assignments for All Layers in the Pennridge Groundwater Model (GWM).

		Kxx and Kyy		Kzz		
FEM#	FEM LAYER	(m/s)	(ft/day)	(m/s)	(ft/day)	WELLS and QUARRIES OPEN IN UNIT
1	Diabase-1	7.5E-07	0.21	1.0E-10	2.8E-05	
2	Bruns-Hornfel-1	9.0E-06	2.55	1.0E-08	2.8E-03	PBA-5, PBA-6, PBA-7,PBA-9, NP-73, NP-74
3	Bruns-Hornfel-1	9.0E-06	2.55	1.0E-08	2.8E-03	PBA-5, PBA-6, PBA-7,PBA-9, NP-73, NP-74
4	Bruns-Hornfel-1	9.0E-06	2.55	1.0E-08	2.8E-03	PBA-5, PBA-6, PBA-7,PBA-9, NP-73, NP-74
5	Lockatong-1	1.0E-06	0.28	1.0E-10	2.8E-05	PBA-7
6	Brunswick-1	6.0E-06	1.70	1.0E-08	2.8E-03	SB-5, Naceville Quarry
7	Lockatong-2	1.0E-06	0.28	1.0E-10	2.8E-05	SB-5
8	Brunswick-2	6.5E-06	1.84	1.0E-08	2.8E-03	PBA-10, PBA-12, TBA-5, SB-4, SB-6
9	Brunswick-2a	6.5E-06	1.84	1.0E-08	2.8E-03	PBA-10, PBA-12, TBA-5, SB-4, SB-6
10	Lockatong-3	8.0E-07	0.23	1.0E-10	2.8E-05	
11	Brunswick-3	1.0E-05	2.83	1.0E-08	2.8E-03	
12	Lockatong-4	6.0E-06	1.70	1.0E-10	2.8E-05	PBA-10, PBA-11, TBA-5, SB-6
13	Brunswick-4	4.5E-06	1.28	1.0E-08	2.8E-03	PBA-11, HT-1, HT-2, TBA-4, TBA-5, TBA-7, SB-6 M & M Telford Quarry
14	Brunswick-4a	4.5E-06	1.28	1.0E-08	2.8E-03	PBA-11, HT-1, HT-2, TBA-4, TBA-5, TBA-7, SB-6
15	Brunswick-4b	4.5E-06	1.28	1.0E-08	2.8E-03	TBA-4, TBA-5
16	Lockatong-5	6.1E-07	0.17	1.0E-10	2.8E-05	
17	Brunswick-5	1.0E-05	2.83	1.0E-08	2.8E-03	TBA-1, TBA-3, TBA-6, BMA-A, BMA-E
18	Brunswick-5a	1.0E-05	2.83	1.0E-08	2.8E-03	TBA-1, TBA-3, TBA-6, BMA-A, BMA-E
19	Lockatong-6	5.1E-07	0.14	1.0E-10	2.8E-05	TBA-1, TBA-3, TBA-6, BMA-A, BMA-9
20	Brunswick-6	5.1E-07	0.14	1.0E-08	2.8E-03	TBA-1, TBA-6, DB-3, DB-5, BMA-2, BMA-9 BMA-A, Blooming Glen Quarry
21	Brunswick-6a	7.0E-06	1.98	1.0E-08	2.8E-03	TBA-6, DB-3, DB-5, BMA-2, BMA-9, BMA-A
22	Lockatong-7	1.0E-06	0.28	1.0E-10	2.8E-05	DB-3, DB-5, BMA-2
23	Lockatong-8	1.0E-06	0.28	1.0E-10	2.8E-05	DB-3, DB-5
24	Lockatong-8a	1.0E-06	0.28	1.0E-10	2.8E-05	DB-3, DB-5
25	Brunswick-7	8.5E-06	2.41	1.0E-08	2.8E-03	DB-3
26	Lockatong-9	8.0E-07	0.23	1.0E-10	2.8E-05	DB-3
27	Lockatong-9a	8.0E-07	0.23	1.0E-10	2.8E-05	DB-1
28	Lockatong-10	8.0E-07	0.23	1.0E-10	2.8E-05	DB-1
29	Brunswick-8	4.0E-06	1.13	1.0E-08	2.8E-03	DB-1
30	Lockatong-11	1.0E-06	0.28	1.0E-10	2.8E-05	
31	Brunswick-9	1.5E-05	4.25	1.0E-08	2.8E-03	NP-29, NP-30
32	Lockatong-12	1.5E-06	0.43	1.0E-10	2.8E-05	NP-29, NP-30
33	Lockatong-12a	8.0E-06	2.27	1.0E-10	2.8E-05	Skunk Hollow Quarry

Final Hydraulic Conductivity Ranges

	Maximum				Minimum			
	Kxx and Kyy		Kzz		Kxx and Kyy		Kzz	
Rock Type	(m/s)	(ft/day)	(m/s)	(ft/day)	(m/s)	(ft/day)	(m/s)	(ft/day)
Brunswick	1.5E-05	4.25	1.0E-08	2.8E-03	5.1E-07	0.14	1.0E-08	2.8E-03
Lockatong	8.0E-06	2.27	1.0E-10	2.8E-05	5.1E-07	0.14	1.0E-10	2.8E-05
Diabase	7.5E-07	0.21	1.0E-10	2.8E-05	7.5E-07	0.21	1.0E-10	2.8E-05

Overlapping capture zones indicate that the wells share the same recharge area and could possibly interfere with one another at high pumping rates. The degree of interference cannot, however, be inferred directly from the extent of the overlap because each well is primarily drawing water from the rock layers in which it is open to the aquifer, which generally dip at about 12° to the northwest. A more reliable identification of interfering wells can be made by comparing the capture zones shown on *Figure 19* with *Table 17*, which shows the rock layers from which the wells are drawing water.

Many of the municipal supply wells in the Pennridge Area are located near streams. When these wells are completed in the same rock layers as the streams dissect or are hydraulically connected to rock layer through which the streams flow, pumping at the wells can cause stream flow losses to the aquifer, thereby diverting stream water to the wells. *Figure 20* shows the sections of the streams that lose water to the bedrock aquifer as a result of collective pumping from the municipal supply wells. Individual wells that receive water from streams were not identified though that can be accomplished through a more detailed analysis of the model simulations. The identified stream sections were, however, used in the delineation of WHP Zone III by providing an indication of the stream catchments that contribute water to the Zone II regions.

More detailed maps of the simulated static and pumping condition water table surfaces and simulated well capture zones in the vicinity of the municipal water supply wells are provided in Volume II of this report.

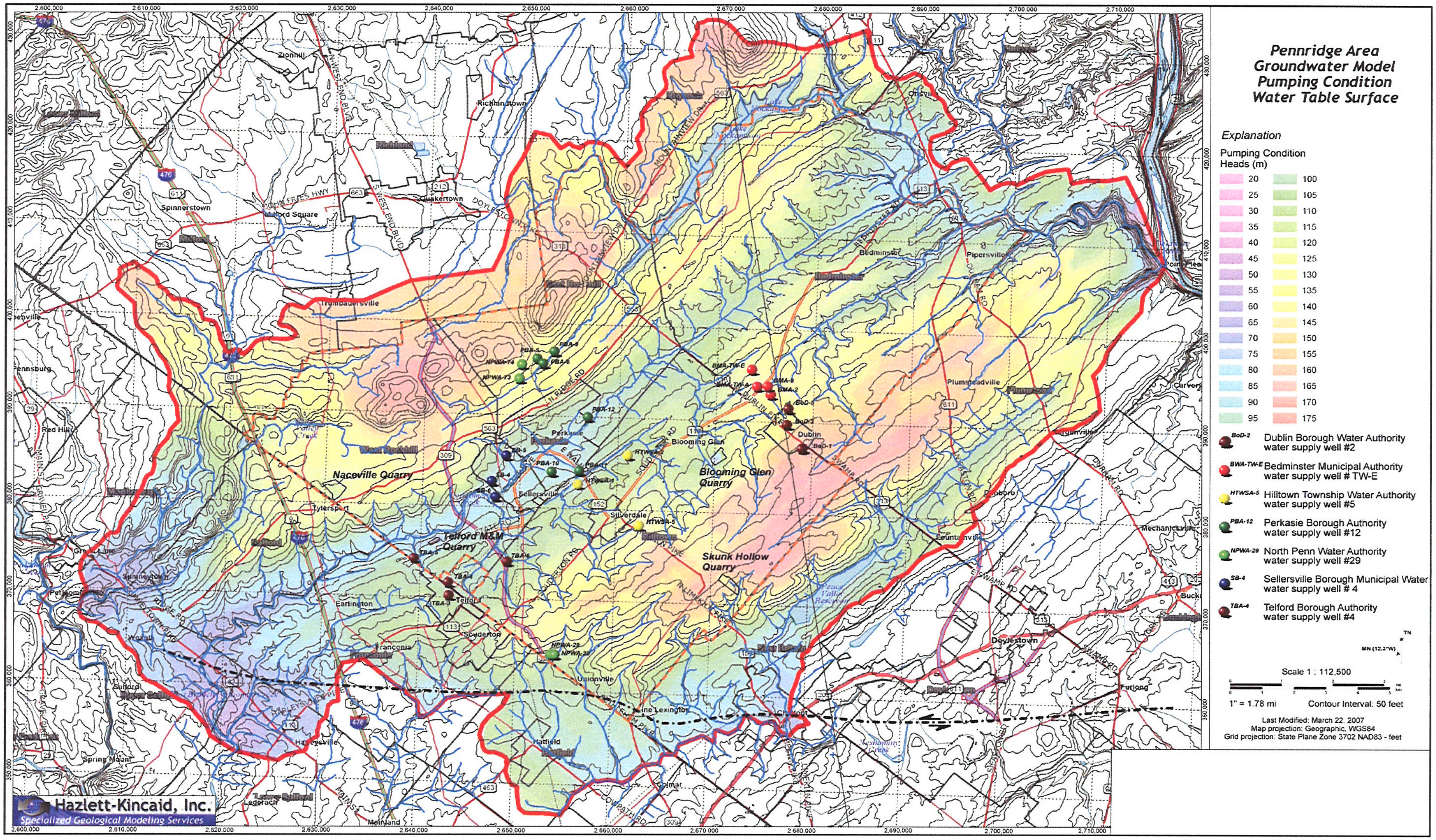

Figure 18. Map showing the simulated water table surface as defined by the pumping condition simulation of the Pennridge Groundwater Model (GWM) relative to topography, hydrologic features, and cultural features in the model area (Bucks County, Pennsylvania).

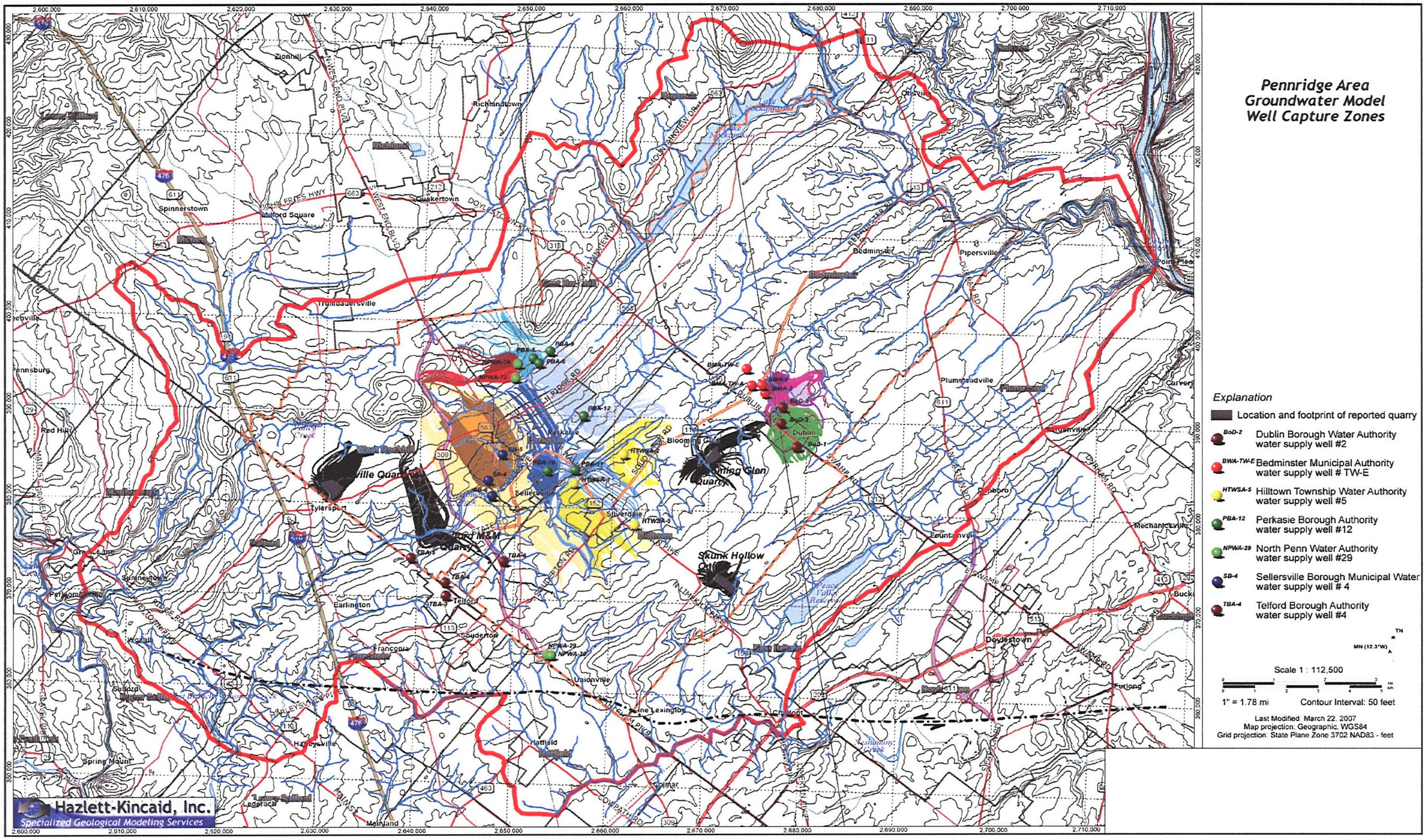

Figure 19. Map showing the capture zones for the Pennridge area municipal water supply wells as defined by the pumping condition simulation of the Pennridge Groundwater Model (GWM) relative to topography, hydrologic features, and cultural features in the model area (Bucks County, Pennsylvania).

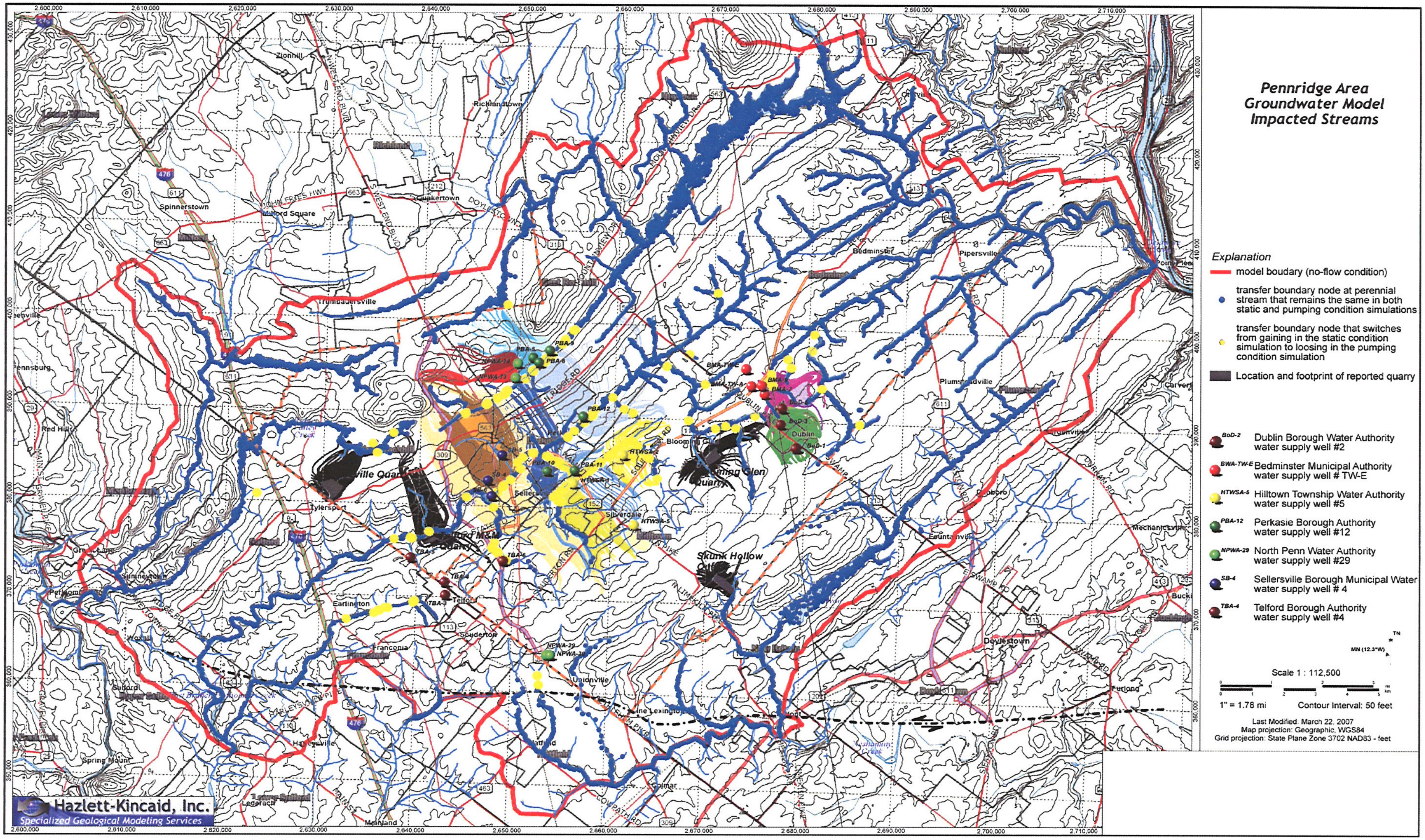

Figure 20. Map showing the sections of streams that are losing water to the aquifer as a result of pumping from the municipal water supply wells as defined by the Pennridge Groundwater Model (GWM) relative to the model-predicted well capture zones, topography, hydrologic features, and cultural features in the model area (Bucks County, Pennsylvania).

h. Discussion and Limitations

The primary purpose of the GWM was to develop a regional assessment of groundwater conditions and the potential inter-relationships between the wells and other hydrologic features in the region such that accurate capture zones could be identified and used to construct effective WHP Zone delineations. As is often the case with groundwater resource management investigations, there was a relative paucity of data with which to construct such a model.

Our approach to the problem was to synthesize the limited available data together with local knowledge and sound hydrologic reasoning into the most plausible and defensible simulation of the regional groundwater flow patterns that control the size and shape of the well capture zones. In its current form, the Pennridge GWM incorporates the best available conceptualization of the hydrogeologic framework, a reasonable and defensible estimate of recharge and aquifer/stream interactions, a reasonable and defensible estimate of quarry impacts to the water table surface, and an accurate and conservative description of the municipal water supply extractions. Specifically, the model accurately represents the actual hydrologic environment according to the following six important criteria.

- The simulated aquifer is 3-D and comprised of dipping rock layers of varying permeabilities that create a strike-parallel anisotropic groundwater flow field driven by recharge along ridges to local perennial streams.
- The simulated aquifer contributes and receives water from streams in the modeled area.
- Recharge is spatially distributed and controlled by soil type, slope, and the degree of urban development.
- The model includes quarries that have been excavated to varying depths in the bedrock aquifer and dewatered thereby causing relatively large local depressions in the water table surface.
- The simulated municipal water supply wells extract water from one or more discrete layers in the bedrock aquifer that receive water from recharge areas defined by the layer outcrop at the bedrock surface and flow into the layers from adjacent layers of different permeability.
- The model reasonably simulates the observed water table surface and aquifer/stream interactions under both static (non-stressed) and pumping (stressed) conditions in the aquifer.

Based on those criteria, we believe that the simulated well capture zones and therefore the WHP Zones to be the best possible delineations given the available data. With that being said, however, there are limitations to the manner in which the model results should be interpreted and applied.

One of the limitations of this model is that it is steady state. Steady state means that it does not consider groundwater levels (or other parameters) varying over time (transient). The model was instead developed for average water level conditions. This was done because of a lack of data describing the variability of groundwater levels and particularly stream flows over time. The limitation of the steady state model lies primarily in that it cannot be used to simulate variations in the shape and size of the WHP zones due to changing environmental conditions. To address this

limitation, the GWM incorporated maximum or near-maximum pumping rates as constant values. The simulated steady state pumping condition water table surface, from which the well capture zones were delineated, should therefore be considered to be a conservative approximation of the capture zones active for any well on any particular day.

Other limitations also stem from lack of available data. For this model, there was poor control on static water levels, stream flows, and pumping and drawdown around the quarries, which reduce the ability to accurately describe the water budget. The paucity of data then translates into greater uncertainty in the accuracy of the model simulations and predictions. If we don't know how much water is flowing in a stream, then we have difficulty saying whether our model prediction of the stream flow is accurate. The best we can do in this case is simply say whether or not a stream is flowing at all. The overall water budget is still valid, however, the amount of water allocated to the various components may not be entirely accurate. Thus the model is limited in its ability to address site-specific conditions such as the probable degree to which the wells interact with nearby streams.

A final limitation of the model is related to the time of travel predictions, which are used in the delineation of the 10-yr time of travel estimates for the WHP Zone II delineations. The limitation stems from a lack of data describing the porosity of the bedrock layers and/or observed groundwater velocities, contaminant transport times, or other measures of travel time that were identified in the data synthesis phase of work and incorporated into the model design. As discussed in Section IV.B.3.e, porosity is the amount of open space in a given volume of rock through which water can flow or be stored and is related to the aquifer storativity. Holding all other variables constant, such as the simulated water table surface, recharge, and pumping rates, higher porosity values will result in lower predictions of groundwater velocity and thus longer travel-times. On the contrary, lower porosity values result in faster predicted travel-times.

For the Pennridge GWM, the porosity value used in the calculation of the particle tracks was set to the storativity value assigned to the bedrock layers in the flow model, which was 0.001 or 0.1%. This value represents the low end of the observed range for fractured bedrock aquifers (Fetter, 1980; Driscoll, 1986). We believe that number to be fairly representative of the bedrock in the Pennridge Area because most of the groundwater flow and aquifer storage is in the limited number of fractured water bearing zones.

Despite the limitations, the GWM can be used to address several important groundwater resource issues other than the delineation of WHP Zones. Scenario analyses can be performed to evaluate the probable impact to groundwater resources in the Pennridge Area due to climate change (i.e. drought or significantly increased rainfall), and/or future significant development proposals. It also provides an approximation of regional flow patterns that should be used as a baseline for any future predictions of contaminant transport in the region thereby ensuring that such predictions are consistent from site-to-site within the Pennridge Area. Finally, the model can be updated in the future as more data (particularly transient data) becomes available. Such updates will provide increased utility for site-scale problems without requiring the substantial work necessary to redevelop such models from scratch.

i. Governing Equations for the Pennridge Groundwater Flow Model

The main equations being solved in the groundwater flow model are forms of Equation 1 and Equation 2, where (*i,j=1,2,3*) (Diersch, 2005). Equation 1 is a generalized groundwater flow equation with variable density, mass, and heat source terms. Equation 2 is a more familiar form of Darcy's Law cast in terms of Darcy velocity.

All of the equations in FEFLOW, which are possible to solve, are included herein for completeness. However, take note that for this particular project, there were no reactions, no variable density, no mass, and no heat in the problem. Therefore, all of those terms in the equations would drop out and the equations would be solved in a simplified form.

$$S_0 \frac{\partial h}{\partial t} + \frac{\partial q_i^f}{\partial x_i} = Q_\rho + Q_{EB}(C,T) \qquad \text{Equation 1}$$

$$q_i^f = -K_{ij} f_\mu \left(\frac{\partial h}{\partial x_j} + \frac{\rho^f - \rho_o^f}{\rho_o^f} e_j \right) \qquad \text{Equation 2}$$

$$\varepsilon R_d \frac{\partial C}{\partial t} + q_i^f \frac{\partial C}{\partial x_i} - \frac{\partial}{\partial x_i}\left(D_{ij} \frac{\partial C}{\partial x_j} \right) + (\varepsilon R \vartheta + Q_\rho) C = Q_c \qquad \text{Equation 3}$$

$$\left[\varepsilon \rho^f c^f + (1-\varepsilon)\rho^s c^s \right] \frac{\partial T}{\partial t} + \rho^f c^f q_i^f \frac{\partial T}{\partial x_i} - \frac{\partial}{\partial xi}\left(\lambda_{ij} \frac{\partial T}{\partial x_j} \right) + \rho^f c^f Q_\rho (T - T_0) = Q_T \qquad \text{Equation 4}$$

$$\rho^f = \rho_0^f \left[1 + \frac{\overline{\alpha}}{(C_s - C_0)}(C - C_0) \right] \qquad \text{Equation 5}$$

$$h = \frac{p_f}{\rho_f^0 g} + x_i \qquad \text{Equation 6}$$

$$K_{ij} = \frac{k_{ij} \rho_0^f g}{\mu_0^f} \qquad \text{Equation 7}$$

$$\overline{\alpha} = \frac{\left[\rho^f (C_s) - \rho_0^f \right]}{\rho_0^f} \qquad \text{Equation 8}$$

$$f_\mu = \frac{\mu_0^f}{\mu^f (C,T)} = \frac{1 + 1.85\omega_{(C=C_0)} - 4.1\omega^2_{(C-C_0)} + 44.5\omega^3_{(C-C_0)}}{1 + 1.85\omega - 4.1\omega^2 + 44.5\omega^3} \cdot \frac{1 + 0.7063\varsigma - 0.04832\varsigma^3}{1 + 0.7063\varsigma_{(T-T_0)} - 0.04832\varsigma^3_{(T=T_0)}}, \varsigma = \frac{(T-150)}{100}, \omega = \frac{C}{\rho^f} \qquad \text{Equation 9}$$

$$D_{ij} = (\varepsilon D_d + \beta_T V_q^f)\delta_{ij} + (\beta_L - \beta_T)\frac{q_i^f q_j^f}{V_q^f} \qquad \text{Equation 10}$$

$$R = 1 + \frac{(1-\varepsilon)}{\varepsilon}\chi(C) \qquad \text{Equation 11} \qquad R_d = 1 + \frac{(1-\varepsilon)}{\varepsilon}\frac{\partial[\chi(C) \cdot C]}{\partial C} \qquad \text{Equation 12}$$

$$\lambda_{ij} = \lambda_{ij}^{cond} + \lambda_{ij}^{disp} \qquad \text{Equation 13} \qquad Q_T = \varepsilon \rho^f Q_T^f \_ (1-\varepsilon)\rho^s Q_T^s \qquad \text{Equation 14}$$

The equations are solved for h_f, q_i^f, C, and T: head, Darcy velocity, concentration, and temperature, respectively. The other model parameters are defined as such:

ρ^f, ρ_0^f	= fluid and reference density, respectively
ρ^s	= solid density
S_0	= specific storage coefficient (compressibility)
K_{ij}	= tensor of hydraulic conductivity
e_j	= gravitational unit vector
f_μ	= constitutive viscosity relation function
Q_{EB}	= term of extended Boussinesq approximation
R	= retardation factor
R_d	= derivative term of retardation factor
D_{ij}	= tensor of hydrodynamic dispersion
ϑ	= decay rate
ε	= porosity
c^f, c^s	= specific heat capacity of fluid and solid, respectively
λ_{ij}	= tensor of hydrodynamic thermodispersion
Q_x	= source/sink function of fluid ($x=\rho$), of contaminant mass ($x=C$) and heat ($x=T$)
$\overline{\beta}$	= fluid expansion coefficient
$\overline{\alpha}$	= fluid density difference ratio
C_0, T_0	= reference concentration and temperature, respectively
C_s	= maximum concentration
p^f	= fluid pressure
g	= gravitational acceleration
k_{ij}	= tensor of permeability
μ^f, μ_0^f	= dynamic viscosity and its reference value, respectively, of fluid
ς	= normalized temperature
ω	= mass fraction
D_d	= molecular diffusion coefficient of fluid
$V_q^f = \sqrt{q_i^f q_i^f}$	= absolute Darcy fluid flux
β_L, β_T	= longitudinal and transverse dispersivity, respectively, of chemical species
$\chi(C)$	= concentration-dependent adsorption function
$\lambda_{ij}^{cond}, \lambda_{ij}^{disp}$	= conductive and dispersive thermodispersion tensors, respectively
λ^f, λ^s	= thermal conductivity for fluid and solid, respectively
α_L, α_T	= longitudinal and transverse thermodispersivity, respectively, of fluid

C. WHP Zone Delineation

The municipal water supply wells are completed in zones of the bedrock aquifer relatively deep below the land surface that are often separated from the land surface by other rock layers of varying permeability. We therefore considered the definition of WHP Zone I to be primarily related to controlling access to the wellheads and wellhead infrastructure rather than the hydrogeology of the aquifer. WHP Zone I was therefore defined as a 400-foot radius around each of the wellheads.

WHP Zones II and III, however, are primarily focused on protecting the well capture zone and zone of contribution from potentially harmful land-use practices and are therefore primarily related to the hydrogeologic controls on groundwater flow and groundwater/surface water interactions. Characterizing those controls was the primary purpose of the Pennridge GWM and the simulated well capture zones and the stream impacts maps *(Figures 19 and 20)* were therefore used as the primary tools for delineating WHP Zones II and III for each of the municipalities in the Pennridge Area.

The primary Zone II and Zone III delineations were constructed from the particle tracks extracted from the GWM that delineate the capture zone for each of the municipal water supply wells. Two interpretations of the Zone II delineations were developed wherein the difference between the two delineations reflects both the relationship between the capture zones and the recharge areas as well as an evolution in the methodology used to make the delineations.

The first interpretation (Zone IIb) was delineated by enclosing the full extent of the model-simulated particle track lines for each well with a 300-foot polygon and then consolidating the polygons where they overlapped. The particle track lines were created using a function provided in the FEFLOW groundwater modeling software that tracks flow to a well from the top of all model layers (FEM layers) penetrated by a well where penetrations were defined by the thickness of the layers and the reported depth of the wells. These are the particle tracks shown in *Figures 19 and 20*. The Zone IIb delineations thus encompass the full extent of the well capture zones as determined by the layer-based approach to particle tracking. These zones are conservative in that they include both the critical recharge areas (the areas where rainfall enters the aquifer) and the confined areas (areas where the aquifer is overlain by low permeability material and thus receives very little recharge) through which the water flows on its path to the wells.

The second set of Zone II delineations (Zone IIa) was developed as part of a subsequent effort to more closely scrutinize their aerial extent. The purpose of this approach was to specifically identify the recharge areas where water that flows to the wells enters the aquifer. For these interpretations, the particle tracks were defined more rigorously where the model was seeded with particles forming multiple rings around each well comprised of 360 points, one degree apart, at 2m (~6 feet) spacings throughout the full extent of the open hole section of the wells. This extra effort resulted in a significantly more detailed definition of the well capture zones. Once the particle tracks were defined, the starting points were extracted from each particle track line and classed based on the time-of-travel from the point to the well to which the line connected. All of the points with travel-times less than or equal to ten years were then used to delineate the most vulnerable recharge areas for each of the wells.

Theoretically, the two versions of the Zone II delineations should overlap in that the points marking the recharge areas should fall inside of the capture zones. There are inconsistencies, however, in some areas due to both the different travel-times reflected and the different methodologies used to create the particle tracks. Regions where there are no recharge area points in the capture zone polygons likely mark areas where the travel-time to the respective well is longer than 10 years. Regions where recharge points fall outside of the capture zone polygons reflect the more detailed methodology used to create the particle tracks from which the recharge areas were defined. The "a" and "b" designations therefore reflect both the degree to which the respective delineations mark the most vulnerable areas and the level of confidence in the delineation method.

Zone III delineations were constructed by defining the surface watersheds that contribute runoff to the sections of streams inside of the Zone IIb regions defined by the GWM as losing water to the

aquifer under pumping conditions *(See Figure 19)*. *Figure 19* provides a map of the Pennridge area showing the Zone IIb and Zone III regions for all of the municipal water supply wells where overlapping zones have been merged together. Zone IIa delineations along with more detailed maps for the individual wells are provided in Volume II of this report.

Though the Pennridge GWM was constructed using the best available data and technologies, it must be recognized as a scientifically based estimation of actual groundwater flow and aquifer vulnerability conditions. Future investigations, new data, and technological advancements could change the simulated conditions and thus any model-based delineation of vulnerability zones. Concerns expressed by some about the limitations of the model-based approach for WHPZ delineations in the face of incomplete datasets and uncertainty compelled the delineation of a third alternative for the Zone II delineation (Zone IIc). Zone IIc was created by drawing a ½ mile radius circle around each wellhead. These are provided for the purpose of comparing the model-defined Zone II regions with the Zone II as it is defined by the original language in the Pennsylvania Code Chapter 109, Safe Drinking Water: 'Zone II shall be ½ mile radius around the source unless a more detailed delineation is approved.'

D. Recommendation for a Continued Monitoring Network

The most significant limitations of the Pennridge GWM are that it cannot be confidently used to assess the degree to which some of the municipal water supply wells likely draw water from nearby streams or the degree to which the wells interfere with each other under various operating configurations (durations and pumping rates). In order to address those problems additional data is needed to describe seasonal variations in stream flow such that the GWM can be converted to a transient model.

The optimal method to collect the needed data is through the development of a stream monitoring network. Ideally, such a network would consist of stations capable of regularly recording both stage and flow in the largest streams. The stations should be distributed such that they can be used to constrain stream flow in each of the largest streams or stream tributaries. There are 10 such stream sections in the Pennridge model area. Four sections of the East Branch Perkiomen Creek are near the majority of the Pennridge Area municipal water supply wells (Indian Creek, Morris Creek, Pleasant Spring Creek, and Mill Creek). Five streams cross the GWM boundaries and are thus very important to the accurate determination of the water budget (East Branch Perkiomen Creek at the southwestern boundary, Tohickon Creek at the eastern and northern boundaries on either side of Lake Nockamixon, Three Mile Run, Neshaminy Creek, and Unami Creek). At a minimum these stations should be operated for a period of 24 months such that a reasonable measure of seasonal stream flow fluctuations can be established. Ideally however, the stations would be maintained permanently such that the data can be used for all future water resource studies.

Additionally, all of the municipal water supply wells should be instrumented with continuous read pressure transducers and flow meters such that long-term pumping rate / water level relationships can be established. Once the data network is established and seasonal average flows and pump rate water level relationships are determined, the Pennridge GWM should be converted to transient, recalibrated, and re-evaluated. Such a modification will capitalize on the current model framework and calibration and will only require the addition and evaluation of the new transient data. Once completed, the model will be able to shed considerable insight on probable well – stream interactions and well interference patterns and can be used to optimize operational procedures and identify the most advantageous source locations for future well installations.

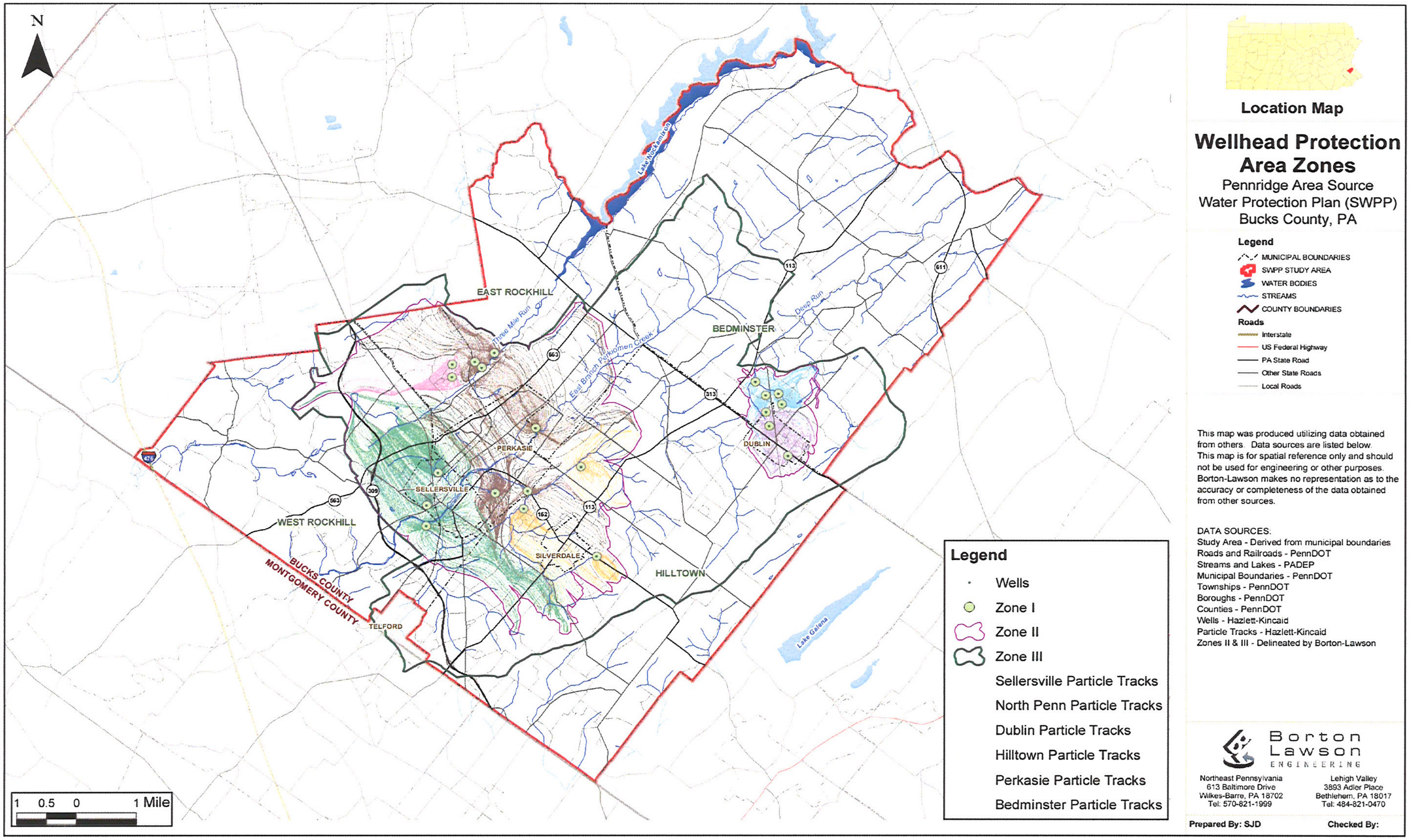

Figure 21. Map showing the Zone II and Zone III Wellhead Protection Zones defined from the well capture zones simulated by the Pennridge Groundwater Model (GWM) relative to hydrologic and cultural features in the Pennridge area (Bucks County, Pennsylvania).

V. POTENTIAL SOURCE OF CONTAMINANT INVENTORY

Please see Volume II for each Water Authority.

VI. WHP AREA MANAGEMENT AND COMMITMENT

A. Introduction

As shown on the Wellhead Protection Area Map (*Figure 21*), the communities potentially involved in this program hold different geographical positions within the WHPA. Likewise, each of the communities contains a different set of potential contaminants and has varying zoning districts. Each of the municipalities has a mixture of existing activities and land uses including industrial, commercial, residential, and agricultural, which dominates the area in terms of land uses. Consequently, each municipality potentially involved in this Wellhead Protection Program is likely to have its own management agenda depending upon its location within the WHPA, potential contamination sources, and future development plans. The purpose of this section is to provide guidance for each municipality with respect to participation in the Wellhead Protection Program (WHPP).

B. Summary of Existing Conditions Relative to Wellhead Protection

The Bucks County Planning Commission (BCPC) completed a report titled *Bucks County Water Supply Plan and Model Wellhead Protection Study* in 1997. The WHP portion of the study includes a description of WHP planning similar to this report and then develops wellhead protection case studies for seven municipalities in Bucks County.

The model *Pennridge Area Water Resources Management and Protection Ordinance* was developed on 2006. The model ordinance contains language that establishes three different zones for wellhead protection. The municipalities may use this as a benchmark for updating the language in both the zoning ordinance and subdivision land development regulations to protect wellhead areas. Table 18 summarizes the wellhead protection language found in the municipality ordinances.

Table 18. Wellhead Protection Summary Matrix for Each Individual Municipality within the Pennridge Area.

Municipality	Wellhead Protection Ordinance - Language contained in SALDO* or ZO*	Limited Development in Groundwater Area - Language contained in ZO or Comprehensive Plan
Bedminster Township	SALDO – Ordinance 129 Wellhead Protection Overlay District.	Comprehensive Plan, 2005
Dublin Borough	-	-
East Rockhill Township	In the process of establishing source water protection program (PACC)	Comprehensive Plan (Chapter F – Natural Resources)
Hilltown Township	-	ZO and Comprehensive Plan
Perkasie Borough	-	Comprehensive Plan -Southeast groundwater protection area
Sellersville Borough	-	Comprehensive Plan
Silverdale Borough	-	-
West Rockhill Township	-	Comprehensive Plan, 2007
Telford	ZO-Part 19 Wellhead Protection Overlay District	-

*Note: SALDO – Subdivision and Land Development Ordinance
ZO – Zoning Ordinance

C. Regional Cooperation

While an individual municipality has the authority to implement a wellhead protection program only within its jurisdiction, the wellhead delineation map indicates that groundwater flow and potential contamination problems in the study area will not respect municipal boundaries and regional cooperation will contribute greatly to protecting groundwater resources for everyone. In many cases, not only are the wells located in more than one municipality, much or all of Zone II may be in one or two other municipalities. Similarly, Zone III extends across all municipalities in a broad manner, and even more so than Zone II.

Given the nature of the area's geology, a problem at one location in Zone III could quite possibly affect not only water suppliers' wells, but any of the private water systems. To be truly effective, wellhead protection planning will require the cooperation of all the municipalities.

In addition to those persons served by the water supplier's water system, every residence, farm, business, or industry with a private well within the potential wellhead protection area will benefit from a protection program; and, as noted earlier, perhaps even more than those on the water supplier's system. For example, if a municipal source were to be contaminated, it would be the water supplier's responsibility to deal with the issue. If an individual's well is contaminated, he or she will likely have to deal with the problem without assistance from the government.

In summary, these communities do actually rely upon one another to maintain a clean water supply even if it is not readily obvious. Communities can also benefit from comparing programs and coordinating their efforts, particularly in education, emergency and contingency planning, and land-use planning. By keeping in mind that groundwater knows no political boundaries and by planning

for this unavoidable fact, the municipalities involved in this program will be able to develop more efficient and effective wellhead protection programs.

D. Steering Committee

The Steering Committee should continue to meet on an annual basis to review activities in the wellhead protection area, to discuss and advise the PACC about possible changes in the WHP program, and to report back to their respective municipalities on the status of the wellhead protection program.

E. Management Tools

When considering a wellhead protection program, there is a range of options with varying aggressiveness that a municipality can consider. The range of options begins at "Do Nothing" and carries up through extremely aggressive activities at the other end. The "Do Nothing" alternative means no changes are made with respect to protecting water supplies. A very aggressive program, on the other hand, could prevent any additional development in a Zone II wellhead area and possibly severely limit it in Zone III. In between these extremes are other options which are likely to be more acceptable to a municipality and its citizens and therefore more easily implemented, yet still provide a good measure of groundwater protection. It is within this context that this wellhead protection program was developed. As a starting point, however, the potential impact for a "Do Nothing" alternative will be considered as a point of reference from which to proceed to a wellhead protection program.

The Steering Committee recognized that with eight municipalities located in Bucks County and one municipality located in Montgomery County, a successful wellhead protection program would have to allow for a "menu" of activities so that the municipalities could select a program that would be compatible with their individual goals and needs while still supporting groundwater protection. The following wellhead management tools were identified as those most likely to be acceptable, individually or collectively, to the municipalities. Based on this review, the consensus of the Steering Committee was that the following management tools would be suitable for application to this wellhead protection program.

Obviously, it is not likely that every one of these protection tools will be applicable in every municipality. However, a series of these tools being used collectively will be a significant step toward protecting the groundwater resources that are common to all people within the WHP delineation area.

The following excerpt from the *Bucks County Water Supply and Wellhead Protection Study* (1997) presents a very good, succinct discussion of the correlation between land use decisions and protection of community water supplies:

> "There is a direct correlation between local land use decisions and the availability and potability of community water supplies. Various water supply protective measures have been adopted throughout the nation including overlay zoning to protect sensitive aquifers, sensitive areas, and land surrounding water supply reservoirs. Another common approach is to prohibit certain land uses, physical facilities or activities in proximity to aquifers, groundwater wells and other drinking water sources. Both approaches have been applied to watersheds and at county and municipal levels. The approach varies based on the enabling legislation, the state government structure, and the selected management technique(s)."

In Pennsylvania, most land use decisions are made at the municipal level and in conformance with the Pennsylvania Municipal Planning Code (MPC). The MPC provides the opportunity for direct municipal implementation of regulations designed to improve the viability of community water supply sources. The following water supply planning and regulatory tools are provided to municipalities through the MPC:

- The municipal comprehensive plan may include a water supply plan. The plan may consider present and future water resource availability, limitations and methods to protect the water supply (MPC: Article III, "Preparation of a Comprehensive Plan," Section 301.b.).
- The subdivision and land development plan may include ways to ensure that new developments provide reliable water supplies to support intended development. The intended supply should be within the "capacity of available resources" (MPC: Article V, "Subdivision and Land Development," Section 503.10).
- The zoning ordinance may include provisions (sighting, density, design) that regulate all types of development, and the water supply should support the intended use. The zoning ordinance provision should "promote, protect and facilitate the provision of safe, reliable and adequate water supply for all uses as well as the preservation of the aquifer (MPC: Article VI, "Zoning," Sections 603.C.6.d, 604.1)."[1]

1. Do Nothing

As already stated, the "Do Nothing" alternative means no changes are made with respect to protecting water supplies. There would be no land use controls in critical areas or local control of potential contamination threats. Existing residential, industrial, commercial, and agricultural activities and new development will continue. The threats of groundwater contamination, in general, will continue and may not always be readily identifiable. While certain commercial and industrial activities may be subject to state or federal regulation, many other activities, that could be groundwater threats, are not regulated and under either state or federal jurisdiction, would not be responsible to local control. If groundwater contamination occurs, it may be very costly to cleanup and, if cleanup is prohibitive, alternate water supply sources may have to be found which could also be very costly and difficult to implement.

2. Water Supply Area Signs

The Water Supply Area sign could be used to notify the traveling public that they will be traveling through a water supply area, the number of miles they will be traveling through this area, and the spill response number to call if there is a hazardous spill or accident.

3. Overlay Zoning for Wellhead Protection

Overlay zoning, along with other tools that can be readily incorporated with this approach, appears to offer a very pragmatic and practical approach to wellhead protection without being overly burdensome on the property owners within the protection area. Overlay zoning

[1] *Bucks County Water Supply and Model Wellhead Protection Study*, Volume II-Technical Report, PENNSYLVANIA DEPARTMENT OF ENVIRONMENTAL PROTECTION Review Draft, February 1996, Bucks County Planning Commission

involves taking an existing zoned area and overlaying additionally defined zones for environmental or other special purposes. Overlay zones are added on top of and provide additional regulations to the already-in-place base zoning. Overlay zones need not conform to the boundaries of existing zones. Overlay zoning typically is administered by plotting an opaque map that delineates existing zones (e.g., residential, commercial, industrial) and then using transparent maps to delineate the overlay zone itself (e.g., a wellhead protection area). The most common type of overlay zoning district in Bucks and Montgomery Counties is a floodplain district. Overlay zoning and related tools to protect local water resources can only be achieved through municipal implementation.

The primary and possibly the most effective recommended wellhead protection program for the nine potential municipalities that could participate is based on an overlay zoning approach. This approach would incorporate key provisions for control of certain land uses and special permitting of others, provisions for control of toxic and hazardous materials, and provisions for land development and subdivisions.

4. Prohibition of Certain Land Uses

Pennsylvania's guidelines for WHPA delineations recommend three zones of protection as the basis of regulatory controls. Source prohibitions simply reduce the concentration of hazardous materials within the WHPA by restricting or prohibiting certain activities within each of these zones. The strictest regulations apply to Zone I because of its proximity to the well itself and decreasingly strict regulations apply to Zones II and III respectively because of their lesser influence on the groundwater supply.

A model ordinance titled *Pennridge Area Water Resources Management and Protection Ordinance* has been prepared for consideration by the eight municipalities which are entirely or partially included in the proposed wellhead protection area. This may be used by municipal officials as a starting point to protect local groundwater resources both for community and individual water supply systems and may be modified as necessary to reflect local concerns.

5. Special Permitting

The recommended management approach to source restrictions include both land uses which are prohibited and land uses which are permitted only if a special permit is granted through a specific application process. It notes in the aforementioned Ordinance, that no activities should be permitted in Zone I of the Wellhead Protection Zones (WHPZ), and limited land uses will be permitted in Zone II and III subject to meeting certain regulations and/or having certain plans and Pennsylvania Department of Environmental Protection permits. Table 311.1 of the *Pennridge Area Model Water Resources Management and Protection Ordinance* provides detailed information.

6. Cluster / PUD Design

Where possible, it is recommended that the municipalities use their zoning ordinance to encourage cluster or PUD[2] development for residential development. By increasing the density of development clustering in the selected areas while maximizing open space, natural recharge areas will be preserved and protected. For long term sustainability, this option promotes long term groundwater recharge to assure groundwater resources will be

[2] PUD = Planned Unit Development

available in the future. Furthermore, with regard to water quality aspect, this option would reduce the number of stormwater outfalls making it easier to monitor point source discharges, thus reducing the chance of contamination of the source water.

7. Toxic and Hazardous Materials Handling Provisions

The community might have the authority to regulate hazardous materials. This is particularly significant with respect to commercial and industrial operations in your wellhead protection area. Many communities require that any facility handling hazardous materials inform the local Board of Health about how it uses, stores, transports, and disposes of these materials. Other regulatory approaches to controlling the use and storage of hazardous chemicals in your wellhead protection area include requirements for periodic testing and replacement of underground fuel tanks, permit requirements and corrosion protection for new tanks, and limitations on herbicide and pesticide applications.

It may be possible for a hazardous waste coordinator to assist the community to identify and control hazardous substances; organize committees to provide advice and support; identify potential sources of contamination; and develop emergency procedures to respond to accidental spills and educate citizens (EPA, 1993).

8. Private Well Protection

The community may adopt health or zoning ordinances to require permits for new private wells to ensure appropriate setback from wells to septic systems and require regular pumping and water quality testing. This option requires local government to review and approve the new proposed plan and provide administrative support to ensure the protection of private onsite water supply wells. Many municipalities already examine separation distance as part of their land development review process. Those municipalities that do not have ordinances addressing well separation should be encourage adopting such an ordinance and enforcing it.

9. Purchase or Donation of Land and Easements

Some communities have purchased property to protect wellhead areas. Acquisition of land is probably the surest method for a community to control land use and is one of the reasons that many states encourage municipal ownership of land in Zone I protection areas. Typically, municipalities will build parks and recreation areas in lands acquired for water supply protection purposes. In situations where purchasing the Zone I property has not been a realizable option, some communities have acquired partial interests in properties. Acquisition of partial interests typically involves conservation easements or development rights which prevent landowners from specified actions on the property covered by the easement, yet allow landowners to continue many other productive uses of their land. An easement for wellhead protection would include prohibitions on certain activities such as hazardous materials storage, junk yards, etc. Easements apply to all subsequent landowners for the full term of the easement, which may either be a finite number of years or perpetual.

10. Groundwater Monitoring

Groundwater inspection and monitoring programs include direct observation of those contamination sources allowed to remain or be constructed within WHPAs. Municipalities use these programs to keep a watchful eye on specific contamination sources such as large industrial facilities, landfills, and junk yards.

Inspection programs require industries to allow community officials to review the operations of the facility on a regular basis and to require preventive or corrective measures to be taken to reduce the possibility of a spill. Some inspection programs are coordinated with efforts to implement community right-to-know requirements. Fire companies are often involved in such programs so that fire fighting plans can be developed which evaluate potential groundwater contamination. Monitoring programs have been developed which require new facilities constructed within WHPAs to install their own monitoring wells and pay for the costs of their sampling and water testing.

11. Stormwater Drainage Requirements

Low Impact Design principle, special stormwater management requirements and Best Management Practices (BMPs) can be used to ensure that subdivision drainage is either directed away from WHPAs or is better managed to remove or eliminate the contamination threat. The PADEP Stormwater BMP contains numerous examples of BMPs that can be installed in new and existing developments to help protect water sources. The community needs to adopt stringent subdivision rules / regulations to regulate road drainage / runoff and dost construction runoff in the subdivisions within WHPAS. This option requires moderate level of inspection and enforcement by administrative staff.

12. Regulation of Underground Storage Tanks

Leakage from underground fuel storage systems (UST) within the WHPAs may contaminate source water especially the groundwater. Because groundwater generally moves slowly, contamination often remains undetected for long periods of time. This makes contaminated groundwater cleanup difficult. If a clean up is undertaken, it can cost thousands to millions of dollars. Not only the cost for remediation is a concern, but the service of water supply will be interrupted if no alternative water supplies are available immediately and a considerable amount of resources including labor, time and will be needed.

Communities may adopt health or zoning ordinances to prohibit the construction of underground storage tanks within WHPAs. This option will require little administrative support. The community instead, may adopt special permits or performance standards for use of UST within the WHPAs. Regulating USTs will require certain amount of administrative support for inspection follow up and enforcement. This comes with a caveat that no USTs should be permitted within Zone I.

13. Prohibit Privately-Owned Small Sewage Treatment Plants

Failure and inappropriate operation of privately-owned sewage treatment plants (STPs) within WHPAs may contaminate source water. A community may adopt health or zoning ordinances within WHPAs to prohibit the construction of such facilities. Similar to the regulation of USTs, this will require little administrative support. The community may also adopt special permits or performance standards for use of privately-owned STPs within the WHPAs.

14. Ban Certain Septic Tank Cleaners

A community may also adopt health or zoning ordinances in the Wellhead Protection Areas prohibiting the application of certain solvent septic cleaners (such as 1,1,1-trichloroethane or other solvent compounds) known to contaminant groundwater.

15. Septic System Upgrades

The steering committee recommends that each borough / township adopt an ordinance requiring pumping of all septic systems on a three-to-six year cycle. A sample copy of a septic pumping ordinance can be found as Appendix B in the Pennridge Area Model Water Resources Management Ordinance. Community may adopt health / zoning ordinance requiring the upgrade of a poorly functionally septic systems. This could be accomplished through an inspection program that periodically observes and tests existing system to determine which system required a newer technology to ensure protection of groundwater. Although beneficial, this option may require significant administrative resources.

16. Support Household Hazardous Waste Collection Events

There are many local environmental management programs that have been developed to address specific pollution concerns. These include used oil collection and recycling programs, household hazardous waste pick-up days, septic system management programs, and manure/nutrient management. These programs are highly successful and can address a wide-range of contamination sources in the WHPAs. Such programs often require substantial amounts of public education and community involvement.

The disposal of household hazardous wastes (i.e., cleaning solvents, paint thinners, etc.) in homes relying on septic systems can be a serious threat to water supplies in the Pennridge Area. Many communities have developed programs aimed at encouraging homeowners to properly dispose of their household hazardous wastes. Typically, these programs include public education and community sponsored household hazardous waste pick-up days. Both Bucks and Montgomery Counties provide this service. The recommended program is to include information about the proper disposal of household hazardous waste as part of public education efforts and the role this plays in protecting everyone's water resources.

17. Encourage the Preservation of Open Space

This management tool encourages land developers to work with communities as part of a cluster/PUD to develop limited portions of a site and restrict other portions, particularly those within WHPAs, to open space.

18. Public Education

Public education programs aimed at groundwater protection issues are an integral and absolutely necessary part of any Wellhead Protection Program. These education programs are used to build understanding and support for regulatory programs, such as zoning and land use controls, and to raise awareness concerning individual efforts that can be made to promote water supply protection. In addition to literature, communities can establish educational programs which help citizens, businesses, and industries to best comply with wellhead protection regulations and prevent contamination of their water supply. Some suggested programs are holding Best Available Technology (BAT) seminars or distributing pamphlets concerning subjects such as above and underground storage tanks and Integrated Best Management Programs. Communities can benefit from utilizing local knowledge as well as draw on resources from outside the community such as university extension programs and conservation districts. Residential development can represent a significant amount of potential contamination when the extent and variety of pesticides, fertilizers, and other applications for lawns and gardens are considered. A program to raise the awareness and cooperation of homeowners about the potential for groundwater contamination by the products they use should be a basic element of a public education program.

Working with the local school district provides a very desirable vehicle for involving students at all levels in learning about the importance of water and the need to protect it through activities such as special projects, lectures, art or slogan contests, essays, field trips, and similar activities.

F. Implementation Status/WHP Area Management and Commitment

The overall development, on-going monitoring and guidance, public education, and related activities are the responsibility of the Municipal Authority. However, the basic designation of wellhead protection areas and certain aspects of implementation, e.g., overlay zoning, are the responsibility of the nine identified municipal government bodies.

The PACC has sponsored the development of the wellhead protection plan; provided presentations and information to the nine municipalities, and has assisted with potential source inventories and public education. It will provide administrative assistance to these municipalities and will provide for overall monitoring of the wellhead protection area.

VIII. PUBLIC PARTICIPATION AND EDUCATION

A. Public Meetings

Ongoing activities of the Pennridge Area Coordinating Committee, including monthly updates on the Source Water Protection Plan, were discussed during each regularly scheduled Pennridge Area Coordinating Committee meeting. These meetings, which are open to the public, are typically held the last Thursday of each month. Meeting information, including status reports dating back to January 2004 are available to the public via the Pennridge Area Coordinating Committee website:

http://pennridgepacc.webs.com

Printed copies of the *Pennridge Area Source Water Protection Volume I and Volume II* documents were distributed to water authority and PACC representatives at the start of the July 8, 2008 public meeting for their review and comment. Printed copies of the documents were mailed to those representatives unable to attend the public meeting. Comments and / or changes received were incorporated into the master documents and the files were renamed *Public Review Draft Pennridge Area Source Water Protection Volume I and Volume II documents*.

Copies of the *Public Review Draft Pennridge Area Source Water Protection Volume I and Volume II* documents were downloaded to CD and mailed to each PACC and steering committee member and water authority representative. A letter was mailed along with the CD, which requested additional comments to be sent (mail or email) to Borton-Lawson by the end of the business day on March 20. Recipients were also advised of the March 31, 2009 public meeting to review and comment on the project and final draft documents. Comments provided by the 5:00PM, March 20 review deadline as well as additional comments submitted at the public meeting, were incorporated into the master documents which were renamed *Public Review Draft Pennridge Area Source Water Protection Volume I and Volume II* documents.

Copies of the *Pennridge Area Source Water Protection Volume I and Volume II* documents were also made available, for public review and comment, in the Samuel Pierce Library located in Perkasie, Pennsylvania.

East Rockhill Township Municipal Office	CD Version
West Rockhill Township Municipal Office	CD Version
Bedminster Township Municipal Office	CD Version
Hilltown Township Municipal Office	CD Version
Dublin Borough Municipal Office	CD Version
Sellersville Borough Municipal Office	CD Version
Silverdale Borough Municipal Office	CD Version
Perkasie Borough Municipal Office	CD Version
Telford Borough Authority (Not a PACC member but serves PACC communities)	CD Version
Samuel Pierce / Perkasie Branch of the Bucks County Library	Printed Copy

B. Newspaper Articles

Four separate newspaper articles highlighted the ongoing activities of the Source Water Protection Plan. Copies of these articles are located in Section V.

- February 3, 2003

  The Intelligencer – Officials consider well protection

- August 4, 2004

  Perkasie News- Herald – State grants Pennridge municipalities money to protect well water

- February 28, 2007

  Perkasie News-Herald – More than $500,000 in grants helps PACC help Pennridge

- March 29, 2009

  The Intelligencer – Officials tap ideas for water safety

- March 31, 2009

  The Morning Call – Pennridge group offers plan to protect water supply

- March 31, 2009

  WFMZ-TV Channel 69 News – interview and video

  http://wfmz.com/view/?id=708689

http://www.wfmz.com/view/print.php?id=708689&t=articleview-print

Water Supply Discussion in Pennridge, Bucks County

- April 1, 2009

  The Intelligencer – Pennridge-area water safety addressed

C. Website Information

Copies of all Source Water Protection Plan draft documents were posted on the Pennridge Area Coordinating Committee website, http://pennridgepacc.webs.com on March 3, 2009. The public was asked to provide feedback and comments no later than the end of the business day on March 20, 2009, via mail or email, to Borton-Lawson, Inc.

D. Other Materials

Copies of the Source Water Protection Plan documents were distributed to water authority, steering committee and PACC members during the July 8, 2008 public meeting. Representatives not in attendance received printed copies of the documents via mail.

Bedminster Municipal Authority	Printed Copy
North Penn Water Authority	Printed Copy
Perkasie Borough Authority	Printed Copy
Hilltown Township Water & Sewer Authority	Printed Copy Mailed
Dublin Borough Water Works	Printed Copy Mailed
Sellersville Borough Municipal Water Works	Printed Copy Mailed

Notices alerting the public to these opportunities were posted on the Pennridge Area Coordinating Committee website. A press release was also distributed in the *Bucks County Herald* in an effort to alert as many people as possible to the public meeting (Appendix D Public Information/Education Volume II documents).

IX. NEW SOURCES

Please refer to Volume II for each water supplier in the Pennridge Area.

X. CONTINGENCY PLANNING

Please refer to Volume II for each water supplier in the Pennridge Area.

XI. WELLHEAD PROTECTION IMPLEMENTATION PLAN

The following is the procedure to implement a wellhead protection plan.

A. Review proposed program with Steering Committee.

B. Meet with corresponding water supplier(s).

C. Provide copies of report, etc., to Bucks County Planning Commission and request support.

D. Submit copy to Pennsylvania Department of Environmental Protection.

E. Meet with municipal councils of corresponding municipalities.

F. Meet with planning commissions of above municipalities, if requested to do so.

G. Finalize wellhead protection plan, develop GIS map, and refine list of potential sources of contamination.

XII. REFERENCES

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Appendix A

Pennridge Area Demographic Summary

Appendix A
Pennridge Area Demographic Summary

Note: This appendix was excerpted from the Pennridge Area Greenway Plan (1999).

The Pennridge Area, which coincides with the Pennridge School District, is located in the northwestern portion of Bucks County. The land area is approximately 92 square miles (58,616 acres), making up approximately 15 percent of the total land area of Bucks County. The Pennridge Area consists of eight municipalities: the boroughs of Dublin, Perkasie, Sellersville, and Silverdale, and the townships of Bedminster, East Rockhill, Hilltown, and West Rockhill.

The Pennridge Area is predominantly rural in nature. Historically, the four boroughs have been the population and commercial centers of the area. However, development in this area has been fairly steady due partly to the existing transportation system leading to and from the area. PA Routes 313 and 309 provide access to the north and south, and PA Routes 563 and 113 provide access to the east and west. Recent development has been primarily in the form of single-family detached dwellings and commercial developments. Based on 1990 land use characteristics, approximately 75 percent of the Pennridge Area is in rural residential, agricultural, or vacant use, while 17 percent of the total land area is in single-family residential use. The four boroughs located in the planning area have received significant nonresidential development since 1970. Due to increased public water and sewer availability, and a strong presence of commercial and industrial uses, this growth trend is expected to increase at a slightly increased rate than in previous decades.

Because of the fact that most new residential and nonresidential development occurs on agricultural or vacant land, it is possible to gauge the rate of land consumption in an area by examining the rate at which agricultural and vacant land is consumed. Upon examination of the agricultural/vacant land use category, it is evident that there has been a steady decrease in the percentage of this land use category, resulting in a drop from 68 percent in 1970 to 60 percent in 1990. Thus, it is evident that the Pennridge Area has been experiencing a fairly moderate but steady rate of growth. While the table indicates that there has been relatively no change in the residential land use category, an increase from 3 to 9 percent in the nonresidential land use category has occurred.

Between 1970 and 1990 there was only a one percent increase in the park and recreation land use category. This indicates that growth rates have not been consistent with that of the residential/nonresidential land use categories. Thus, there may be a need to provide an increase in the amount of park and recreation lands to serve existing and future population.

Land Use Comparison

General Land Use	1970	1980	1990
Residential	26%	27%	27%
Nonresidential	3%	5%	9%
Agriculture/Vacant	68%	64%	60%
Park and Recreation	3%	4%	4%

The municipal population and housing projections illustrated in the tables below depict the anticipated future growth of the Pennridge Area.

Population Characteristics

Municipality	1980 Census	1990 Census	2000 Census	2005 Projection	2010 Projection
Bedminster	3,611	4,602	4,804	4,923	5,025
Dublin	1,565	1,985	2,083	2,118	2,162
E. Rockhill	2,971	3,753	5,199	5,847	6,542
Hilltown	9,326	10,582	12,102	13,599	14,586
Perkasie	5,241	7,878	8,828	8,600	8,835
Sellersville	3,143	4,479	4,564	4,697	4,768
Silverdale	499	881	1,001	913	923
W. Rockhill	3,776	4,518	4,233	4,881	5,000
Total	**30,132**	**38,678**	**42,814**	**45,578**	**47,842**

Housing Characteristics

Municipality	1980 Census	1990 Census	2000 Projection	2005 Projection	2010 Projection
Bedminster	1,265	1,733	1,832	1,881	1,931
Dublin	710	840	884	906	928
E. Rockhill	1,073	1,359	1,882	2,143	2,404
Hilltown	3,099	3,659	4,404	4,777	5,149
Perkasie	2,084	3,089	3,317	3,430	3,544
Sellersville	1,153	1,703	1,778	1,816	1,853
Silverdale	177	309	322	328	334
W. Rockhill	1,328	1,684	1,795	1,851	1,907
Total	**10,889**	**14,376**	**16,212**	**17,130**	**18,049**

Population Age Characteristics

Municipality	1980 < 18	1990 < 18	% Change	1980 18-64	1990 18-64	% Change	1980 64 >	1990 64 >	% Change
Bedminster	1,033	1,123	9%	2,221	2,950	32%	357	529	48%
Dublin	376	560	49%	1,039	1,276	23%	150	149	0%
E. Rockhill	856	1,031	20%	1,833	2,355	28%	282	367	30%
Hilltown	2,872	2,898	1%	5,736	6,622	15%	718	1,062	48%
Perkasie	1,399	2,201	57%	3,187	4,702	48%	655	975	49%
Sellersville	893	1,292	45%	1,911	2,830	48%	339	357	5%
Silverdale	153	291	90%	313	543	73%	33	47	42%
W. Rockhill	1,057	1,090	3%	2,258	2,677	19%	461	751	63%
Total	**8,639**	**10,486**	**21%**	**17,460**	**23,955**	**37%**	**2,995**	**4,237**	**41%**

As can be seen from the population characteristics table, the Pennridge Area is made up of residents predominantly in the 18-64 age group. However, between 1980 and 1990 there was a 21 percent increase in residents under the age of 18. Additionally, residents age 65 and over

increased by 41 percent. The substantial increase in these two age groups emphasizes the need for a comprehensive greenway system, for they will most likely represent a large portion of the users of the system. Children and the elderly alike have a need for recreational areas that will offer a safe environment from motor vehicles. The greenway network will provide these users with this amenity.

Income Characteristics

Municipality	1980 Median Household Income	1989 Median Household Income	Percent Change 1980 - 1989
Bedminster	$21,000	$42,660	103%
Dublin	$18,571	$33,450	80%
E. Rockhill	$18,962	$43,284	128%
Hilltown	$22,677	$44,717	97%
Perkasie	$18,261	$39,193	114%
Sellersville	$19,579	$37,851	93%
Silverdale	$21,827	$41,429	90%
W. Rockhill	$20,849	$37,479	80%
Area	**$20,216**	**$40,008**	**98%**

Income levels may have a bearing on the directions taken towards implementing the goals and objectives set forth in this plan. The figures may indicate the ability of residents to assist in financially supporting the open space and greenway preservation and acquisition efforts. In 1989, the median household income for the Pennridge Area was $40,008, which was slightly below the median household income for Bucks County. However, the figures in the above table show a percent increase of 98% during the period of 1980-1989. During this same time period, the Bucks County median household income rose from $22,016 to $43,347, an increase of 97%. This shows that the Pennridge Area is consistent with the income characteristics of the county.

Wellhead Protection Tools Matrix

Table 4-6. Summary of Wellhead Protection Tools

	Applicability to Wellhead Protection	Land Use Practice	Legal Considerations	Administrative Considerations
Regulatory: Zoning				
Overlay GW Protection Districts	Used to map wellhead protection areas (WHPAs). Provides for identification of sensitive areas for protection. Used in conjunction with other tools that follow.	Community identifies WHPAs on practical base/zoning map.	Well-accepted method of identifying sensitive areas. May face legal challenges if WHPA boundaries are based solely on arbitrary delineation.	Requires staff to develop overlay map. Inherent nature of zoning provides "grandfather" protection to pre-existing uses and structures.
Prohibition of Various Land Uses	Used within mapped WHPAs to prohibit ground-water contaminants and uses that generate contaminants.	Community adopts prohibited uses list within their zoning ordinance.	Well-organized function of zoning. Appropriate techniques to protect natural resources from contamination.	Requires amendment to zoning ordinance. Requires enforcement by both visual inspection and onsite investigations.
Special Permitting	Used to restrict uses within WHPAs that may cause ground water contamination if left unregulated.	Community adopts special permit "thresholds" for various uses and structures within WHPAs. Community grants special permits for "threshold" uses only if ground water quality will not be compromised.	Well-organized method of segregating land uses within critical resource areas such as WHPAs. Requires case-by-case analysis to ensure equal treatment of applicants.	Requires detailed understanding of WHPA sensitivity by local permit granting authority. Requires enforcement of special permit requirements and onsite investigations.
Large-Lot Zoning	Used to reduce impacts of residential development by limiting numbers of units within WHPAs.	Community "down zones" to increase minimum acreage needed for residential development.	Well-recognized prerogative of local government. Requires rational connection between minimum lot size selected and resource protection goals. Arbitrary large lot zones have been struck down without logical connection to Master Plan or WHPA program.	Requires amendment to zoning ordinance.
Transfer of Development Rights	Used to transfer development from WHPAs to locations outside WHPAs.	Community offers transfer option within zoning ordinance. Community identifies areas where development is to be transferred "from" and "to."	Accepted land use planning tool.	Cumbersome administrative requirements. Not well suited for small communities without significant administrative resources.
Cluster/PUD Design	Used to guide residential development outside of WHPAs. Allows for "point source" discharges that are more easily monitored.	Community offers cluster/PUD as development option within zoning ordinance. Community identifies areas where cluster/PUD is allowed (i.e., within WHPAs).	Well-accepted option for residential land development.	Slightly more complicated to administer than traditional "grid" subdivision. Enforcement/inspection requirements are similar to "grid" subdivision.
Growth Controls/ Timing	Used to time the occurrence of development within WHPAs. Allows communities the opportunity to plan for wellhead delineation and protection.	Community imposes growth controls in the form of building caps, subdivision phasing, or other limitation tied to planning concerns.	Well-accepted option for communities facing development pressures within sensitive resource areas. Growth controls may be challenged if they are imposed without a rational connection to the resource being protected.	Generally complicated administrative process. Requires administrative staff to issue permits and enforcement growth control ordinances.

Table 4-6. Summary of Wellhead Protection Tools (Continued)

	Applicability to Wellhead Protection	Land Use Practice	Legal Considerations	Administrative Considerations
Performance Standards	Used to regulate development within WHPAs by enforcing predetermined standards for water quality. Allows for aggressive protection of WHPAs by limiting development within WHPAs to an accepted level.	Community identifies WHPAs and established "thresholds" for water quality.	Adoption of specific WHPA performance standards requires sound technical support. Performance standards must be enforced on a case-by-case basis.	Complex administrative requirements to evaluate impacts of land development within WHPAs.
Regulatory: Subdivision Control				
Drainage Requirements	Used to ensure that subdivision road drainage is directed outside of WHPAs. Used to employ advanced engineering designs of subdivision roads within WHPAs.	Community adopts stringent subdivision rules and regulations to regulate road drainage/runoff in subdivisions within WHPAs.	Well-accepted purpose of subdivision control.	Requires moderate level of inspection and enforcement by administrative staff.
Regulatory: Health Regulations				
Underground Fuel Storage Systems	Used to prohibit underground fuel storage systems (USTs) within WHPAs. Used to regulate USTs within WHPAs.	Community adopts health/zoning ordinance prohibiting USTs within WHPAs. Community adopts special permit or performance standards for use of USTs within WHPAs.	Well-accepted regulatory option for local government.	Prohibition of USTs require little administrative support. Regulating USTs requires moderate amounts of administrative support for inspection followup and enforcement.
Privately Owned Wastewater Treatment Plants (Small Sewage Treatment Plants)	Used to prohibit small sewage treatment plants (SSTP) within WHPAs.	Community adopts health/zoning ordinance within WHPAs. Community adopts special permit or performance standards for use of SSTPs within WHPAs.	Well-accepted regulatory option for local government.	Prohibition of SSTPs require little administrative support. Regulating SSTPs requires moderate amount of administrative support of inspection followup and enforcement.
Septic Cleaner Ban	Used to prohibit the application of certain solvent septic cleaners, a known ground water contaminant, within WHPAs.	Community adopts health/zoning ordinance prohibiting the use of septic cleaners containing 1,1,1-trichloroethane or other solvent compounds within WHPAs.	Well-accepted method of protecting ground water quality.	Difficult to enforce even with sufficient administrative support.
Septic System Upgrades	Used to require periodic inspection and upgrading of septic systems.	Community adopts health/zoning ordinance requiring inspection and, if necessary, upgrading of septic systems on a time basis (e.g., every 2 years) or upon title/property transfer.	Well-accepted purview of government to ensure protection of ground water.	Significant administrative resources required for this option.

Table 4-6. Summary of Wellhead Protection Tools (Continued)

	Applicability to Wellhead Protection	Land Use Practice	Legal Considerations	Administrative Considerations
Toxic and Hazardous Materials Handling Regulations	Used to ensure proper handling and disposal of toxic materials/waste.	Community adopts health/zoning ordinance requiring registration and inspection of all businesses within WHPA using toxic/hazardous materials above certain quantities.	Well accepted as within purview of government to ensure protection of ground water.	Requires administrative support and onsite inspections.
Private Well Protection	Used to protect private onsite water supply wells.	Community adopts health/zoning ordinance to require permits for new private wells and to ensure appropriate well-to-septic-system setbacks. Also requires pump and water quality testing.	Well accepted as within purview of government to ensure protection of ground water.	Requires administrative support and review of applications.
Non-regulatory: Land Transfer and Voluntary Restrictions				
Sale/Donation	Land acquired by a community with WHPAs, either by purchase or donation. Provides broad protection to the ground-water supply.	As non-regulatory technique, communities generally work in partnership with non-profit land conservation organizations.	There are many legal consequences of accepting land for donation or sale from the private sector, mostly involving liability.	There are few administrative requirements involved in accepting donations or sales of land from the private sector. Administrative requirements for maintenance of land accepted or purchased may be substantial, particularly if the community does not have a program for open space management.
Conservation Easements	Can be used to limit development within WHPAs.	Similar to sales/donations, conservation easements are generally obtained with the assistance of non-profit land conservation organization.	Same as above.	Same as above.
Limited Development	As the title implies, this technique limits development to portions of a land parcel outside of WHPAs.	Land developers work with community as part of a cluster/PUD to develop limited portions of a site and restrict other portions, particularly those within WHPAs.	Similar to those noted in cluster/PUD under zoning.	Similar to those noted in cluster/PUD under zoning.
Non-regulatory: Other				
Monitoring	Used to monitor ground water quality within WHPAs.	Communities establish ground water monitoring program within WHPA. Communities require developers within WHPAs to monitor ground water quality downgradient from their development.	Accepted method of ensuring ground water quality.	Requires moderate administrative staffing to ensure routine sampling and response if sampling indicates contamination.
Contingency Plans	Used to ensure appropriate response in cases of contaminant release or other emergencies within WHPA.	Community prepares a contingency plan involving wide range of municipal/county officials.	None.	Requires significant up-front planning to anticipate and be prepared for emergencies.

Table 4-6. Summary of Wellhead Protection Tools (Continued)

	Applicability to Wellhead Protection	Land Use Practice	Legal Considerations	Administrative Considerations
Hazardous Waste Collection	Used to reduce accumulation of hazardous materials within WHPAs and the community at large.	Communities, in cooperation with the state, regional planning commission, or other entity, sponsor a "hazardous waste collection day" several times per year.	There are several legal issues raised by the collection, transport, and disposal of hazardous waste.	Hazardous waste collection programs are generally sponsored by government agencies, but administered by a private contractor.
Public Education	Used to inform community residents of the connection between land use within WHPAs and drinking water quality.	Communities can employ a variety of public education techniques ranging from brochures detailing their WHPA program, to seminars, to involvement in events such as hazardous waste collection days.	No outstanding legal considerations.	Requires some degree of administrative support for programs such as brochure mailing to more intensive support for seminars and hazardous waste collection days.
Legislative:				
Regional WHPA Districts	Used to protect regional aquifer systems by establishing new legislative districts that often transcend existing corporate boundaries.	Requires state legislative action to create a new legislative authority.	Well-accepted method of protecting regional ground water resources.	Administrative requirements will vary depending on the goal of the regional district. Mapping of the regional WHPAs requires moderate administrative support, while creating land use controls within the WHPA will require significant administrative personnel and support.
Land Banking	Used to acquire and protect land within WHPAs.	Land banks are usually accomplished with a transfer tax established by state government empowering local government to impose a tax on the transfer of land from one party to another.	Land banks can be subject to legal challenge as an unjust tax, but have been accepted as a legitimate method of raising revenue for resource protection.	Land banks require significant administrative support if they are to function effectively.

Source: Horsley and Witten, 1989.

Appendix C

Minimum Elements for Local SWP Programs (Groundwater Sources)

MINIMUM ELEMENTS FOR LOCAL WHP PROGRAMS (February 2000)

This section describes the minimum elements necessary for a local wellhead protection (WHP) program to receive DEP approval. Local WHP program plans will be reviewed and approved by regional Water Supply Management staff. If necessary, coordination with other programs could be accomplished in a manner similar to that for permit coordination. Essentially, the plan should not only detail the provisions of the local program including a schedule for implementation, but should also demonstrate the commitment needed to support the on-going efforts necessary for a successful local WHP program. Therefore, the plan should not only describe how sources will be protected but also document the resources necessary to implement the plan, thus linking implementation and management to finances.

Each plan should have a table of contents, an introduction that includes the goal or purpose of the plan along with a general description of the area (demographics, topography, local/regional hydrogeologic setting, source characteristics, etc.), concise narrative descriptions for each of the following sections plus any other relevant supporting information. Each plan must have a WHP area delineation map using an appropriate base map with a scale ranging from 1:400 to 1:24,000 that accurately and legibly depicts source locations, WHP area boundaries and potential contaminant sources (preferably a USGS 7.5' quad or GIS-generated map with adequate cultural features/landmarks). The map must also have a bar scale and north arrow.

A local WHP plan must contain the following minimum elements in order to be considered for DEP approval:

1. Steering Committee & Public Participation
This section of the plan will document the formation and meetings of the local WHP steering committee along with provisions for public involvement. The committee chairperson, the chairperson's telephone number, members, a description of roles and responsibilities of the committee and dates/locations of meetings must be listed. Ideally, meeting locations should vary if possible and a tour/inspection of the wellfield/well sites should be conducted. The narrative must also demonstrate that adequate opportunities for public participation were in place at the beginning of and throughout the project (copies of public notices such as flyers, newspaper notices, etc.). This section should also document all public education activities and describe how the final plan will be accessible to the public (on file at municipal government office or public water system office, libraries, etc.).

2. WHP Area Delineation
This narrative must completely describe the methodology used, justification for methodology, and who performed the delineation. For delineations in carbonate and fractured bedrock aquifers that utilize the ½ mile radius as the default WHPA, the justification must demonstrate that it is adequately protective. Rigorous delineation methods must be performed by or under the supervision of a Registered Professional Geologist. This section must also include a description of the local hydrogeologic setting and a formulation of a *conceptual* ground-water flow model. Relevant hydrogeologic data with sources/references, supporting calculations and any other information necessary for the reviewer to reproduce the steps involved in delineating the WHP area must be provided. The level of delineation will be commensurate with the type of management option to be utilized.

3. Contaminant Source Inventory
A description of the methods used to conduct an inventory of existing and potential sources of contamination must be provided in this narrative. Documentation of field verification of computerized database searches and actual inspection of the WHP area must be provided. Contaminant source locations must be plotted on the accompanying WHP area map(s) and keyed into a table listing the facility name, owner, type of contaminant and a relative prioritization of risk (low, moderate, high) from the source. (DEP can assist with assessing relative risk if requested). This section must also include documentation that these sources are targeted for or were provided specific education regarding potential risks to the water supply.

4. WHP Area Management and Commitment

This section will provide a description of current land use and describe the management method(s) appropriate for the delineated WHP area. What is the cost to do the activities and where will resources come from? Commitment may be demonstrated by:

a.) In-kind services
b.) Dedicated funding (water rate)
c.) Tax/fee dedicated to WHP
d.) General revenue
e.) Other acceptable means

A table listing management options for each identified threat along with a schedule for implementation must also be provided.

5. Contingency Planning

This section will contain a Revised Emergency Response Plan that includes realization of potential threats through spills and any other unintended releases and describes coordination with water supplier, municipalities and local emergency management agency to address contingencies commensurate with risks for each identified threat. Provisions for alternate water supply must be described such as arrangements for bulk hauling or sources of interconnection.

6. New Sources

This section addresses adequate planning for new wells including careful consideration of potential sites, existing land use, predicted Zone I area, how to obtain access and rights to areas if necessary and how the areas will be protected.

Those water systems capable of satisfactorily addressing each of the above elements will be considered approved under §109.713 and would be issued an approval letter. Additionally, an annual report/update will be required that describes changes in WHP area boundaries, land use, potential threats and contingency planning. Specific requirements may also be contained in DEP's approval letter. For those systems that do not initially address the minimum elements adequately, a review letter will be issued pointing out what needs to be strengthened in order to receive approval.

Appendix D

Public Information/Education Materials

Meeting to look at Pennridge water plan

A public meeting to review the draft Pennridge Area Source Water Protection Plan will take place 7 to 9 p.m. March 31, at the West Rockhill Township Municipal Building, 1028 Ridge Road, Sellersville.

The public meeting will allow Pennridge Area water authorities, Pennridge Area Coordinating Committee (PACC) members, municipal officials and the general public an opportunity to provide input prior to the draft plan being submitted to the Pennsylvania Department of Environmental Protection for review and final approval.

MEETING NOTICE

Who: Pennridge Area Source Water Steering Committee members, municipal authorities' staff, PACC members, PACC consultants and the general public.

What: Public meeting and review of Public Review *Draft Pennridge Area Source Water Protection Volume I* & *Volume II* documents

Date: Tuesday, March 31, 2009

Times: Public meeting — 7:00PM to 9:00PM

Where: West Rockhill Township municipal building (boardroom), 1028 Ridge Road Sellersville, PA 18960

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Steering committee members, municipal water authorities' staff, PACC members, consultants, and the general public will have an opportunity to review and discuss the *Public Review Draft* Pennridge *Area Source Water Protection Plan Volume I* & *Volume II* documents.

The final draft, to include comments provided at the March 31 public meeting, will be sent to DEP for review and approval.

For additional information or to RSVP, please contact Rea Monaghan @ (215) 345-3267 or remonaghan@co.bucks.pa.us.

MONTGOMERY NEWSPAPERS

02/28/2007

More than $500,000 in grants helps PACC help Pennridge

By: Emily Morris , Staff writer

The Pennridge Area Coordinating Committee works on the theory that individual municipalities can't ignore the big picture. And looking at that bigger picture has earned PACC more than $500,000 in grant money over the last several years.

The overall work of PACC may seem vague and intangible for some residents. The group consists of representatives from the eight municipalities in the Pennridge School District (Bedminster, Dublin, East Rockhill, Hilltown, Perkasie, Sellersville, Silverdale and West Rockhill) as well as representatives from the school district, Bucks County Community College and the Pennridge Chamber of Commerce, and it meets once a month. The goal of the group is to remain aware of the issues on the table in surrounding communities and, wherever possible, help one another out and seek ideas for improvement that can benefit everyone financially, environmentally and more.

While it may seem like good common sense to create such a group, PACC is almost one of a kind in Pennsylvania.

"This is very innovative in the state and that's part of why this has been able to achieve a lot of the funding it has," said Paul Gordon of the Bucks County Planning Commission, who works closely with PACC members on water issues in the region. "Because the state kind of recognizes us as being a role model for municipalities jointly cooperating. It is very unique within the state."

PACC's grant money comes in large part through its work with the county planners. The group has developed a Pennridge Water Resources Plan that is able to benefit public health and pollution by finding methods to improve all aspects of the public water supply - and so far, it has paid off.

For example, a major $228,276 grant saved the Pennridge municipalities a fairly nice chunk of change - almost $72,000 to be exact - on a project that would have required each municipality to pay $50,000. Pennsylvania Department of Environmental Protection requires each municipality to upgrade its source water protection ordinance. Since the municipalities applied as a group under PACC, DEP gave the group a discounted rate for cooperating and understanding the importance of inter-municipal communication and how it can save in the long run.

"It does give us a leg up on the competition, because a lot of the grantors of these funds are very interested in that cooperation level," said Gordon. "If you're just a sole municipality who's having a myopic view of the world, you're less apt to get the funding."

Still, not all the municipalities commit to the group at the same level. The average monthly meeting of PACC has just three or four municipalities present, typically East Rockhill, West Rockhill and Bedminster, the Chamber of Commerce and occasionally a school district representative. While all the municipalities still receive the information PACC continues to work on, some say it is just an issue of timing.

"Too many meetings, too few people," said Sellersville Borough Manager Alan Frick of why that borough does not regularly attend PACC meetings. Frick said the borough council is always willing to look at PACC's major projects as they needs approval or examination from the individual municipalities. Sellersville, Perkasie, Silverdale, Hilltown and Dublin have all sent representatives to PACC over time but on a much less frequent basis. However, Gordon says that PACC would not even exist in its current state without support from all eight municipalities and PACC continues to seek ways to keep each municipality informed and interested in the long-term projects.

Those that do attend regularly are constantly trying to look for ways that the cooperative effort can help the municipalities meet requirements or improve services to residents and save money for everyone. One of the major topics of discussion over the past couple months has been the idea of creating a joint composting site where municipalities or their residents could take yard waste to be composted and incorporated into mulch that could then be reused by farmers or local residents. It would help each municipality meet the requirements of the DEP regarding yard waste as well as help save money and keep grant funding for recycling programs.

In other grant money, PACC has received more than $76,000 in state Growing Greener grants, which allowed the group to undertake the process of creating the plan and continuing to work on its implementation including designs for how to improve storm water basins. Another $27,860 in a LUPTAP grant allowed PACC to work on a model ordinance that each municipality can adopt to help link water resources to land development and the impact development has on the area's water, said Gordon.

To educate the community and the area's students about the important of water protection, PACC has received $8,200 in grants from the League of Women Voters Water Resources Education Network (WREN). With that funding, PACC was able to create an informational brochure that is handed out at events and each municipality's office, as well as hold a Water Awareness Day to help the public understand all the issues surrounding one of humanity's most basic fundamental needs.

A Coastal Zone Management/Coastal Non-Point Source Pollution Program grant was received by PACC in the amount of $40,000 to assess the Perkiomen Creek Watershed and its storm water basins. Once that assessment was complete, it was clear some storm water basins might need improvement or retrofit. The Growing Greener Grants are being used on an ongoing basis to develop a retrofit design for those basins - a confusing concept.

"In the past, the design focused around getting water off property as quickly as possible, but over years engineers have found that overwhelms streams," which can result in erosion of the stream banks and water quality problems relating to that erosion, said Gordon. "So now we try to keep water on property to reinfiltrate the groundwater."

PACC is looking into how best to create a design that will allow older storm water basins to serve that purpose of retaining the water on the property. That project is still in the design phase with the hopes of future implementation.

For every grant PACC receives, which have thus far amounted to nearly $385,000, the municipalities have contributed funding - but not nearly as much. The cash match total for all of the five major grants has only totaled $75,460 spread out over the municipalities involved and in some cases the Pennridge School District. Bucks County Planning Commission has also contributed $101,970 in resources and staff time to PACC to help out with what it believes is a crucial cause. The total in grant money, cash matches and in-kind contributions for PACC thus far is $562,346, and there are several more major grants PACC has on its agenda to work on in the coming months or years.

The Intelligencer

Pennridge-area water safety addressed

By: THERESA HEGEL
The Intelligencer

Engineer Paul DeBarry remembers in college hearing a story about a particular diner that served the best coffee for miles around.

People who drank the famed brew described it as "full-bodied."

They later found out the diner was "down slope of a cemetery," said DeBarry of NTM Engineering.

Nothing so dramatic is likely in store for the Pennridge region, thanks to the efforts of water and geology experts who have mapped out where groundwater in the area flows and also where potential contamination sites lie in relation to that water.

Besides cemeteries, landfills, gas stations, auto shops and storm and farm water runoff are among potential contaminants.

DeBarry and several others were on hand Tuesday night to detail the results of their years-long study into protecting the sources of Pennridge's drinking water. The handful of township and water authority officials in attendance were given a final opportunity to comment on the plan before it is submitted Friday to the state Department of Environmental Protection for approval.

Ben Greeley, a geologist in the DEP's southeast regional office, explained that his organization had been mandated to urge municipalities to develop and then implement water protection plans.

"The assessments were a starting point," he said. "That's not where we end. It's where we begin."

Still, how far Pennridge towns take the study's findings is voluntary.

"We can't hard hammer you folks, but we can certainly encourage," Greeley said.

The study delineates where municipal well water recharges, so regional officials can take steps not to dry up or allow contamination into those sources.

But even with all the time and data collected, there are limitations.

Todd Kincaid, a geologic modeler with HH Associates, helped to develop the computer simulations that determined the origins of the Pennridge area's groundwater.

A lack of data and funding precludes his company's predictions from being 100 percent accurate, however.

They don't take into account real-world fluctuations and assume that area water authorities are pumping from their wells nonstop, Kincaid said.

Still, the models are a good tool for local officials, he said, adding that they will work best if used to supplement future site-specific analyses.

Once the plan is approved - which should happen in a matter of months - municipalities can use its findings to tweak their zoning and subdivision development ordinances to "ensure that growth does not outpace resources," said Rea Monaghan of the Bucks County Planning Commission.

Officials in attendance seemed receptive to the presentation though several had questions on the specifics.

Gary Winton, manager of the Perkasie Borough Authority, said that while he understood the premise behind the study and though it was good idea, he worried about the most effective way to use those findings at the local level.

"The implementation of it becomes a little gray for me," he said.

Theresa Hegel can be reached at 215-538-6381 or thegel@phillyburbs.com.

April 01, 2009 02:30 AM

2/5/2003

On the Web at: www.phillyburbs.com

Officials consider well protection

So far, the response has been tepid. Some local officials fear a loss of control.

By Patrick Lester
Staff Writer

Region

A plan to better protect public water wells in the Pennridge area hasn't been getting the immediate support from water suppliers some officials anticipated.

The Bucks County Planning Commission in recent weeks has been pitching a regional well protection plan to six water suppliers with the hope that a group effort would keep costs down.

The county planners want to develop ways to protect more than a dozen public wells in the Pennridge area from potential contamination with a wellhead protection ordinance, education programs and well-drilling regulations, among other initiatives.

One potential measure, for example, would be to place signs near wells to warn the public of their location. If one of those wells were located near a major roadway where the potential for gas spills exists, a swift cleanup response plan could be developed.

The ultimate goal is to better protect the area's drinking water.

Dublin councilman Jeffrey Sharer voiced some skepticism while his board was batting around the proposal last week. He feared the borough would have no control over the plan and would be forced to enact ordinances.

"I don't think you're going to be forced to do anything," county planner Dennis Livrone said. "We're not regulatory, we're just providing planning assistance."

Three water suppliers — Bedminster, Dublin and North Penn water authorities — have already decided to join the effort. The others — Perkasie, Sellersville and Hilltown — are still debating the idea and must make a final decision by today, when the planning commission will apply for state funding.

If all six get involved, they could pool their resources of engineers and other professionals to spread out the cost. Early estimates show it could cost about $30,000 to develop the plan. The state Department of Environmental Protection will give out as much as $50,000 from its Growing Greener grant program to any one group.

Livrone said the chances of getting adequate funding for the project are better if more water suppliers apply for the funding.

"How can this hurt us?" Kent Moore, Dublin's mayor, asked council last week.

"It might be better for us to be proactive here rather than have something forced on the borough down the road," said Dublin councilman Robert Pellegrino.

Officials from Hilltown, Perkasie and Sellersville water providers have expressed interest in getting involved, said Cynthia Unangst of the Bucks County Planning Commission. They're all waiting for approval from their boards of directors. County officials are hoping Perkasie Borough Authority does participate because it is the largest water supplier in the area with six wells and about 8,200 customers.

"They're very interested in doing this with us," Unangst said. "But they certainly have some concerns."

Patrick Lester can be contacted via e-mail at plester@phillyburbs.com.

Millions to be spent on homeless

By Greg Coffey
Staff Writer

NORRISTOWN — Montgomery County will spend more than $2 million in 2003 to buy and renovate homes to help the homeless and low-income residents.

County officials also plan to create a computer system to track the number of homeless people in the county and determine what services they need and use.

When last counted in 2001, Montgomery County had 694 homeless people, said Ivy Torres, assistant director of the county's Department of Housing and Community Development.

The Indian Valley Housing Corp. will receive $17,000 from the county to renovate three homes in Souderton, and Lansdale-based Community Housing Services will receive $200,000 to buy a new building. Interfaith Housing Alliance, a homeless shelter in Ambler, will receive $80,000 to increase space and provide an additional 13 beds.

The goal of the program is to help homeless people and low-income families obtain and remain in a home. Once the homes are renovated, clients will receive job assistance and other help to increase their independence.

"It's worth the effort," Torres said.

Much of the money will come from the county's Affordable Housing Trust Fund, which receives money from the Recorder of Deeds office. The Recorder of Deeds collects a fee for every land transaction that is filed. Such transactions include sales, mortgage, refinancing and easements.

For several years, the filing fee has generated about $1 million for the trust fund. Because of a record year of filings, the trust fund received about $2.4 million in 2002, Torres said.

The county also will spend $409,000 to develop and operate a computer system to help housing officials determine what services the homeless need, which in turn will help them better determine how much money to spend on programs, Torres said.

The federal government mandated the county develop the system by 2004 and is footing the bill. Officials are reviewing several programs and aren't sure how the final version will work, Torres said.

However, it is hoped the system will help officials keep a more accurate count of the county's homeless population by assigning each person a number and a file.

That number won't reveal who they are, but the file will contain information about their medical and counseling histories, what shelters they have stayed at, and the progress they are making, Torres said.

Housing officials plan to count the county's homeless population by spring.

Greg Coffey can be contacted via e-mail at gcoffey@voicenet.com.

Pennridge group offers plan to protect water supply
Tonight it seeks input on how to ensure there's enough for growing area.

By Robert H. Orenstein | Of The Morning Call

March 31, 2009

With an increase in population of nearly 50 percent since 1980, Pennridge School District communities have been examining ways to plan for future growth.

"They wanted to take a proactive measure to address these issues -- not to halt development but plan for development in appropriate areas," said Rea Monaghan, an environmental planner with the Bucks County Planning Commission.

Monaghan has been working with the Pennridge Area Coordinating Committee, which will present a draft of its plan to protect the area water supply at 7 tonight in the West Rockhill Township Municipal Building.

The plan presents options municipalities can adopt to protect streams, creeks and wells in the 93-square-mile area.

"Water availability is one of the most critical items the area is going to face over the next 10 to 25 years," Monaghan said.

The committee began in 1997 at the request of school officials, who were concerned about an increase in students and wanted to improve communication among its member municipalities as a way to track new home construction, according to its Web site.

Over the years, the committee prepared other reports, including one for open space and another for water resources.

Elsewhere in the county, Riegelsville has completed a similar water source protection plan, Monaghan said. And officials in Quakertown Community School District municipalities recently contacted the county Planning Commission to consider examining their water resources, similar to what Pennridge is doing.

Monaghan said the Pennridge committee will take comments from people tonight and include those in the plan, which must be approved by the state Department of Environmental Protection. She expects that to happen by the middle of this year.

The 116-page draft report contains technical data examining several areas such as geology, area, groundwater and climate. It offers methods, ranging from posting signs near water supplies to using zoning, that municipalities can adopt to protect water resources.

Residents were served about equally by private wells or public water systems in 2000, according to the report.

The draft suggests ways to help residents avoid contaminating their water, such as making it easier for them to recycle household hazardous wastes.

It can "educate the public," Monaghan said, "by identifying potential sources of contamination and reach out to residents ... to protect their source water."

IF YOU GO

What: Presentation of a draft of the Pennridge Area Source Water Protection Plan
When: 7-9 p.m. today
Where: West Rockhill Township Municipal Building, 1028 Ridge Road
Information: pennridgepacc.webs.com

MONTGOMERY NEWSPAPERS

08/04/2004

State grants Pennridge municipalities money to protect well water

By Bill Hunsberger

Municipalities across the Pennridge area are each ready to put $38,046 of state Source Water Protection (SWP) grant money to work to protect groundwater supplies. Each municipality has signed and accepted (or soon will) contracts with the state Department of Environmental Protection defining agreements on use of the grant for wellhead protection in its area.

The local agencies receiving the DEP grants are Sellersville Borough Municipal Water Works, Perkasie Borough Authority, Bedminster Township Municipal Authority, Dublin Borough Municipal Water Works, Hilltown Township Water and Sewer Authority, and the North Penn Water Authority.

The grants are one-time, five-year grants.

In addition to the DEP funds, the above municipalities will receive in-kind services from Bucks County valued at $5,000, and each must come up with its own in-kind services valued at no less than $5,000.

The county contribution includes approximately 100 hours of staff time, and some time for engineering and legal consultation to satisfy the state's stipulation for a 10 percent in-kind match from the local governments.

This state grant program focuses and pulls together parts of several different environmental initiatives and funding sources, which in turn gain further focus through the Bucks County Planning Commission (BCPC).

The funding stream starts with the federal Environmental Protection Agency (EPA).

The federal money flows through an initiative called the Drinking Water State Revolving Fund, and in Pennsylvania, the DEP's State Water Plan, which includes the Source Water Protection plan (SWP). This in turn has two pieces: one deals with surface drinking water sources, the other - which pertains to Pennridge - deals with well water in the ground.

The effort in the Pennridge municipalities receives coordination and support from the BCPC and the Pennridge Area Coordinating Committee (PACC). The county programs have received partial funding from other sources such as the commonwealth's Growing Greener initiative and the Governor's Center for Local Government Services.

Despite the labyrinthine flow of money, a key point emerges: federal, commonwealth and county resources are being made available to support locally designed and driven initiatives to protect local water supplies. In other words, through these grants local people are empowered to solve problems where they live.

A second point obscured by the organizational complexity is that this money is intended to nip problems in the bud.

To quote state DEP literature: "The underlying principle of the program is that it is much less expensive to protect ground water than it is to try to restore it once it becomes contaminated."

Put succinctly by Patrick Bowling, DEP geologist in Bureau of Watershed Management, "Contamination in ground water can take decades to flush out."

The Bureau of Watershed Management is the agency that awards and monitors the grants.

Ground water is a far less expensive source than surface water (lakes, reservoirs, rivers, etc.) because of the costs associated with surface water treatment, distribution and ownership of real estate and watersheds. However, once fouled, the clean-up of subsurface water makes it far more costly.

The intention of the wellhead protection grants is to give local officials and residents a picture of the water supply in the aquifers on which they live.

It is quite literally a picture - a high-tech snapshot of the extent, shape and tilt (or 'strike') of the subterranean rock formations through which flows the water that penetrates down from surface sources and rain.

Bowling refers to this picture as "the zone of contribution" mapped in concentric rings about the well being studied. For the participating Pennridge communities, this mapping will be done by Borton-Lawson, an engineering firm headquartered in Wilkes-Barre with offices in Bath.

Paul DeBarry, of Borton-Lawson, will oversee the various specialists brought in to map zones of contribution. He said the kind of specialists brought in depends on the local hydrology and geology, and expects it will include some drilling, geological surveys, Global Positioning Satellite (GPS) elevations, and computer models that look at precipitation, run-off, evaporation and transpiration, and water usage. Sometimes more exotic techniques such as sonic reflection are used to map ground-water structures.

DeBarry said that step one is creating the underground map; step two is then mapping the surface influences on the ground water, including the potential sources of contamination, called "contaminant source inventories."

Other activities grant money may foster include transfer of development rights, monitoring wells, public education activities, road signs, emergency response arrangements and contingency planning.

Bowling's experience leads him to believe that the technical steps to mapping ground water are the easy part.

He said, "As technically challenging as it is to delineate the contributing area, it is more challenging to do the fix and prevent things above ground. This gets into land-use laws, politics."

According to the BCPC. "... the assessment provides a basis of information upon which to establish a long-range plan for restoring and protecting the groundwater and surface water. The plan [Pennridge Water Resources Plan] and its implementation activities are coordinated with municipal land use planning documents (i.e., comprehensive plans, zoning ordinances, subdivision/land development ordinances, and sewage facilities plans), the goal being to provide for Pennridge's fair share of development while at the same time not overtaxing the water resources upon which the population depends.'

The six grants were written under the auspices of the BCPC and the Pennridge Water Resources Plan. BCPC's Cindy Unangst said that her agency wrote all six grants at once, and that presented a substantial savings to the municipalities and the Commonwealth. The coordination also enabled the municipalities and county to contract with a single engineering firm (Borton-Lawson) which further added to cost efficiencies in the project.

Unangst applauded the municipalities and PACC for establishing a high-water mark in cooperation. She said that most of the municipalities have already signed agreements with the state for funding, and expects all to be onboard by the end of August.

Gary Winton, head of the Perkasie Borough Authority, said, 'It is good to create a Pennridge model."

But he went on to note, "We are together ... and we are not. We [the various water authorities] will try to do what is right for us and our customers."

He said that in a commonwealth, the rights and management of water and minerals are managed in ways that support the 'common wealth.' He noted that local authorities are created by local municipalities, but operate as "instruments of the commonwealth."

Despite the theory, the local authorities have a history of mutual distrust and occasional animosity since their infrastructure by law can - and does - extend across municipal borders.

PBA's best wells are in East Rockhill.

Winton described some of the differences facing the different municipalities. Perkasie, for example, the largest supplier in Upper Bucks, is an old company (established in the 1890s) and "... has learned quite a bit over the years.'

His concern is that in a unified study with a single engineering consultant, "people could establish models of ground water sources, and then fit the data to a given model rather gathering data and building a useful model that reflects what is really going on.'

He said aquifers can be linear or star-shaped, depending on fracture paths in the ground; you cannot draw rings around a well with a compass and get a good handle on the zones of influence on the ground water. And they don't abide by municipal boundaries.

In order to back up any engineering findings of the collected municipalities, Perkasie's in-kind contribution to the state grant is about $14,000 for its own engineering services.

The Borough of Telford applied for and received a wellhead protection grant more than a year ago, and has had valuable experience it is interested in sharing with its Bucks County neighbors.

Telford's Mark D. Fournier wears two hats - political and technical - which are critical to the success of wellhead protection. With the political hat, Fournier is Telford Borough manager; with technical hat, he is manager of the Telford Borough Water Authority.

His vision and hope is for the political zoning/land-use maps to one day correspond to the hydrogeological map of aquifers.

Telford used its $50,000 grant to initially purchase several thousand dollars worth of equipment to ascertain the shape and flow of underground water supplies. The equipment, called data-loggers, was placed in private wells at various locations around each of Telford's five production wells. That data combined with pumping data, rainfall, and other information created a computer model of the area's aquifers.

Fournier said that rather than being neat circles around the public wells, the model showed elliptical or 'cigar-shaped' supplies. That model, when mapped to the surface, shows areas where the municipality will or will not allow certain types of enterprises or buildings based on their known contribution of contaminants.

He referred to this surface mapping as the "overlay zoning district.' Fournier believes the ultimate value of the grant money will come when an area like Pennridge and its neighbors will have an integrated overlay zoning district that will guide development in ways that are safe for the ground water.

Unangst added that while a program like this depends greatly on the technological foundation, the thing that makes it work is the people in the communities. She emphasized the importance the county, state and federal governments place on broad public education and involvement to understand and protect water at its source.

BCPC has documented anticipated growth in the Pennridge area.

The data shows that the percentage of residential land use in the area compared to all land uses, remained fairly constant between 1970 and 1990, a period in which the percentage of nonresidential land use tripled from 3 to 9 percent. Agricultural use and vacant land decreased from 68 to 66 percent.

Housing increased about 13 percent between 1990 and 2000, and is projected to increase another 11 percent by 2010.

DEP's Bowling summed up the key ingredient for the grants to be successful. He referred to "... the strong component of public education. People need to know what's going on and what's at stake.'

The Intelligencer

Officials tap ideas for water safety

By: THERESA HEGEL
The Intelligencer

For Pennridge area officials, the best way to keep drinking water clean, safe - and, indeed, flowing - is to go to the source.

With the help of the Bucks County Planning Commission and a slew of scientists, they've been able to map out where each spray of your hose and dribble from your tap originated.

The region's source water protection plan - currently in draft form - delineates those origins and identifies "actual and potential sources of contamination," said Rea Monaghan, an environmental planner with the Bucks County Planning Commission.

The plan, which will be reviewed at a public meeting on Tuesday, could also be an invaluable resource in case of an emergency, she added.

About eight years ago, the Pennridge Area Coordinating Committee began an initiative to link land development to water resources. The idea is that housing and other types of development should not exceed the capacity of area water systems.

Water availability "is going to be one of the most critical items that we deal with and face in the next 25 years," said Don Duvall, a West Rockhill supervisor and PACC member.

Tackling the issue through a multi-municipal entity makes sense because "water doesn't follow municipal boundaries," he said.

The coordinating committee includes representatives from the eight municipalities that make up the Pennridge School District.

In addition to identifying areas vulnerable to contamination, the protection plan includes sample ordinances for towns to adopt or modify. The ordinances can be used to help manage water resources and keep development from depleting those resources, he added.

Both Duvall and Monaghan stress, however, that the plan is a "tool" that can be used to guide development, not a mandate.

The state has regulations for basic wellhead protection; local regulations to protect water sources are voluntary, Monaghan said.

Tuesday's meeting will the be the last time PACC members, municipal water authorities and residents will be able to comment on the water protection plan before it is submitted to the state Department of Environmental Protection for review.

Theresa Hegel can be reached at 215-538-6381 or thegel@phillyBurbs.com.

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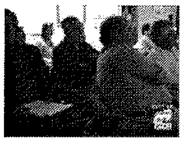
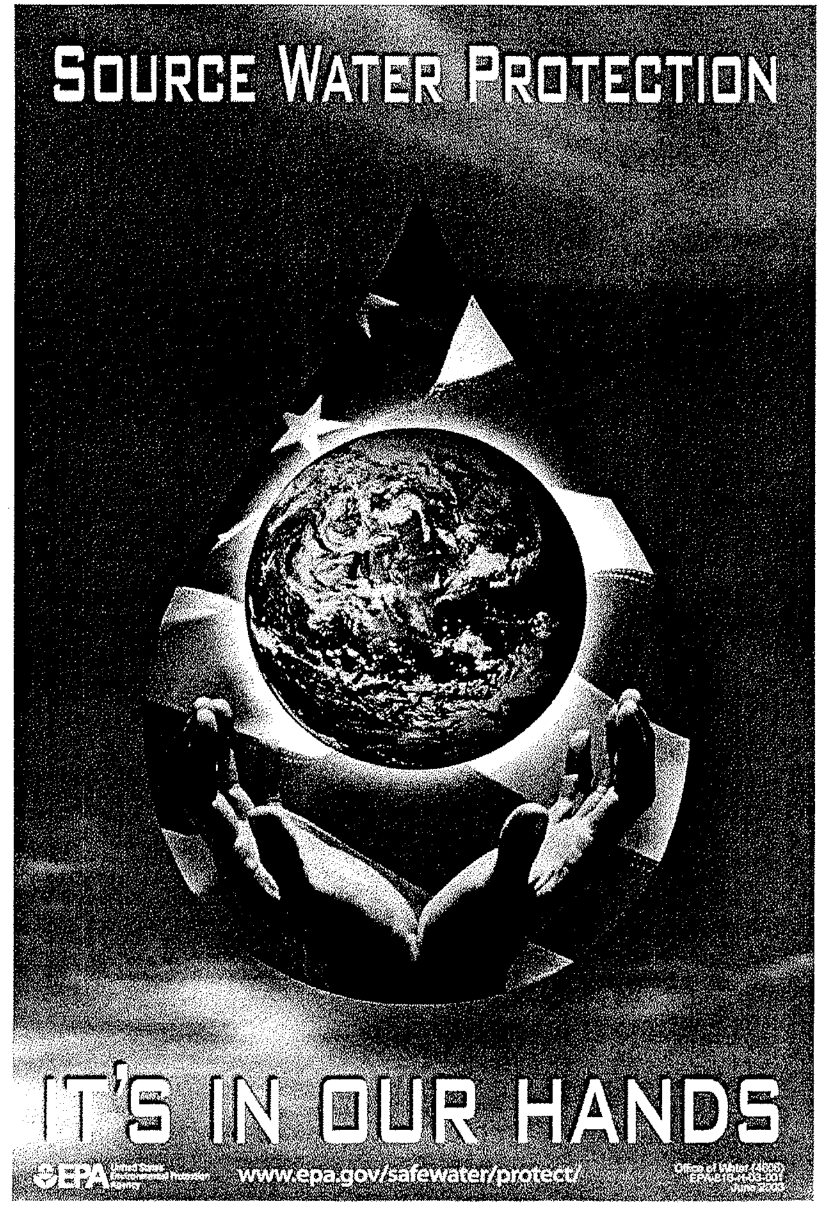


Water Supply Discussion in Pennridge, Bucks County

Clean, safe drinking water is something most of us enjoy ... without thinking much about. But, Tuesday night, in one Bucks county school district, they were also making sure they don't just take it for granted either. WFMZ's Jackie Shutack explains.

>> REPORTER: As the Pennridge area grows, residents want to make sure their water supply is clean, and uncontaminated.
>> REPORTER: That's why many gathered at this water supply meeting at the West Rockhill Township municipal building.
>> DENNIS LIVRONE/BUCKS COUNTY PLANNING COMMISSION: "To prevent contamination before it happens is a lot more cost effective than to clean it up if there is a problem."
>> REPORTER: This Bucks County community grows by 1 percent every year. 6 water suppliers provide the water for the community, which essentially consists of the Pennridge School District.
>> DOROTHY LONGACRE/BEDMINSTER TOWNSHIP RESIDENT: "At this point, it's with the public systems that supply our housing developments, commercial areas, and industrial."
>> REPORTER: The water plan addresses ways to keep development from contaminating the water supply. From here, the plan will be submitted to the Pennsylvania DEP for approval. In Sellersville, Bucks County, Jackie Shutack, 69 News.



http://cfpub.epa.gov/safewater/sourcewater/index.cfm

Case Study:

Title: Pennsylvania: Telford

Subtitle: Development of Source Water Protection Options for Individual Towns

Case Study Type: Protection

Lead Organization:

Participants:

Water Source: Ground Water

Scope of Case Study: Local

Date Updated: 09/01/2003

Related Topics: *Outreach Information; BMPS; Monitoring; Protection Planning; Land Use Control/Land Acquisition; Regulations; ;*

Description:

The Borough of Telford, Pennsylvania, population 5,500, is located in Montgomery County, northwest of Philadelphia. Telford has coordinated its efforts with several adjacent watershed communities in both Bucks and Montgomery counties. On January 24, 1996, the TBA organized its initial meeting regarding watershed protection, partly in response to incidences of TCE pollution in some of its wells. Representatives from five other towns within the Telford watershed were invited in order to provide a comprehensive, resource- driven approach to Telford's water protection program. In each of these municipalities, there were potential sources of contamination to one or more of Telford's wells.

Search
Subjects

PENNSYLVANIA Department of Environmental Protection

The Wellhead Protection Program in Pennsylvania:

An Overview (March 2006)

Almost half of Pennsylvania's residents rely on ground water as a source of drinking water. Ground water used as a public water supply is less expensive to use than surface water due to land acquisition costs and various treatment requirements for surface-water supplies. However, if ground-water contamination occurs, it is very costly to employ remedial activities and to provide the necessary treatment to comply with drinking water standards. Also, once ground water is polluted, it remains contaminated for a long period of time. Even if ground-water remediation is undertaken, it is a long and difficult process to attempt to restore water quality.

The Federal Safe Drinking Water Act (SDWA) required States to submit plans to the U.S. Environmental Protection Agency (EPA) that describe how they will protect ground-water sources used by public water systems from contamination. The **Wellhead Protection Program (WHPP)** is a proactive effort designed to apply proper management techniques and various preventive measures to protect ground-water supplies thereby ensuring public health and preventing the need for expensive treatment of wells to comply with drinking water standards. The underlying principle of the program is that it is much less expensive to protect ground water than it is to try to restore it once it becomes contaminated. Pennsylvania's WHPP was approved by EPA in March 1999 and it is the cornerstone of the Source Water Assessment and Protection Program (SWAP) which is also required under the SDWA. The Department of Environmental Protection **(DEP)** is the primacy agency for the Safe Drinking Water Act and the Source Protection Section in the Bureau of Watershed Management is responsible for administering the WHPP and other drinking water source protection efforts in Pennsylvania.

The responsibilities for wellhead protection **(WHP)** in Pennsylvania are shared among many stakeholders. Public water suppliers are responsible for assuring the continuous supply of safe and potable water to the consumer. The authority to regulate land use is primarily seated in the local governments whereas the Commonwealth has primary responsibility in regulating public water supplies and most discharges of potential contaminants. Other interested parties may include facility operators, landowners, local agencies and the public. Recognizing the need to balance the interests of all stakeholders, the WHPP emphasizes technical, financial and educational assistance to facilitate the development of voluntary local WHP programs. Pennsylvania's Safe Drinking Water Regulations (25 Pa. Code § 109) incorporate aspects of wellhead protection including new community water system well permitting requirements, a three-tiered approach for wellhead protection areas and minimum elements for DEP approval of voluntary local WHP programs. Strategies for the delineation of wellhead protection areas have been developed based on hydrogeologic investigations conducted by the U.S. Geological Survey for DEP. Funding for local WHP program development is available through DEP's Bureau of Watershed Management. Although WHP is voluntary at the local level, a growing number of municipalities and water systems across the state are already implementing local WHP programs in order to protect public health and safety by ensuring the quality of their drinking water sources. In addition to the public health and economic benefits associated with preventing costly contamination of ground-water sources, an effective local WHP program may help to secure a monitoring waiver for certain synthetic organic chemicals, thereby reducing analytical costs to a water

system. Wellhead protection also promotes sound land-use planning and complements the principles of pollution prevention.

For information on the WHPP, contact the appropriate regional DEP office (see next page) or the Source Protection Section at 717-772-4048.

A comprehensive **local WHP program** consists of several discrete and vital components:

I. **Designation of Responsibilities/Formation of Steering Committee**
- A Steering Committee composed of the necessary representatives to designate responsibilities for planning and
implementing wellhead protection activities should be formed to guide the effort. Objectives should be defined and
methods to achieve goals should be stated.
- Sources of information/Organizations potentially involved:
* U.S. EPA: guidance, information and support
* Pennsylvania DEP (Source Protection Section & Regional Water Supply Management Program): state coordination,
technical oversight/guidance, grants
* County Planning Commission: coordination of land-use issues
* Municipalities: implementation of land-use tools
* Water Supplier: implementation, administration and coordination of local WHP program, public education
* Other organizations that could be involved include Conservation Districts, agricultural groups, potentially affected
industries/businesses, local universities, civic groups, etc.

II. **Public Participation**
- Public participation and education activities are critical to the success of a local WHP program. If the public and local
officials understand the adverse health and economic effects associated with contaminated ground-water sources, they
will be more willing to support protection measures designed to safeguard their drinking water supply.

III. **Wellhead Protection Area (WHPA) Delineation** (See Figure 1)
- A WHPA is defined as the surface and subsurface area surrounding a public water supply well, wellfield, spring or
infiltration gallery through which contaminants are reasonably likely to move toward and reach the water source. Chapter 109 currently establishes three zones of protection. Zone I is the immediate area surrounding the source
which may range from a radius of 100 to 400 feet depending on site-specific source and aquifer characteristics. A
compliance assistance document on Zone I delineation for new sources is available. Zone II is a radius of 1/2 mile,
unless a more detailed delineation is established to identify the surface area overlying the portion of the aquifer
through which water is diverted to a well or flows to a spring or infiltration gallery (capture zone for a well; note that
this is not the same as the zone of influence). Zone III is an area which contributes surface water or ground water to
Zone II which may be significant to protecting the source. Collectively, Zone II and Zone III constitute the
contributing area of the source.

- WHPA delineation initially involves the formulation of a **conceptual** ground-water flow model followed by stepwise
refinement based on the availability of site-specific data. The level of delineation should be commensurate with the
level of the WHPA management approach. Delineation methods include:
* Fixed Radii Methods * Simplified Variable Shapes
* Hydrogeologic Mapping * Numerical Modeling
* Analytical Methods

IV. **Identification of Contaminant Sources** (See Table 1)
- Within each WHPA, all man-made sources that may adversely impact public health or prevent compliance with the
Safe Drinking Water Act should be identified.

V. **Development of WHPA Management Approaches**
- Implement appropriate ground-water protection tools to manage existing sources of contamination within the WHPA
and to ensure that future land use activities do not pose a threat to ground water. Regulatory management approaches
will require a rigorous WHPA delineation.
- Various regulatory or non-regulatory tools are available; examples include:
* Zoning * Public Education
* Health Regulations * Technical/Financial Assistance
* Transfer of Development Rights * Implementation of Best Management Practices
* Subdivision Control * Purchase/Donation of Property/Land Trusts
* Transfer of Development Rights * Ground-Water Monitoring
* Household Hazardous Waste Collection Programs

VI. **Contingency Planning**
- Develop provisions for alternate water supplies in the event of well or wellfield contamination and emergency
response planning for environmental incidents and security threats that may impact a well or wellfield.

VII. **New Water Supply Source Protection**
- Adequate planning for the protection of potential new well sites.

Regional Offices:

Southeast Region (Norristown) 484-250-5980
Counties: Bucks, Chester, Delaware, Montgomery, Philadelphia.

Northeast Region (Wilkes-Barre) 570-826-2511
Counties: Carbon, Lackawanna, Lehigh, Luzerne, Monroe, Northampton, Pike, Schuylkill, Susquehanna, Wayne, Wyoming.

Southcentral Region (Harrisburg) 717-705-4708
Counties: Adams, Bedford, Berks, Blair, Cumberland, Dauphin, Franklin, Fulton, Huntingdon, Juniata, Lancaster, Lebanon, Mifflin, Perry, York.

Northcentral Region (Williamsport) 570-327-0540
Counties: Bradford, Cameron, Centre, Clearfield, Clinton, Columbia, Lycoming, Montour, Northumberland, Potter, Snyder, Sullivan, Tioga, Union.

Southwest Region (Pittsburgh) 412-442-4217
Counties: Allegheny, Armstrong, Beaver, Cambria, Fayette, Greene, Indiana, Somerset, Washington, Westmoreland.

Northwest Region (Meadville) 814-332-6899
Counties: Butler, Clarion, Crawford, Elk, Erie, Forest, Jefferson, Lawrence, McKean, Mercer, Venango, Warren.

This fact sheet and related environmental information are available electronically via Internet. Access the DEP Web Site at www.depweb.state.pa.us.

Commonwealth of Pennsylvania *Department of Environmental Protection*

DEP Fact Sheet

Commonwealth of Pennsylvania • Department of Environmental Protection

SOURCE WATER PROTECTION TECHNICAL ASSISTANCE PROGRAM (SWPTAP)

Local source water protection (SWP) programs are community-based voluntary efforts to protect drinking water sources used by community water systems. Local SWP programs are effective tools for public health protection, water supply security and managing operational and capital costs through improved or maintained source water quality. The Source Water Protection Technical Assistance Program (SWPTAP) can help develop and establish local SWP programs.

WHAT IS PROVIDED BY SWPTAP?

DEP has secured the services of a contractor to provide technical expertise and assistance to interested community water systems for the development of local SWP programs. SWP programs can involve wellhead protection for groundwater sources, watershed protection for surface water sources or both for systems using both groundwater and surface water.

Community water systems receiving services through the Source Water Protection Technical Assistance Program must establish local SWP programs through a steering committee that will develop a source water protection plan detailing a program that meets DEP's minimum elements (see box). Assistance can be provided for developing a complete program or just specific elements needed to complete a program.

The SWP plan should incorporate:

- Public education;
- Program promotion;
- Support for pollution prevention methods;
- Integration with land-use planning; and
- Restoration and/or conservation of the source water protection area.

The SWP plan should include a strategy addressing both existing sources of contamination and potential sources of future contamination identified in the Source Water Assessment. The strategy can include the use of other funding sources and existing grants. Applicants eligible for SWPTAP include a community water system (CWS), an individual municipality with a community water system, or a group of adjacent municipalities.

The minimum elements of a local source water protection program include:

- Local steering committee and public participation;
- Source water protection area delineation;
- Contaminant source inventory;
- Source water protection area management methods and commitment;
- Contingency planning; and
- Protection of identified new source sites.

HOW WILL PROJECTS BE SELECTED FOR ASSISTANCE?

DEP Source Water Protection staff in conjunction with the contractor will assist the community water system in developing a Scope of Work.

DEP will consider the following criteria when developing and reviewing proposals:

- How well does the project adhere to DEP's minimum requirements for a SWP plan?
- What is the likelihood of successful completion within the projected time frame?
- Does the project have a clear source water protection focus?
- Does the water supplier and/or local government(s) demonstrate a commitment to develop, implement, support and sustain a local SWP program after funding is received?
- Will all of the components of a local SWP program be in place at completion?

HOW DOES IT WORK?

Interested parties should complete and submit a SWPTAP Information Request Form.

The form and information for this program can be obtained by:

- Visiting the DEP Web site at www.depweb.state.pa.us, keyword: Source Water and Groundwater Protection.
- Contacting the appropriate DEP Regional Office; or
- Contacting the DEP Source Protection Section at 717-772-4048.

SWPTAP requests for enrollment in the program may be submitted to DEP at any time. There is no application period or closing date.

SWPTAP Information Request Forms must be sent to:

PA DEP
Bureau of Watershed Management
Source Protection Section
Rachel Carson State Office Building, 10th Floor
400 Market Street
PO Box 8555
Harrisburg, PA 17105-8555
Telephone: 717-772-4048

Assistance will be provided following completion of the Information Request Form. DEP will review the form and initiate a scoping meeting with the CWS and the contractor to determine what is needed and who will be responsible for each task. A formal Scope of Work (workplan, budget and schedule) is developed and approved by all parties. With DEP oversight, the contractor will assist the CWS in developing the SWP plan. The final SWP plan is then submitted to the DEP regional office for review and approval.

Before completing the request form, note the following:

- Table 1 of this fact sheet lists a summary of the requirements for SWPTAP. Read the summary to verify that your project meets these requirements;
- Construction, including buildings, building materials and fencing, is not an eligible category for SWPTAP. Lighting fixtures/standards, telemetry equipment and computers are also not allowed. Land acquisition and activities related to permitting/regulatory requirements for community water system wells are also not eligible for funding under the Source Water Protection Technical Assistance Program.

For more information, visit DEP's Web site at www.depweb.state.pa.us, keyword: Source Water and Groundwater Protection.

Table 1. - SOURCE WATER PROTECTION TECHNICAL ASSISTANCE PROGRAM SUMMARY

Characteristic	Explanation
Eligible Applicants	Municipality with a community water system, group of adjacent municipalities, community water system
Project Duration	No more than 2 years
Types of Projects	• Rigorous wellhead protection area delineation • Enhanced contaminant source inventories • SWP area management or planning (ordinance development, transfer of development rights, early warning monitoring systems, public education activities, road signs, emergency response plan enhancements/contingency planning)
Sources	All active permitted sources must be included in the SWP program
Allowable Costs	• Professional services not obtainable through voluntary personal, regular organizational staff or this program • Materials and supplies necessary for program development
Final Product	"Approvable" local SWP plan (describes local SWP program that meets DEP Minimum Elements for Local SWP Programs)

DISCIPLINES

Civil Engineering

Professional Land Surveying

Environmental Engineering

Transportation Engineering

Process Automation

Mechanical Engineering

Structural Engineering

Electrical Engineering

Architecture

Construction Administration

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